A STUDY TO ELIMINATE BARRIERS OF INDIAN POWER TRANSMISSION SYSTEM

A thesis submitted to the
University of Petroleum and Energy Studies

For the award of
Doctor of Philosophy
in
Energy Management

BY
Naveen Upreti

September 2020

SUPERVISOR (s)

Dr. Raju Ganesh Sunder
Dr. Narendra N. Dalei
Dr. Sandeep Garg

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Department of Energy Management
School of Business
University of Petroleum & Energy Studies
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I would like to dedicate this thesis to my loving Parents…

DECLARATION

I declare that the thesis entitled "**A Study to eliminate barriers of Indian Power Transmission" System** has been prepared by me under the guidance of Dr. Raju Ganesh Sunder, Professor & HOD, CCE- Academic Unit, University of Petroleum & Energy Studies, Dr. Narendra Dalei, Assistant Professor, Department of Economics & International Business, University of Petroleum & Energy Studies and Dr. Sandeep Garg, Chief Operating Officer, GoLED Pvt. Ltd. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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Date: 9th September 2020

THESIS COMPLETION CERTIFICATE

I certify that Naveen Upreti has prepared his thesis entitled **"A Study to eliminate barriers of Indian Power Transmission System"** for the award of Ph.D. degree of the University of Petroleum & Energy Studies, under my guidance. He has carried out the work at the Department of Energy Management, University of Petroleum & Energy Studies.

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ABSTRACT

Power is the most critical component that supports the economic growth of any country. The power value chain, generally, comprises of generation, transmission, and distribution sectors that play a primary role in transferring the electricity. The power sector in India is considered to be the world's most diversified sector in the world. It has witnessed massive reforms and policy initiatives to implement the growth in the sector. The liberalization in the power sector in the Indian context has opened many prospects. India has also targeted to escalate the integration of renewable energy in the generation sector of the power system to address climate concerns.

The Indian power sector is undergoing considerable changes because of sustained economic growth, an increase in population, an increase in manufacturing activities, and rapid urbanization. These financial and demographic changes have prompted substantial growth in the power demand. An increase in the power demand requires a robust power system that can efficiently transfer the generated electricity to the end consumers. For the past ten years, the generation capacity has observed admirable progress to minimize the difference between supply and demand. Furthermore, policy planners and other stakeholders have concentrated majorly on the Generation and Distribution sectors only. However, the Transmission sector has not been adequately addressed, resulting in issues like transmission congestion, which further aggravates the power deficit situation due to a lack of adequate Power Evacuation transmission infrastructure. Indian Power Transmission System (IPTS) constitutes a vital link between the Generation and Distribution system of the power sector. The development of the sector cannot be realized in the absence of a robust and non-collapsible transmission network.

This study, therefore, provides an overview of the current deficient status of IPTS. It highlights and discusses critical barriers present in the IPTS, which are not permitting to carry increasing

generation capacities to the end consumers. These barriers are identified through a rigorous literature review. These barriers are further analyzed using Analytic Hierarchy Process (AHP) by conducting pairwise comparisons among them under three criteria (cost, time, and social impact) to understand them in detail. This technique measures the criticality of each barrier by computing priority weights.

Further, Theory of Constraints (TOC) has been practically applied to eliminate the critical barriers to the Indian Power Transmission System (IPTS) that were limiting the entire power service quality. TOC framework provides practical guidance to stakeholders of the power transmission sectors through situational assessment, conflict resolution, planning, and implementing changes required in the IPTS. This research establishes the utility of the five-steps Thinking Process (TP) of TOC, especially in the IPTS sector. The study also describes how each step of TP can improve the performance of IPTS against its specified goal.

The result of the study clearly defines that the current system has inadequate strategic planning. The growth of the entire power sector cannot be realized in the absence of a robust and non-collapsible transmission network. Hence, policymakers must execute re-planning of the whole Transmission sector, aligning it with the Generation sector to make the power sector more robust with the increasing demand. This study suggests that the policy-level interventions are urgently needed to remove bottlenecks of IPTS, enabling the revival of the overall growth of the power sector. The study brings management's attention to the system's weak links that must be leveraged by eliminating them from the system. Significant types of constraints are related to the restrictive policy of the sector that mainly include lack of strategic planning, lack of investments, and lesser participation of the private players in the IPTS. These constraints are generally located internal to the IPTS process. For eliminating the critical barriers of IPTS, the strategy identified by the experts is “appointing the nodal agency, which will be responsible for both planning and monitoring the IPTS.” The nodal agency has the capability to eliminate the critical barriers of IPTS by synchronizing the planning of IPTS. Finally, it can be concluded that the current research is one of the first efforts that investigate the barriers that are critical to IPTS and provide a strategy to eliminate critical barriers.

This thesis has six chapters. The first chapter (**Introduction)** presents the structure of the Indian power system. This chapter discusses the transmission system of India in detail. This chapter also highlights some of the significant issues that the transmission sector is facing. The second chapter, **Literature Review,** presents the existing extant literature on IPTS. The literature is categorized into five different themes: (a) Power sector in India, (b) Restructuring of Power Sector, (c) Transmission System in India, (d) Incapabilities in Power Transmission System, and (d) Planning in Transmission System. This chapter also discusses in detail different barriers that exist in IPTS. The third chapter, **Research Methodology and Scope of the Study**, discusses the business problem, research problem, research questions, research gaps, and research objectives addressed in this research. This chapter also discusses the underpinning theory “Theory of Constraints” used in this research. This chapter, finally, presents the research framework that depicts various phases of the research. The fourth chapter, **Prioritization of IPTS Barriers**, investigates the criticality of the barriers using the Analytic Hierarchy Process. This chapter highlights the data collection process and discusses the results obtained using AHP in detail. The fifth chapter, **Identification of strategies to eliminate the critical barriers of IPTS**, presents a practical and sequential application of the TOC to eliminate the critical barriers of IPTS that were limiting the entire power service quality. This chapter suggests a strategy to eliminate the critical barriers of IPTS through the application of the Thinking Process of TOC. The sixth chapter, **Conclusion and**

Recommendation, presents the conclusion of the research undertaken, the significant managerial implication of this research, the contribution of the research to the related literature, limitations and the future scope of the research.

ACKNOWLEDGEMENT

ॐ अहि ह्रीं हनुमते श्री राम दूताय नमः ||

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(Naveen Upreti)

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LIST OF ABBREVIATIONS

1. GDP: Gross Domestic Product
2. GW: Giga Watt
3. USD: United States Dollar
4. INR: The Indian Rupee
5. HVDC: High-Voltage Direct Current
6. PGCIL: Power Grid Corporation of India
7. IPTS: Indian Power Transmission System
8. AHP: Analytical Hierarchy Process
9. CEA: Central Electricity Authority
10. ANP: Analytic Network Process
11. NR: North Region
12. ER: Eastern Region
13. SR: South Region
14. WR: West Region
15. NER: North-East Region
16. kV: Kilo Volt
17. ckm: circuit-kilometer
18. MVA: Mega Volt Amperes
19. MW: Mega Watt
20. PWC: PricewaterhouseCoopers
21. KPMG: Klynveld Peat Marwick Goerdeler
22. CEA: Central Electricity Authority
23. CAC: Central Advisory Committee
24. PPP: Public Private Partnership
25. T&D: Transmission & Distribution
26. OECD: Organization for Economic Co-operation and Development
27. MWh: Mega Watt hour
28. kWh: Kilo Watt hour
29. ROW: Right-of-Way

30. GNA: General Network Access
31. UHVAC: Ultra-High Voltage Alternating Current
32. VAR: Volt-Ampere Reactive
33. IT: Information Technology
34. ISM: Interpretive Structural Modeling
35. RE: Renewable Energy
36. CBET: Cross Broder Electricity Trade
37. GERMI: Gujarat Energy Research and Management Institute
38. CR: Consistency Ratio
39. CI: Consistency Index
40. RI: Random Index
41. EPC: Engineering, Procurement, and Construction
42. SEM: Structural Equation Modeling
43. TOC: Theory of Constraints
44. TP: Thinking Process
45. mtoe: million tons of oil equivalent
46. GDP: Gross Domestic Product
47. Genco: Power Generating Companies
48. CERC: Central Electricity Regulatory Commission
49. CPSUs: Central Public Sector Undertaking
50. IPPs: Independent Power Producers
51. USD: United States Dollar
52. TWh: terawatt hours
53. PTC: Power Transmission Capabilities
54. PIT: Implementation of the new Transmission network
55. INR: The Indian Rupee
56. InSTS: Intra-state Transmission system
57. ISTS: Inter-state Transmission system
58. CTU: Central Transmission Utilities
59. STU: State Transmission Utilities
60. ISTS: Inter-state Transmission system

61. NLDC: National Load Dispatch Center
62. ATC: Average Technical & Commercial losses
63. MTOA: Medium Term Open Access
64. T&D: Transmission & Distribution
65. SEBs: State Electricity Board's
66. SERC: State Electricity Regulatory Commission
67. TBCB: Tariff-Based Competitive Bidding
68. CBET: Cross Border Electricity Trade
69. POSOCO: Power System Operation Corporation
70. NKTCL: North Karanpura Transmission Co. Ltd.
71. IPS: Indian Power System
72. CRT: Current Reality Tree
73. EC: Evaporating Cloud
74. FRT: Future Reality Tree
75. PRT: The Prerequisite Tree
76. TRT: Transition Tree
77. UDEs: Undesirable Effects
78. GHG: Greenhouse gas
79. MoP: Ministry of Power
80. DEA: Data Envelopment Analysis
81. KERA: Karnataka Electricity Reforms Act
82. OSEB: Orissa State Electricity Board
83. FACTS: Flexible alternating current transmission system
84. TRM: Transmission reliability margin
85. LTT: Light Triggered Thyristors
86. AC-DC: Alternate current-Direct current
87. IEPL: Ideal Energy Projects Limited
88. IEX: Indian Energy Exchange
89. KKNPP: Koodankulam Nuclear Power Project
90. HPC: High Performance Conductor
91. ACSR: Aluminum Conductor Steel Reinforced

92. DBR: Drum-Buffer-Rope
93. CI: Consistency Index
94. CR: Consistency Ratio
95. RI: Random Index
96. AIJ: Aggregate the individual judgments
97. ERP: Enterprise Resource Planning
98. TA: Throughput Accounting
99. AIP: Aggregating the resulting priorities
100. SS: Six Sigma
101. LP: Linear Programming
102. PTS: Power Transmission System
103. RO: Research Objective
104. IO: Intermediate objectives

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CHAPTER 1 – INTRODUCTION

1.0 INTRODUCTION

Power is the most critical infrastructural sector, central to the expansion of the economy and prosperity of nations. The power sector in India is considered to be the most varied sector in the world.

The Energy demand in India in the year 2017 was nearly 934 mtoe (million tons of oil equivalent) and, it is further expected to grow three times between 2017 and 2042 (Thambi et al., 2017; Enerdata, 2018).

India is now rapidly moving towards industrialization with initiatives by government like "Make in India," "Digital India" etc. The country is also passing through the most Energy-intensive phase of economic growth (Garg, 2012).

"Causal relationship between 'Energy consumption' and 'Economic growth' has been the prime focus of economists and policy analysts of India since the 1970s (Gosh, 2002)." Power being a major constituent of energy, significantly affects the economic development and societal welfare of the nation. Since the economic activities in India are at a peak, electricity demand is expected to get triple between the years 2018 – 2040 (World Bank, 2018).

The Indian power system ranks fourth in the Asia Pacific region and is considered to be the most complex one, with more than 200 million diverse consumers spread across the country (Daruka, 2015; IBEF, 2019).

The ratio of electricity and GDP elasticity in India is 0.8, and as a result, electricity will remain a crucial contributor to the economic growth of India (Fintech, 2015; IBEF, 2018).

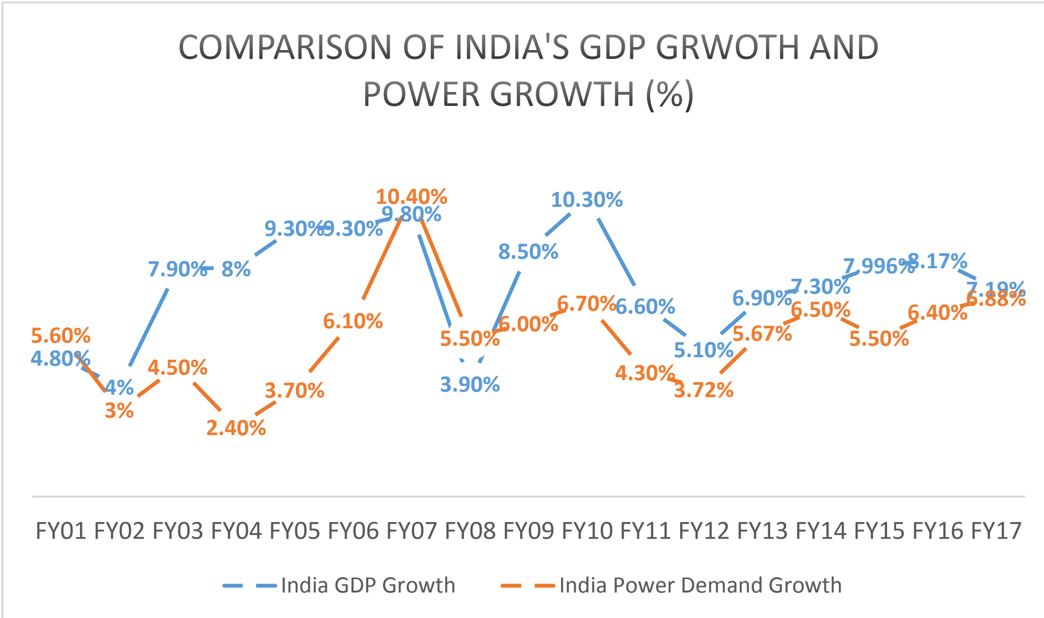


Fig. 1.1. Comparison of India's GDP growth and Power growth (World Bank, 2018)

The chart in Fig. 1.1 depicts the comparative growth of power demand with GDP growth. It indicates that the increase in power demand is always lesser than the rise in the GDP of the country.

1.1 STRUCTURE OF INDIAN POWER SECTOR

The power sector in the Indian context comprises of three critical systems, i.e., Generation system, Transmission system, and Distribution system. The structure of the power sector in the country has been depicted in Fig. 1.2.

The Generation capacity of India is proliferating to meet the demand, which is increasing due to upsurge in the economic activities of the country. The installed Power Generation capacity of India is 350.162 GW. However, the power demand in India is 177.022 GW (as of February 2019). Despite the higher Generation capacity than power demand, India is still facing a peak power deficit of 0.8% (1.6 GW) (Ministry of Power, 2019). The economy of the country has been severely affected by power shortages. In one of the instances, India faced a GDP loss of USD 68 billion in the year 2012-13 only due to power shortages. This impacted many crucial industries, such as manufacturing, agriculture, and service industries (Bajpai and Srivastav, 2015). It is essential to bring growth in this sector, which is fundamental for the economic prosperity of the nation and also in improving the quality of the living

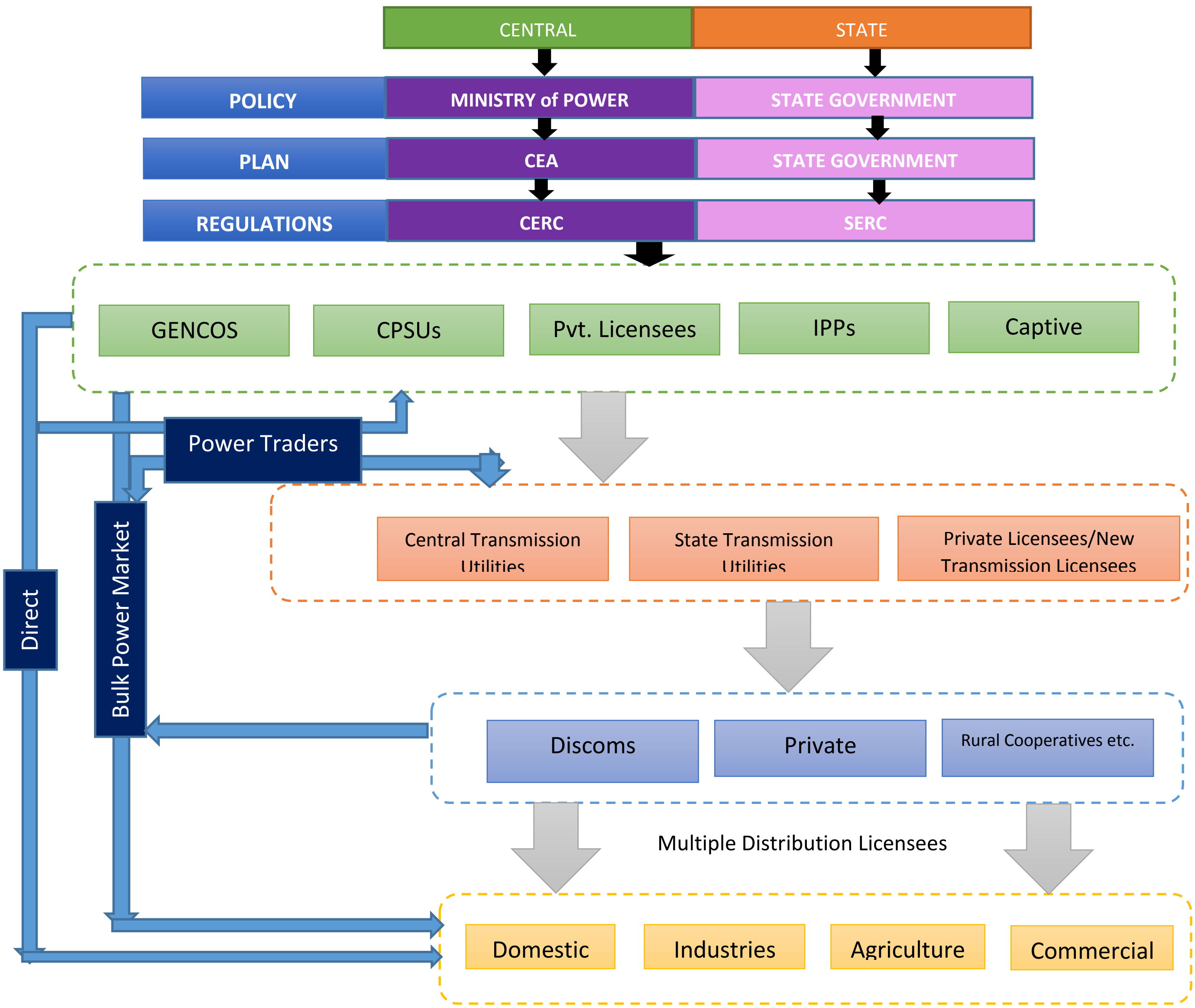


Fig. 1.2. Power Structure of India (Adapted from Singh, 2006)

According to the 13th Five Year Plan, the generation capacity of India is further planned to expand to around 100GW. This will further demand future expansion of the Transmission sector. To meet this need, huge investment in the Transmission sector is required for an approximate addition of 62,800 circuit-km (ckm) of 765-220 kV lines, 128,000 MVA (Mega Volt-Ampere) of transformation capacity of the 400 KV and above, and 15000 MW of HVDC terminal capacity national grid capacity (CEA, 2014b). For this reason, it is planned to invest USD 37.23 billion in the IPTS. During the 12th Five Year Plan, about USD 19 billion has been invested by Power Grid Corporation of India Limited (PGCIL), and the remaining 46% of the investments in the sector, i.e., USD 16 billion has been provided by private players (Singh, 2013).

1.1.1 TRANSMISSION SECTOR IN INDIA

Transmission infrastructure can be considered as a backbone for effectively operating a robust power network and a vital link in the power value chain that connects the Generation system with the Distribution system. The power demand side is further projected to increase, which requires a robust Generation, Transmission, and Distribution system (KPMG, 2010). The average electricity demand has increased from 50 terawatt-hours (TWh) to 75-80 TWh per year from the past five years. The increase in industrial and electricity-based product consumption has put stress on transmission grids at the time of economic boom (PWC India, 2012).

To make Transmission network robust for the adequate evacuation of power, following components plays an important role and the same must be reviewed, planned, and implemented:

1. **Adequacies of existing network/ Power Transmission Capabilities (PTC)**
2. **Planning Vs. Implementation of a new Transmission network (PIT)**

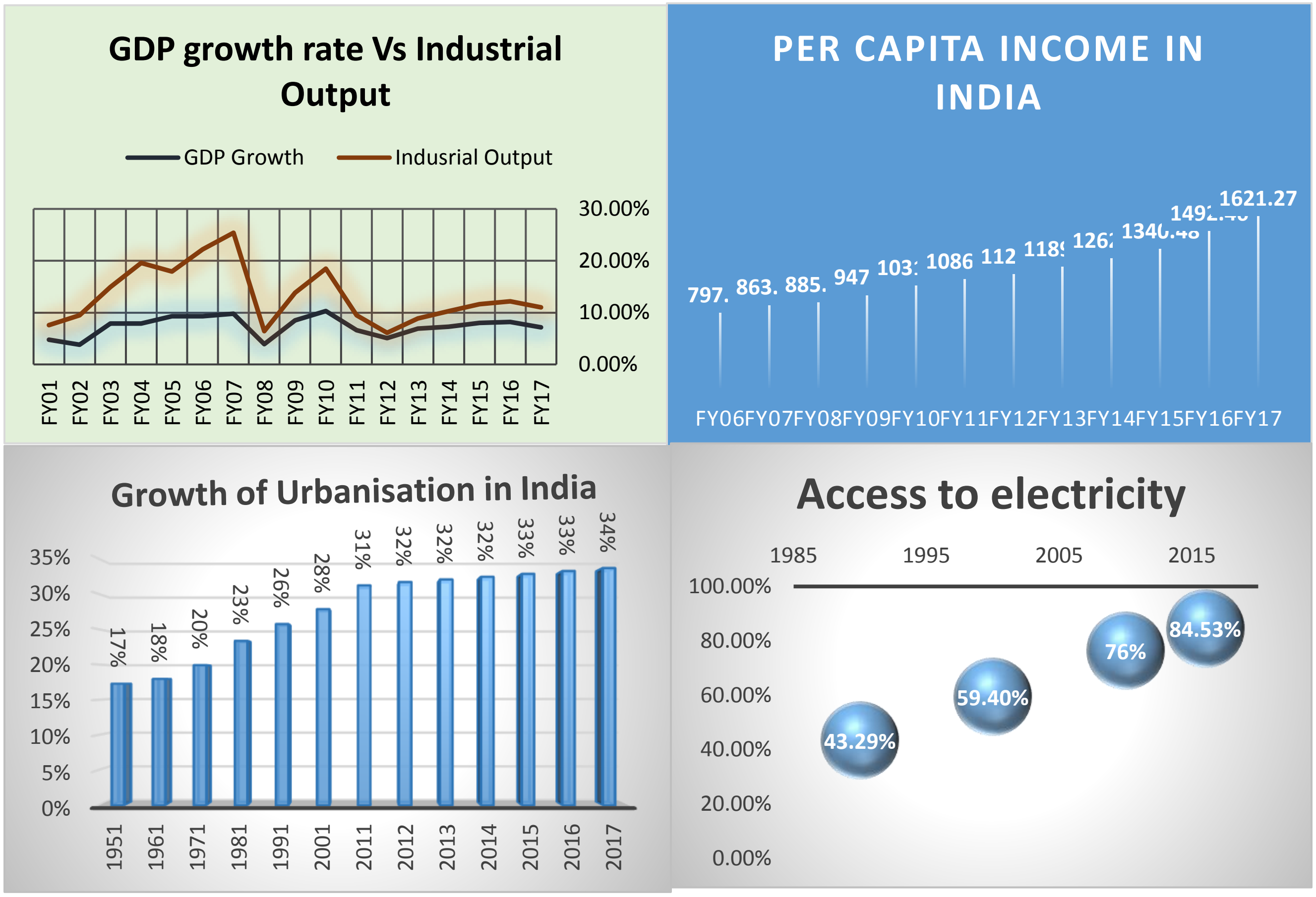


Fig. 1.3. Growth in GDP, industrialization, and urbanization

1.1.1.1 Adequacies of existing network/ Power Transmission Capabilities (PTC) of India

The Indian economy is continuously growing, with GDP reaching 7.3% for the year 2018-19 (World Bank, 2019). The increase in GDP can be accounted for rapid industrialization in the country. The growth in industrialization can be measured through the growing industrial production output with a 3.8% rise in production for the year 2017. Thus, there is a direct relationship between industrialization with the growth in GDP (World Bank, 2019).

Also, the trend of urbanization in the country is increasing from 17.29% in the year 1951 to 33.60% in the year 2017. Also, an upsurge in the per capita income has been observed from USD 1049 in the year 2008 to USD 1621.27 in the year 2017 (Statistica, 2018).

Fig. 1.3 depicts the growth in GDP, industrialization, and urbanization. This confirms that rapid industrialization, urbanization, and an increase in per capita income have a direct impact on the increase in the power demand in the country (World Bank, 2019).

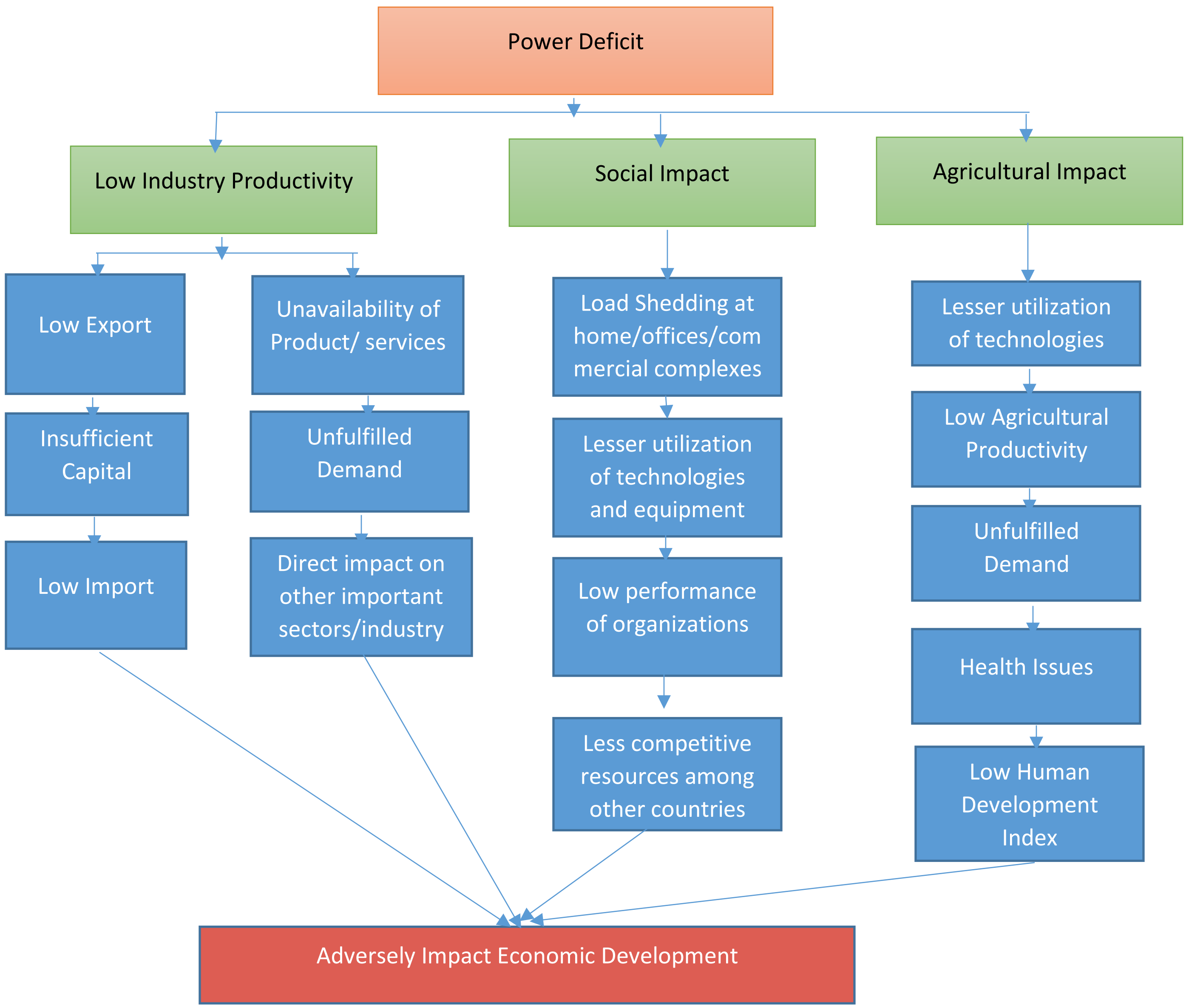


Fig. 1.4. Impact of Power Deficit in country

Today, the current state of affairs of the power system in the country is alarming as demand is exceeding the supply rate in this sector, giving rise to power deficit situation in many states. This not only has an adverse impact on production as well as service industries but also has major implications on the lives of people (Bhattacharya, 2007).

The impact of the power deficit has been summarized in Fig. 1.4. This problem will further aggravate as demand will shoot up in the coming years, where the government is planning to develop Smart Cities. The issues related to power outages for more than an hour or a day are more prevalent due to shortages of transmission capacity. There are also a few thousands of towns not associated with the national grid due to the absence of transmission infrastructure (Sinha et al., 2011). Although the power is available, power accessibility issues have unfavorably influenced the nation's economy and accounted for substantial GDP loss, which in turn has impacted various other sectors (Singh, 2013). Policymakers are perplexed with the distressing state of power deficit, regardless of having surplus power.

Power will no doubt act as a lifeline to the whole nation, and its improvement is essential to run the nation successfully (Singh, 2013). As a consequence, Power is a critical fuel to the country's economy. Thus, there is an urgent need to match supply with the growing electricity demand.

Problems of power deficiency and accessibility in India lie mainly with the transmission infrastructure, and these problems are further expected to proliferate in the next few years if not given appropriate attention. Pressure on the existing network to transfer more power has led to transmission congestion (CEA, 2016; Xue and Xiao, 2013). It has been estimated that the enervated energy wasted due to transmission bottlenecks is approximately 1.93 × 109 kWh of electricity (Kovendan and Sridharan, 2017).

According to the 12^{th} Five Year Plan, the government has increased the Generation capacity by approximately 50% over the last five years (Joseph, 2010), whereas the Transmission capacity is generally placed behind the generation capacity. Despite the increase in the transmission capacity, the capability of the transmission system to transfer the power still remains a major constraint.

Unlike many other countries, India has a federal structure wherein the power and controls are distributed between central as well as state governments of the country. Consequently, the responsibility of the sector lies with both state and central governments. The inter-state Transmission system (ISTS) is governed by the central government, with the primary objective of national grid development. ISTS is the prime responsibility of Powergrid Corporation of India, which is a Central Transmission Utility (CTU). Whereas, Intra-state Transmission system (InSTS) is governed and owned by State Transmission Utilities (STUs) belonging to each state of the country under the powers of state governments (CEA, 2016)

1.1.1.1.1 Inter-State Transmission Capabilities (ISTC)

Currently, the Indian Transmission structure is divided according to the four zones, namely, North Route (NR), South Route (SR), East Route (ER), and West Route (WR) as shown in Fig. 1.5 (Shahi, 2015). There are various challenges or bottlenecks that Generation companies face at the time of dispatching power due to Transmission congestion (CEA, 2016; Ministry of Power, 2016). These are as follows:

NR Import - Northern Region generally faced a power deficit condition for a year. The average short-term power requirement of this region varies between 1000 MW in winter seasons and 3500 MW in summer or monsoon seasons. NR generators do not meet the full demand for power. Due to the lack of adequate power, the states in the NR region procure power from the generation companies outside the NR region. The procurement is done for the short-term duration that varies between 1000 MW and 2000 MW. Since there are no transmission corridors available in the

WR-NR route, therefore, the NR states are left with the ER-NR route to get the power. This route has approximately 500 MW (winters) and 1500 MW (summers/monsoon) of the Average Technical & Commercial losses (ATC) Due to this, the suppliers of power to the NR region face transmission capacity constraints to transfer the power especially during summer and monsoon season.

The power requirement of Karnataka state is about 185 million units of electricity every day. However, only 135 million units of electricity are available every day. This deficit in power demand is further worsened during the drought situations due to weak monsoon in the state. Due to the unavailability of corridors, states like Karnataka remain a power deficit regions (Krishnan, 2015).

As per the 12th Five Year Plan, resource-rich state Chhattisgarh expected the power Generation capacity to be increased to 30,000 MW with the peak demand of the state is only 3,300 MW, whereas, Transmission Capacity is about only 7000 MW ***(IBEF Report 2013).***

SR Import – Similarly, in the southern region of the country, there are inadequate transmission corridors to transfer power using WR-SR and ER - SR routes on short term basis Also there was non-availability of the transmission corridor under Medium Term Open Access (MTOA) till the FY 2016 to import the power from the new grid of the region (NLDC, 2016)

In the year 2013-14, Northern-North Eastern-Eastern-Western had a power surplus of 2.3% of the total power demand in the region, whereas it was anticipated to have a peak-time power deficit of about 26% of the total power demand in the Southern region (Singh, 2013).

WR Import - ER – WR corridor generally remains 0 MW for short term open access. This means that there is no margin available for short term open access, but there are long as well as mid- term open accesses available in this route. As a result, no power is directly transferred from the ER to the WR route. Thus, the power is being scheduled to transfer via the ER to the NR to the WR route. However, this route is heavily experiencing congestion (NLDC, 2016).

NER Import –The states in the NER region are also facing heavy power deficit situations during winter months. Thus, during winter seasons, NER States imports around 200 – 300 MW of power from the other regions.

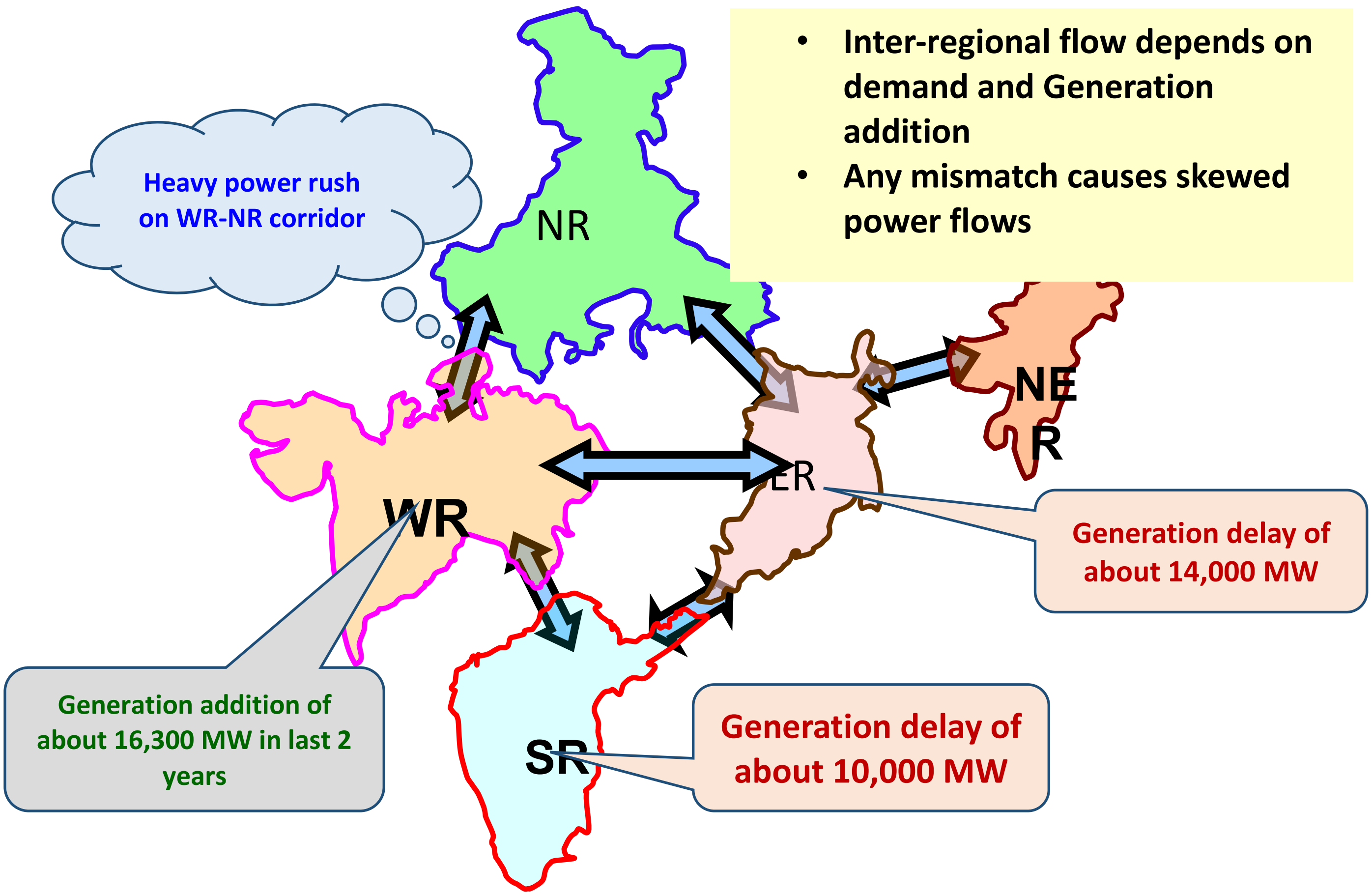


Fig. 1.5. Various Zones in Indian Transmission sector (CAC, 2015)

1.1.1.1.2 Intra State Transmission Capabilities (InSTC)

Another reason for the Transmission constraints is also the inadequacies of STUs to evacuate power from the National Grid. The power from the National Grid can be transmitted into the State Grid, but due to inadequacies in the availability of

State-level transmission or sub-transmission system, it is not possible to evacuate the power from the National Grid (Gupta et al., 2012).

According to the international experience of POSOCO, the transfer capability of the Transmission network in the developed countries is about 21% of the Transmission Capacity. One of the reasons for such an inefficient power system is the inability in transferring the power to the consumers. As compared to other emerging market countries, India faces a huge amount of T&D losses. Due to such high transmission losses, the financial condition of state electricity boards of the country is quite weak.

A Generation Plant of 1980MW capacity in Maharashtra sets a good example that exhibited that the generation capacity of the state was commissioned without the commissioning of the Transmission system. Overburdened Transmission lines are unable to carry all the power generated by the plant. Similarly, is the case of Ideal Energy wherein 270 MW is yet to be utilized due to Transmission constraints (CEA, 2016). Further, many states keep on changing their plans of whether to source the power or not. This creates an imbalance by increasing surplus in some networks and deficits in some other networks. This also led to a hike in the purchasing price of the power in the south to INR 11-20 per unit at the time of summer seasons (Jai, 2016).

In India, due to delays in various generation projects of about 8000 MW, there is an acute power shortage in the southern region.—This the problem of severe power shortage has been further aggravated by the fact of the inadequacy of the gas for the projects of about 7000 MW.

The commissioning of many generation projects in the southern region has made this region a power surplus, where there are no Discoms that have applied to have long-term access to power. The Raichur-Sholapur Transmission system was at first used to transmit power to the western region from the southern region. But now, this transmission line has become a lifeline as most of the generations projects did not materialize

1.1.1.2 Planning Vs. Implementation of a new Transmission network (PIT) in India

Since the Power Generation has surpassed Power Transmission in terms of investment inflows, this creates a mismatch between Generation and Transmission and leads to inadequacies in the national Transmission capacity. The problem of transmitting power is further aggravated by the fact that there exist inefficiencies in the establishment of the new Transmission system infrastructure. Thus, it is equally important to address and, consequently, moderate the Transmission issues persisting in the system. Some live cases of our country will give more insights into how Transmission bottlenecks negatively affect the entire system.

- *The Empowered Committee on Transmission of the Central Electricity Authority (CEA)* has suggested to award Transmission projects worth INR 9,468 crore through **Tariff-Based Competitive Bidding (TBCB)** (CEA, 2012) but still, the required Transmission capacity has not been realized. One of the key challenges encountered by this sector is many delays in the execution of the projects. Many instances happened while handling the transmission projects, where transmissions lines were not laid in the planned routes and were forced to consider a new route altogether. This results in an increase in the actual budget allocated. **For example, North Karanpura Transmission Co. Ltd. (NKTCL), a subsidiary of Reliance Power Transmission Corporation Ltd.,** was awarded to construct Bareilly-Merrut 765kV D/C line. The commissioning of the transmission line was scheduled in November 2013. The project has been stuck over the six years with the developer requesting the Central Electricity Regulatory Commission (CERC) for a cost revision. It is expected that if CERC revises it, the cost incurred will be passed on to the consumer, in which case, the whole purpose of TBCB is lost (CEA, 2019).
- The issue of transmission congestion is aggravating due to inadequate planning and delays in acquiring approvals such as Right-of-Way (RoW) and forest clearances. A transmission project faces huge delays of eighteen

months was not commissioned due to issues of ROW and forest clearances. These delays not only resulted in an increase in the transmission projects' time and cost but also resulted in generation losses (CEA, 2019).

It has been the plan to add 176 GW of renewable energy in the power generation capacity. However, it does fit well with the current availability and state of the country's transmission infrastructure. The addition of renewable energy power to the grid has developed immense pressure on the transmission network to provide last-mile connectivity to the renewable energy generation plants. Another challenge that the transmission network might face is due to the unpredictable nature of the power generated by RE sources (Kamat, 2015).

- In a span of three years, Gujarat has commissioned solar power of about 800MW (*Gujarat Energy Research and Management Institute (GERMI))*. This has made this region a Power Surplus state in the country. But there are no Transmission linkages to connect a power surplus state to a power deficit state. The issue of **Cross Border Electricity Trade (CBET)** has been emerging now-a-days. It is pointless for a nation like India to import the power from Bhutan and Nepal when the country has power surplus situations it the states like Gujarat. Initially, building transmission linkages between power surplus states to power deficit states will seem to be expensive. But, these investments will payback, especially after the opening of the open energy market. Establishing robust transmission linkages will provide immense possibilities. Envision a day when the textile industry operating in Tiruppur, Tamil Nadu, procures solar power from the power surplus state like Rajasthan (Magal, 2015).
- More than a dozen of transmission lines of 765 kV and 400 kV capacities were collapsed in the year 2015 due to pre-monsoon winds. Such incidences indicate the fragility of the grid infrastructure of the country (Sasi, 2015).
- *Power System Operation Corporation POSOCO* has raised a red flag against the PGCIL since the 765 kV double-circuit Transmission towers

hook up power lines that typically carry electricity to the tune of 3,000-5,000 MW and the collapse of more than one tower could potentially trigger a cascading grid failure unless Special Protection Schemes are in place or the Transmission system is spruced up to handle such a huge loss of power (Sasi, 2015).

- India faced blackouts for two subsequent days in the year 2012 due to due to failure of the power grid. In another power outage incidence, over 600 million people in the country were left with no electricity. These incidences of severe blackouts show that the country is still struggling to supply the growing power demand. They have also exposed the weak links existing in the IPTS, inadequate planning, and inadequate robust fail-safe system to prevent such cascading grid failures (Romero, 2012).

Thus, the existing Power Transmission System is inefficient and continues to be incompetent to supply power effectively. The root causes of these problems are various issues present in the Transmission system.

The flat performance of the transmission sector can be attributed to various barriers, as well as gaps that are underlined in the Transmission sector. These barriers are spread over the complete life cycle of the Transmission line, i.e., time of conceptualizing a Transmission line till its operation, as shown in Fig. 1.6. Thus, these issues can be classified under the following broad categories:

1. Planning a Transmission Project: This phase generally comprises of conceptualizing the need for Transmission corridor over a specific area. During this phase, decisions on approved venders, route selection, types of equipment to be installed, project scheduling, sequencing of tasks, optimum utilization of resources, budget assignment, activity-based cost allocation etc.is taken. It has been rightly said that the success of any project is a testament to its good project planning. Any issue such as lengthy conceptualization phase in a Transmission project may have an immense bearing on the functioning of transmission of power. Thus, problems arising out during this phase must be identified and addressed.

2. Transmission Project Cycle: This phase of Transmission includes the implementation and execution of the plan prepared. Any issues during this phase, such as difficulty in obtaining Right-of-Way or forest clearances, unavailability or under-utilization of resources, increase in cost, less technology utilization, etc. can impact the project time length and project costs. Such issues must be resolved on priority as these issues may slacken the growth in Transmission capacity and may have a straight impact on the functioning of Transmission lines.

3. Project Commissioning: It is a crucial phase of the Transmission project as commissioning is the process of assuring that all components installed in the system are functioning according to the operational requirements. It investigates the performance of equipment installed individually and synchronization of the system as a whole. Addressing issues arising during the commissioning of Transmission projects may reduce risks of unplanned outages and downtime at the time of its operation.

4. Operation and Maintenance: A Transmission line after successful commissioning is suitable to transmit the load to end-users and finally comes into real operations. Issues such as technical issues, maintenance issues, etc. arise during the operation of a Transmission line. These issues may have a direct impact on the reliability of transmitting power efficiently to the end-customers. The tower failure generally is a function of time and expense required for repairs and maintenance.

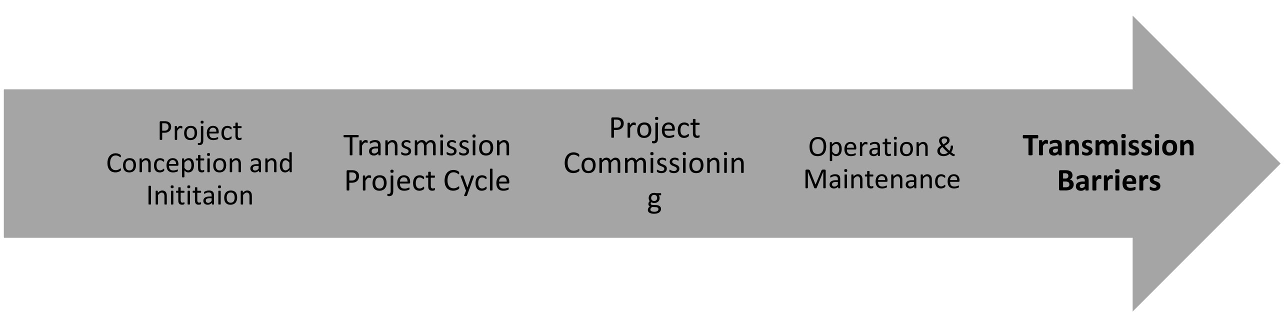


Fig. 1.6. Different phases in Power Transmission System

1.2 SUMMARY

Power Transmission line bottlenecks may impact various stakeholders such as Generation Companies, Distribution Companies, Electricity market, Equipment Manufacturers, etc.

***Table 1.1: Impact on* major stakeholders of Indian Power System**

Stakeholders	Impact of Power Transmission Issues
Generation Companies	Due to congestion in Transmission lines and inadequate Transmission capacity, most of the Generation capacity is kept idle, making the problem comparable to the issue of acute fuel scarcity in generating plants. Regulatory authorities must impose strict restrictions on the optimum utilization of existing networks and must keep a large amount of Transmission capacity idle as a safeguard for future requirements.
Distribution Companies	Inadequate Transmission of power may directly impact the performance of Distribution. This further can aggravate the financial crisis of already debt-ridden distributors. Moreover, the situation of power deficit due to distribution losses as well as power theft can be compensated with the efficient and reliable transmission of power.
Power Trading	Power Transmission bottleneck can hamper the smooth trading of power in the market. Selling of power on trading companies may get impacted due to Transmission issues, directly hitting the revenue Generation of trading companies. This can stop the dynamic wheeling of power from the regions where power supply is more than the regions where there is a power deficit.
Equipment Manufacturers	Equipment manufacturers are going through a dull phase due to lack of focus of government towards stability & upgrading of existing grid and policy paralysis. According to IEEMA, manufacturing for the sector has reported a negative growth of 7.8% during the year 2012-13. They are now eyeing on an ambitious Integrated Power Development Scheme (IPDS), which targets to strengthen the Transmission and last-mile connectivity and delivery of power.

The impact on major stakeholders of the Indian Power System has been briefly discussed below in Table 1.1. One of the key reasons for the country's power deficit situation is inadequate Transmission capacities that do not match the Generation capacities and load requirements. Moreover, the chocked Transmission network leads to the under-utilization of Generation capacity. Unlike other infrastructural public utilities, no alternative exists to Transmission lines, which makes the system entirely dependent on the Transmission network.

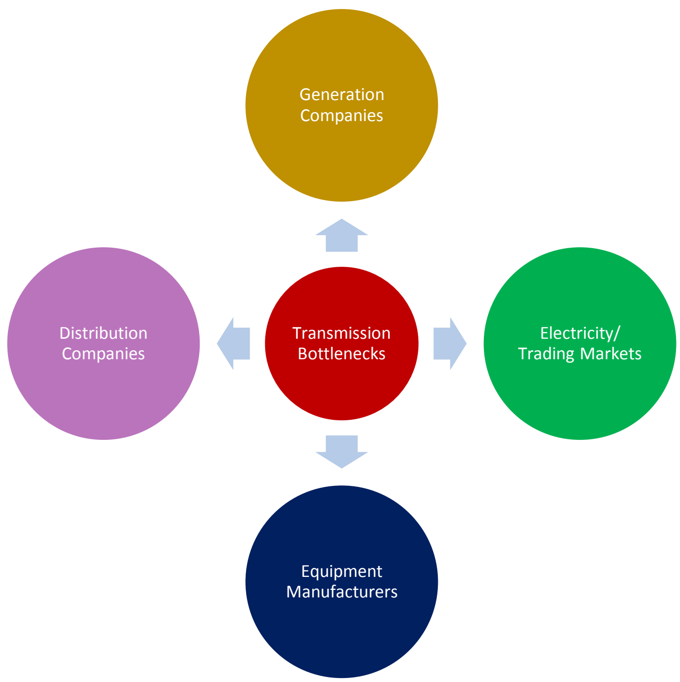


Fig. 1.7. Stakeholders affected by Transmission Bottlenecks

Power evacuation has thus, turned out to be the most prevalent challenge as compared to the power Generation in the Indian Power System (IPS) (Financial Express, 2013). It is further expected that capacity at the demand side is further expected to increase as the country keeps on focusing on Open Access, wherein every end-user in the country is allowed to select Transmission lines. If India's Transmission issues are not timely addressed, the problem of power shortages is expected to increase further.

There are issues while installing new Transmission lines, and there are issues in upgrading the existing transmission lines. While installing new Transmission lines, there are issues related to delays in Transmission capacity addition. Many times, the new Transmission lines installed on an unplanned route, bring alterations in a complete project plan. Ministry of Power (MoP) has accepted this as a severe issue of IPTS and emphasized its significance in the development of a National Grid (Ministry of Power, Annual Report (2009-10). Investments in the Transmission sector by the government is limited and still not adequate. This further aggravates the problem of the decision-making process during the execution of the project. Thus, a transmission project experiences various challenges during its execution, such as inconsistency in sharing the risks, setting and alterations in tariffs, disputes related to regulation, ambiguities in contracts, renegotiations due to abrupt allotments of contracts. This makes the processing time of a project, i.e., from its conceptualization till it's commissioning very long.

The problem is further aggravated as the Transmission sector in India is devoid of full-blown competition and participation of private players. It has been observed that only 2% of the Transmission sectors have been owned by private players. Almost all projects are awarded to Power Grid and get big-tickets Transmission projects from the government. Policy mistakes in this sector have ensured that the private participation in the sector is either crimped or is stunted. Less participation of private players decreases competition, which compromises on costs and quality of the project. Moreover, since more projects are awarded to Power Grid, major Transmission lines are pending with the company. In most cases, the commissioning dates are extended by more than three years.

Existing Transmission lines are commonly, facing huge Transmission losses, which need to be curbed with up-gradation of these lines with high voltage and super-efficiency conductors. Further, most of the Transmission lines are aging and have become inefficient. However, there is an insufficient focus of the industry to upgrade the existing Transmission lines. This is important since acquiring new land for the installation of new Transmission lines is relatively costly, time-consuming, and usually marred with uncertainties in implementing projects. Moreover, limited availability of land, resources, capitals, and incentives has made up-gradation of existing corridors a potential alternative. The integration of renewable energy with existing grids has further added challenges in the sector. This will also require integration of new Transmission infrastructure and efficient Transmission planning with the existing one.

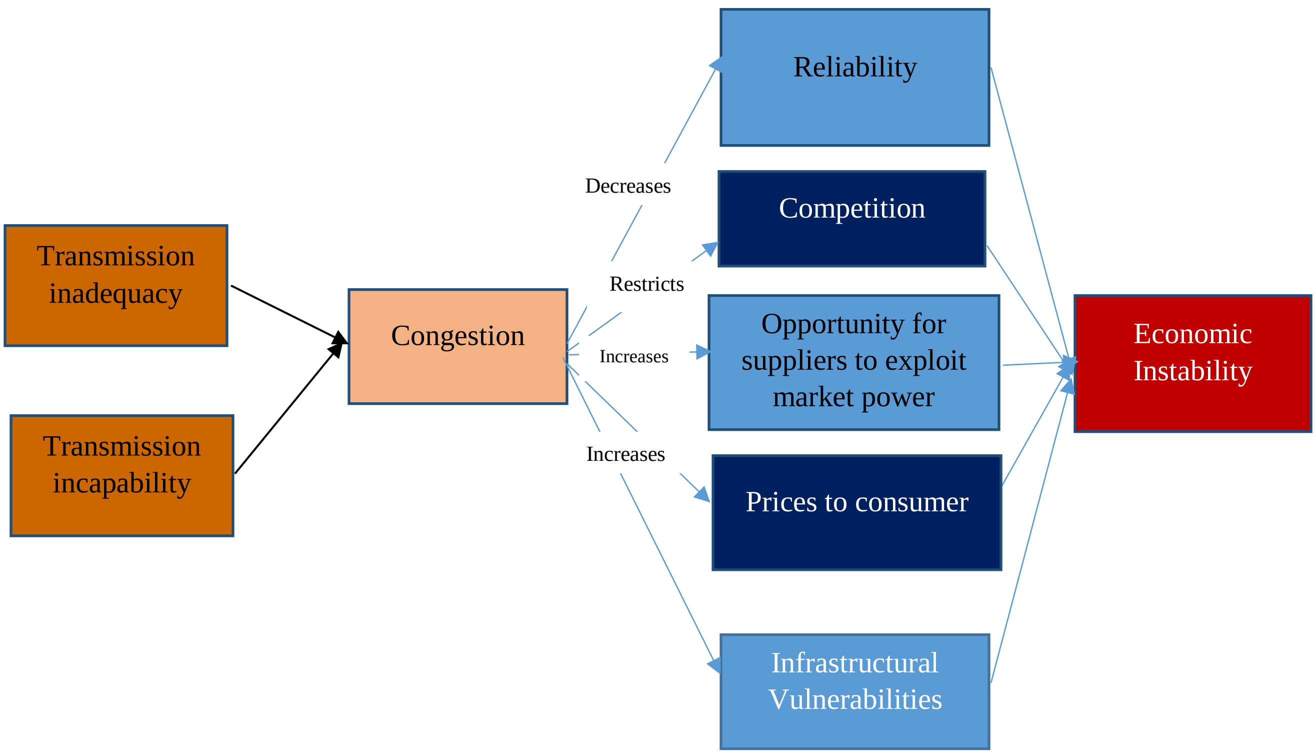


Fig. 1.8. Impact of Transmission inadequacy and incapability of transferring power

It can be inferred that the power deficit situation has a significant impact in slowing down the growth in the economy. In this perspective, it is important to minimize the gap between supply and demand. To bridge this gap, a large number of projects have been commenced in the generation, transmission, and distribution segments of the power sector. IPTS requires timely and sincere reforms to avoid any spiral effect on the remaining power sector, other sectors such as agriculture, service, and manufacturing, as well as on the country's economy. To initiate such reforms, the first step is to identify various barriers that are persistent in this sector and provide implementable solutions to minimize those barriers. The barriers can also be mitigated by recognizing the present opportunities and adopting new and innovative strategies from the traditional approach.

1.3 MOTIVATION OF THE RESEARCH

Power evacuation has been emerged as a major challenge due to **choked and congested transmission networks**. This has huge implications on the economic stability of the country. There is an **urgent need** to have a dedicated focus on the Indian Power Transmission sector. This has motivated to study and to strengthen the overall power transmission infrastructure of India.

1.4 FACTS OF INDIAN POWER TRANSMISSION SYSTEM

Table 1.2: Various facts of transmission sector in India

Region	Remarks
NR Import	Always remain power deficit on short term (NLDC, 2016)
SR Import	Non-availability of the corridor in WR-SR and ER - SR routes on a short term basis (NLDC, 2016)
WR Import	no power flow from ER to WR for short term (NLDC, 2016)
NER Import	facing congestion during winter months (NLDC, 2016)
Karnataka	Power deficit state due to unavailability of corridors (Krishnan, 2015)
Chhattisgarh	Power Surplus (Generation-30000 MW, Demand-3300 MW, Transmission-7000 MW (IBEF, 2013)
Maharashtra	270 MW yet to be utilized from Tiroda Generation Plant (CEA, 2016)

- Collapsing of transmission lines of 765 kV and 400 kV capacities in 2015 due to winds highlighted the fragility of the country's grid infrastructure (Sasi, 2015).
- The blackouts that happened in July 2012 exposed weak links in current infrastructure (Romero, 2012). The shutdown of even a single transmission tower resulted in a continuous grid failure in 2015 (Sasi, 2015).

The problem further aggravated by the fact that there are existing inefficiencies in the establishment of new transmission system infrastructure:

- Delays in TBCB projects, resulting in cost overrun and Time overrun (Kamat, 2015).

- Inadequate planning and long delays in getting legal approvals (Amarnani, 2013).

- Due to the further addition of 176 GW of renewable energy, power will aggravate more congestion to the current transmission infrastructure (Kamat, 2015).

- No transmission linkages to connect a power surplus state (Gujarat, 800 MW solar commissioned) to power deficit state (Magal, 2015).

CHAPTER 2 –LITERATURE REVIEW

2.1 SEARCH PROCESS

With the intent to probe the existing literature of the Indian Power Transmission system, the literature review is done by reviewing numerous research articles, manuscripts, reports, and orders. Literature reviewed from different sources is thematically collated as:

1. Power Sector in India
    a. Power Sector- general
    b. Indian Power sector performance before the reform
    c. Indian Power sector performance after the reform
2. Restructuring of the Power Sector
    a. Process of restructuring
    b. Impact of the reforms on the sector
3. Transmission System in India
4. Incapabilites in Power Transmission System
5. Planning in Transmission Sector

For a systematic and scientific exploration of literature related to the Indian Power Transmission System, a categorization framework has been developed. This categorization is based on five broad categories; namely, Power Sector in India, Restructuring of the Power Sector, Transmission system in India, Incapabilities in Power Transmission System, Planning in Transmission Sector. In other words, research papers, articles, and other supporting material have been searched and sorted as per the given categorization. The details are depicted in Figure 2.1.

Theme 1: Power Sector in India

Saini (2018) has discussed about the evolution of the entire power sector, including generation, transmission, and distribution. The author explained that the public entity commonly dominates the sector. It was further concluded that the power sector requires more development to boost economic growth.

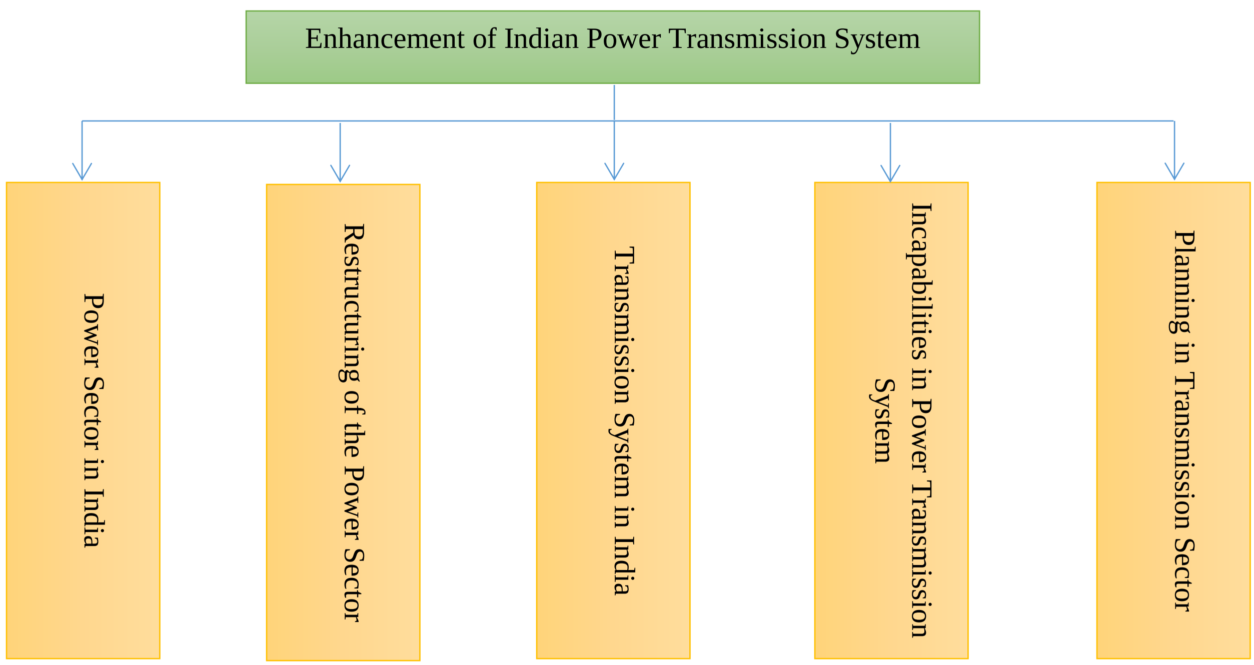


Fig.2.1 Categorization of Literature Review

Wang et al. (2015) have assessed Indian power companies' performance using Data Envelopment Analysis (DEA). The performances were evaluated in recent years and for the next consecutive years. The results showed that there were not any abrupt changes in the performance of the power companies. The study provided the past-present-future scenarios of the Indian power industry.

Bhattacharyya (2008) analyzed the requirement of power capacity expansion, investments, and issues related to funding to the power sector. The author emphasized that the electricity capacity would increase and reach up to 900 GW by the year 2030. It was further discussed by the author that the financial condition of the utilities is worsening. Therefore, investments and funding in the sector would be a challenge. The author further suggested that accurate forecasting, use of technologies, demand management, and engagement of franchisees would improve the performance of the sector.

Sharma et al. (2005), in their study, have assessed the sector's performance after the restructuring process by the Indian government. The study critically analyzed the success of sector reforms in terms of the country's social development. It was inferred in the study that the sector's performance is not as expected, and it further required efficiency improvement measures, demand management, etc. must be adopted for improvement.

Thakur et al. (2005) analyzed the benefits of the government's policy reforms introduced to reshape the power sector. This study also discusses the new provisions and features that has bought the alterations in the industry structure.

Nouni et al. (2008) estimated the costs incurred while generating power using conventional fuels such as coal, nuclear, hydro, etc. The authors also estimated the cost of transmitting and distributing electricity to different regions in the country. The study has uniquely attempted to identify the potential areas where generation based on renewable energy can be commercially feasible.

Pradeep et al. (2007) discussed the role of four different types of interoperability in the power system of the country. These include organizational, application, information, and technical interoperability. It was found that interoperability among various power grid systems is necessary to derive benefits out of the open architecture based future control centers.

Kannan and Pillai (2001) discussed the inefficiencies in terms of costs of SEBs functioning in India. The study has provided an analysis of the physical performance of the SEBs on various parameters such as technical efficiency, T&D losses, etc. They have also evaluated the performance on some aspects of institutional as well as organizational inefficiencies.

Ruet (2006) has assessed the profitability of the investments carried out in the sector from the viewpoint of micro-economics and macro-extrapolation. The study further compares the profitability of various investment strategies that can facilitate the generation capacity expansion in the country.

Bose et al. (2006) have empirically analyzed the cost of unutilized or unserved power in agricultural and industrial sectors. In this study, about 500 manufacturing companies and 900 framers were surveyed using two-stage random sampling in the state of Karnataka in India. The results provided a clear understanding related to the perceptions of consumers and their inclination to pay varied tariffs. The results showed that the economic loss to the agricultural sector due to power outages had been ranged from 1.9 to 3.6 as a percentage of the state domestic product, while in the industry it varies from 0.04% to 0.17% of state domestic product.

Theme 2: Restructuring of the Power sector

Rajkumari and Gayithri (2018) have assessed the performance of a complete power system in the state of Karnataka after the Karnataka Electricity Reforms Act (KERA), was introduced in the year 1999. A Performance index was computed using many technical and financial indicators. It was observed that indicators like peak deficits, installed capacity, revenue realization rate, and per capita energy consumption had been improved as compared to other states. Also, T&D losses have also reduced tremendously. The overall ranking of the state after the reforms has been improved from 8^{th} to 3^{rd} position.

Saha and Bhattacharya (2019) have analyzed the benefits of reforms in the state of West Bengal. The study also assessed the way reforms in this sector have impacted the capacity to become a power surplus state. It was inferred in the survey that the sectoral performance had been diminished due to the de-integration of the sector into public and private.

Veluchamy et al. (2018) have discussed reforms introduced in the power sector that have bought improvements in the sector. However, distribution companies are still facing a financial crisis. The study has identified various factors that lead to financial losses to the distribution companies. It discusses various policy initiatives required to reform the distribution sector of India.

Agrawal et al. (2017) critically evaluated various key features of the Electricity Act 2003 with special emphasis has been given to the losses in the distribution sector. The study has thoroughly discussed the Electricity Amendment Bill 2014. The study also emphasizes that there is a requirement to introduce new reforms in the power sector.

Rajan (2000) has studied and identified various factors leading to the sectoral reforms in developing countries. A case study of the country's Orissa State Electricity Board (OSEB) has been discussed to identify these factors. These factors are categorized as a contextual, trigger, and facilitating factors.

Dubash and Rajan (2001) have discussed in detail the political as well as social circumstances under which restructuring of the sector is introduced in the country. The study also examines about substantial failures were due to the state-led power sector. It also discusses various forces and actors that have led the power sector reforms.

Shukla and Thampy (2011) have discussed the electricity market and its competition after reforms. The paper has analyzed the market structure, probably as a key reason for the hikes in the prices of the electricity. The market power has been calculated using concentration ratios, Herfindahl–Hirschman index, Residual Supply Index, and Supply Margin Assessment.

Singh (2006) discusses the condition of the country's power sector before and after reforms. The study has intensively discussed the major amendments bought in the regulatory regimes after the reforms were introduced. The author has also discussed the impact of different issues, including issues related to multi-year tariff and pan access to electricity on the sector's performance.

Theme 3: Transmission System in India

Pandey (2007) have explained the five regional load dispatch center and their role in the power systems. The author has also discussed the functions and the operation of grid management in the country. The study also examines about various challenges faced by the grid network of the country.

Khan and Siddiqui (2017) identify an optimal location of the FACTS device by minimizing installation costs in a deregulated power system to remove the transmission grid's congestion in the transmission grid. The study has emphasized the thyristor-controlled series capacitor that has a better capability to transfer power. The placement of the capacitor in the congested transmission line is determined using a sensitivity analysis of the power flow.

Kirthika and Balamurugan (2016) have analyzed the transmission congestion challenges faced by Utilities. According to the study, this challenge can be dealt with FACTS devices that can control the flow of power lines. The study has developed an algorithm, which will be used to deploy to control the FACTS devices to be connected in the transmission lines.

Balijepalli et al. (2010) have discussed the benefits of introducing Smart Grids that have the capability to open new avenues as well as opportunities with financial implications. It has reviewed the current scenario of Smart Grid implementation in the Indian power market. The study has also discussed the initiatives related to the Smart Grid along with their impacts on the sector's performance.

Seddighi and Ahmadi-Javid (2015) have addressed the sustainability issue in the generation as well as transmission system. The model has considered the uncertainties related to the prices of fuel, power demand, and environmental emissions. While developing the mathematical model, various regulations, and policies related to sustainability in the power system. This includes social as well as ecological responsibility of the power grid.

Khan et al. (2014) developed a mathematical model based on the methodology matrix. This model addresses usage, transmission reliability, margin allocation, and loss. A modified Kirchhoff matrix has been developed to allocate usage. In order to allocate the transmission losses and Transmission Reliability Margin (TRM) of each transmission line to the generation systems, this study has also developed a loss allocation matrix and modified Kirchhoff matrix.

Kunz and Zerrahn (2015) developed a model that addresses the benefits of coordination required to re-dispatch among the transmission lines operators. For the study, a case study of the four geographical regions of Germany was considered, each region having a transmission line operators as an in-charge of the respective transmission networks.

Ravikumar et al. (2008) have discussed using knowledge-base to diagnose post-fault. The information related to line currents, line voltages, and their phasor values can be used after the detection of the faults. The approach discussed in this study can be used to diagnose any type of faults in the operations of the relays that can disturb the functioning of the neighboring line of the similar sub-station. This process has the capability to monitor or diagnose faults, which will ensure the robust operation of the entire power system.

Kanevce et al. (2013) has developed an OPA module of the electric transmission system comprising of nodes that are interconnected by the transmission lines. Long-term planning to develop the complex and robust electrical transmission networks can be done using the model proposed in this study. The model also provides information related to the number of networks and production facilities to be upgraded so as to fulfill the growing power demand.

Theme 4: Incapabilities in Power Transmission System

Xue and Xiao (2013) have analyzed the factors that can cause massive blackouts. The authors have emphasized the key role of developing a robust smart grid and better defense mechanisms to deal with severe black-outs. The study highlights the weak infrastructure, defense mechanism, and management structure of China. The study suggests to focus more on innovation to improve the reliability of the sector.

Nappu et al. (2014) have elaborated on many issues of the transmission system. The study has also discussed economic and optimal ways to dispatch power. The authors have also presented a scheme to manage congestions in the transmission network using OPF.

Mohapatra et al. (2006) have discussed crucial concerns related to risk management and asset management, which involve failure of equipment, rate of failures, network reliability issues, shut down of station. The study has also discussed various strategies to minimize cost, and risk, increasing the life of assets, improving performance, and reliability by optimally utilizing assets such as preventive maintenance practices, condition monitoring parameters, replacement decisions, condition monitoring.

Pérez de Andrés et al. (2004) identified various bottlenecks in Transmission efficiency, such as issues of overloading, outages, short circuit, etc. The study has discussed the benefits of Light Triggered Thyristors (LTT) for HVDC and FACTS to improve the performance of the transmission line. Utilization of Power

Electronics (power flow controller) in eliminating bottlenecks. The problem of overloading of the current power system could lead to bottleneck and reliability issues. The enhancement of power systems will be done by FACTS and HVDC.

Beckman (2013) has discussed the Regional Postage Stamp Method and the limitations of this method. The study has also discussed the advantages of using point of connection charging method and its implications of the overall power system. The study has compared the situation in an international context. The obstacle of power transactions at long distances can be eliminated using a novel cost allocation approach.

Min and Golden (2014) have discussed the statewide trends from 1970 to 2010 and examined the distribution of electricity, losses in transmission lines, and billing from the year 2000 to 2009. The data showing variations arising in the power losses due to state-wide elections were collected from the Uttar Pradesh state of the country. It was inferred in the study line losses are correlated to the politics, and they increase during the electoral competition in the state under the study.

Rahman and Khan (2007) have studied the feasibility of converting the double circuit ac line to a composite alternate current-direct current (ac-dc) line. The feasibility of the conversion was investigated considering minimal modifications in the existing transmission infrastructure such as line conductors, insulators, and transmission towers. The results indicated that the conversion could lead to a significant increase in the load capacity of the line by about 83.45%.

Theme 5: Planning in Transmission System

Kumara et al. (2014) have discussed key challenges in preventing cyber-attacks by identifying the impact of cyber threat, the discovery of threat, the source of threat, appropriate response to threat, degree of sharing the information, degree of collaboration, jurisdiction, inadequate international governance or regulatory framework. The study also explains various threat exposure in the entire power system. The authors have also assessed the adequacy of regulatory frameworks and standards for cybersecurity.

Bhandari et al. (2014) have summarized different mathematical models developed for renewable-based power systems. The study has discussed the non- linear characteristics such as voltage, current, and power projected by wind-based and PV-based power system. The study also discusses different MPPT models and techniques of the storage device. The design goals, such as minimizing generating cost of power, purchasing power from the grid, emissions, cost related to the life cycle, and maximizing the reliability of the power system, were also discussed.

Haller et al. (2012) have presented a framework that highlights the integration of decisions related to long-term fundraising in the generation and transmission sector of power systems. The framework also highlights the impact of the fluctuation of power supplies based on renewable energy. The study inferred that long-haul transmission and storage of power have a huge impact on linking the renewable sources of energy into the power system on a large scale. It was further observed the investments required for the transmission and storage of power is comparatively smaller than the investments required for the power generation.

Li and Chang (2015) have identified different barriers to implement region-based power interconnection. These barriers are particularly categorized as financial and institutional barriers. The authors have also developed a sub-model based on the financial aspect of international trade and transmission of power in the Association of Southeast Asian nations. It was further deliberated in the study that the trade pattern that is currently based on the existing infrastructure can be changed after establishing new transmission lines. This will assess determine the consumption of the new asset and hence, the financial feasibility of it.

Sharan and Balasubramanian (2012) have developed an optimization model that focusses on minimizing the capital costs related to the installation of new transmission lines to fulfill the forecasted demand of the target year. Various generation bottlenecks have been considered in the model, which comprises of limits to the availability of fuel, its transportation, limits of transmission of power via power transmission lines, and power generating capacity of different generating units.

Moreira et al. (2017) have acknowledged that transmission capacity expansion planning has not kept pace with generation capacity expansion. In this context, the study has presented a model that can co-optimize transmission expansion and renewable energy generation. The proposed model's applicability has been investigated using a real case study using realistic data of the Chilean system.

Hajebrahimi et al. (2017) have also acknowledged that the transmission expansion plan is a critical challenge under the smart grid environment. The authors have developed a non-linear economic model to investigate the impact of demand response resources. The model was developed using genetic algorithm II. The capability of the proposed framework has been confirmed by carrying a several analyses.

The detailed literature review has been provided in Table A2 in Annexure.

2.2 IDENTIFIED BARRIERS OF IPTS

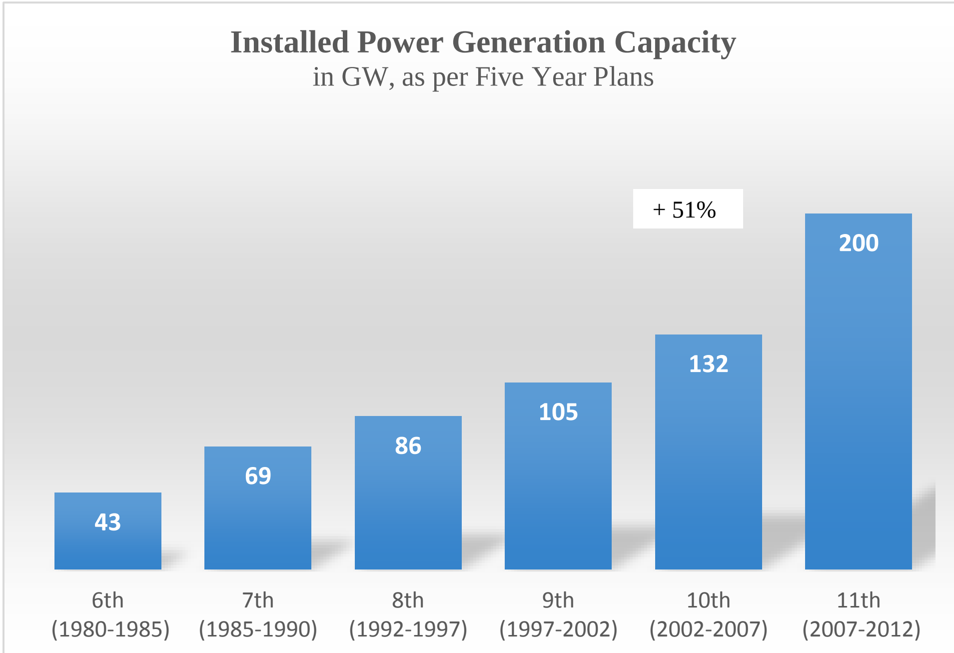
From the extensive literature review under various themes, the following barriers of IPTS have been identified:

2.2.1 Absence of strategic planning by Govt.: Transmission planning is a continual process of determining the expansion prerequisites of the transmission sector. Growing demand, additions to generation, and the need to strengthen the existing system will ultimately require more transmission capacity (MOP, 2012). The Central Electricity Authority (CEA) is the nodal planning agency for preparing five-year plans for the power sector. Installed capacity and peak demand of the country, planned by CEA is presented in Table 2.1 below. Presently, transmission capacity is insufficient relative to generation capacities and load requirements

(Singh, 2013). Growth in transmission capacity was only 27%, compared to 50% growth in generation capacity during the years 2011–2016, as shown in Fig. 2.2. According to the National Electricity Policy, the power transmission system is considered to be a vital link that must be in place before the addition of any generation capacity (CAC, 2015). The 20-year (2016-36) perspective Transmission Plan Report was prepared in December 2014 by CEA, the Technical wing of the Ministry of Power, to bring focus on the transmission sector. This report was amended in January 2016 with more precise inputs on power transmission planning. Transmission planning is done centrally for ISTS and at the level of states for InSTS.

Table 2.1: Total installed Generation Capacity and Demand

Year	Installed Generation Capacity (GW)	Peak Demand (GW)
9th Plan (1997-2002)	105	75
10th Plan (2002-2007)	132	101
11th Plan (2007-2012)	199	130
12th Plan (2012-2017)	326	159
13th Plan (2017-22)	377	239
14th Plan (2022-27)	750	369
15th Plan (2027-32)	1047	536
16th Plan (2032-36)	1337	720



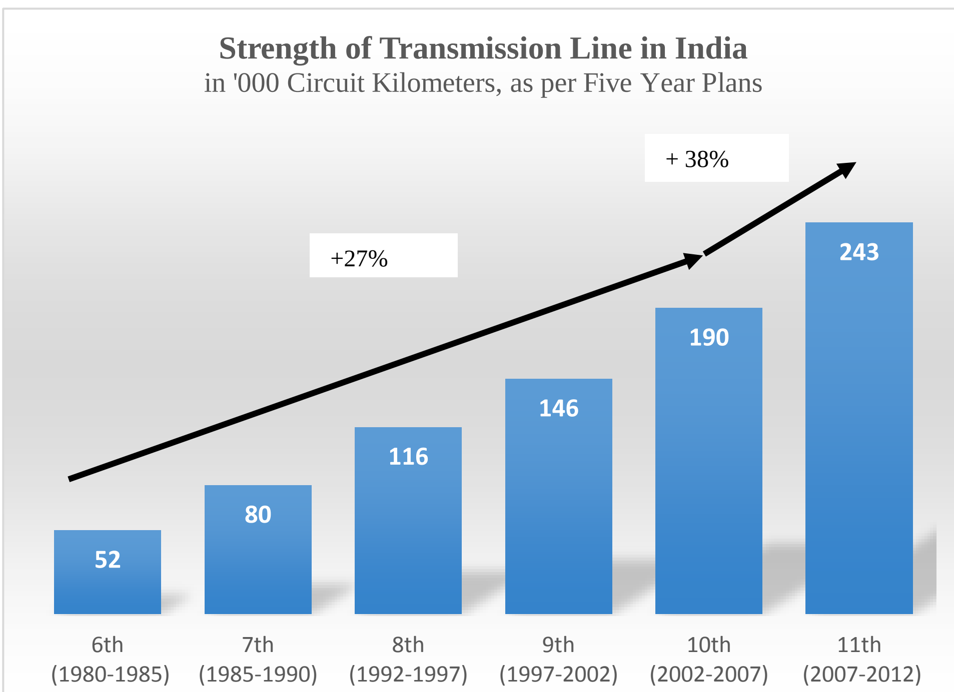


Fig. 2.2. Comparative Analysis of Generation and Transmission capacities (Source: Planning Commission, 2014)

2.2.2 Low investments in Power Transmission

Despite investing USD 75 billion in the power sector within the period of the 12th and 13th Five-Year Plans (2012–2022), the funds allocated to the transmission sector are still insufficient. This has resulted in the unavailability of required transmission networks in a number of states (Bhattacharyya, 1994). It has been estimated that at least half of the total investments of the power sector must be made in transmission. The ratio stands at only 30% in India (Singh, 2013). For the immediate addition of transmission capacity, financial limitations have been seen as one of the major bottlenecks (Sanghvi, 1991). Resource-rich areas like Chhattisgarh are witnessing substantial industrial development and a surplus of power. However, the transmission infrastructure in the state is still inadequate (Kovendan and Sridharan, 2017).

To add a 90,000 circuit-kilometer (ckm) of 220–765 kV lines, substation with a capacity of 154,000 MVA and a national grid with a capacity of 27,350 MW are required during the years 2017–2022, and this requirement will increase with increasing demand. Thus, there is an urgent need to invest in the IPTS to add more power evacuation capacity.

2.2.3 Fewer private players in Transmission

In 1991, the government encouraged private enterprises to participate in the power sector of the country (Singh, 2013). Since then, the generation sector has been de-licensed resulting in continuous generation capacity additions. Policymakers encourage captive production (localized source of power) to increase total generation. Private captive producers were advantaged by the Electricity Act 2003, which opened the generation sector. Therefore, captive producers can serve numerous consumers in the bulk market by acting as private generators. Similarly, distribution companies can purchase power from private producers competing with state utilities (Joseph, 2010). Thus, the private sector has contributed to adding generation (to 35% of the total) as compared to transmission, where policymakers have not focused on private participation (MOP, 2005).

Adding transmission capacity poses a major challenge for IPTS in a de-licensed regime (Bhattacharyya, 2007). As per the 12th Five-Year Plan (2012–2017), approximately USD 35 billion of investments are needed in IPTS. The public utility had planned to provide about USD 19 billion and the remaining USD 16 billion were planned to come from private players (Singh, 2013). However, private participation in the transmission sector constitutes only 3% of the total transmission capacity (CAC, 2015). As a result, to add transmission capacity, funds are mainly gathered from budgetary allocations, internal accruals from public-sector undertakings, and borrowing (Planning Commission, 2014). Competitiveness based on costs and quality of the project decreases due to the less number of private players. The Power sector in the country faces a shortage of financial resources in the center and state utilities (Gupta and Sarvat, 1998). To attract private sector participation, an initiative was taken in the transmission sector in the year 2000, when the Central Government issued guidelines under joint venture and independent routes. However, the sector has not yet seen much private participation (Planning Commission, 2014).

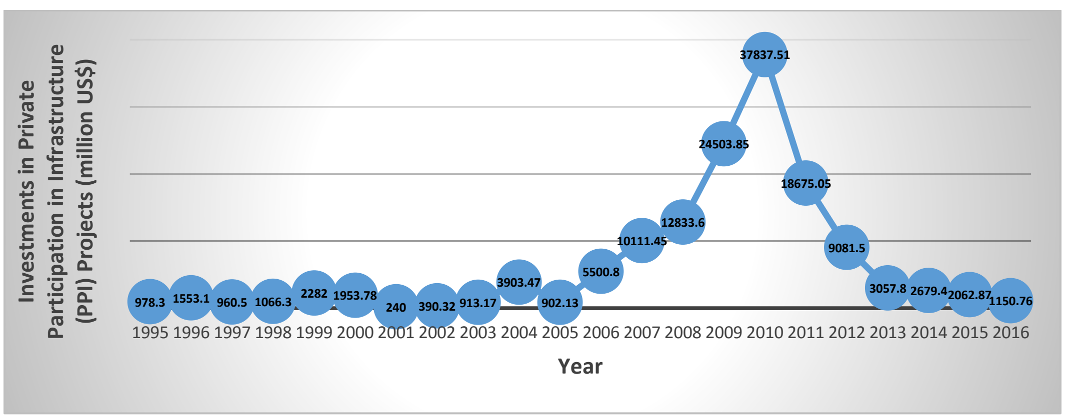


Fig. 2.3 Public Private Partnership in Power Sector in India (Source: World Bank, 2016)

Fig. 2.3 depicts the unsteady investments attracted by the Power sector in the last 20 years. Investments were mostly attracted during the period when policymakers were viewing the revival of the sector through generation. The entire focus of

Public Private Partnership (PPPs) was on power generation, with the transmission and distribution sectors left out. Policy reforms are necessary to make PPPs successful and ensure that they contribute to the aims of developing the grid, fulfilling the demand, and effectively use of generating capacity (Singh, 2013).

2.2.4 Transmission congestion

According to the Indian Electricity Grid Code 2010, congestion in the transmission line is a situation when the load of the transmission network exceeds its available transfer capability (Swami, 2013). In the wake of the de-licensing of generation and the recent surge in power generation, IPTS faces serious transmission congestion arising from increasing demand, waning networks, and linking renewable energy into the grids (Kumar et al., 2004). Ideal Energy Projects Limited (IEPL) commissioned a 270 MW thermal power plant, and Maharashtra state commissioned a 1980 MW Tiroda Generation Plant in May 2013 and June 2013 respectively, without commissioning of the required number of transmission lines (CAC, 2015), resulting in congestion in the existing networks.

In 2014-15, the Indian Energy Exchange (IEX) experienced the impact of congestion, which was estimated at 3.1 × 109 kWh loss of electricity (Bahuguna, 2015) as shown in Fig. 2.4, enough to serve the monthly demand of Delhi or Maharashtra for more than a week.

Congestion and choking lead to power interruptions, outages, and deficits and add to significant power losses (Xue and Xiao, 2013). As a result, power demand is not fulfilled even if surplus power is available elsewhere (Bahuguna, 2015). Congestion also limits the capacity of the network and meddles with the efficient power exchange from an arrangement of power transactions (Nappu et al., 2014; Brunekreeft et al., 2005). The current transfer capability of the transmission network ranges between 20 and 30 percent of its total transmission capacity (CAC, 2015).

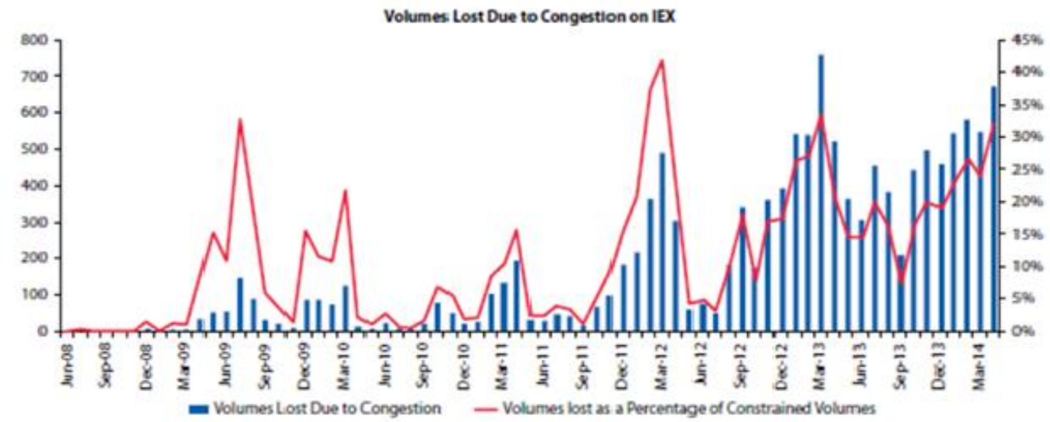


Fig. 2.4. Total Volume Lost due to congestion on IEX from 2008 to 2014 (Source: IEX, 2014)

Most of the states do not purchase power as per the plans of power sourcing due to transmission congestion. This results in a deficiency in one system and surplus on another. It also inflates the cost of power, which reached to USD 0.17–0.31 per kWh during summer season (Jai, 2016). There is thus an urgent need to make a transmission system robust to mitigate congestion in the transmission network (CAC, 2015; Verma, 2016).

2.2.5 Transmission Loss

The difference between total power generated and power distributed is known as transmission and distribution (T&D) losses. It generally covers technical and commercial losses. Technical losses occur because of losses in the energy in the electrical equipment such as conductors, transformers used in transmission lines, sub-transmission lines, and distribution lines. Commercial losses occur at the distribution side due to bypassing meters, use of error-prone meters, and errors in meter reading (Bhattacharyya, 1994).

Fig. 2.5 reveals that power losses in India are higher than those of other countries, and are estimated to be approximately 21.5% of total power available. Such losses are very high if compared to developed countries like the US, where T&D losses are about 6% (Omer et al., 2013). The cost of T&D losses is projected to account for 1.5% of the country's annual GDP. Out of these cumulative 21.5% T&D losses, transmission losses are approximately 6% due to highly leaking and aging transmission lines (Sachchidanand, 1999; CEA, 2014b). Aggregate technical and commercial losses in India are estimated at 27% (Planning Commission, 2014). These losses further strain the finances of its public electricity providers (Min and Golden, 2014; Omer et al., 2013). For example, in the country's largest state Uttar Pradesh, it was found that 29% of the power distributed from 1970 to 2010 remained unbilled due to technical losses, irregularities in billing, and theft. Such losses cumulatively estimated to be about 300 million megawatt-hours (MWh). Transmission losses in Uttar Pradesh are continuously increasing since the 1970s despite several policy initiatives and measures to minimize power theft (Min and Golden, 2014).

2.2.6 *Delay in project execution*

The Indian transmission system faces serious issues related to rights of way (ROW), land acquisition, forest clearance, and statutory approvals. ROW is a key reason for the delay in new capacity addition (Rahman and Khan, 2007). The licensees are empowered with ROW according to the Electricity Act 2003. However, it is uncommon to execute transmission projects without any delays due to ROW or land acquisition issues (Omer et al., 2013; Schmidt and Lilliestam, 2015). Due to delays, the gap between the planned transmission lines and lines actually achieved is widening (Omer et al., 2013; Singh, 2013). There also are various inherent risks associated with overhead line projects, such as disproportionate allocation of budget to the projects, lack of coordination among key stakeholders, lack of skilled personnel, and inefficiencies in the execution of projects that lead to further delays (Moazzam Jazi et al., 2015). In 2011, more than 120 transmission projects were delayed as developers failed to get timely approvals. In the same year, the Power Grid Corporation of India (PGCIL) was unable to spend its planned USD 901.88 million for building the transmission lines between states primarily due to land acquisition and ROW problems (Singh, 2013). The list of delayed line and substation projects totals 378 (MOP, 2017a,b), as shown in Table 2.2.

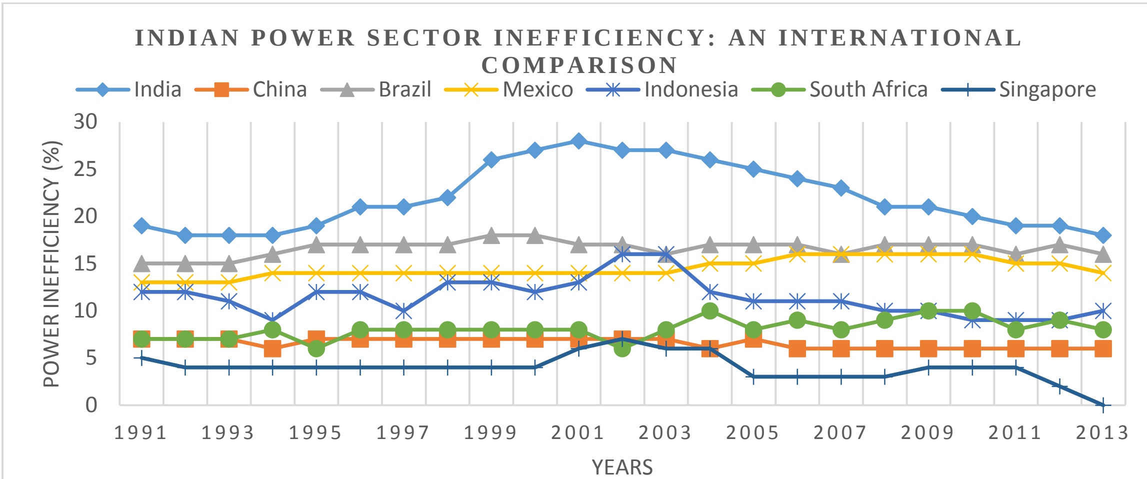


Fig. 2.5 Power sector inefficiency in terms of Transmission and Distribution (T&D) losses (World Bank, 2016)

Table 2.2: Delayed Transmission Line and Substation Projects

Line/ Substation	**Total Projects (A)**	**Commissioned (B)**	**Reason for delay/still known (C = D)**	**At least one of the reasons for delay (D= E+F+G+H+I)**				
				RoW (E)	Forest Clearance (F)	Force Majeure (G)	Legal (H)	Other (I)
Delayed								
Transmission Line	552	199	93	52	23	7	11	-
Substation	16	1	2	-	-	2	-	-
Stalled								
Transmission Line	7	N.A.	7	-	-	-	7	-
Substation	2	N.A.	2	-	-	-	2	-

Source: Ministry of Power, 2017

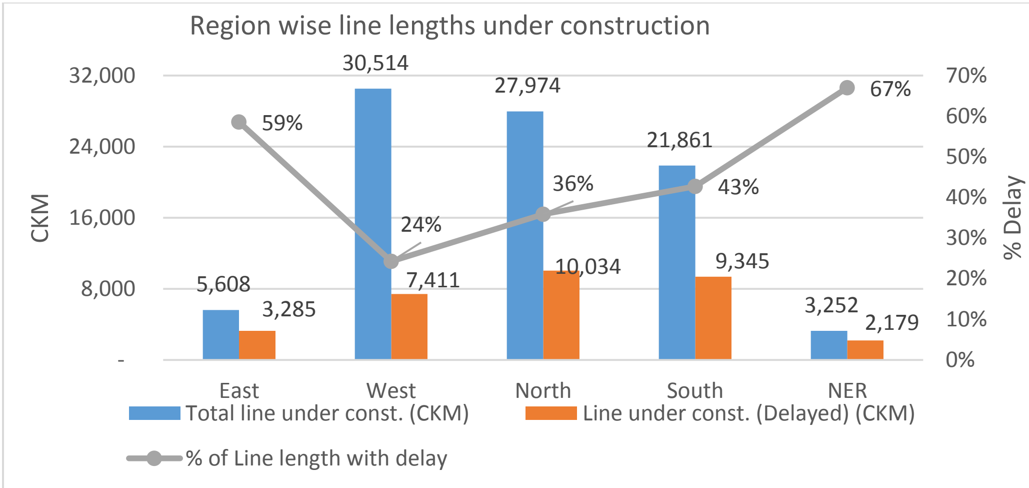


Fig. 2.6(a) Percentage delay in Transmission line projects (Source: MOP, 2017)

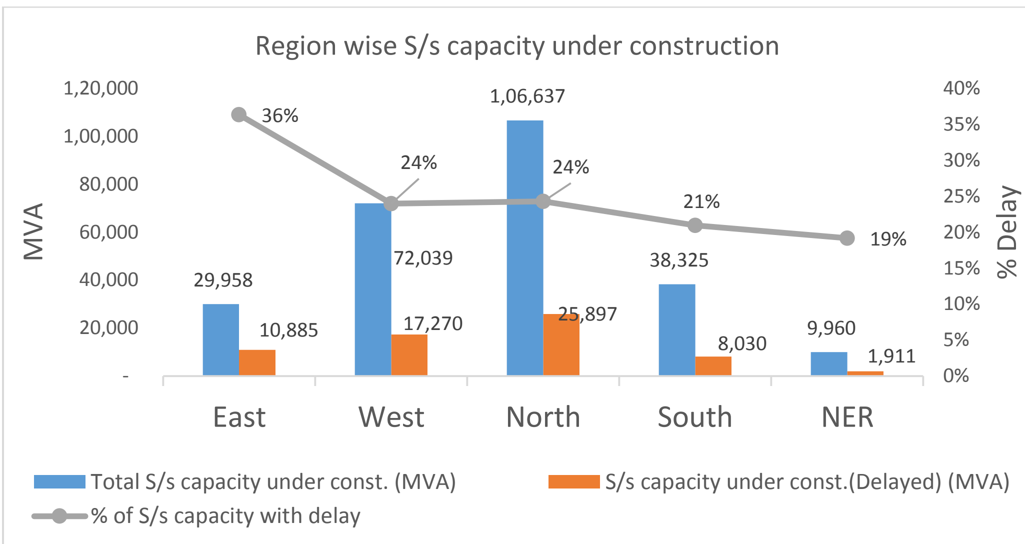


Fig. 2.6(b) Percentage delay in Substation projects (Source: MOP, 2017)

The Ministry of Power (MoP) has acknowledged ROW as a major issue and emphasized its implications for improving the national grid. Also, CEA guidelines emphasize ROW as a key challenge to setting up new transmission lines (Singh, 2013). Fig. 2.6(a) and 2.6(b) demonstrate the percentage delay in Transmission Line and Substation projects, respectively.

Facing ROW issues, transmission infrastructure developers are compelled to use alternate routes, leading to an entire revision of the project plan and further escalating the costs and timelines. For instance, in order to draw power from the Koodankulam Nuclear Power Project (KKNPP), Kerala government has planned to reroute the 310-km-long transmission corridor on the Edamon to Pallikkara stretch; 170 km of this corridor was stalled in view of the absence of ROW clearances (Singh, 2013).

2.2.7 Failure to upgrade technology

India has an immediate need to upgrade the degree of innovation and technology in the power sector as a whole (Singh, 2013). There is less technological awareness among transmission utilities and low investment in research and development. Technology utilization must be encouraged to meet demand, electricity rural areas, manage load optimally, and reduce financial and technical inefficiencies (Samantaray, 2014).

Table 2.3: Techno-economic Analysis of Power Transmission Line

Items	% of project cost	Cost of New Transmssion Line with *ACSR	Cost of New Transmission Line with *HPC	Differential (%)
		in USD million		
Tower Cost	20%	6.764	5.862	-13.3%
Conductor Cost	38%	12.626	37.203	195%
Erection and Foundation	15%	4.96	4.81	-3%
Other costs	27%	8.718	8.267	-5%
Total Cost (100 kM Line)	**100%**	**33.06**	**56.142**	
Transfer Capacity		**3400 MW**	**6800 MW**	**100%**
Cost in USD/MW/kM		**972.38**	**828.229**	**-15%**

*ACSR is
*HPC is High-Performance Conductor
Source: Singh (2013)

Currently, there are no guidelines for the utilization of these technologies. The sector focuses instead on lowering costs through competitive bidding. The standard bidding documents, varying from state to state, allow changes in the route and tower design as per the geography of the region. However, no provisions or policies are available in these bidding documents that allow or incentivize the use of any new technology or construction methods. Table 2.3 shows the techno-economic analysis of a transmission line.

2.2.8 Grid instability due to Renewable Energy:

India is the third-largest greenhouse gases (GHG) emitter in the world. Fig. 2.7 shows the share of the power sector in GHG emissions. It can be inferred from the figure that the generation of electricity is the highest contributor of GHG emissions among all other sectors. In the Paris Agreement, India has pledged to reduce its emissions share by 33-35% by the year 2030 (Timperley, 2019). To reduce the GHG share, there is a shift of power generation using renewable sources from fossil fuels.

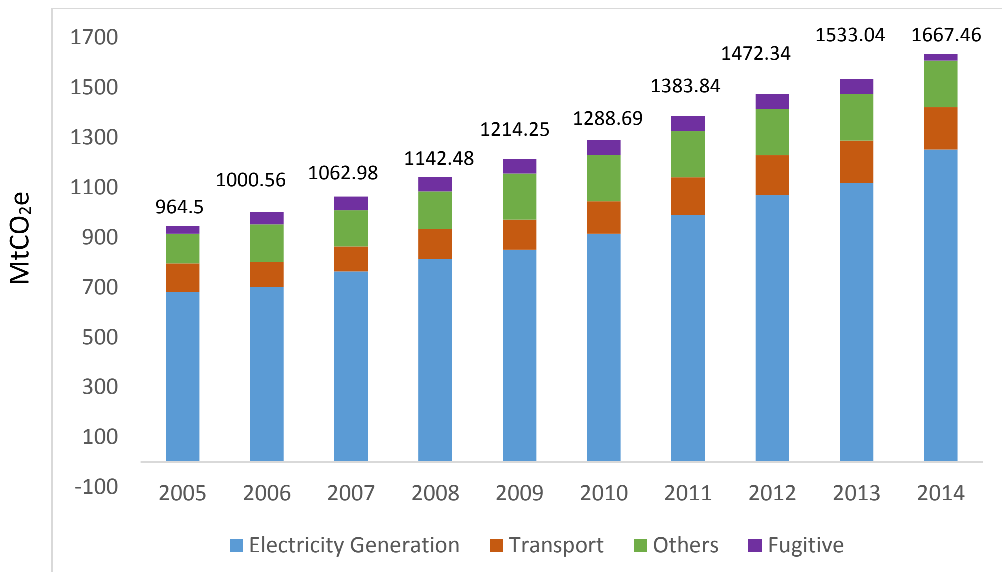


Fig. 2.7 Emissions from the power sector (Ananthakumar and Malik, 2017)

Green and clean sources characterize renewable sources of power. Although such resources have tremendous potential to meet future demand, but their share in developing countries like India is meager as compared to fossil fuel sources. The electricity using renewable energy is generated from a gamut of technologies such as solar, wind, hydro and bioenergy. India has the potential to generate approximately 1000 GW of power using renewable sources. However, currently, only 64 GW of power is generated using renewable resources in the country (Kumar and Pal, 2020). The portion of renewable energy is projected to rise in India by 91% from 2017 to 2022, as the share of thermal generation declines. Bringing higher shares of renewable electricity into the existing energy mix is a fundamental concern due to variability (intermittency) in its nature (Kanase-Patil et al., 2010). The integration of cleaner, green, and reliable sources of energy may have a noteworthy influence on the existing transmission system. Renewable energy needs to be connected to the main grid but cannot support the entire network by themselves (Banerjee et al., 2013).

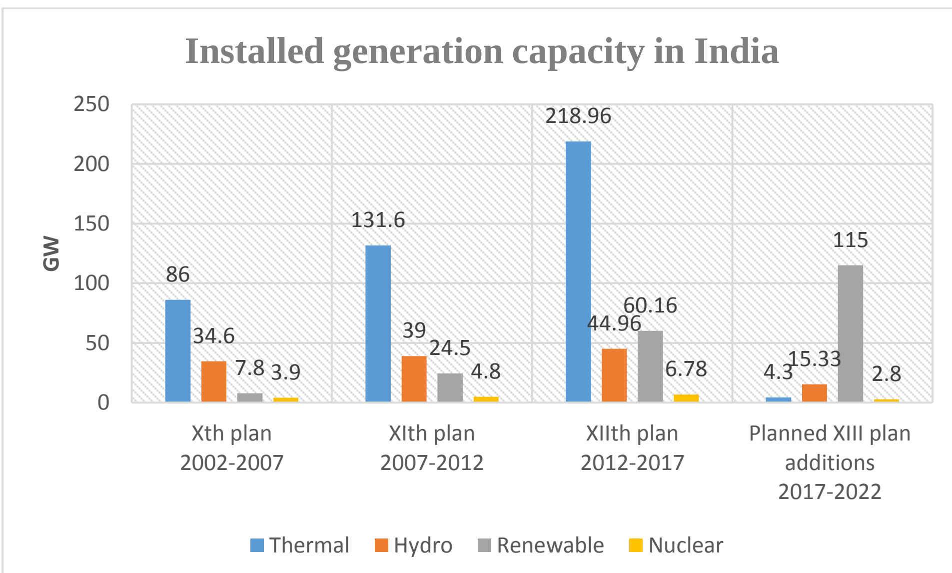


Fig. 2.8 Share of renewable energy sources per year

Operators and planners of the power system are experiencing major bottlenecks in integrating renewable energy sources into power grids (Smiti, 2017). The technical challenges include power quality, power fluctuations, storage issues, protection issues, constraints to accommodate renewable energy systems in existing transmission grids, and non-technical issues such as lack of skilled workers (Sandhu and Thakur, 2014). Fig. 2.8 depicts the share of renewable energy sources per year. Thus, power generation from renewable energy sources must be integrated into the grid through control measures (CAC, 2015). Fig 2.9 indicates the growth in the share of various sources of renewable energy in the electricity generation from the year 1990 till 2017. It can be inferred from the figure that hydropower remains the largest source of renewable power. However, there is substantial growth in bio, wind, and solar energies since the year 2000, which has lowered the share of hydropower.

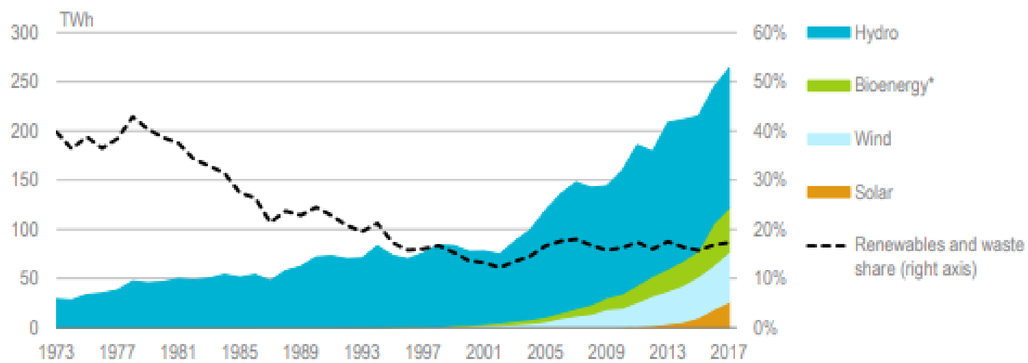


***Fig. 2.9** Share of various sources of renewable energy in electricity generation (IEA 2019)*

2.2.9. Poor performance and financial health of Utilities

The state utilities of India are experiencing heavy financial losses because of their poor financial performances. The key reasons for poor performances are rising debt to equity ratios (from 10:1 to 20:1) charging non-remunerative tariffs to some consumers, poor collection rates, and an increase in input costs (Bhattacharyya, 1994). The debt of the power sector reached USD 75156.89 million in 2013 (Pandey, 2015). The poor financial health of utilities, requiring subsidization from the government, accounts for about 1.5% of national GDP (Thakur et al., 2004). This is reflected in a large gap between national average generation costs (currently INR 3.50 per kWh) and the average realization from consumers (currently INR 2.50 per kWh), and this gap is increasing (Thakur et al., 2004). These conditions adversely affect the utility's day-to-day performance due to the lack of adequate revenue generation (Schramm, 1993). They also affect the utility's ability to raise capital investment for system improvement. This is reflected in the low investment in the sector by the states, predominantly in the transmission sector.

CHAPTER 3 –RESEARCH METHODOLOGY AND SCOPE OF STUDY

3.0 BUSINESS PROBLEM

Power evacuation has become a significant issue for our country. Indian Transmission networks are inadequate, which has put immense pressure on the existing network to transfer power, resulting in congestion and chocked Transmission networks. (CEA, 2016; Xue and Xiao, 2013; Singh, 2013).

Table 3.1: Various issues persisting in the IPTS

Issues	Intensity of Loss
Power Deficit in India (2012-13)	USD 68 billion losses in GDP (0.4% of GDP) (Singh, 2013)
Non-closure of contracts	USD 7.23 billion (Thakkar, 2014)
Losses of Generation due to transmission capacity bottlenecks by plants supplying electricity to (SEBs) under PPA	Loss of 1.93 billion units (Mohammad, 2013)
Losses in Generation due to inadequate transmission capacity (Tirunelveli and Udumalpet, Tamil Nadu)	Loss of 559.03 Million units per annum (Singh, 2013)
Power losses during transmission	4-6% out of 21% of the total energy lost (Sachchidanand, 1999; CEA, 2014)
Delays in transmission projects	As many as 120 transmission projects have faced delays due to ROW issue (CEA, 2018)

3.1 RESEARCH PROBLEM

Although studies are undertaken in the power system as a whole, however, a systematic approach to eliminate existing constraints of IPTS is still conspicuously missing.

3.2 RESEARCH GAPS

Although in existing literature, various studies about identifying barriers in IPTS have been conducted, stating them as significant bottlenecks to the enhancement of IPTS. After reviewing the literature, the following research gaps have been emerged out:

1. Criticality of each barrier on IPTS is not known
2. Measures to eliminate the barriers of IPTS are not known

3.3 RESEARCH QUESTIONS

This study will help in addressing the following research questions, which have been coming up during the literature review. Answering these research questions is significantly required to enhance as well as to strengthen the IPTS.

1. Which of the identified barriers of IPTS are extremely critical?
2. How to eliminate the critical barriers of IPTS?

3.4 RESEARCH OBJECTIVES

1. To identify the critical barriers among the identified barriers
2. To develop strategies for eliminating the critical barriers of IPTS

An attempt was made to prioritize barriers to ascertain the critical barriers of IPTS. Furthermore, various strategies have been suggested to eliminate these barriers to enhance and strengthen the Indian Power Transmission System. The proposed study has laid to a foundation of assessing the identified barriers to PTC and PIT at various stages of the Indian Power Transmission System (IPTS). The assesments of IPTS barriers will assist in achieving Growth, Survival, and Profitability for the sector while abiding the legislative regulations related to its operations.

This study will showcase the criticality of the barriers persisting in IPTS and further proposes the adoption of various strategies to eliminate these barriers from the system.

3.5 UNDERPINNING THEORY OF THE RESEARCH

The foundational theory used in this research is the "Theory of Constraints (TOC)." This theory identifies the most important constraint in the system that limits the system in achieving the goal. It also improves the constraint using a systematic way so that it no more is a constraint of the system. TOC was developed by Dr. Eliyahu Goldratt in 1984 (Pegels and Watrons, 2005).

This theory uses a systematic technique to improve the system. It assumes that every system comprises of multiple activities that are linked to each other, out of which one activity is a constraint. One of the appealing characteristics of the TOC is that it inherently arranges the activities according to their priorities.

The detailed literature related to TOC has been provided in Table A3 in Annexure. According to the literature, TOC has benefitted both manufacturing as well as service industry. It has been applied and eliminate the constraints of diverse areas such as project management, performance measurement, total quality management, etc. In this study, the benefits of TOC will be extended to the Power industry and, in turn, will be added to TOC literature.

Literature has reported about the organizations that have adopted TOC techniques. Many organizations confirmed that TOC has improved the output while minimizing the constraints. Benefits achievable through adopting this approach are lower lead-time, lower cycle-time, lower inventories, and improved productivity and quality. Hence, TOC-brings change at three levels: the mindset, measures, and methods.

TOC consists of basically three components, i.e., logistics branch, performance measurement system, and problem-solving or thinking process. TOC works on a system that consists of various constraints wherein the *System* is a set of arrangements of things that are connected to each other. The objective of any organization is to increase profitability, but the constraints present in the system limit this goal.

Thus, it is necessary to eliminate the constraints from the system. TOC is a systematic approach to organizational problems that are solved by its “5 focusing steps”. The five steps of TOC include (Mabin et al., 2001):

1. *Identify* the constraint(s): Recognize the critical limitation of the system that confines the degree at which the objective is achieved.
2. Decide how to *exploit* the constraint(s): Eliminate the constraints and improve the output of the systems using existing resources.
3. *Subordinate* everything else to the decision taken in step 2: Review all other non-constrained resources that are aligned with the constraint and supporting it.
4. *Elevate* the constraint(s): If the constraint still exists, take further action to eliminate and break it by taking strategic actions.
5. Do not let *Inertia* cause the next constraint: After the constraint is eliminated, the system needs to be checked for the new constraint with the subsequent action for its elimination.

It is a five focusing steps based technique that is used to identify problems in the system, devise advanced solutions, and finally, successfully implement these solutions. TOC includes various sophisticated problem-solving methodologies and has been widely used in many industries. These include the Drum-Buffer-Rope (DBR) technique, Thinking Process (Mabin et al., 2001), and Throughput Accounting (Motwani et al., 1996; Ioannou and Papadoyiannis, 2004). However, after studying this theory in detail, it was observed that this theory has various limitations that are pointed as follows:

1. In the case of DBR technique, since the non-constrained resources of the system have to work at the pace of the constraint, the full capacity of non-constrained resources is not utilized. This may again lower the overall throughput of the system and causes local efficiency ratios to suffer.
2. While suggesting the strategies to eliminate the constraint, expenses of implementing such strategies are not considered.
3. There may be cases where there is more than one equally critical constraint persisting in the system. This theory does not allow to consider more than one constraint at a time. This increases the time and costs of eliminating the constraint from the system.
4. The action plan set to eliminate the constraint is not validated, resulting in the ambiguity of whether such a plan will increase the performance of the system and by how much.

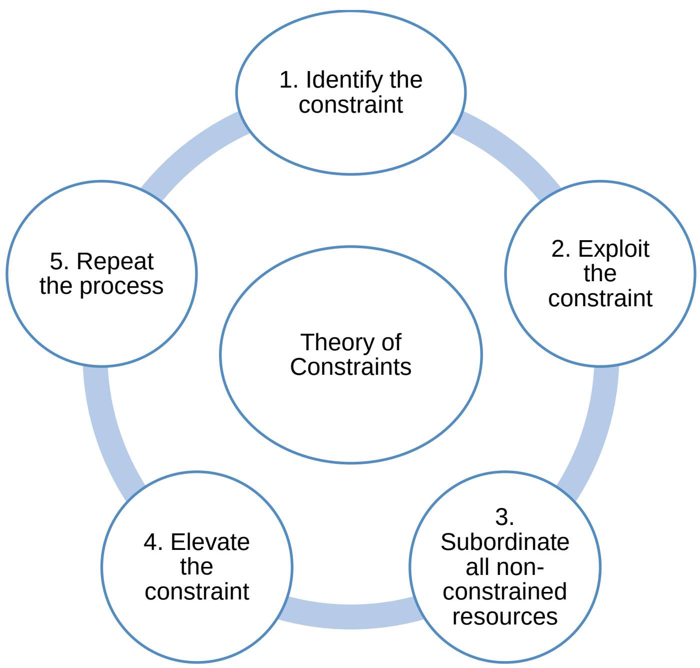


Fig. 3.1. Theory of Constraints

3.6 RESEARCH FRAMEWORK

To depict various planned phases and steps of the research accompanied by the methodologies the accomplishment of research objectives, a pictorial process for

IPTS Enhancement has been prepared, as shown in Fig. 3.2. The entire research is divided into two phases. Each phase has been explained in detail in this section.

3.6.1 PHASE 1: EVALUATION OF CRITICALITY OF BARRIERS

In this phase, the barriers will be extensively prioritized and ranked using the Analytic Hierarchy Process (AHP). The ranking of the barriers will be done based on various criteria, namely, costs impact, social impact, and time impact. This stage will provide critical barriers to decision-makers of the sector that need immediate attention to eliminate bottlenecks from IPTS, as shown in Fig. 3.3. Fig. 3.4 summarizes sequential steps and methodologies involved in this phase.

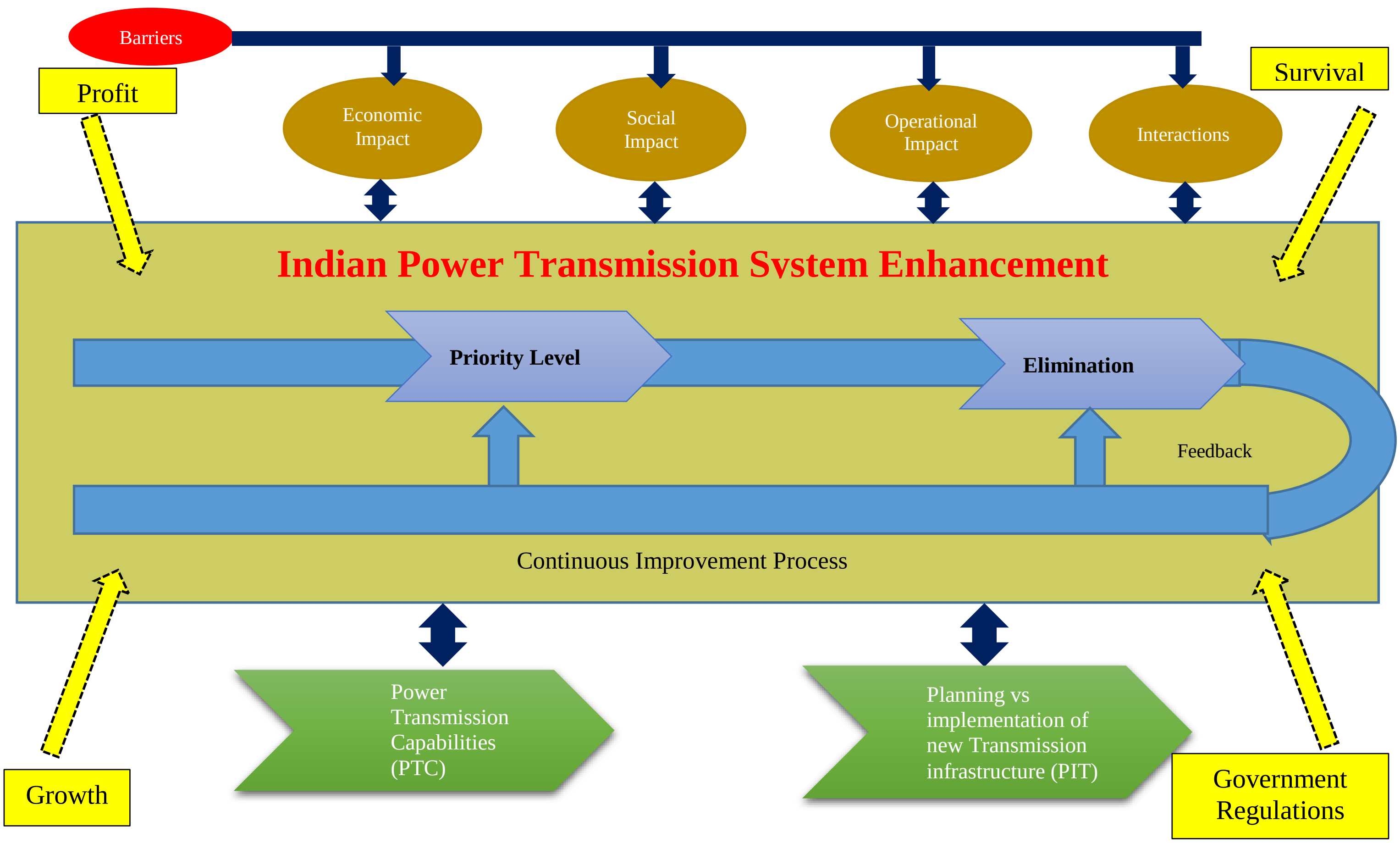


Fig. 3.2. **Process of IPTS Enhancement**

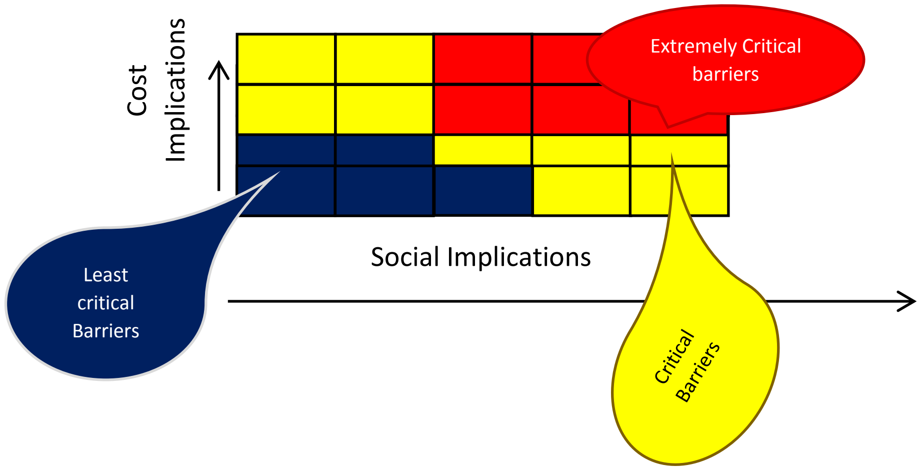


Fig. 3.3. **Various categories of barriers identified in the research**

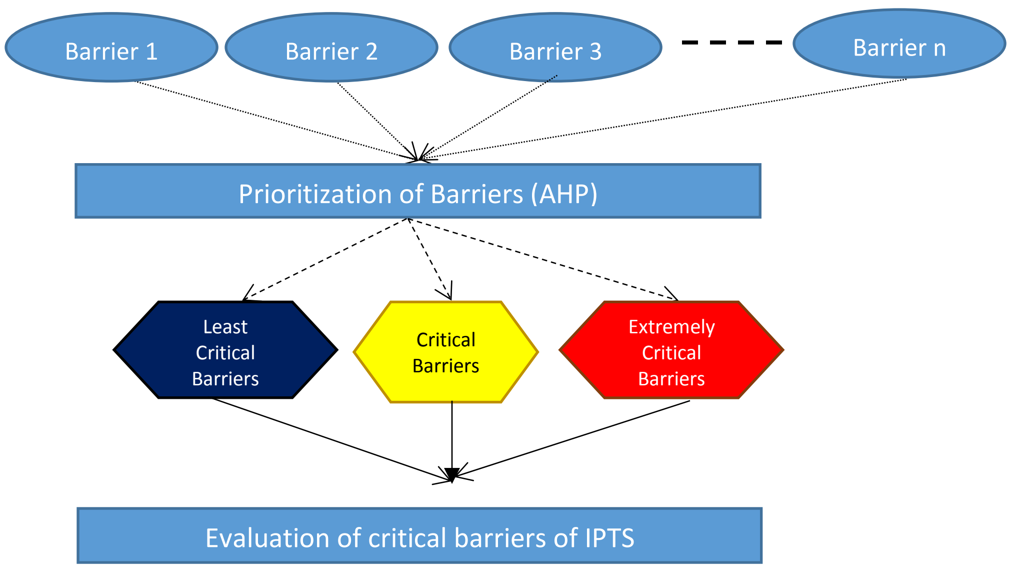


Fig. 3.4. Steps for Phase 2 of the research

3.6.2 PHASE 2: STRATEGIES TO ELIMINATE THE BARRIERS OF IPTS

This phase will mainly focus on eliminating the critical barriers of IPTS. Subsequently, an attempt will be made to identify various strategies that must be adopted by the Power Industry, which can help the system to remove these barriers. The strategies to eliminate critical barriers will be identified using the Thinking process of TOC theory. These strategies will help to remove the extremely critical barriers from the system. At this phase, various strategies are identified, and their impact in terms of minimizing barriers will be studied.

The various planned phases and steps of research, along with the methodologies for the accomplishment of research objectives, a research framework has been developed and summarized, as shown in Fig. 3.5.

3.6 RESEARCH OBJECTIVES AND PROPOSED METHODOLOGY

Table 3.2 indicates the methodology used under each objective considered in this research.

Table 3.2: Research Objectives and Proposed Methodology

Research Objectives (ROs)		Proposed Methodology
Modeling of Barriers		
RO 1	To identify the critical barriers among the identified barriers	Analytic Hierarchy Process (AHP)
Strategies Identification		
RO 2	To develop strategies for eliminating the critical barriers of IPTS	Thinking Process (TOC)

Objective 1: To identify the critical barriers among the identified barriers

This objective identifies the severity level of the barriers to IPTS. This is done by using the Analytic Hierarchy Process (AHP) to sequentially arrange the barriers from the most severe to least severe barriers. The AHP is first introduced by Saaty (1980). Many researchers have used this methodology due to its mathematical complexity. Another advantage of using such a technique is the fact that obtaining data for this technique is quite easier. It is a decision support tool that helps in ranking alternatives of the study based on their priority and solves complex problems.

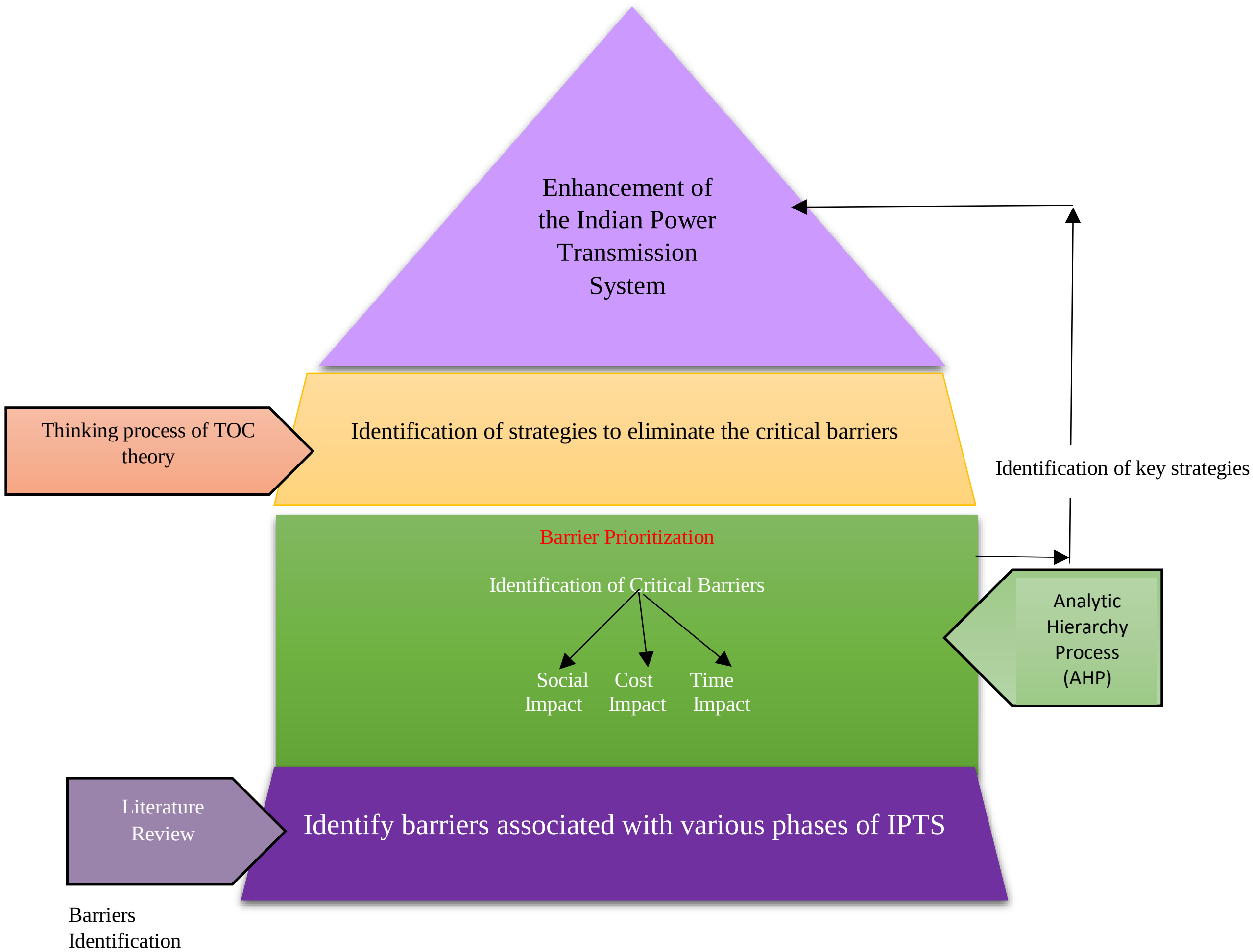


Fig. 3.5. Framework of Research

It comprises of goals, criteria, sub-criteria, and alternatives. The data is collected through pair-wise comparisons matrices. These comparisons help in computing the weights of the alternatives, which show the importance of each alternative.

Objective 2: To develop strategies for eliminating the critical barriers of IPTS

This paper has sequentially applied the Thinking Process in the Power Transmission System (PTS) of the Indian power sector. This is the first study in the literature that addresses the barriers persisting in the Indian Power Transmission System (IPTS) using TOC.

CHAPTER 4 – IDENTIFICATION OF CRITICAL BARRIERS OF IPTS

4.0 INTRODUCTION

In total, nine key challenges that are persisting in the IPTS for many decades were identified through a rigorous literature review, as discussed in Chapter 2. These challenges include (i) absence of strategic planning by the government, (ii) low investments in power transmission, (iii) fewer private players in transmission, (iv) transmission congestion, (v) transmission losses, (vi) failure to upgrade technology, (vii) delay in project execution, (viii) grid instability due to renewable energy, and (ix) poor performance and financial health of utilities. Once the barriers of IPTS are identified, it is necessary to analyze them and develop strategies for minimizing their impact. However, attempting to minimize the barriers at one go may result in resource allocation issues as well as financial losses. This is because low focused approach may lead to allocating maximum resources to the barrier, which may have the least or lesser impact on the system, and vice-a-versa is also true. Thus, a first step in dealing with the barriers, it is necessary to comprehend the severity level of each barrier based on their overall impact on the system and subsequently, treating the severe barrier first. In this research, an Analytic Hierarchy Process (AHP) technique is used to eliminate the ambiguity related to the degree of focus to be prearranged for each IPTS challenge. This is a very well-known and extensively applied methodology that has the capability to prioritize the factors. This approach will assist policy makers in making informed decisions while sequentially eliminating challenges of IPTS.

4.1 DATA COLLECTION

As the first step of AHP, evaluation of barriers generally begins with the data collection. This research has used two sampling techniques: (a) random sampling technique and (b) judgmental sampling for the data collection process. The organizations operating in the IPTS are randomly selected for data collection. The organizations operating in the IPTS are as shown in Table 4.1 have been selected for the data collection.

Table 4.1: List of organizations selected for data collection for this research

S. No.	Organizations	Selection
1	Central Transmission Utility (CTU)	Mandatory
2	State Transmission Utilities (STUs)	Randomly
3	Government Advisory Body	Mandatory
4	Consultants	Randomly
5	Electrical Equipment Manufacturers	Randomly
6	Industry Association	Randomly
7	Private Licensee	Randomly

Out of these mentioned organizations, fifteen STUs, three consultants, three industry associations, four private licensees, and nine electrical equipment have been randomly selected. The main advantages of this sampling technique are: error-proof, removes biases, requires less knowledge on population, and reduces the cost of sampling. Furthermore, this methodology involves an interview with experts having varied knowledge and experiences in the field. The data was drawn out in the form of expert opinions from the stakeholders. **Subject-matter experts or domain experts** are those professionals that have acquired requisite knowledge, skills, and experience in the field to the extent that his or her opinions might assist in finding facts, solving problems, or understanding the logical inferences of the system. For this research, any professional with in-depth knowledge, skills, and practical understanding of Power Transmission has been considered as Experts. The experts from the randomly selected organizations are chosen using judgmental sampling. In the judgmental sampling, the experts are selected only based on their knowledge and experience of the related field.

This objective has considered a sample size of eighty-eight experts. According to Malhotra and Dash (2011), the minimum size of 30 experts, i.e., $n \geq 30$, accurately represents the population parameters. Therefore, the sample size considered in this study is sufficient to represent the IPTS system. The experts considered in this study include Central Transmission Utility, State Transmission Utilities, Private licensee, government advisory body, Industry association, Consultants, and Equipment manufacturers having relevant experience in the power transmission area. Considering such a large number of expert opinions has helped the study to view the diverse perspectives of stakeholders. Table 4.2 shows diverse expert groups formed from different organizations operating in the IPTS. These expert groups comprising of experts with diverse educational levels and experiences.

Table 4.2: List of expert groups formed for data collection for this research

Groups	Name	Affiliation	Age Range	Educational Level	Experience	No. of experts
Expert Group 1	Transmission	1. Central Utilities (10) 2. State Utilities (35) 3. Private Licensee (6)	42-58	Bachelors	≥ 15	51 (58%)
Expert Group 2	Substation	1. Central Utilities (5) 2. State Utilities (6) 3. Private Licensee (7)	42-55	Bachelors	≥ 15	18 (21%)
Expert Group 3	Industry Association	Autonomous (2)	41-56	Masters or above	≥ 20	2 (2%)
Expert Group 4	Power Advisors/Consultants	1. Government Advisory body (5) 2. Private Consultant (3)	45-65	Masters or Above	≥ 20	8 (9%)
Expert Group 5	Electrical Equipment Manufacturers	Private Sector (9)	42-57	Bachelors or above	≥ 15	9 (10%)

In this study, the data collection process involves the following:

The AHP questionnaire was floated amongst the experts of the related field via mail or personal visit to the experts. Initially, a preliminary set of barriers identified in the study were explained to them. Expert opinions were sought for pair-wise comparisons among barriers and criteria to understand the relative importance of each criterion and alternative.

For comparisons of barriers, experts were asked following question:

"How much critical Barrier A is as compared to Barrier B with respect to Criteria C_1?"

Therefore, comparisons among nine barriers under three criteria were asked similarly. For comparisons of criteria, following question was asked

"How much more Criteria C_1 is preferred overC_2?"

If these comparisons are found to be inconsistent, then the comparisons are revisited to make them more consistent.

Fig. 4.1 summarizes the data collection process used in this objective of the study.

In this objective, the questionnaires were floated among 115 experts. Out of the 115 experts, ninety-four experts have provided their responses. Fig 4.2 shows the share of different expert groups considered in this study.

Also, Fig 4.3 shows the number of experts provided their responses and the experts who did not provide their responses. While processing the opinions, it was found that the opinions of forty-one experts were not consistent in the first phase of the study. Therefore, as part of the AHP process, the experts were contacted again, and their opinions were sought. In the second phase, the consistencies of the responses were re-investigated, and 68 responses were observed to be consistent. The remaining twenty-six experts were again asked to modify their opinions to bring their views close to the consistency threshold. In the third phase, the inconsistent opinions were reduced to six. Therefore, it was decided not to consider the inconsistent opinions of six experts while evaluating the criticality of barriers.

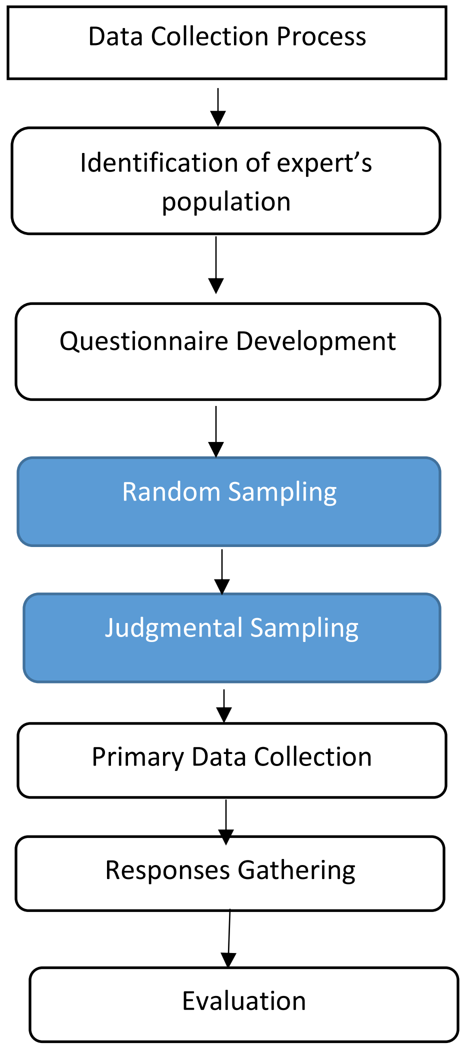


Fig. 4.1. Data Collection Process

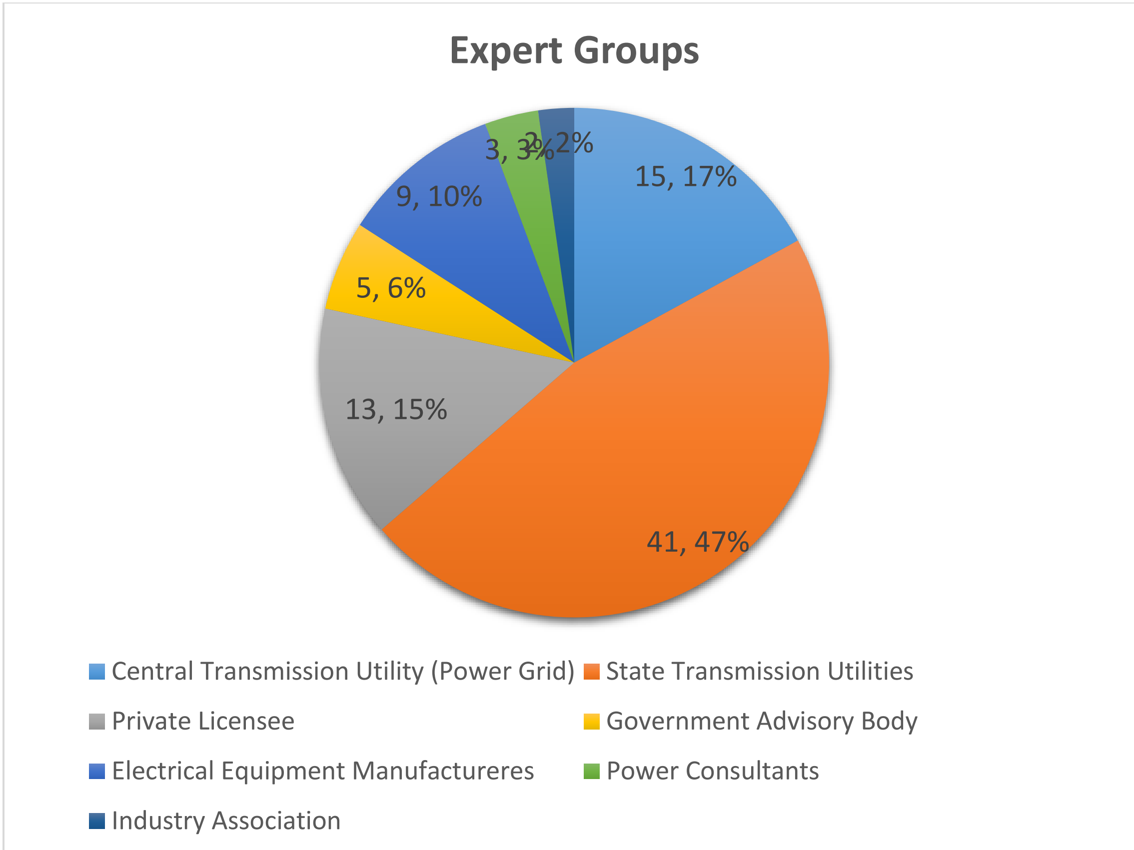


Fig 4.2. Share of expert groups considered in this study

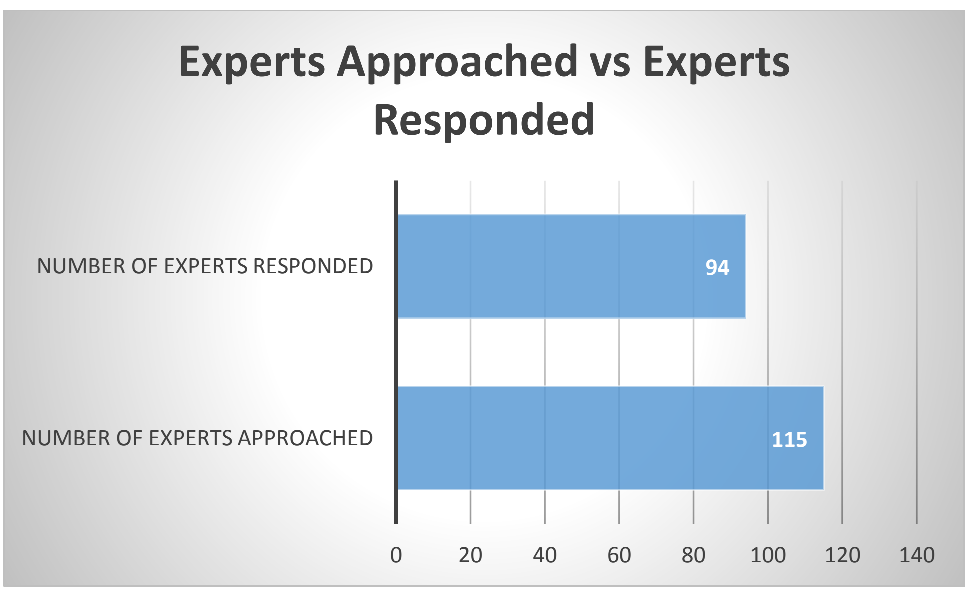


Fig. 4.3. Number of Experts approached versus the number of experts responded

Fig 4.4 indicates the number of inconsistent as well as consistent responses of the experts during the three phases of data collection.

Finally, weights are obtained using the eighty-eight expert opinions indicating the importance of each alternative considered.

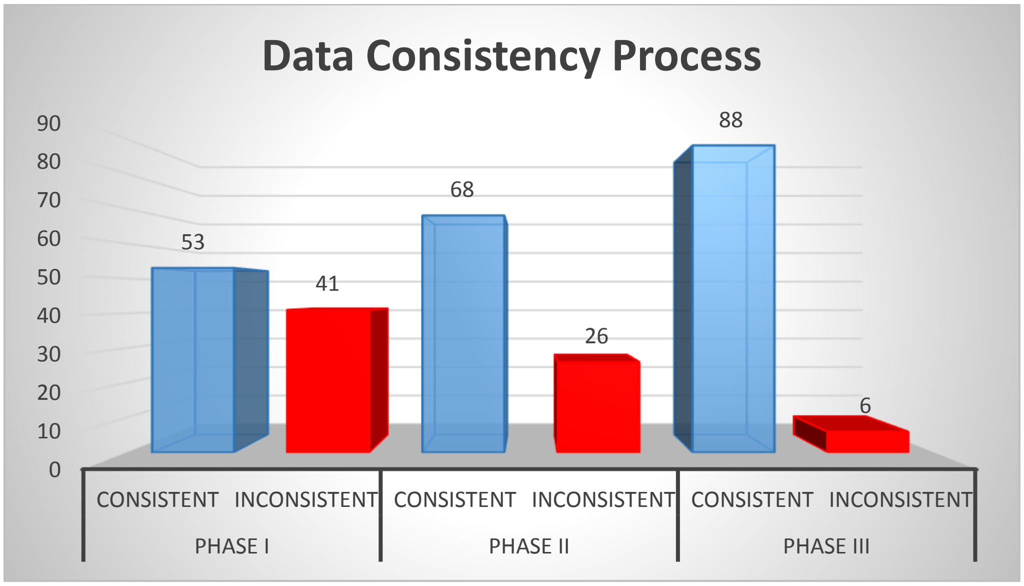


Fig. 4.4. Consistent and inconsistent responses in three phases of the data collection process

4.2 VALIDATION AND RELIABILITY OF AHP METHODOLOGY

Any research methodology can be validated in two different ways: (a) Validation of the questionnaire, and (b) Validation of results.

(a) Validation of the questionnaire: It is necessary to validate a newly designed questionnaire for seeking any input from the relevant stakeholders. The advantage of AHP methodology is that it works on its defined questions; therefore, the validation of the AHP questionnaire is not needed. A detailed explanation is given below:

- The AHP questionnaire is not newly designed, and it involves one type of question about the comparative importance of the criteria or alternatives (Basak, 1998). These questions demand a multi-criteria logic, which falls into mathematical and behavioral science interests and is quite different from statistical theories (Marcarelli et al., 2013).

- The pairwise comparison judgments in the AHP are applied using a fundamental Saaty scale. This effectiveness of the scale has been validated through its applications in various studies and also through theoretical justifications (Saaty and Varges, 2001).

Table 4.3: Validation of results obtained in Research Objective 1

Name of the barriers	**Final priorities aggregating 30 experts' priority vectors**		**Final priorities aggregating 60 experts' priority vectors**		**Final priorities aggregating 88 experts' priority vectors**	
	Weights	Rank	Weights	Rank	Weights	Rank
Absence of strategic planning by Govt. (B1)	0.237	1	0.224	1	0.186	1
Low investments in Power Transmission (B2)	0.218	2	0.193	2	0.157	2
Fewer Private Players in Transmission (B3)	0.120	4	0.112	4	0.097	4
Transmission Congestion (B4)	0.074	5	0.074	5	0.076	5
Transmission Losses (B5)	0.037	7	0.048	7	0.058	7
Failure to upgrade Technology (B6)	0.055	6	0.057	6	0.068	6
Delays in project execution (B7)	0.135	3	0.121	3	0.144	3
Grid instability due to RE (B8)	0.022	9	0.026	9	0.027	9
Poor performance and financial health of Utilities (B9)	0.028	8	0.035	8	0.044	8

(b) The validity of the results obtained: The results obtained in the AHP are validated using the following procedure

   (i) The final priorities of the barriers are computed by aggregating 30 experts' priority vectors
   (ii) The final priorities of the barriers are computed by aggregating 60 experts' priority vectors
   (iii) The final priorities of the barriers are computed by aggregating 88 experts' priority vectors

The results obtained using the following procedure indicated that the critical barriers were similar in all three cases. This validates that the results obtained in RO 1 are robust.

4.3 RELIABILITY OF THE DATA

The reliability of the data obtained from the experts has been tested by computing the consistency ratio in the AHP methodology. First consistency index (CI) of each pair-wise comparison matrix is calculated according to the following formula:

CI = (λ_{max} – n)/ (n – 1), where λ_{max} is the maximum eigenvalue of the matrix, and n is the number of elements in a matrix.

Then Consistency Ratio (CR) is calculated with the help of CI and Random Index (RI) determined for any matrix having size n, i.e., CR = CI/RI, where RI is the ideal consistency values computed in the various experiments conducted by Saaty. In case the value of CR exceeds 0.1, then it is generally considered that expert opinions are inconsistent and must be reconsidered (Cheng and Li, 2001).

In our study, the AHP questionnaire was circulated to 94 experts initially, out of which data of 41 experts were found to be inconsistent in the Phase-I. In Phase-II, questionnaires were again distributed among these 41 experts asking them to revisit and review their responses to make them more consistent. In Phase-II, after the experts resubmitted their reviewed responses, data of 26 experts were again found to be inconsistent. A similar procedure of Phase-I of the study was adopted, and finally, in Phase-III, the data of only six experts were found to be inconsistent. It was, thus, decided not to consider the inconsistent data of 6 experts. Finally, data of 88 experts, which were found to be consistent, were considered for the analysis of this study.

4.4 METHODOLOGY

Saaty (1990) provided the AHP methodology to rank the alternatives. The methodology is initiated by developing a hierarchy structure that descends from the overall goal of the problem to the criteria (first level factors) and alternatives (second level factors). There are two approaches to aggregate the judgments provided by more than one expert (Forman and Peniwati, 1998)

(a) Aggregate the individual judgments for each set of pair-wise comparisons into an aggregate hierarchy (AIJ)
(b) Aggregating the resulting priorities of each expert (AIP)

In this study AIP approach (b) has been used to aggregate the final priorities of 88 experts by using Geometric Mean. Two types of paired comparisons are performed throughout the hierarchy (Dos Santos et al., 2019):

(a) Criteria with respect to the goal
(b) Alternatives with respect to the criteria

The pair-wise comparisons are made using a Saaty scale, whose effectiveness has been validated not only by applying the scale in many studies but also through theoretical comparisons with many other scales. With the standard computation procedures provided by the Saaty (1990), the priority weights of the criteria, as well as the priority weights of alternatives wrt each criterion is calculated. However, these are called as local priorities. But the study aims to calculate global priorities or, in other words, the final weights of the alternatives. According to the computation procedures, it is calculated by multiplying local priorities of criteria with the local priorities of alternatives obtained wrt to each criterion. The alternative, which gets the highest global priority, is considered critical to the problem (Vaidya and Kumar, 2006).

The step-wise procedure used in AHP has been discussed below in detail:

Step 1: Establishment of the decision-making hierarchy

The initial step in AHP is to develop a hierarchy in the form of a network associated with the decision-making process. Such hierarchy comprises three components (i) mentioning a specific goal of assessment on the top of the hierarchy, (ii) determine critical criteria for achieving the specified goal, and (iii) listing the alternatives to be selected. In this study, the overall goal is to prioritize the identified barriers involved in the IPTS. After goal identification, the next step is to identify the criteria based on which prioritization shall be done. For this study, three criteria, namely, **Cost, Time, and Social Impact** (Sathaye and Gupta, 2010; Singh, 2013), have been selected that mainly describes the criticality of any barrier. For instance, barriers incurring high costs with increasing time delays, and overall social costs will be regarded as extremely critical barriers. Therefore, these barriers of IPTS are considered as alternatives in the problem. The AHP framework used in this study has been shown below in Fig. 4.5.

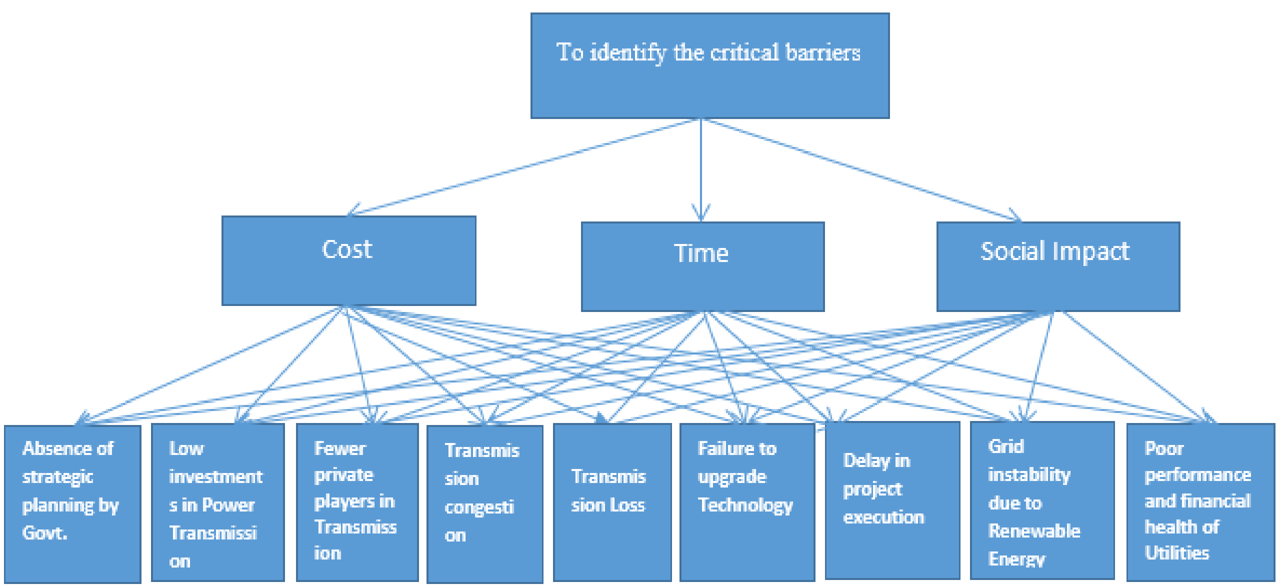


Fig. 4.5. The framework of Analytic Hierarchy Process

Step 2: Establishment of the pair-wise comparison matrix

To make relative comparisons among criteria and barriers of IPTS, a fundamental scale is required that will indicate or quantify the importance of one barrier over other barriers wrt selected criteria. AHP uses the Saaty scale, which provides a broad range of *1-9* scales to record responses where '*1'* indicates an equally critical barrier, and '*9'* indicates an extremely critical barrier. This assists decision-makers to crisply provide relative importance of barriers and criteria. Table 4.4 shows the Saaty scale used in this study.

Table 4.4: Saaty scale used in the study

Intensity of importance	**Definition**
1	Equal Importance
2	Weak
3	Moderate Importance
4	Moderate plus
5	Strong Importance
6	Strong plus
7	Very strong importance
8	Very, very strong importance
9	Extreme Importance

Initially, the pair-wise comparisons for the criteria, i.e., Cost (C1), Time (C2), and Social (C3), were made using the Saaty scale. It was observed that 6% of the experts gave equal priority to criteria C1 and C2, 31% of the experts considered C2 as more important than C1, and 64% of the experts believed that C1 is the most important criterion than C2. Fig 4.6 shows the experts' preferences while comparing the criterion C1 with criterion C2.

While comparing the costs and social criteria, it was observed that 76% of the experts consider that the impact of barriers will be on the costs than on society. 16% of experts think that social criterion is more vital than the cost criterion. Only 8% of the experts consider that barriers if they continue to persist in the IPTS, will equally impact the cost and society. Fig 4.7 shows the experts' preferences while comparing the criterion C1 with criterion C3.

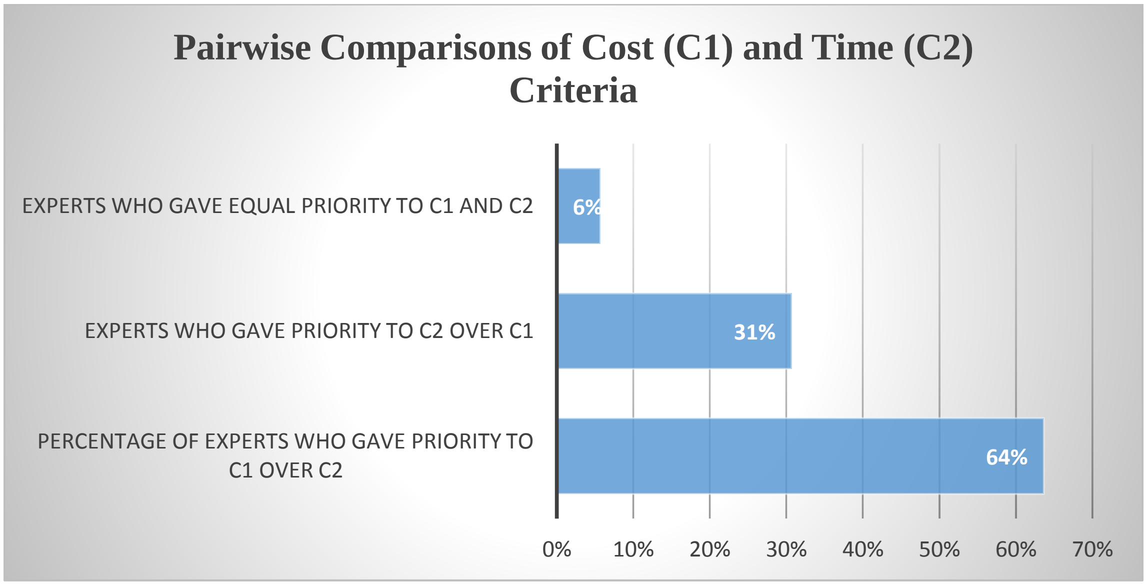


Fig. 4.6. Pairwise comparisons of cost and time criteria

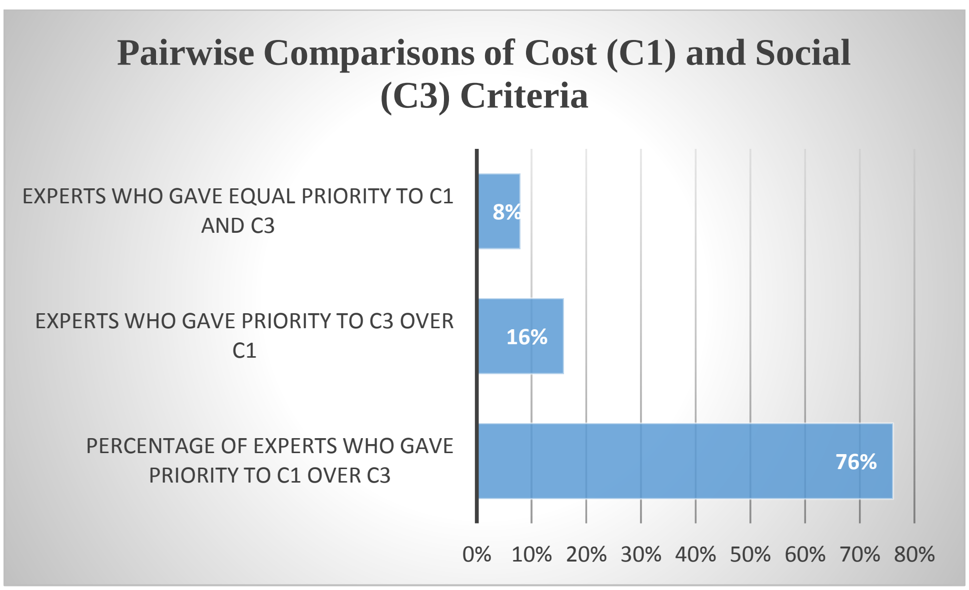


Fig. 4.7. Pairwise comparisons of cost and social criteria

Further, while comparing the time and social criteria, it was observed that 73% of the experts consider that the impact of barriers will be more on time than on society. 22% of experts think that social criterion is more vital than time criterion. Only 6% of the experts consider that barriers if they continue to persist in the IPTS, will equally impact the time and society. Fig 4.8 shows the experts' preferences while comparing the criterion C2 with criterion C3.

Step 3: Estimating the relative weight of each barrier and criteria

After pair-wise matrices are developed, the priority vector of each matrix is evaluated and normalized to 1.00. The elements of each column are divided by the sum of each column to obtain a priority vector. Then, the Eigenvector is determined by summing the row of the resultant matrix. The Eigenvector is the non-zero vector that is associated with the linear systems of equations. The Eigenvector obtained is further normalized, and this normalized Eigenvector is called as the priority vector. Fig 4.9 shows the ranks obtained by calculating the priority vectors for each criterion considered in this study.

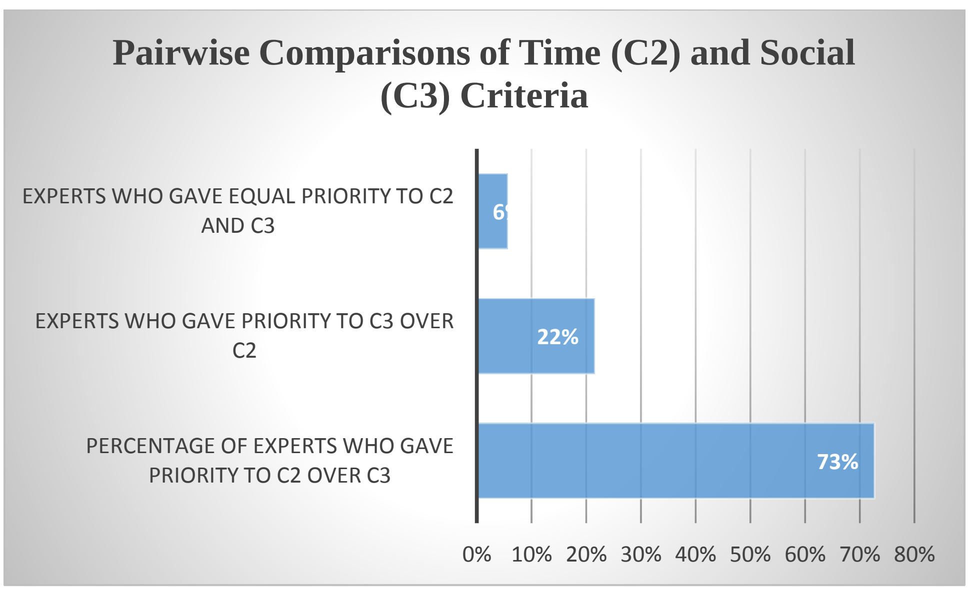


Fig. 4.8. Pairwise comparisons of time and social criteria

It was observed that 60% of the experts had given first preference to cost criteria followed by time and social criteria, respectively, in the Rank 1 category. Under the Rank 2 category, 64% of the experts consider time is the second most important criterion followed by costs and social categories with 24% and 9% of the support, respectively. Under the Rank 3 category, 72% of the experts consider time is the second most important criterion followed by costs and social categories, with 11% of the support to each criterion.

It can be inferred from the graph that the barriers of the IPTS will have a major impact on costs of transmission projects followed by the time of the projects and lastly to the society of the country.

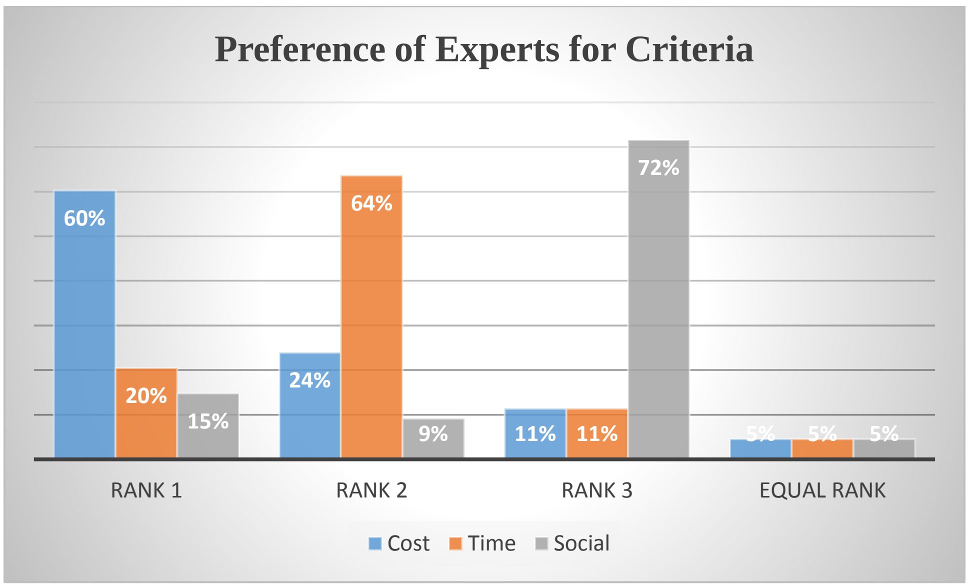


Fig 4.9 Rank-wise preferences of experts for each criterion

Step 4: Calculation of Consistency Index

Experts may sometimes provide inconsistent responses. Consistency Ratio (CR) is a metric that determines the consistency in the expert opinion while making the pair-wise comparisons. The procedure to calculate the CR is as follows:

a. A new vector P is calculated by multiplying matrix A (a_{ij}) representing pair-wise comparison with solution vector B (b_j), as shown in Equation 1.

$p_i = \sum_{j=1}^{n}(a_{ij})\ (b_j)$, where, i = 1,2,…,n …(1)

b. A new vector E is calculated when vector P is divided by the corresponding vector B.

c. Consistency Index (CI) is computed according to the following formula: CI = (λ_{max} – n)/ (n – 1).

d. The CR is computed with the help of CI and Random Index (RI) determined for any matrix having size n, i.e., CR = CI/RI

The pair-wise comparison matrices in the AHP methodology are obtained from the preferences of experts, which are very subjective in nature. Therefore, it is difficult to avoid inconsistencies in such matrices. An essential question is how much inconsistency in the matrix is permitted. CR basically answers this question by comparing the CI of the matrix with the CI of the random matrix, also known as RI. In a random matrix, the judgments are randomly provided, and therefore, this matrix is highly inconsistent. RI is specifically considered as the average CI of 500 matrices that are randomly filled. The calculated values of RI for different matrix sizes are provided by Saaty (2012). It should be noted that the value of CR must be below 0.1. In case the value of CR exceeds 0.1, then it is generally considered that expert opinions are inconsistent and must be reconsidered (Cheng and Li, 2001).

Step 5: Determining relative weights of barriers:

The priority weight obtained using expert opinions is computed by multiplying the priority vector of criteria and the priority weight of barriers. A final assessment value for each barrier is calculated by taking Geometric Mean of all the priority vectors obtained for each expert. Table A4 in Annexure and Fig. 4.10 show the final aggregated priority vector and final ranking obtained for each barrier.

4.4 RESULTS

This chapter of the study identifies critical barriers from the identified barriers to the IPTS, wherein the barriers are further prioritized using Analytic Hierarchy Process (AHP) to identify critical barriers requiring primary focus from the key stakeholders. Relative weights of barriers in IPTS are provided in Table A4 of Annexure. The challenges must be screened and ranked according to their criticalities in the IPTS. The ranking of the factors will assist regulators to optimally select the critical factor at the very initial stage that is deteriorating the IPTS. As per Table A4 in Annexure, it can be observed that poor planning for the transmission sector by regulators emerged out to be the critical challenge responsible for the withering of the sector. The practitioners of the sector have raised a red flag on the current policies support to the backbone of the power sector. The weakness of the country's grid demonstrated by the cascading grid failure cannot be spruced up until Special Schemes are placed to handle transmission congestion and huge power losses.

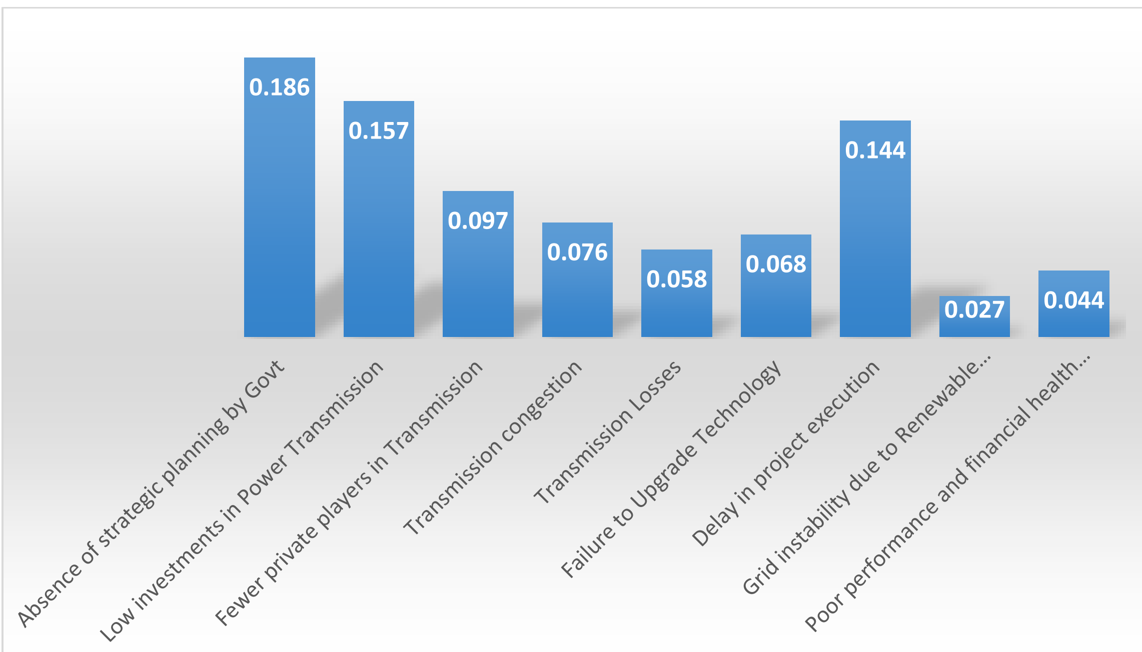


Fig 4.10 Final Priority Vectors of IPTS barriers

The second critical challenge to IPTS is low investments in the sector. After more than two decades of underinvestment, the transmission sector remains to be in a malnourished situation and is craving for up-gradation of centuries-old aging infrastructure with new enabling technologies. This also requires adding new infrastructure altogether into the existing system. However, the whole process is plagued with delays in project execution, which is the third critical challenge to the IPTS. On the one hand, many awarded projects are embroiling in this situation, and on the other hand, the policymakers are planning to award the next thousands of projects. As a consequence, this has hampered the ease-of-doing-business and interest of private players in the sector. The unattractive sector is again deprived of the private players who play a significant role in making the sector more competitive and financially robust.

4.5 INTERPRETATION OF THE RESULTS

- Table A4 in Annexure represent the prioritization of the barriers to the IPTS
- The barriers are ranked according to the decreasing assessment values
- The barrier with the highest weight has been considered as the critical barrier and ranked as one.
- From the table, it is evident that the Absence of strategic planning by the government emerged out to be the critical barrier responsible for the withering of the sector.
- The second critical barrier to IPTS is low investments in the sector, followed by delays in project execution and a lesser number of private players, which are the third and fourth critical barriers to the IPTS.
- Grid instability due to renewable energy is the least critical barrier among all the barriers

4.6 FINDINGS OF OBJECTIVE 1

- The study confirms that planning for IPTS is essential to conduct the current assessment, providing a clear visualization of the future, and taking concrete action. Improper planning has a direct impact on costs and timelines.

- Appropriate allocation of funds and private player participation are also considered necessary for an improved IPTS system.
- Streamlined processes from improved planning may also help in addressing the delays in project execution

4.7 CHAPTER SUMMARY

The power deficit situation has gripped the country over the last many decades. This has undeviating implications on the social and economic security of the country. The direct correlation between the power availability and social development cannot be ignored. If the issues leading to power crisis are continuously neglected, the crisis can severely tear the social fabric of the country, impacting crore of lives to be standstill. To immediately curb this critical situation, this chapter has attempted to analyze the key challenges to IPTS. The fundamental reason to select the transmission sector lies with the fact that despite being major power producers in the world, the country is still grappling with the power deficit situation. The country requires timely reforms in the transmission sector, which acts as a vital link between the generation and distribution sectors. This weak link must be patronized immediately to avoid any cascading risks on the economy of the country.

The results of AHP suggests that more policy-level interventions are required to expedite the procedure of removal of key challenges persisting in IPTS. It can be further observed that automatically other challenges will be partially or impartially detached from the system if an appropriate focus is given to challenge B1 (Absence of strategic planning by the government). The first step to rejuvenate the IPTS is to maintain an equilibrium between transmission capacity and generation capacity. A biased focus of the policymakers towards increasing generation capacity has resulted in relatively low transmission investments by the government. Certainly, an immediate alteration in the policies synchronized with a well-coordinated regulatory framework to increase the transmission capacity may act as a key catalyst to IPTS. Such policies must not only encourage the role of private players' participation in the transmission sector, but they also provide equal stature to them while awarding new power transmission projects. Standard bidding documents for EPC in IPTS must be developed to give a fair chance to private bidders.

A transformational change related to manpower planning and training, continuous support of funding, implementation of technologies can accelerate the growth of the sector. The landscape of transmission in India is expected to keep growing at a fast pace, especially to meet the evacuation requirements of renewables to demand centers. Therefore, all stakeholders must contribute their long-term efforts for sustained alterations in the existing system. The growth of the entire power sector in India depends upon a robust and non-collapsible transmission network. Our findings recommend policy changes of adequate investment to execute planning of the IPTS as a whole.

CHAPTER 5 – IDENTIFICATION OF STRATEGIES TO ELIMINATE THE CRITICAL BARRIERS OF IPTS

5.0 INTRODUCTION

"Theory of Constraints (TOC)" is a popular management technique developed by Dr. Eliyahu Goldratt in 1984 (Pegels and Watrons, 2005) through a revolutionary book, '*The Goal*.' According to Goldratt, the goal of any organization is to earn profit regardless these organizations focus on profit or not. Every organization can be considered as a complex system comprising of multiple activities or processes that are linked to each other (Motwani et al., 1996). However, one of the activities within the system can be turned up as a limiting factor for the entire system. These limiting factors or in technical terms "constraints" can be considered as the weakest links of the system that defer the organizations in achieving their specified goals. TOC helps in identifying the critical "constraints" persisting in any system or process. The interesting characteristic of the TOC is that it also suggests development activities that would elevate the constraints and inherently prioritizes them. TOC is a concept, principle, tool, and philosophy designing in such a way that manages and improves the system better (Zadry and Yusof, 2006).

Thus, TOC provides a scientific and practical framework for system improvement using its "five focusing steps." The five steps of TOC include (Mabin et al., 2001):

1. *Identify* the constraint(s): Identification of the critical limitation present in the system that restricts the rate of achieving the goal
2. *Exploit* the constraint(s): Increase the throughput of the constraint(s) using the existing resources to its maximum capability
3. *Subordinate* everything else to the decision taken in step 2: Align and synchronize the behavior of the non-constrained resources with the constrained resources

4. *Elevate* the constraint(s): Eliminate the constraints by taking strategic actions, if the constraint still exists in the system
5. *Prevent Inertia:* Identify the next constraint of the system after resolving the current constraint of the system by returning to the Step 1.

Within the TOC framework, includes two groups of problem-solving techniques. The first technique deals with the physical production constraints, and the second technique is a generic problem-solving tool (Hsu and Sun, 2005). The physical production constraints are improved using five focusing steps explained above and using the Drum-Buffer-Rope (DBR) technique. These techniques can be easily applied to the manufacturing set-up where the job-shops are capacity-constrained or resource-constrained. Ifandoudas and Chapman (2009) used the DBR techniques to adopt the agility in manufacturing to sustain competitive advantage. Ehie and Sheu (2005) examined the possibility of linking the six sigma (SS) with TOC for improving the overall manufacturing performance. Balakrishnan and Cheng (2000) compared the TOC with linear programming (LP). It was found that using LP with different stages of TOC analysis is preferable than individually using these techniques. Other than the manufacturing sector, TOC is also applied to the distribution system and inventory management. Yuan et al. (2003) elucidate a generic safety stock management procedure for an efficient distribution system, based on the concept of TOC. Costas et al. (2015) have applied the DBR technique to minimize the bullwhip effect in the supply chain management area. The five steps of TOC have also been used to the service sector, such as the healthcare area (Gupta and Kline, 2008) banking sub-system (Reid, 2007), implementation of enterprise resource planning (ERP) (Ioannou and Papadoyiannis, 2004).

However, these tools have limitations, where the constraints are more subjective and qualitative. These tools are also not much suitable in the service context, which comprises of interaction among people, customers, and processes at the high contact end. In contrast, the low contact end includes quasi-manufacturing. Thus, measuring the goals daily in service-type organizations is difficult, as here throughput is not related to the flow of products along a production line. Therefore, generic problem-solving tools are mainly used to address policy-related constraints and provide new strategies using cognitive knowledge-base and logic. Such tools include Thinking Process (TP) (Mabin et al., 2001) and Throughput Accounting (TA) (Motwani et al., 1996; Ioannou and Papadoyiannis, 2004). Techniques like DBR helps in eliminating physical constraints by using all the five focusing steps, whereas soft techniques of TOC like **TP uses only step 1, 4, and 5 of the focusing steps of TOC** (Motwani et al., 1996). Siha (1999) demonstrates the use of TOC to the four different kinds of service organizations. Similarly, Motwani et al. (1996) propose to use the Socratic thinking process to deal with the essential changes at the organizational level using TP of TOC. Mabin et al. (2001) used the TP tool to provide a practical approach to manage change in the organization. Chaudhari and Mukhopadhyay (2010) have applied TP in the integrated poultry industry. This study uses the Thinking Process approach to eliminate the barriers present in the Indian Power Transmission System. Tanner et al. (1996) discuss the impact of reengineering on the sales force and used the TOC to eliminate the process barriers.

This paper has sequentially applied the three-step Thinking Process in the Power Transmission System (PTS) of the power sector in India. This is the first study in the literature that addresses the barriers persisting in the Indian Power Transmission System (IPTS) using TOC. First, the thinking process approach is described, and its steps are evaluated in constraint management. Then, the structure and various constraints that are limiting the performance of IPTS are explained in detail. Next, a comprehensive illustration of the application of the thinking process provides insights into managing constraints within the IPTS. Finally, some inferences are drawn from the use of the thinking process in the IPTS.

5.1 THINKING PROCESS FOR MANAGING CONSTRAINTS IN THE SYSTEM

Thinking Process (TP) uses only 1, 4, and 5 out of the five focusing steps of TOC to eliminate the policy level constraints (Motwani et al., 1996). TOC has benefitted both manufacturing as well as service industry. The literature related to TOC has been shown in the Annexure (ii). Literature has reported evidence from the organization which has adopted TOC techniques, observed increased output while minimizing constraints of the system (Zadry and Yusof, 2006). The IPTS literature does not generally include TOC. As the theory uses a system thinking approach that mainly deals with problem-solving and decision making, the theory seemed highly appropriate for this study. Therefore, it appears that the TOC can well provide a management model for IPTS.

The thinking processes of TOC comprise a set of five logic diagrams. These logic diagrams consist of four trees and a cloud along with a specific set of logic rules. Current reality tree, future reality tree, and transition tree are the three diagrams that use sufficiency logic or cause-and-effect logic using IF . . . THEN... statements and examining ``sufficient cause". The other two logic tools, i.e., the prerequisite tree and the evaporating cloud, use conditional logic ``To have A, B is required".

a. Current reality trees (CRT): The first step in TOC is to develop CRT representing an existing condition or reality. The CRT is basically formed by a chain of cause and effect for a specific and fixed set of situations. A top-down approach is used to construct a CRT, where the topmost factor indicates an undesirable effect followed by causes for the effect. The key objectives of CRT are as follows:
    - forms the foundation to understand the complex systems;
    - reveals the causes of the undesirable effects (UDEs) persisting in a system;
    - identify the core problem that results in the UDE;
    - provides information related to the change to be made in the system that will have the greatest impact on the overall system.
b. Evaporating clouds (EC): Once it is known "what to change" in the system, the next step is to search for a plausible solution to the root cause to answer, "what to change to." This is done by developing an evaporating cloud (EC)

and the future reality tree (FRT). EC is developed by a set of five boxes. Initially, two wants that are conflicting in nature are identified, and a common objective is formed that fulfills the need for conflict. The two principal purposes that EC is intended to achieve are to identify the conflict leading to a major problem and to resolve the conflict by creating a win-win solution to both the conflicting wants.

c. Future reality trees (FRT): After a solution (also known as an injection) identified through the EC method, TOC practitioners develop the future reality tree (FRT) that presents the expected optimistic system. It also alerts the practitioners about the negative side effects of the change on the system. The FRT serves the following purposes:
   - delivers an effective planning tool that identifies a desired course of action to improve the performance of the system;
   - determines the effectiveness of the new solution before dedicating resources for implementation;
   - reveals that the proposed changes in the system will lead to new problems through negative branches while solving the existing problems and determines additional actions required to prevent the occurrence of any negative side effects;
   - develops a self-sustaining optimistic system by positive reinforcing loops;

d. Prerequisite trees (PRT): The next step is to identify the obstacles that prevent the injection of the solutions identified from the EC into the system. The key objectives of developing PRT are as follows:
   - identifies obstacles that prevent achieving the desired objective through a course of action or injection
   - identifies the remedies to overcome or neutralize the obstacles coming on the way of implementing solutions

e. Transition trees (TRT): The last logical tree in the thinking process of TOC is the transition tree. It determines the actions required to implement the change or solution. The basic purposes of a Transition tree are:
   - provides a step-by-step procedure for implementing strategic action plans;
   - enables effective navigation of practitioners through a change process;
   - detects a deviation in progress and redirect the efforts toward the objective;
   - executes the intermediate objectives identified in a PRT;

In this study, the barriers of IPTS have been treated as constraints of the Indian Power Transmission System that need to be eliminated to make the system work efficiently.

Thinking Process (TP) of the TOC will help in answering three questions i.e.

a) What to change in the system for eliminating the barrier?
b) In what form will the changes have to be made such that the barrier is eliminated?
c) How can this change be brought upon?

There is an urgent need to timely address underlying issues in the transmission sector to ensure power demand is adequately met in the future. This study, therefore, attempts to mitigate the key causal challenge, i.e., the absence of strategic planning by the government, using a system thinking approach of TOC. This process first allowed us to assess the current situation of IPTS with the help of graphical representation or cause-effect diagram and linkages among various issues that lead to a particular barrier within the system. The next step was to work on the root causes that lead to a barrier, with the help of the identification of proposed actions required to eliminate that barrier. It also assisted in the identification of some undesirable effects that may arise by taking a particular action. This prompted system the trade-offs of taking that specific action. Furthermore, it also bought focus on the obstacles while implementing the actions in IPTS. In short, a complete knowledge tree in the graphical form is prepared that indicate barriers of the system with proposed strategies. Additionally, it assisted in articulating thoughts or explicit/implicit knowledge of experts into a more structured form. The contribution of the paper has been summarized in Figure 5.1

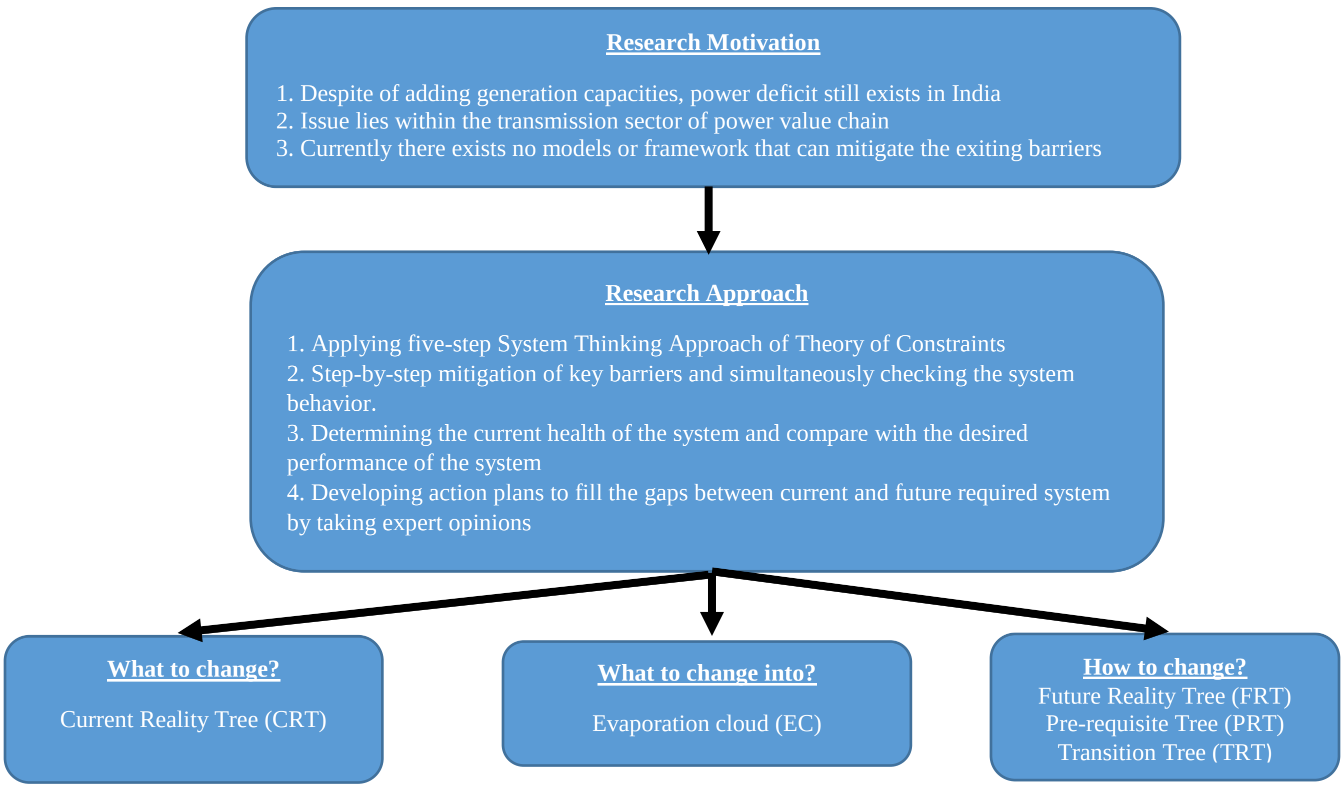


Fig 5.1. The research framework of the study

5.2 APPLICATION OF THEORY OF CONSTRAINTS IN INDIAN POWER TRANSMISSION SYSTEM

The theory of constraints (TOC) is applied in the Indian Power Transmission context mainly for two purposes: (i) to understand the current state of affairs of IPTS (ii) to address the real bottlenecks existing in the system. The study identifies the “absence of strategic planning by the government” as a key causal barrier. The authors also suggest that this barrier has the potential to negatively impact the efficacy of the complete IPTS system. TOC-based management philosophy focuses on change at three levels (3Ms): the mindset of the organization, the measures that drive the organization, and the methods employed within the organization. Therefore, it appears that the theory of constraints can well provide a management model for IPTS.

5.3 DATA COLLECTION

The data for logic trees were collected by focus group discussions in two phases with the experts working in the related field. These experts were selected using judgmental sampling techniques and random sampling techniques. The organizations from which experts were selected were randomly selected as explained in Table 4.1. Furthermore, the criterion for the selection of the experts was the vast experience of the experts in the power transmission field, as shown in Table 4.2. The experts were invited for the focus group discussions from the list of eighty-eight experts who previously participated in Research Objective (RO) 1. The data collection process for RO2 was conducted in two phases. Out of eighty-eight experts who participated in RO2, thirty-seven experts willingly participated in Phase 1 in this objective. For Phase 2, all the experts participated in Phase 1 were invited again, out of which 31 experts participated in Phase 2, to assist in developing various logic trees for the Thinking Process of TOC. Based on the information provided by the experts, the current state of the IPTS was mapped, followed by the identification of the undesired effect of the existing processes. After this, a work plan was created, proposing key strategies to achieve the desired goals.

5.4. VALIDITY AND RELIABILITY OF TOC METHODOLOGY

According to Yin (2008), the multiplicity of the sources considered to achieve the data triangulation enhances validity and reliability. Thus, to ensure rigor in the data collection and data analysis processes of this study, three types of triangulations were adopted. Firstly, data were collected from different expert groups such as transmission, sub-station, power advisors, electrical equipment manufacturers (as shown in Table 4.2). Secondly, data were further collected from the experts having diverse experience and knowledge in the related field of the study working in different organizations, as shown in Table 4.1. Thirdly, the data for RO2 was collected from the same experts who participated in establishing the criticality of the barriers using the AHP technique in RO2. Also, only the experts who participated in the focus group discussion in Phase I of this study were the only experts who participated in Phase II of this study. This ensures that the results obtained during Phase-I and Phase-II are consistent and validated by the same experts. This is another type of triangulation adopted in this study to ensure internal validity and reliability in data analysis.

5.5 STEPWISE THINKING PROCESS APPLIED TO MITIGATE KEY BARRIER OF IPTS

A brief overview of the logic diagrams developed and finalized in the workshop by the experts is provided in this section.

Step 1: Current Reality Tree

The construction of the CRT begins with the identification of the list of undesirable effects (UDEs) persisting in the IPTS by the expert groups. These UDEs include:

a. Improper monitoring of existing system
b. Exact requirement of additional transmission networks is not known
c. Undue focus on generation and distribution
d. Non-synchronized planning of Center and State utilities
e. Improper monitoring of on-going projects
f. Health of the existing system is not known
g. Planning is done in isolation
h. Non-involvement of stakeholders of other sectors

The CRT has been developed using the cause and effect logic to understand the core issues underlying the IPTS. The CRT consisting of UDEs, core problems, and the cause-effect relationships among them have been shown in Fig 5.2. The diagram can be read from downwards to upwards using IF-THEN statements. Interestingly, while making CRT experts faced many challenges in deciphering the underlying complex interactions among UDEs. No one was aware that the situation is so much bleak as depicted by CRT. Experts were surprised to find that the federal structure in the power system and the conventional mindset of the stakeholders are the core problems of the IPTS. The federal structure of the power system comprising of two different regulatory bodies is responsible for the fragmented outlook towards the transmission sector. The conventional mindset of the policymakers provides more priorities to the extreme ends of the power value chain and do not allow them to focus on the intermediary transmission sector. Consequently, both core problems are responsible for the absence of strategic planning by the government. It was further revealed from the CRT that lack of coordination between state and center utilities and non-involvement of stakeholders of other industrial sectors affect strategic planning of the sector. Consequently, monitoring of the on-going project and the existing system becomes difficult due to non-transparency in IPTS. Therefore, the current health of the existing system and the additional requirement of the transmission infrastructure remain unknown. All these undesirable effects eventually lead to inadequate and inappropriate planning within the power transmission sector in India. Once the CRT was developed, the current situation that leads to inadequate strategic planning became clearer, and the logic that compels the requirement to change within IPTS became more apparent. Fig 5.2 shows that the Current Reality Tree (CRT) developed for the IPTS.

Step 2: Evaporation cloud

To initiate the change process, it is important to identify the core problem within the IPTS. The core problem is generally, the uppermost entity of the CRT. In this study, the federal structure of IPTS is observed to be the core problem. However, this core problem cannot be changed. Therefore, the core problem that the policymakers can deal with is "how to make transmission network requirement more transparent to do adequate strategic planning?"

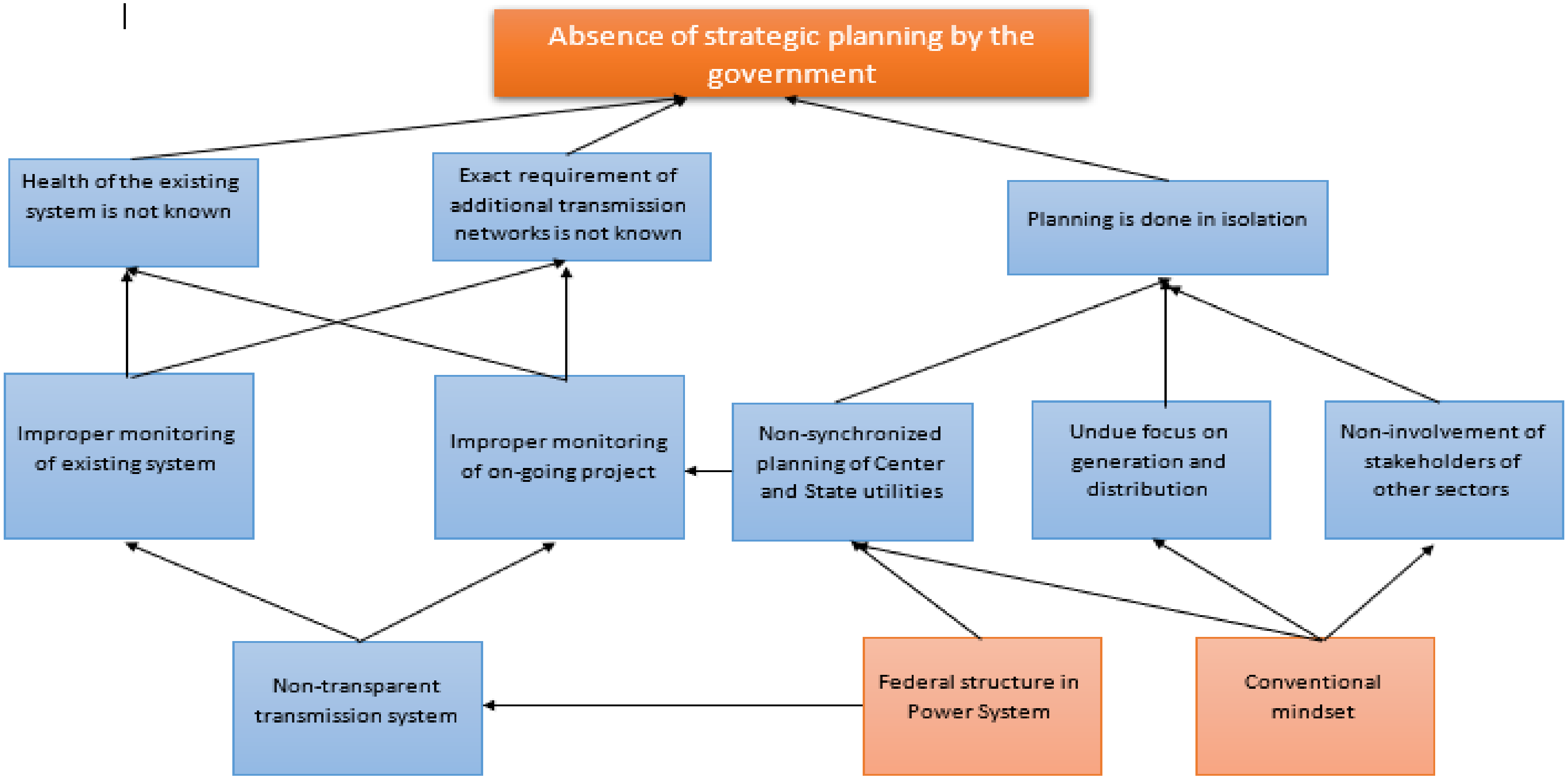


Fig. 5.2. Current Reality Tree for Indian Power Transmission System

Therefore, the focus of the evaporation cloud is to do adequate strategic planning for IPTS, as shown in Fig 5.3. The evaporation cloud shows two ways to achieve the objective of adequate strategic planning. The first prerequisite deals with the requirement to appoint a nodal agency to monitor the entire IPTS system. In this case, inter-state and intra-state transmission networks will be planned separately by Center and State Transmission Utilities, respectively. On the other hand, the second prerequisite deals with the nodal agency required for both planning and monitoring. In this case, stakeholders from both inter-state and intra-state transmission utilities will be commonly involved in transmission sector planning.

However, these two needs create a dilemma in achieving the objective of adequate strategic planning as both needs are in direct conflict with each other. To decide which path to follow (upper path or lower path) for achieving the key objective, the reasons or assumptions underlying each path were deciphered. This would clear the reasons as to why we think a particular path is not appropriate to take. In the case of the lower path of the conflict cloud, the onus of both planning and monitoring lies with a single independent nodal agency. Contrary, in the upper path, two different bodies, i.e., CTU and STU, are involved in managing the planning process only and not monitoring process. In this case, there is a need to coordinate between these two bodies to ensure adequate strategic planning. Therefore, the experts finally decided to include the lower path of the evaporation cloud in the analysis process. It was thus, concluded by the experts that there is an urgent need to improve the strategic planning of the transmission sector by establishing a nodal agency responsible for both planning and monitoring.

Evaporation Cloud

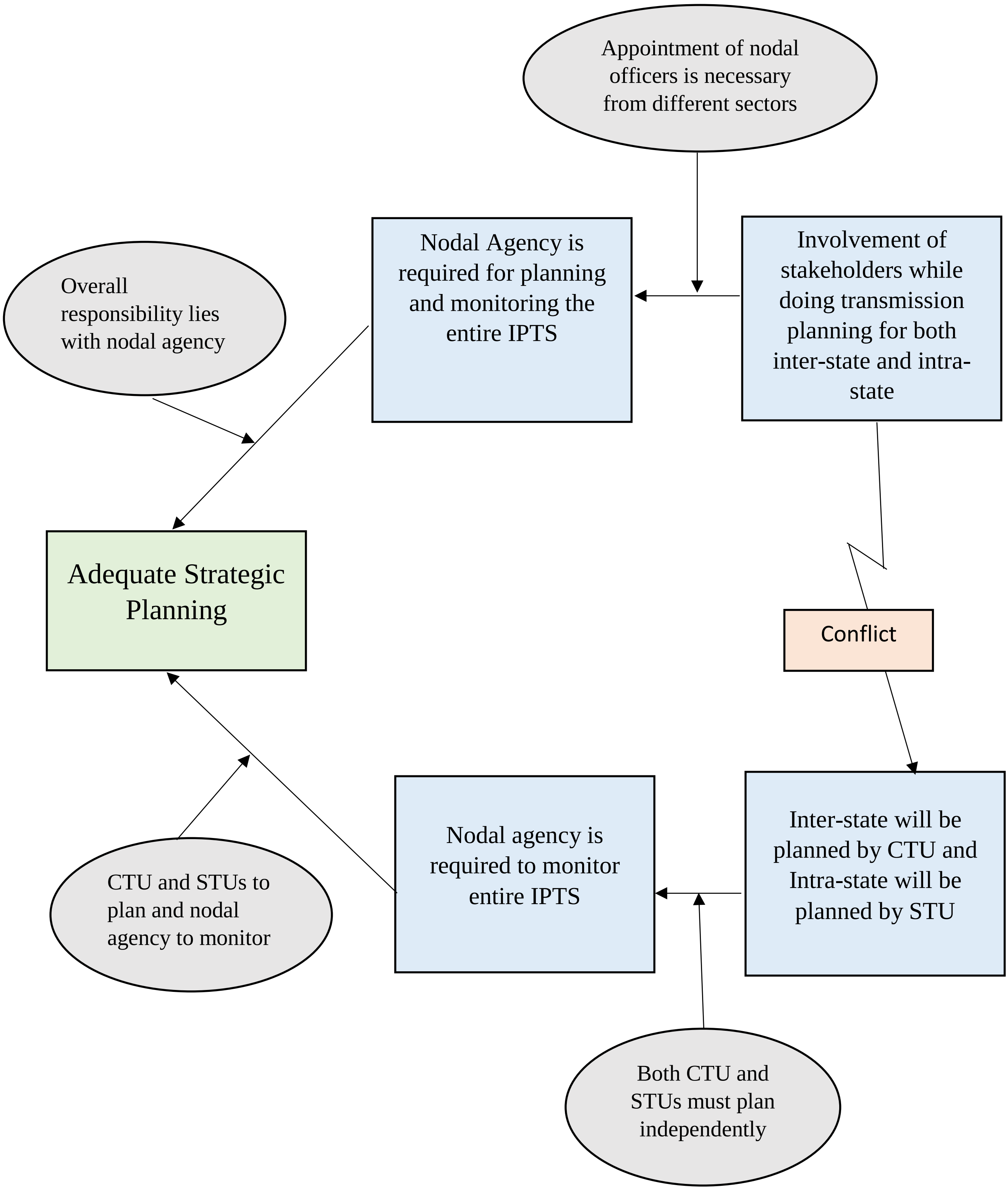


Fig. 5.3. Evaporation cloud for Indian Power Transmission System

This nodal agency is expected to operate under the Ministry of Power (MoP) and must exhibit the following responsibilities:

i. coordinates the overall requirements of new transmission networks for both inter-state transmission system (ISTS) and intra-state transmission system (InSTS) from different stakeholders such as CTU, STUs, MoP, CEA, Ministry of renewable energy, distribution companies and stakeholders from various sectors.

ii. constitutes a nodal agency for IPTS, which is responsible for preparing a perspective plan for the transmission sector and carrying out the periodic review of the plan.

iii. monitors the timely completion of the on-going transmission projects.

iv. resolves any issues among the stakeholders related to interfacing, transmission network requirement, and non-compliance of the strategic planning conducted for the IPTS.

v. develops an online web portal dedicated to structurally disseminate the progress that has been made according to the plan among various nodal officers.

Step 3: Future Reality Tree (FRT)

In the next step, FRT was developed, which reveals what improvements are required for efficient strategic planning, as shown in Fig 5.4. In other words, FRT can act as a new policy framework that needs the urgent attention of policymakers of the IPTS. In this step, a number of improvements were identified by the experts that have the potential to bring the IPTS sector out from the gloomy situation. In the FRT, one of the undesirable effects, i.e., absence of strategic planning by the government" was treated using various injections. These injections are the broad actions required to mitigate the adverse impact from the system. From the evaporation cloud, the experts decided to appoint an independent nodal agency that has the responsibility of planning the new transmission network requirement and monitoring the existing transmission projects. This nodal agency must comprise of nodal officers each from generation, transmission, and distribution sectors of power. It should engage these nodal officers to precisely understand the power requirement from different sectors. These nodal officers would periodically intimate about their requirements, address any grievances related to non-coordination with other sectors, and conduct regular meetings.

With this nodal agency, planning is expected to be done multi-laterally without any ministerial interference. According to the experts, this would help to tighten the planning phase of the transmission. Appointment of the nodal agency would also ensure a balanced focus towards the generation, transmission, and distribution sectors by the policymakers. The focused and balanced planning would, in turn, significantly impact power quality, power reliability, and system resilience.

With the advent of new technologies, the importance of training has become significantly critical within the power transmission sector. Currently, money spent in the training activities is considered as the expenditure and not investments, wherein the funds related to training are broadly categorized into capital outlay and recurring expenditure. The experts feel that the sector needs huge investments in the training programs aligned with the changing business environment. This is because 80% of the power sector personnel are working in the transmission and distribution sectors. Such trainings would involve orientation of the transmission personnel, wherein the roles of engineers would be defined as business managers. Further, research in the training must be encouraged that would not only open new avenues for the sector but also evolve the sector through continuous technical skill and knowledge up-gradation, improvement of overall personality, and enhancement of IT skills. It can be concluded that better skills will help in attaining better planning for the sector.

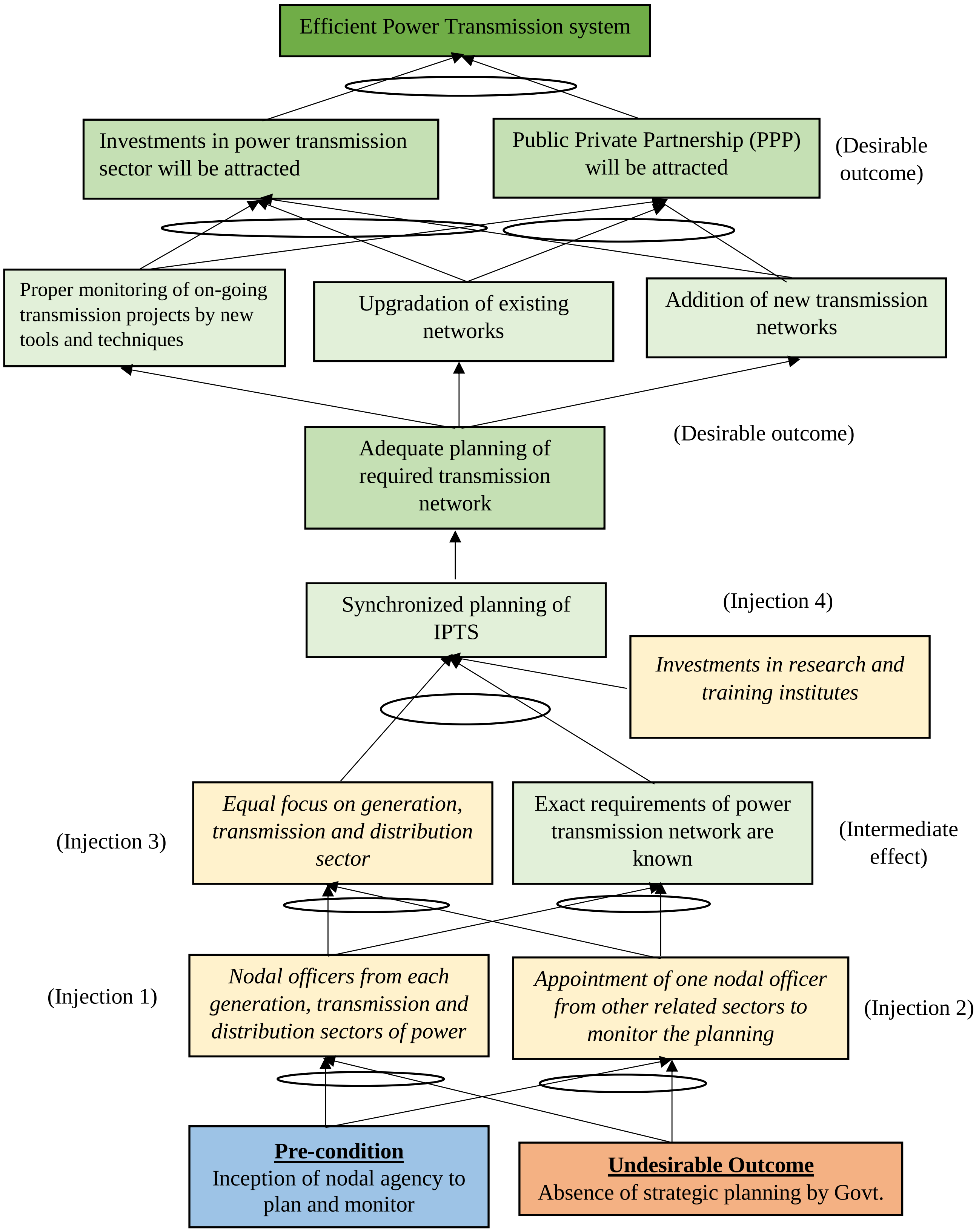


Fig. 5.4. Future reality for Indian Power Transmission

The four injections into the current system will synchronize the planning for IPTS. Consequently, the accurate requirement of the transmission infrastructure to transmit the available generating capacity will be known. This will, in-turn provide three benefits (a) accurate addition of new transmission network, (b) properly monitoring of the on-going transmission projects, and (c) up-gradation of the existing networks. Accordingly, the specific investments required in the sector will become more explicit. It will also raise the participation of private players in the sector, which can make the sector more competitive and can also support the investments required for the sector. An infrastructural investment made ahead of the demand and benefits of private player participation has the potential to make the IPTS more efficient and robust.

Step 4: Pre-requisite Tree (PRT)

The Pre-requisite tree (PRT) is considered to be the most important logical tree of the Thinking Process. It identifies various obstacles that hinder the implementation process. FRT provides the solution to minimize the core problem, but PRT provides a list of bottlenecks that can arise at the time of implementing the solutions. PRT is generally composed of obstacles and intermediate objectives (IOs). The obstacle may be existing in the system at present or may arise in the near future that needs to be overcome. In contrast, the IO is generally the action taken to overcome the obstacle. To develop a PRT, firstly, one of the injections identified in the FRT is taken into consideration. Next, all the obstacles, as well as IOs, are identified around the selected injection. Finally, the pairs of obstacles and IOs are sequenced and connected to each other to make a logical tree. Here, the key objective is to identify the intermediate objectives require to complete the implementation plan of FRT.

The PRT for the IPTS has been shown in Fig 5.5. In this case, the experts decided to identify obstacles around the pre-condition of the FRT, i.e., “inception of a nodal agency to plan and monitor.” According to them, this would cover the obstacles of all the four injections identified in FRT and will, therefore, minimize the iteration time that would have taken by developing PRT for all the injections. The first obstacle that would come in the way while appointing a nodal agency is the conventional mindset of the stakeholders. Here, the conventional mindset indicates the priority given to the generation and distribution sector by the policymakers and lesser focus on the transmission sector of the power value chain. The policymakers are following the traditional process of planning for the sector and are reluctant to make any further amendments to the existing policies and laws of the IPTS. Thus, there is a need to implement change management through an extensive training process. A proper strategic change management process would address the resistance to change among the stakeholders and bring about successful transitions of the system. Another obstacle that can arise while appointing nodal agency is unethical practices followed by the stakeholders of the sector. The unethical conduct within the sector can be attributed to the fact that the policymakers of both state and central utilities are not willing to grant the authority of planning and monitoring aspects of the sector to the independent nodal agency. This, again, successively make the conventional mindset more rigid. Such political corruption cannot be ignored as it significantly impacts the overall functioning of the IPTS and investments flow into the sector. Unfortunately, the unethical practices cannot be tackled with stricter regulations and better policy framework. Therefore, experts accorded to make the system more transparent, where information is flowing seamlessly using new technologies. The same inter-mediate action will also minimize the obstacle related to less information sharing. However, another obstacle that can hinder the new technologies implementation is the lack of finances. This can be minimized by allocating enough funds by the government and increasing the private player participation.

Another obstacle that can hinder the implementation plan is the lesser availability of human resources. This can be dealt with by developing a resource efficient system by initiating skill development programs. Furthermore, the planning tools and techniques used in the sector are also conventional, which need to be replaced by using new planning tools.

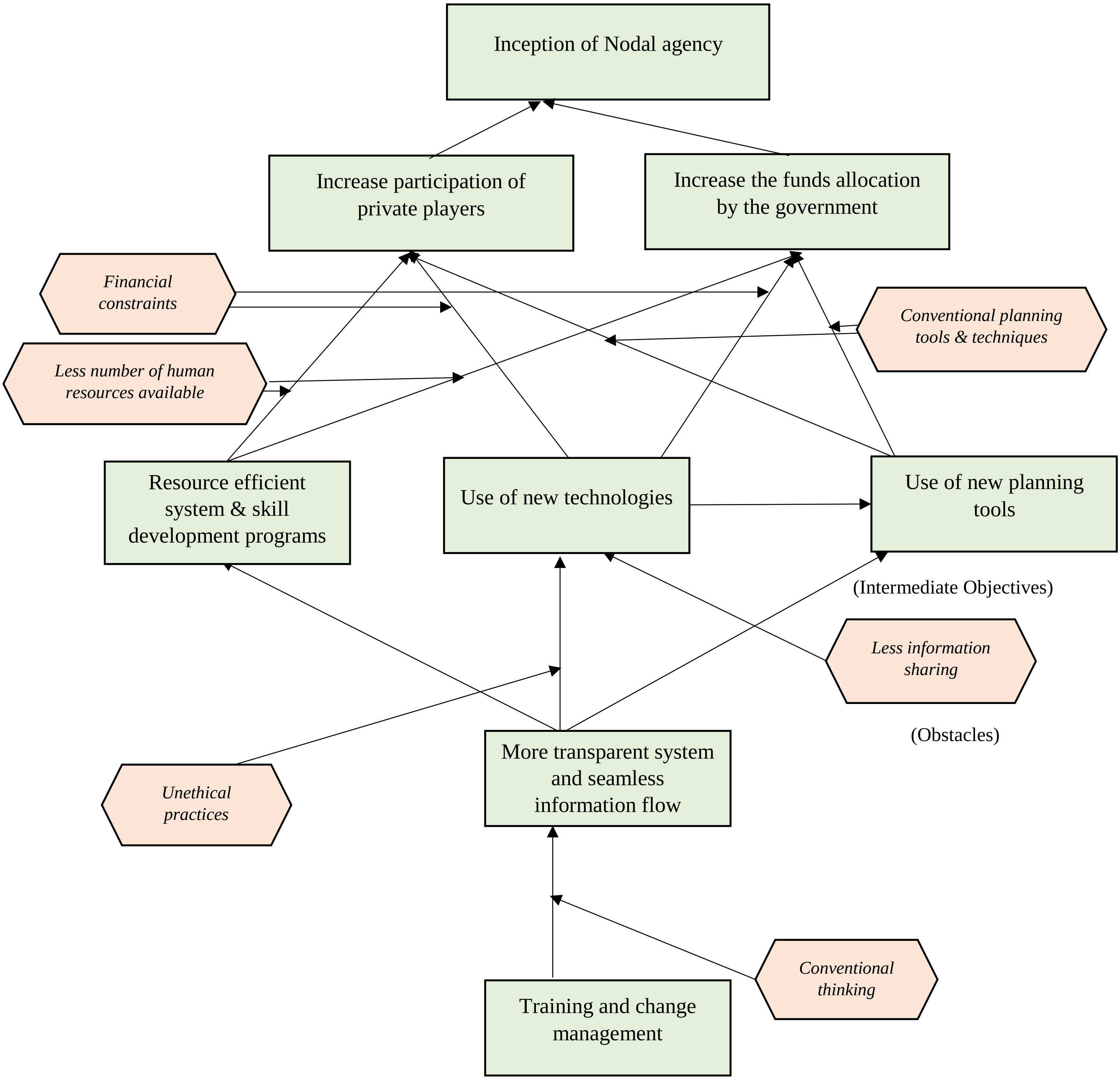


Fig. 5.5. Pre-requisite Tree for Indian Power Transmission System

Step 5: Transition Tree (TRT)

Transition Tree is the last logical tree of Thinking Process that provides a step-by-step procedure to implement the change. It comprises four main components (a) existing realities identified in the CRT, (b) need to deal with the existing realities, (c) action to be taken to satisfy the need, and (d) the logic behind taking action. It constructs the sequence of actions required to reach the intermediate and ultimate objectives. The current constraint that needs to be elevated is the "absence of strategic planning," which is responsible for inadequate power transmission networks. The major actions required to transform the processes are shown in Fig. 5.6 and the same are broadly explained below.

- The first and foremost action required is to adopt the change management and processes. This would change the conventional mindset of stakeholders and motivate them to take decisions more rationally.
- To deal with the unethical practices a transparent system is required where the information is flowing among various stakeholders seamlessly using various technologies instead of encouraging decade long rigid departmental silos.
- Further, for the development of the sector and its efficient operations, there is an urgent need for skilled workers.
- The exact requirement of transmission networks not only requires synchronized planning of different sectors but also the use of new planning tools and techniques. These tools would ensure adequate planning with less complexity and time.
- The policymakers must provide equal focus on generation, transmission, and distribution sectors to increase the private players' participation and increase the investments into the sector.

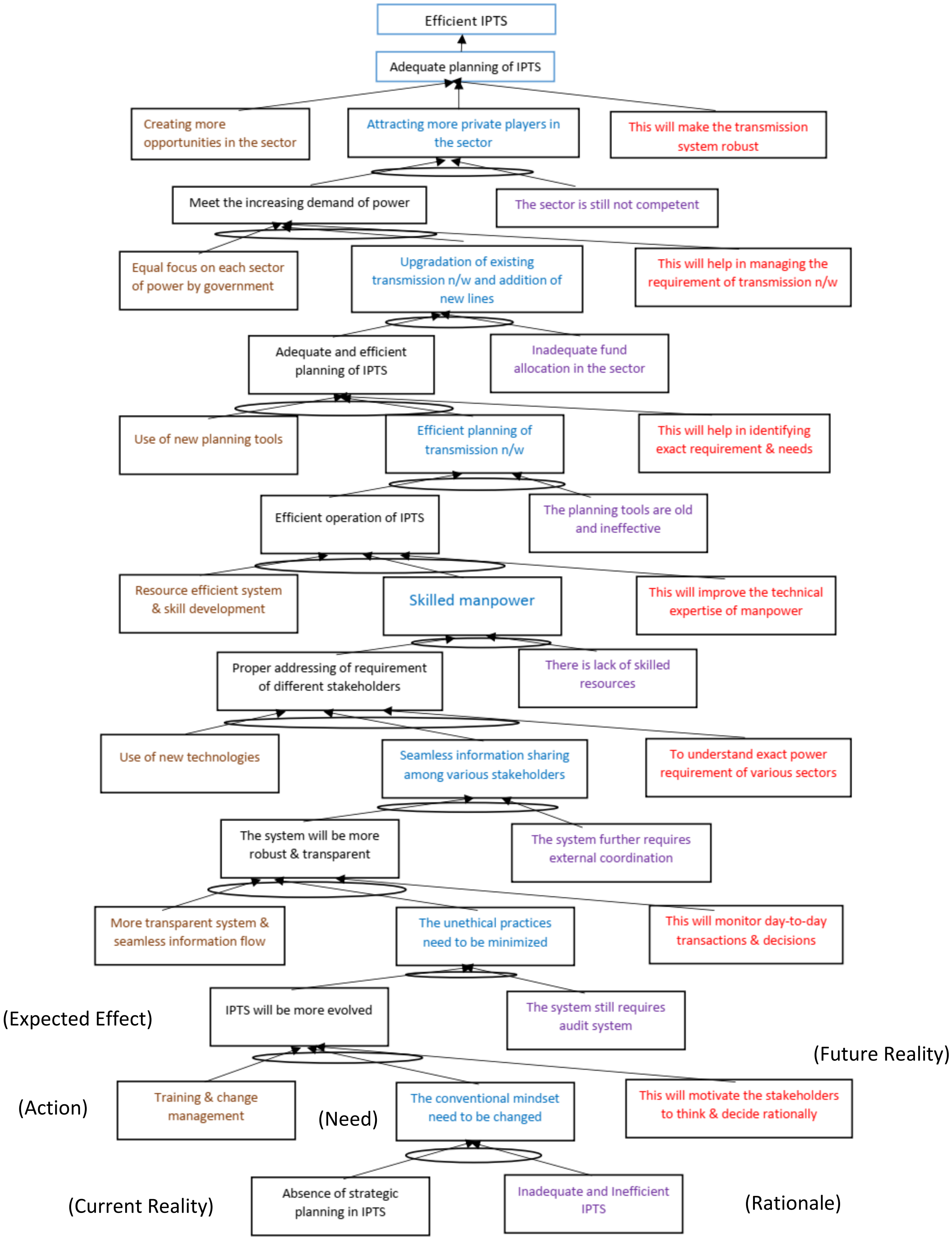


Fig. 5.6. Transition Tree for Indian Power Transmission System

5.6. DISCUSSION

This study is the first attempt to minimize the consequent effect of the absence of strategic planning on the overall sector using the Theory of Constraints (TOC). Out of the three main techniques of TOC, Thinking Process (TP) was found to be well fitted with the problem. This is because the IPTS is a service organization where policies and procedures related constraints are found much rather than equipment or capacity-related constraints.

The philosophy of TP, therefore, has been effectively adopted in this study to improve the overall performance of IPTS by locating the causal constraint of IPTS as the dominant issue and develop a practical implementation process around the key constraint of the system. The focus of the study was to use TP as a tool to minimize the key constraint of the IPTS. The advantages of integrating TP tool with the Indian power transmission sector are:

- a comprehensive view of the policies and processes adopted in the IPTS
- a holistic view of the key causal issue of the IPTS
- Redesigning of the complete process to improve the system throughput

The TP of the TOC seeks to acknowledge three questions. The solutions obtained for each question after critical analysis have been summarized below.

What to change?

The process of TP was initiated by asking the question, “what are the key issues of the IPTS ?” that needs to be addressed first. The study conducted by Upreti et al. (2018) identified that the key issue lies with the way planning is done for the sector. Thus, a CRT was developed that decoded various undesirable effects (UDEs) arising out of the core problems. These UDEs are then sequenced among each other through cause and effect relationships to reach the undesirable outcome, i.e., inadequate strategic planning of the sector. Table 5.1 shows that procedural, structural, compliance, leadership related issues are generating policy constraint that needs to address on an immediate basis.

Table 5.1: Various issues of Indian Power Transmission System

Causes	Outline	Type	Nature
Federal structure in the power system	Controls are divided into Central as well as State utilities leading to decentralized planning	Core Problem	Sector Structural issue
Conventional mindset of the stakeholders	Reluctance of the stakeholders to change according to the changing market demand	Core Problem	Procedural issue
Non-transparent transmission system	Absence of transparent mechanisms and processes of IPTS	UDE1	Procedural issue
Non-synchronized planning of Center and State utilities	Independent planning of generation, transmission, distribution sector of the power system as well as non-integration of the power requirement of other sectors	UDE1	Organizational structure issue
Non-involvement of stakeholders of other sectors	Silo-based planning by policymakers with lesser involvement of other stakeholders	UDE2	Compliance related issue
Undue focus on generation and distribution	More priorities are assigned to generation and distribution sector whereas the transmission system has been downplayed by policymakers for many years	UDE2	Leadership related issue
Improper monitoring of on-going projects	Inadequate cost and time-based evaluation of transmission projects	UDE2	Procedural issue
Improper monitoring of existing system	Lack of real-time monitoring of existing functioning of transmission grids	UDE2	Procedural issue

Planning is done in isolation	Only stakeholders working in the transmission sector are involved for planning	UDE3	Leadership related issue
Exact requirement of additional transmission networks is not known	The transmission networks required to evacuate power from the generating stations are generally approximated	UDE3	Procedural issue
Health of the existing system is not known	Operational health of the existing transmission is not made clear due to the increased use of transmission network	UDE3	Leadership related issue
Absence of strategic planning	Non-optimal planning leads non-evacuation of power through limited transmission infrastructure	Undesirable Outcome	Policy constraint

What to change into?

The gloomy picture depicted by the CRT generated an urge within the experts to deep dive into the solutions that can be practically implemented. After identifying the core problems underlying the key constraint of the system, the next basic question to be answered was, "what is the most desirable system?" For this, the evaporation cloud (EC) was constructed. EC illustrated that the best path to initiate the change process is the inception of an independent nodal agency that can both plan and monitor the IPTS. Table 5.2 shows the comparison of the current and new stakeholders involved in the planning and monitoring of the system.

Table 5.2: Comparison of the current scenario and the solution suggested by the experts in Evaporation Cloud

Scenario	Stakeholders involved in the planning process	Stakeholders involved in the monitoring process	Comments
Current scenario	Central Utility (CTU) and State utilities (STUs)	Central Electricity Authority (CEA), Ministry of Power (MoP)	The accurate requirement of the transmission network is not known
Evaporation cloud (Path 1)	Central Utility (CTU) and State utilities (STUs)	Nodal Agency	Require coordination among CTU and STU, which can lead to information loss
Evaporation cloud (Path 2)	Nodal Agency	Nodal Agency	The responsibility of monitoring and planning lies with only one body

How to change?

The purpose of this fundamental question is to implement the solutions that can either minimize or eliminate the constraint of the system. To answer this fundamental question, the path selected in EC was considered as a base, FRT was developed, which depicted the desirable system that has the potential to eliminate the key constraint of the system. In FRT, four key actions were injected into the system that has the capability to transform the gloomy picture of CRT into an improved system. These injections are

- Appointment of one nodal officer from different sectors to monitor the planning
- Appointment of nodal officers each from generation, transmission, and distribution sectors of power
- Equal focus on generation, transmission, and distribution sector
- Investments in research and training institutes

These injections are expected to bring positive change into the system through synchronized planning, considering the power requirement of other sectors.

Table 5.3 highlights the major transformations required within the power transmission sector of India.

Table 5.3: Major transformations required in the Indian Power Transmission System

Conventional IPTS	Transformed IPTS	Action/tool required
Decentralized planning and monitoring by both Central and State utilities independently	Centralized planning for IPTS by a nodal agency	Appointment of committee members
Use of decades-old traditional business methods	Automation of business processes	a) Initiation of the change management process b) Investments in R&D for the sector
Increasing gap between the availability of skilled manpower and transmission sector's need	Improved skill development index of the sector	Skill development by conducting periodic training and assessments
Monopolistic structure of the transmission sector	Higher competitiveness of the sector	a) Implementation of National Tariff Policy for competitive procurement b) Liberal policy measures, which allows active participation of private players rather than monopolistic structure c) Fiscal incentives through active investments into the sector
Higher transmission project costs and time	Zero delays in projects	a) Monitoring of project cost and time appropriately b) Easy availability of Right-of-way (ROW) clearances for a long-distance evacuation plan
Long-term planning	Hybrid way of planning which involve both short-term, medium-term as well as long-term planning	a) periodic meeting of nodal officers for monitoring the status-quo

Table 5.4: List of obstacles that can hinder the implementation process

Obstacle	Major uncertainties involved	Nature of risk
Conventional Thinking	a. Low allocation of funds for transmission sector b. Non-up-gradation of existing networks c. Continuation of monopolistic structure d. Cost-based bidding e. Project delays due to non-clearances	Financial risks, Operational risks, Strategy risks
Unethical Practices	a. Support for a non-transparent system b. Biased assigning of tenders for new transmission projects c. Non-amendments in policy measures d. Decentralization of the power and control	Financial risks, Operational risks, Strategy risk, Legal risk
Less number of human resources available	a. Social disadvantage for the sector in the changing economy b. Less flexibility to bring out change into the transmission sector c. Increased costs of the transmission sector d. Loss of knowledge within the sector	Operational risks, Financial risks, Competitive risks
Conventional planning tools & techniques	a. Inaccuracy in the evaluation of the transmission network requirement b. Increased complexity while planning c. Time-consuming procedures d. Incapable of tracking and monitoring the hybrid planning system	Operational risks, Legal risks, Strategy risks
Financial constraint	a. Difficult in implementing new technologies b. Low development of the overall transmission sector.	Operational risks, Competitive risks

Furthermore, a PRT was constructed to understand the obstacles that can come into the way while implementing the change process. These obstacles are listed in Table 5.4, along with the major risks involved. It can be interpreted from

Table 5.4 that these obstacles possess financial, operational, legal, strategy, and competitive risks to the IPTS. To minimize these obstacles, various inter-mediate objectives were identified by the experts in the FRT. These intermediate objectives have the capability to take-off the obstacles from the implementation process and, ultimately, null the severe impact of risks on the transmission sector.

The intermediate objectives identified in the FRT were later used in the TRT. The TRT constructed in this study can be used as a transformed policy framework to implement the required changes. Table 5.5 lists out the major actions needed to initiate the transformation process within the IPTS. Table 5.5 shows that various stakeholders such as CTU, STU, Private licensee, CEA, CERC, MoP, EPC contractors, electrical equipment manufacturers have a greater role to play in this transformation process. It was further noticed during the analysis process that, along with the barrier absence of strategic planning, two other barriers, i.e., fewer private players, and low investments in power transmission, were also eliminated.

Table 5.5: List of major actions required for the transformation process within the IPTS

Corrective Action	Category of Actions	Benefits	Stakeholder(s) involved
Training and change management	Process strategy	a. Defining change management strategy b. Developing a change management team c. Preparing action plans d. Initiating training programs	Central and State Utilities
Seamless information flow	Process design	a. Use of Information Technologies (IT) and ICTs for information sharing b. Wireless communication	Central utilities, State utilities, Private licensee, EPC contractors, electrical equipment manufacturers
Use of new technologies	Process design	a. Digitalization that allows open, real-time,	Central utilities, State

		automated communication and operation of the system. b. Network technologies such as smart sensors, smart devices, internet-of-things (IoT) c. Cybersecurity	utilities, Private licensee, EPC contractors, electrical equipment manufacturers
Resource-efficient system & skill development	Process controlling	a. Development of a National skill development plan for the transmission sector, b. Assigning funds towards training programs through Public-Private Partnership (PPP) models c. Continuous up-gradation and feedback of training programs	Policymakers (CEA, CERC, MoP)
Use of new planning tools	Process design	a. Statistical tools for analysis b. Use of big data analytics	Nodal agency
Equal focus on each sector of power by government	Process strategy	a. Synchronized planning b. Increasing investments c. Adequate monitoring of the current health of the system	Policymakers (CEA, CERC, MoP)
Creating more opportunities in the sector	Process Implementation	a. Replacing traditional transmission utilities with an independent new transmission grid manager b. Integration of renewable energy with the transmission grid c. Increasing competitiveness through enhanced private player participation	Policymakers

5.7 RESULTS AND DISCUSSIONS

For eliminating the critical barriers of IPTS, the strategy identified by the experts is **"Appointing the nodal agency, which will be responsible for both**

planning and monitoring the IPTS.” The nodal agency has the capability to eliminate the critical barriers of IPTS by synchronizing the planning of IPTS. Furthermore, it also enables proper monitoring of on-going transmission projects through the inclusion of nodal officers from generation, distribution, and transmission sectors as well as the inclusion of nodal officers from different sectors to monitor the planning. The appointment of the nodal agency not only eliminate the absence of strategic planning by the government but also eliminate the other three critical barriers, i.e., fewer private players, low investments in power transmission and delays in project execution

However, there could come up with many obstacles that can hinder the implementation of this strategy. These obstacles include conventional thinking, unethical practices, less information sharing, financial constraints, a smaller number of human resources available, and conventional planning tools & techniques as identified through PRT of TOC These obstacles can be overcome by taking following actions by the stakeholders:

- A change management process must be initiated to deal with the reluctance of the policymakers to alter the conventional planning process.
- Improve the percentage of private player participation to deal with the financial constraints of the IPTS, simultaneously increasing the competitiveness of the sector.
- Initiating the skill development programs specifically for the IPTS to improve the resource efficiency of the sector.
- System and processes within the IPTS must be made transparent using software technologies. This will help in seamless information flow among various stakeholders and also curb any unethical practices taking place in the process.
- The conventional tools and techniques must be replaced by the new planning tools that are efficient in projecting, forecasting, and budgeting the sector’s needs and requirements.

- The financial crisis of the sector can be further reduced by increasing the investments of the sector through various government financial instruments.

5.8 CHAPTER SUMMARY

This study has used the principles of TOC to minimize the critical barrier, i.e., "absence of strategic planning of Indian power transmission system identified in the study Upreti et al. (2018). Since IPTS is a service industry and the constraint of the system is procedural in nature, the Thinking Process technique of the TOC was found to be most suitable. The key objective of the study is to enable the planning of the transmission sector holistically, using realistic and proactive approaches. CRT, EC, FRT, PRT, and TRT have been used in this study as guiding tools by the team that identifies causal relationships among UDEs, underlying conflicts among the solutions, and finally creates the solutions framework. The strategy identified in the RO2 using the Thinking Process of Theory of Constraints is **"Appointing the nodal agency, which will be responsible for both planning and monitoring the IPTS."** For this, the study provides various practical intricacies that can improve the planning process for both the existing and new transmission grids. An equal focus to generation, transmission, and distribution sectors is an essential aspect that can improve the sector performance through better planning. It was further noticed during the analysis process that, along with the barrier absence of strategic planning, two other barriers, i.e., fewer private players and low investments in power transmission, were also minimized. Once the strategic planning is adequately done, the problems related to power evacuation will be curtailed, which will ultimately make the IPTS more efficient. The stakeholders of the IPTS must be aware of the policies that have an overall impact on organizational performance. In short, the Thinking Process tools provided a transformed policy framework by assessing the current situation and injecting potential solutions into the IPTS.

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

6.0 INTRODUCTION

Indian Power Transmission sector in India plays a crucial role in supplying electricity to the end consumers. It is imperative that the growth of the power sector depends on the robust transmission network and non-collapsible transmission infrastructure. Further, the country is witnessing the growth of renewable capacity addition. This requires green transmission corridors and enhancement of the existing conventional transmission grids and sub-stations. In addition to this, the current regulatory dynamics in the power sector is moving towards open access transactions. Also, the government is planning to electrify nearly 4 crores of a rural household, which require additional inter-regional power transmission & distribution infrastructure.

The existing infrastructure of the Indian Power Transmission System (IPTS) is inadequate and will not be able to fulfill future requirements. This can be supported by the fact that there are many power surplus regions that are still facing power shortages due to inadequate availability of power evacuation infrastructure. Thus, there is an urgent need to identify various barriers that are hindering the efficient power evacuation from the transmission infrastructure. Literature survey and interaction with various stakeholders also revealed that there are certain fundamental barriers to IPTS that need to be addressed with immediate policy-related and strategic actions. This research has, thus, attempted to identify and mitigate the critical barriers persisting in the IPTS.

This chapter highlights the conclusion of the study, summarizing the key findings of the research. It also presents significant implications of the research to academia and practitioners. It also discusses the limitations and directions for future research, followed by the recommendations based on findings.

6.1 CONCLUSIONS OF THE RESEARCH

This study is principally, divided into two phases. This section of the chapter summarizes the key findings obtained in the two phases of the research.

6.1.1. PHASE I: EVALUATION OF CRITICALITY OF BARRIERS

In the first phase, the barriers persisting in the IPTS identified through rigorous literature review are categorized into most and least critical barriers using the Analytic Hierarchy Process (AHP). AHP has the capability to analyze the experts' opinions and prioritize the key barriers based on their severity level. The key findings obtained in this phase has been summarized below:

- The study has identified nine key barriers that are persisting in the IPTS. These barriers include the absence of strategic planning by government, low investments in power transmission, fewer private players in transmission, transmission congestion, transmission loss, failure to upgrade technology, delay in project execution, grid instability due to renewable energy, and poor performance and financial health of utilities.
- The results obtained using AHP confirm that the absence of strategic planning by the government is a critical barrier to the IPTS. Lack of adequate transmission capacity can be attributed to ineffective and unfocussed transmission planning by the policymakers. There is an urgent need for policy interventions to ensure adequate strategic planning and infrastructure investment in the transmission sector.
- Other barriers that were emerged as the critical barriers using AHP include low investments in power transmission, fewer private players in transmission, and delays in project execution. To rapidly augment the transmission capacity, huge investments both from the public as well as private players are required. Further, delays in the existing transmission projects must be minimized to reduce the overall transmission project costs as well as time for transmission corridors availability.
- Due to higher generation of the GHG emissions, the generation of power using renewable energy sources are increasing. Therefore, renewable

energy sources must be integrated into the grid through control measures.

6.1.2. PHASE II: ELIMINATION OF CRITICAL BARRIERS

In Phase-II of this study, the critical barrier, i.e., the absence of strategic planning by the government, has been eliminated using the Thinking Process (TP) approach of "Theory of Constraints." The key strategy identified in the RO 2 that can eliminate the abovementioned critical barrier using the Thinking Process of Theory of Constraints is **"Appointing the nodal agency, which will be responsible for both planning and monitoring the IPTS."** While mitigating the severe barrier to the IPTS, i.e., the absence of strategic planning by the government, it was revealed that the federal structure of the power system and the conventional mindset of the stakeholders are the core problems that are leading to the inefficient planning by the government. Thus, it became prominent that the policymakers need to first tackle the structural as well as the procedural issue of the transmission sector. To deal with core problems identified during the mitigation process of the critical barrier, it was found out that the appointment of the nodal agency is the most effective strategy. The nodal agency is to be required for both the planning and monitoring stages of the IPTS. This would help in fetching the accurate information related to the required amount of the transmission infrastructure. The strategy of appointment of nodal agency can be successfully implemented through training and change management, a more transparent system and seamless information flow, use of new technologies, use of new planning tools, resource-efficient system, and skill development programs. It was further observed that while eliminating the critical barrier through the nodal agency, i.e., absence of strategic planning, three other barriers, namely, fewer private players, low investments in power transmission, and delays in project execution was also simultaneously minimized. Thus, in total, four barriers that were found to be critical barriers to the IPTS were eliminated from the transmission system.

6.2 SIGNIFICANT MANAGERIAL IMPLICATIONS OF THE RESEARCH

The research provides considerable managerial implications to both academia and practitioners in the field of IPTS. The results obtained in this research provide significant insights that would assist in making IPTS more efficient.

6.2.1 Implications of research to academia

- This study has comprehensively conducted a literature review in the field of IPTS. In this study, a total of five major research themes were identified. These include the power sector in India, restructuring of the power sector, transmission system in India, incapabilities in the power transmission system, and planning in the transmission sector.
- Many researchers have asserted that barriers are persisting in the IPTS for many decades. These barriers were more or less identified in a fragmented manner and were snubbed under the barriers of the entire power sector. However, this study fills the gap by identifying the critical barriers in a more structured way and also provides key strategies for mitigating them from the transmission system.
- This study has integrated TOC with the power system for the first time in the literature. In this process, the IPTS has been thoroughly studied, along with the experts, wherein core problems were identified, and they were mitigated by analyzing causal relationships among UDEs, highlighting underlying conflicts among the solutions, and finally creating the solutions framework

6.2.2 Implications of research to practitioners

The research implications for the practitioners working in the IPTS have been concisely provided below:

- The list of barriers identified in this research can be used by the practitioners. The degree of criticality of each barrier obtained using AHP provide information related to the area that needs the urgent attention of the stakeholders to improve the overall performance of

IPTS. The practitioners can structure their focus to the critical barrier first, followed by the least critical barriers.

- The practitioners can also adopt the strategies provided in this research to mitigate the critical barrier of IPTS. The research advises them first to appoint a nodal agency that can coordinate the overall planning as well as monitoring of the ISTS and InSTS. They can practically test the efficacy of this strategy by monitoring the system performance.
- The research also recommends the policy-makers of IPTS to provide an adequate focus on the transmission sector in the required focus ratio of Generation, Transmission, and Distribution. This would increase the funds flow within the sector, which is one of the prime obstructions of the power evacuation issue
- The researcher further recommends the policymakers to incentivize the IPTS for bringing more private player participation in the system. This would not help in bringing more investments into the transmission sector but also help in building the competition within the sector.

6.3 CONTRIBUTION TO THE LITERATURE

In the literature, the barriers to IPTS are partially explained. Also, their criticalities are not quantitatively mentioned. This research fills this gap by computing the degree of criticality of each barrier using the most popular technique, i.e., AHP. The quantitative value obtained by conducting pair-wise comparisons among the barriers provides information related to the severity of the barriers that are persisting in the IPTS. Further, the literature does not provide any recommendations or actions that are required to be taken to mitigate the barriers. This study also offers various strategies to eliminate the critical barriers of IPTS that are identified in this study.

6.4 CONTRIBUTION TO THE THEORY

Thinking Process of the Theory of constraints (TOC) has been widely applied in diverse fields of study. However, according to the literature survey conducted, it is seldom applied in the power sector. For the first time, this theory has been applied in the Power industry. Infrastructure requirements, service offerings, and skill-level requirements make this industry different from other industries. Therefore, the models developed using TP for other service industries cannot apply to this industry. This research has, therefore, attempted to apply TOC to mitigate the critical barriers that are acting as a constraint to the system. Another contribution that has been made to this theory is the approach to initiate the process of application of TOC. Earlier studies used to apply TOC on the constraint that may not be much critical to the system. This may result in little alleviation of the system efficiency. To address this limitation, this study has first analyzed the criticality of the constraints and then applied TOC to the critical constraint of the system. One of the advantages of using this process is that it is a more focused approach wherein the constraint, which is riskier to the system, is mitigated first. Then the system is reinvestigated, whether still there are constraints present in the system or not. This approach saves both time and money in understanding and adopting strategies for the less severe constraint, which can be mitigated by eliminating the severe constraints at the very initial stage.

6.5 LIMITATIONS OF THE RESEARCH

The study has eliminated the critical barrier from the IPTS. In this process, few other critical barriers were also eliminated. However, the system has not been re-investigated to test the degree of severity of the remaining barriers persisting in the IPTS after the elimination of the critical barriers. Thus, system behavior can be further analyzed, and the barriers can be eliminated.

6.6 FUTURE SCOPE OF THE RESEARCH

- As the future scope of this research, it can be further extended by re-investigating the critical barriers among the barriers remaining in the system and further eliminating them using the TP of the TOC.
- Further, a conceptual model can be developed that can provide a roadmap for the implementation of the strategies recommended in this research for the elimination of the critical barrier. This model would help

the policymakers will avoid the ‘go from the guts’ approach towards a more “structured approach” at the time of implanting the strategies.

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ABOUT THE AUTHOR

Naveen Upreti completed his **Electrical Engineering** from Maharishi Dayanand University, Rohtak, India, in 2008. He has more than 11 years of professional experience in the power industry. He is currently working with the **Indian Electrical and Electronics Manufacturers Association (IEEMA),** India, as Assistant Director in the domain of the Indian Power Transmission System. He has earlier worked in **Feedback Infrastructure Services Ltd. and Rural Electrification Corporation, India** in Transmission and Distribution domains. His expertise includes power Transmission, quality assurance, multi-criteria decision-making analysis (MCDA), policy analysis, and project management. During his research, he has published many articles in the reputed Scopus indexed journals. He has also organized and attended many international and national conferences in the field of his expertise. He is also a reviewer of one of the reputed journals published by Elsevier.

LIST OF PUBLICATIONS & CONFERENCES

1. Published: Upreti, Naveen, Sunder, Raju Ganesh, Dalei, Narendra N. and Garg, Sandeep, 2018. "**Challenges of India's power transmission system**," Utilities Policy, Elsevier, Vol. 55(C), pp. 129-141.

2. Published: Upreti, Naveen, Sunder, Raju Ganesh, Dalei, Narendra N. and Garg, Sandeep. "**Revisiting the Challenges of Indian Power Transmission System: An Integrated Approach of Total Interpretive Structural Modeling and Analytic Hierarchy Process**", The Electricity Journal, Elsevier, Vol. 32 (10), pp. 1-7

3. Published: Upreti, Naveen, Sunder, Raju Ganesh, Dalei, Narendra N. and Garg, Sandeep. "**Application of Theory of Constraints to foster the services of Indian Power Transmission System**" International Journal of Energy Management, Emerald, Vol. 14 (3), pp. 547-568.

4. Presented a souvenir "**Power Evacuation: Biggest Challenge in Indian Power System (IPS)**" in an International Conference organized by UPES.

ANNEXURE

Table A1: Theme wise Literature review

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
1	**Power Sector in India (21)**	Bhattacharya (1994); Sanghvi (1991); Schramm (1993); D. Parameswara Sharma, P.S. Chandramohanan Nair, R. Balasubramanian (2005); Kanan and Pillai (2001); Ranganathan (1996); Ruet (2006); Ranjan Kumar Bose, Megha Shukla, Leena Srivastava, Gil Yaron (2006); Tongia (2004); Harbans L Bajaj and Deepak Sharma (2006); Yemula Pradeep, Abhiroop Medhekar, Piyush Maheshwari, S. A. Khaparde, Rushikesh. K. Joshi (2007); Tripta Thakur, S.G. Deshmukh, S.C. Kaushik(2006); Amulya K.N. Reddy (2001); M.R. Nouni, S.C. Mullick, T.C. Kandpal (2008); P. Garg (2012); Chia-Nan Wang, Nhu-Ty Nguyen and Thanh-Tuyen Tran (2015); Huang Liming (2009); Jack M. Hollander and Thomas R. Schneider (1996); Subhes C. Bhattacharyya (2008); Saini (2018); CEA (2018)	1. Two-stage random sampling 2. Cost-Benefit Analysis 3. Data Envelopment Analysis (DEA)	1. Technical performance 2. Operational Performance 3. Economic Performance	Studies have been made in regard to power system as a whole and barriers have been identified. There are inadequacies/ incapabilities/ inefficiencies persisting in the power transmission system. These are impacting the performance of power transmission, in turn impacting the overall power system.	1. Lack of focus on addressing Transmission related issues. 2. Lack of adequate number of transmission indicators assessing power system performance 3. Lack of measures to overcome Power Transmission issues

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
2	**Power Sector Reforms (22)**	Bhattacharya (2007); Rajan (2000); Dubash and Rajan (2001); Tongia (2003); Jyoti P Gupta and Anil K Sravat (1998); Umesh Kumar Shuklaand Ashok Thampy (2011); B. Venkatesh, T. Geetha, V. Jayashankar (2011); Anoop Singh (2006); T. Thakur, S.C. Kaushik, S.G. Deshmukh, S.C. Tripathi (2004); Puneet Chitkara, Rajiv Shekhar, and Prem K. Kalra (2001); Anoop Singh (2010); Subhes C. Bhattacharyya (2007); Kelli L. Joseph (2010); Animesh Pal (2013); Njeri Wamukonya (2003); Rabindra Nepal, Tooraj Jamas (2015); Anoop Singh (2009); Bhattacharya (2007); Laxmi Rajkumari & K. Gayithri (2018); Debalina Saha & Rabindra N. Bhattacharya (2019); A Veluchamy, Dr Raju Ganesh Sunder, Dr Rajesh Tripathi & Dr R Mohamed Nafi (2018); Atul Agrawal, Anil Kumar, & T. Joji Rao (2017); K. Singh and S. Vashishtha (2019)	1. Mixed Integer Linear Programming 2. Breusch-Pagan Lagrangian Multiplier test 3. Time series cross section	1. Installed capacity from utilities, 2. Gross generation and sales, 3. Power consumption by sector, 4. Average cost of supply 5. Financial status of SEBs, arrears to SEBs, 6. T&D losses, 7. power theft	1. Reforms do not bought benefits in reducing the loss or increasing the efficiency 2. The implementation rate of reform in the sector is low because of due to poor compliance of policies established in the reform	1. Barriers to IPTS are not addressed and possess fragmented views during reforms. 2. Lack of assessment of Power Transmission post-reform performance 3. Lack of measures to eliminate barriers
3	**Transmission system**	Vivek Pandey (2007); Edgar Tapia-Hernández, Santiago Ibarra-González & David De-León-Escobedo (2016); N.	1. Algorithm and Simulation	1. Transmission cost 2. Cost of building transmission line	1. With the increase in complexity of transmission network,	1. Lack of studies pertaining to

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
	in India (22)	Kirthika, S. Balamurugan (2016); V. S. K. Murthy Balijepalli, S. A. Khaparde, R. P. Gupta and Yemula Pradeep (2010); Amir Hossein Seddighi and Amir Ahmadi-Javid (2015); Baseem Khan , Ganga Agnihotri, Gaurav Gupta and Pawan Rathore (2014); Tajudeen H. Sikiru, Adisa A. Jimoh, Yskandar Hamam, Yasser Alayli and John T. Agee (2014); Giuliano Andrea Pagani and Marco Aiello (2013); Giuliano Andrea Pagani and Marco Aiello (2014); Johannes Urpelainen (2014); B. Ravikumar, D. Thukaram and H.P. Khincha (2008); Bhaveshkumar Dobaria, Mahesh Pandya, Mohan Aware (2016); Valentina Cupac , Joseph T. Lizier, Mikhail Prokopenko (2013); Friedrich Kunz and Alexander Zerrahn (2015); Neeraj Gupta, Rajiv Shekhar and Prem Kumar Kalra (2012); Aleksandra Kanevce, Igor Mishkovski and Ljupco Kocarev (2013); Vasundhara Gaur and Eshita Gupta (2016); Ishan Sharan and R. Balasubramanian (2012); Mohd Tauseef Khan & Anwar Shahzad Siddiqui (2017); A.K.P Kovendan & D. Sridharan (2017); Vaishali Rampurkar,	2. Multistage stochastic programming 3. Graph Theory based 4. Mixed Integer Programming 5. Complex Network Analysis 6. Support Vector Machine (SVM) 7. Performance indices 8. Generalized Nash Equilibrium Model 9. Genetic Algorithm 10. Monte Carlo	3. Penalty cost for unserved energy 4. Congestion costs 5.T&D Losses 6. Theft-loss ratio, 7. Theft Loss per capita, 8. Illegal Electricity Use	electricity markets and uncertainties, the pressure to The pressure to function the power system at high risk is also increasing 2. Provided evidence that line losses are politically correlated 3. Access to electricity to all, power supply reliability and its quality still remain bigger challenges for the country. 4. The initiatives related to smart grid in the country are notable improvements that can make the power sector of the country at par with international standards.	holistic view on Transmission barriers 2. Orientation of research is more towards technical aspects to eliminate barriers and lack of managerial studies to remove them.

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
		Polgani Pentayya, Harivittal A. Mangalvedekar and Faruk Kazi (2016); Furkan Ahmad, Mohammad Saad Alam, Reena Suri, Akhilesh Awasthy and M. Shahidehpour (2018); S. Paramanik, K. Sarker D. Chatterjee, B.K. Goswami (2019); F. Ahmad, M.S. Alam, S.M. Shariff, M. Krishnamurthy (2019); P.K.S. Rathore, D.S. Chauhan, R.P. Singh (2019)	simulation			
4	**Incapabilities in Power Transmission System (23)**	Yusheng Xue and Shijie Xiao (2013); A.Didar Singh (2013); Muhammad Bachtiar Nappu, Ardiaty Arief and Ramesh C. Bansal (2014); Harry Singh, Shangyou Hao, Alex Papalexopoulous (1998); S.K. Ray Mohapatra, Subrata Mukhopadhyay (2006); Brian Min, Miriam Golden (2014); Ankur Omer, Smarajit Ghosh, Rajnish Kaushik (2013); Guo Chen, Zhao Yang Dong, David J. Hill, Guo Hua Zhang, and Ke Qian Hua (2010); Liang Chang and Zhigang Wu (2011); Ram Joshia, Maharshi Pathak (2014); Sudheer Kasa, Prabhu Ramanathan, Sudha Ramasam, D.P. Kothari (2016); KPMG (2010); Juan Miguel Pérez de Andrés, Miguel	1. Optimizing Tool/ Mathematical Modelling 2. Error and attack tolerance 3. Simulation/MATLAb/SIMULINK 4.Matrix-based system reliability 5.Edge load model 6.Sensitivity	1. Congestion costs 2. Cascading failures 3. Active and reactive power	1. Access to electricity to all, power supply reliability and its quality still remain bigger challenges for the country. 2. The investments allocated to the transmission sector were much lesser in the 10^{th} and 11^{th} five year plan as compared to the generation sector, which resulted in the inadequate transmission capacity. 3. The issue of	1. Barriers of IPTS have not been studied 2. Root cause of the existence of barriers have not studied 3. Inter-relationships among the barriers have not studied 4. Categorization of barriers based on their

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
		Mühlenkamp, Dietmar Retzmann and Siemens AG (2004); Colin Gunnar Beckman (2013); PWC, BHEl, ONGC, NTPC, PFC, Indian Oil, Gail, REC and World Energy Council(2012); Guidong Zhang, Zhong Li, Bo Zhang and Wolfgang A. Halang (2013); Jian-Wei Wang and Li-Li Rong (2011); K.S. Verma, S.N. Singh, H.O. Gupta (2001); S. R. Samantaray (2014); H. Rahman and B. H. Khan (2007); Moazzam Jazi, Zohre, Hamedi Maryam, Gholamreza Esmaeilian (2015); Rohit Verma (2016); SandraTenggren, Josefin Wangel,Måns Nilsson and BjörnNykvist (2016)	Analyses 7.TOPSIS		transmission congestion is the key issue that has the capability to raise other issues. 4. It is important to review the transmission projects and their execution so as to ensure their timely completion. 5. Due to deliberate edge attacks in the transmission grid the sector is facing cascading failures.	impact have not been studied 5. Comprehensive study to remove the barriers in the system have not been studied
5	**Planning in Transmission System (18)**	Central Electricity Authority (CEA), PGCIL and POSCO (2014); Central Electricity Authority (CEA); IEEFA; CEA, 2016; V. Ananda Kumara, Krishan K. Pandey and Devendra Kumar Punia (2014); Binayak Bhandari, Shiva Raj Poudel, Kyung-Tae Lee and Sung-Hoon Ahn (2014); Markus Haller, Sylvie Ludig and Nico Bauer Potsdam (2012); Yanfei Li and Youngho Chang (2015); Ishan Sharan and R. Balasubramanian (2012);	Mixed Integer Linear Programming Mathematical Modelling Regression Analysis	Transmission losses Power flow in transmission lines New transmission lines Capacity of the transportation route Cash of support cash flow of federal support Tax reductions State level support	1. Power system in India is facing various challenges. 2. Government of India is planning to overcome these challenges by implementing various strategies 3. The transmission requirements has been arised due to increase in	1. Lack of studies focusing on the analysis of planning of transmission by government of India. 2. Require studies on

#	Theme	Authors	Tools used	Variables	Inferences	Gaps
		Gireesh Shrimali, Saurabh Trivedi, Sandhya Srinivasan, Shobhit Goel and David Nelson (2016); Geoffrey Wood and Stephen Dow (2011); Planning Commission, Government of India (2013-14); Central Electricity Authority (2013), Government of India, Ministry of Power; Komali Yenneti (2016); Peter Viebahn, Daniel Vallentin, Samuel Höller (2014); Alexandre Moreira, David Pozo, Alexandre Street & Enzo Sauma (2017); Ali Hajebrahimi, Amir Abdollahi & Masoud Rashidinejad (2017); MOP (2017); N. Bansal, V. K. Srivastava, J. Kheraluwala (2019); M. Irfan, Z.Y. Zhao, M. Ahmad, M. C. Mukeshimana (2019)			the addition of the generation capacities, increase in demand, and strengthening of the power system.	long term planning to eliminate barriers so as to have long term implication on IPTS. 3. Broad view on IPTS issues in place of narrow-down approach

Table A2. Literature Review

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Bhattacharya (1994)	Science direct	Indian Power Sector	To overview the problems of power sector of India and analyze the future prospects of the industry			5 issues in power sector has been identified (growth in demand, delays in power projects, lower utilization of the capacity of thermal generating units, inadequate transmission and distribution facility, poor financial performance).	There are many factors that are affecting functioning of the power system and there are many solutions that can improve the current situation.	Interconnections among the barriers of IPTS are not known	Power Sector in India	Delay in project execution Poor performance and financial health of Utilities
Sanghvi (1991)	Science direct	Economic costs, Electricity supply, shortages,	To analyze the short run as well as long run economic impacts of inadequate power supply	Spoilage costs, Direct cost, Adjustments costs, Total unplanned costs, Breakdown costs		Discussed reasons for unreliable power supply mainly in developing countries especially India and Pakistan (capital constrained, poor state of transmission, poor supply quality). The paper has further measured the short run costs as well as long run costs incurred due to unreliable power supply using country specific examples. Finally implications of policies to reduce the power shortage situation has been discussed	There is huge power shortages especially in developing countries like India. It is important to improve the efficiency of the power system, managing power demand, establishing the market and organizational structure	Impact of each barrier is not known. Measures to eliminate the barriers of IPTS are not known.	Power Sector in India	Low investments in Power Transmission Transmission Losses
Schramm (1993)	Science direct	Environment, Power Sector performance, Developing countries,	To improve the operational performance of the power system to reduce its capital needs and environmental impact	Financial rate of return, electricity tariffs, generating capacity reserve margins, total system losses, generation capacity, utility		7 issues in the power sector as a whole has been discussed (Poor Financial performance, disproportionate inappropriate investment schemes, high losses in the system, low operational performance, issues related to manpower, institution and management)	There exists technical in-competencies in the power sector. The sector has witnessed more political and social goals, which have little impact on the primary objective of the power sector i.e. providing access to safe and reliable electricity at lower costs. This will lead to required successful and sustainable reforms in the financial, physical and other institutional areas.	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Low investments in Power Transmission Poor performance and financial health of Utilities

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
				customers per employee						Transmission Losses
Parameswara et al. (2005)	Science direct	Indian power sector; Power sector restructuring, Performance evaluation of power sector	To evaluate performance of the power sector after the reforms introduced in the country from the year 1991-2001	Technical performance, operational performance and economic performance		Total 16 technical performance indicators have been used to assess performance of Indian power sector after a decade of the implementation of the power sector reform	The power sector reform introduced during the year 1991 has little affect on the improving the technical and financial efficiency of the sector. The reform was also failed in reducing the power losses and improving the overall satisfaction of the customers. Further, the reform process has not much helped in achieving the social objectives of the sector.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Transmission losses Poor performance and financial health of Utilities
Animesh Pal (2013)	ICERTSD	Investment, Economic growth, Legislations, Power sector reforms, Per capita energy consumption	To review the Power sector performance of India during the pre and post reform eras			Discussed the before and after eras of Indian power sector. Briefly discussed about the Electricity Act 2003 and potential benefits obtains with its enactment. Discussed challenges power sector is facing (peak shortage, land acquisition, equipment shortage, in efficient project execution)	It has been inferred that lack of adequate power supply is one of the big barriers for the India's plan to become super power with 3rd largest GDP by the year 2030	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Delay in project execution
IEEFA (2015)	IEEFA, Ministry of Power	Indian Power sector	To achieve sustainable power by reducing technical and commercial losses, integrating renewable energy and increasing			Discussed about the Indian electricity sector as a whole (generation, transmission, distribution). Discussed about the integration of renewable energy (175 GW) by 2022 with the aid of international funding. Discussed about improving Grid efficiency (increase in investments, reduction in	Indian Power sector is facing various challenges The planning by the Indian government to overcome these challenges by implementing various strategies	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the	Planning in Transmission System	Absence of strategic planning by Govt. Grid instability due to Renewable Energy Low

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
			generation capacity			AT&C losses) and development of integrated national grid. Discussed briefly about challenges faced by thermal power plants		barriers of IPTS are not known		investments in Power Transmission
CEA, 2016	CEA	National Transmission Plan	To highlight the transmission system required in India in the next 20 years			Discussed about load demand estimates for 2021-2022 state wise. Analyzed installed generation capacity available and required by 2022. Assessed state-wise transmission capacity required by 2021-22	Inter Transmission capacity requirements have been assessed based on advance estimates of peak load demand and state wise transmission is based on assumptions for next 20 years	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Planning in Transmission System	Absence of strategic planning by Govt. Fewer private players in Transmission Transmission congestion Poor performance and financial health of Utilities
. Reddy (2001)	Science direct	Power sector reform, Indian Power Sector, sustainable development	To evaluate the World Bank's diagnosis approach to address the crisis of utilities in developing countries			Discussed crisis of electricity boards (capital crisis, access/equity/distribution crisis, environmental crisis, performance crisis) in detail. Discussed and analyze the diagnosis done by World Bank to investigate the weakness of the electricity board (centralization and disproportionate size, inflexibility, monopoly in power controls and dominance of public ownership A comparison of the general solutions prescribed by the World Bank was carried out with	To ensure a sustainable and socially beneficial power sector, various strategies (promotion of competition, integrated resource planning, widening access and promoting equity, environmental protection, pricing, Protecting state-inspired stranded investments) are required.	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not known	Power Sector in India	Fewer private players in Transmission Low investments in Power Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						the real-case study of the state Karnataka				
Nouni et al. (2008)	Science direct	Decentralized electricity generation options; Delivered cost of electricity; Critical distance for grid extension, Rural electrification	To highlight the efficacies of the initial efforts made to generate power through the decentralized renewable energy options.			Discussed about few transmission issues in India (high losses related to transmission & distribution, frequent interruption in the power supply; challenges and financial limitations to extend the power grid to distant areas; diverse population in rural areas leading to lower peak loads, deprived financial wellness of SEBs). Discussed the status and growth of the sector, rural electrification, delivering cost of electricity in small villages, estimating the loads required in the rural areas.	It has been inferred that about 19% of Indian villages lack access to the electricity mainly because of inadequate generation, transmission and distribution capacities. It has been further estimated that it costs INR 26 per kWh to deliver the electricity to a rural village, with a 5 km distance from the grid, 20 households with 5kW of peak load and 0.2 load factor	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Transmission Losses
Li and Chang (2015)	Science direct	Power infrastructure, Financial viability, Commercial viability, Cross-border power trade	To develop a systemic method in measuring the viability of investments done in the power infrastructure in the ASEAN plus China and India context			Identified the institutional barriers that arises during the implementation of region-wise interconnection of power, Developed a sub-model that shows the financial viability of establishing transmission lines in the cross border regions of ASEAN+2.	The current power trade arrangements might get changed after establishing a new transmission line. This will further regulate the patterns of asset utilization and their financial feasibility.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Planning in Transmission System	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Sharan and Balasubramanian (2012)	Science direct	Fuel transportation Transmission, network planning, Generation expansion planning	To present a comprehensive optimization model for expanding the integrated generation as well as transmission system	Total energy generated, quantity of fuel transported, power flow in transmission lines, new transmission lines, fuel available, capacity of the transportation route	Mixed Integer Linear Programming	The objective of the mathematical model proposed in the study is to minimize the overall costs of expansion. These costs include capital cost of generating unit, cost related to fuel incurred in the operation of generating units, transportation costs of fuel, capital costs of new transmission lines. The constraints include fuel availability limit, fuel transportation limit, capacity of generating units	Illustrated the benefits of following an integrated approach in generation and transmission expansion planning rather than doing both the planning in isolation.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Absence of strategic planning by Govt. Transmission Congestion
Xue and Xiao (2013)	Springer	Multi- domain interaction, Complex system, Domino effect, Comprehensive defense, Risk control, Energy security, Power congestion	To analyze the unavoidability of India's huge blackouts			To identify the factors that had led to huge black-outs and analyze the evolving process adopted by the system. The study also emphasizes the importance of smart grids and defense system to reduce the risk of power disruptions.	There is an urgent need to upgrade the Chinese power sector through innovation due to the high risk susceptibility of its infrastructure, organizational structure and response to emergency situations.	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission congestion Failure to upgrade Technology
Planning Commission, Government of India (2013-14)	Planning Commission of India	State Power Utilities	To provide policy makers an in-depth statistical document and an analysis of the in power sector			Discussed an overview of Power sector in India. Identified various issues in the sector on the basis of operational and financial performance	The economic debts of many State utilities are increasing continuously. Since previous few years, there is a rise in the average power tariff. But this rise in the tariff has not remained equal with the rise in the supply cost. The fixed cost as well as O&M related costs have been reduced since past few years but there is substantial rise in T&D losses.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Planning in Transmission System	Poor performance and financial health of Utilities Transmission Losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Central Electricity Authority (2013), Government of India, Ministry of Power	Central Electricity Authority		To carry out electric power survey for each DISCOM			Discussed the electrical energy requirement, annual peak electric load, category wised forecast of cities. Analyzed the pattern of electricity.	There is a need to substantially increase the transmission infrastructure to meet the target of reducing the T&D losses	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Transmission congestion Transmission losses
Singh (2013)	FICCI	Power Transmission System	To identify variouschallenges of Indian Transmission system			Discussed about various issues of transmission system (power evacuation, chocked transmission network, delays in transmission capacity addition). Discussed challenges in transmission project cycle (selecting players, planning of projects, granting the project, implementing & commissioning of project, O&M, project exit). Provided various recommendations to overcome challenges	In the 11th and 12th Five-Year Plan, the transmission investments were quite lower than the investments in the generation system. This resulted in lack of transmission capacity to transfer increase in the generating supplies. Further there are various challenges that are limiting the quick execution of transmission projects.	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not knownMeasures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Absence of strategic planning by Govt. Low investments in Power Transmission Delay in project execution Transmission Congestion
Nappu et al. (2014)	Science direct	Transmission congestion and management, Network losses, Economic dispatch, Electricity market, Locational	To control the transmission congestion by formulating LMP scheme using an optimization approach	Supplier Surplus, Customer Surplus, Production Cost, Customer Benefit, Active Power Output, active power demand, Total	Optimizing Tools	Discussed many issues of transmission system of the power industry. Discussed the economical and optimal way of dispatching the power. . Explored the issue of congestion and the equilibrium between the supply/demand. Presented a LMP scheme to manage	There are three transmissions issue that need to be addressed (transmission congestion, transmission losses and usage tariff of transmission). The issue of transmission congestion is the key issue of the sector as it leads to several other problems related to market inefficiencies.	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Congestion Transmission Losses Absence of strategic planning by Govt.

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		marginal price (LMP)		social costs, congestion costs		transmission congestion.. Proposed an enhanced technique of OPF for LMP.				
Kanan and Pillai (2001)	Economic and Political weekly	Power Sector in India, performance, state electricity board	To examine important reasons of monetary inefficiencies involved in the operations of SEBs	Supply costs of electricity, tariff and revenue, financial performance		Discussed and assessed the physical performance of power sector using various key indicators such as capacity addition, load factor, transmission losses, technical inefficiency	Lack of government policies, government subvention has resulted in the inefficiencies of SEBs. Inefficiencies at technical, organizational, financials as well as policy level endures to deteriorate the system.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Power Sector in India	Absence of strategic planning by Govt. Poor performance and financial health of Utilities Transmission losses
Ranganathan (1996)	Science direct	Electricity; Privatization; IPPs; Restructuring	To understand the barriers to privatization and investments from foreign IPPs	Attractive return on equity, counter guarantees by government permit to direct sale by IPP, Lenient operating norms, income tax, Higher depreciation provision, repatriate dividends		Discussed the factors leading to power crisis These factors include inadequate institutional focus in the process of making decisions, lack of professional regulators and lack of coordinated policies	Electricity privatization is without strategy. One of major constraints is lack of commercial focus of the state electricity boards. The government is more focused on generation privatization	Impact of each barrier on IPTS is not known	Power Sector in India	Absence of strategic planning by Govt. Poor performance and financial health of Utilities Fewer private players in Transmission
Ruet (2006)	Science direct	Investment; Electricity; Profitability; Network rehabilitation	To examine investment profitability from the perspective of micro-economics in the Indian power sector			Discussed various issues such as power shortages, lower utilization of plant capacities and technical losses. It has proposed and compared various technical strategies (developing new plants, improving PLF and reduction in technical losses) to	To meet the increasing demand or reducing losses has been proved more preferable than adding new capacities. the reduction of technical losses proved to be preferable to new capacity addition	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Power Sector in India	Transmission losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						overcome such issues. Further, it has evaluated the various SEBs on the same				
Bose et al. (2006)	Science direct	Opportunity cost; Electricity shortages, Willingness to pay	To examine and analyze cost related to unserved energy or lost load in both agriculture sector and industrial sector	Production loss per unit of power outage, annual electricity consumption, annual hours of electricity not available, annual production opportunity loss	two-stage random sampling	Discussed the perception of the consumer and their willingness to pay higher or differential tariffs in industrial and agricultural sectors of the Karnataka state perceptions and willingness to pay different or higher tariffs in the industrial and agriculture sector in Karnataka state. Three alternative methods (production loss, captive generation and willingness to pay) provide useful insights to address tariff revision.	The methods provides an estimate about maximum level of tariff that can be paid by the consumer and his willingness to pay the price. It has been shown that the willingness of the consumer to pay the price lies somewhere between upper and lower bounds using production loss and captive generation methods respectively.	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Absence of strategic planning by Govt.
Tongia (2004)	Carnegie Mellon University	Power Sector, Reforms, Information Technology	To assess the long term benefits and disadvantages by implementing IT solutions	Equipment costs, IT infrastructure, annualized cost of capital rate, electricity costs, utility costs	Cost-benefit analysis	Discussed goals and drivers (power losses, power theft, automated meter reading, Universal Prepayment Card) for using IT in Indian power sector. A case study for a major utility in South India has been developed to inspect the significance of IT by using cost-benefit analysis smart IT system for power distribution	It was observed that use of IT may reduce power losses and power theft with 6-7 years of payback and can avoid expenditure. The power sector in India must develop a long-term IT vision.	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not knownMeasures to eliminate the barriers of IPTS are not known	Power Sector in India	Failure to upgrade Technology Transmission losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Rajan (2000)	Science direct	Power sector reform	To identify and study in detail factors that compelled to introduce reforms in the power sector of the developing countries			Discussed factors leading to power sector reforms. These factors are categorized as contextual, triggering and facilitating factors. A case of Orissa power sector reform has been used to identify the factors	The reasons behind the restructuring the power sector are financially non-performing utilities, , conditionality of the agencies providing loans, lack of support of government to utilities. Restructuring strategies such as support from the government, lack of consumer lobby, top management support from the utilities would facilitate power sector reforms. Such reforms especially in the developing countries have resulted in the substantial rise in the tariff as the utilities are adopting commercial regime.	Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Absence of strategic planning by Govt. Poor performance and financial health of Utilities
Dubash and Rajan (2001)	Economic and Political weekly	Power Sector Reform	To analyse the socio-political and political environment in which restructuring and reforms in the power sector were introduced in India.			Discussed the pre-reform situations of power sector in India on various factors such as agriculture subsidies, condition of state run electricity sector. Discussed various factors that lead to reforms such as macro-economic reforms, less control of government, privatization. Discussed the replication of restructuring model of Orissa and role of international consultants while implementing reforms	Power sector policy reforms happened two times in Indian history. First, when consumption of agriculture was deteriorated and wide-ranged subsidies were presented. . Second, when IPP contracts were widely accepted. Third when the Orissa model of restructuring was replicated on the national level.		Power Sector Reforms and restructuring	Absence of strategic planning by Govt. Poor performance and financial health of Utilities
Tongia (2003)	Carnegie Mellon University	Power sector reform	To assess the Indian Power Sector history and summarized its present status	Installed capacity from utilities, gross generation and sales, power consumption by sector, average cost of supply, average tariffs, percentage of recovery		Reviewed the condition of power sector before the reforms. Identified various drivers that laid the stone of reforms. Discussed in detail the implementation of reforms in three phases (Increase in power generation capacity, structural & establishment of autonomous regulators and involvement	Worldwide trend towards reforms, India's shortfall in capacity and deregulation led to reforms. However, reforms do not guarantee success in terms of improving efficiency or reducing losses. It is the capability of the state governments to carry out improvement plans successfully. Early reforms focused mainly on IPP. It was further observed that reforms were not able address primary issues such as		Power Sector Reforms and restructuring	Fewer private players in Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
				through tariff, financial status of SEBs, arrears to SEBs, plant load factor, costs to SEBs, T&D losses, power theft		of central government) It further discussed and analyzed the potential benefits incurred after restructuring the sector	lower average tariff than the average cost for utilities. In turn, reforms have further escalated the average costs of SEBs at a higher rate as compared to the average revenue of SEBs.			
Gupta and Sravat (1998)	Science direct	Privatization, development, power projects, financing, risk factors, Dabhol power project	To analyze key challenges faced during the development and investments of Independent power projects (IPP)	Risks, Credit support capability, financing		Discussed a brief profile of Indian power sector. Discussed the policies, procurement, risks, investments, fuel logistics related challenges faced by the private entities during the development and execution of the projects. Discussed and analyze the real case of the Dabhol Power Project, which was among the initial IPPs introduced in the country by foreign investors.	Although privatization is encouraged in the power sector of India, various factors such as expansion of private projects in the country such as high political risk, unstable economy, extremely bureaucratic structure, poor reliability of power purchaser, and fuel supplier)	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Power Sector Reforms and restructuring	Fewer private players in Transmission
Shukla and Thampy (2011)	Science direct	Competition, Electricity, Market power	To analyze the market structure and competitiveness in Indian Wholesale Electricity Market	Average price of electricity traded, unscheduled interchange (UI) rates, volume of UI billing, generation capacity, firm market share, market's peak day demand, supply margin in market, quantity demanded, market price, supplier's cost		Examined the prospective for the implementation of market power by using both 5 ex-ante indices (and examined the post implementation of market power using the price–cost mark-up of the prominent electricity generator.	Using the Herfindahl-Hirschman index and concentration ratio, electricity market in the country is mainly concentrated in north-east regions. It was further showed that each generator is important to meet the electricity demand and thus, each generator has the market power.		Power Sector Reforms and restructuring	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Venkatesh et al.(2011)	IEEE	IPPs,Indian Power System, Availability Based Tariff	To develop an optimization model to assign schedule units for entire day in the utility	power input/output and energy into pump hydro, System frequency, cost of un-scheduled interchange, demand and supply gap, operational cost of pumped hydro, efficiency of pumped hydro	Mixed Integer Linear Programming	Discussed about unscheduled interchange, availability based tariffs. Presented the energy dispatch model and its structure Indian utility of Tamil Naidu state. Developed an optimization model with the minimization objective of the system costs endured by the The model has been computed with MOSEK solver.	The results of the model is tested on operational strategies, frequency regulation and pure arbitrage modes. These modes have effects on frequency, costs, and ABT rates	Impact of each barrier on IPTS is not known	Power Sector Reforms and restructuring	
Bajaj and Sharma (2006)	IEEE	Indian Power Sector, Distribution, Generation, Open Access, Power sector reforms, Power Markets, Regulatory Commission, Transmission	To review the impact of restructuring on the entire power system of India since last one and a half decade.			Discussed about the power sector and reforms associated with the sector in India. Discussed main objectives and additional provisions of Electricity Act 2003. Evaluated power sector performance during the process of restructuring as per the policies post-reform.	Although key purpose of the reforms in the sector in developed countries was increase competition, in India fiscal health of SEBs and private sector participation were the main reasons for reforms. Reforms resulted in AT&C and commercial losses	Interconnections among the barriers of IPTS are not known	Power Sector in India	Fewer private players in Transmission Poor performance and financial health of Utilities
Singh (2006)	Science direct	Bulk power market; Electricity sector reform; Regulation	To analyze situation before the introduction of reform policies in the power sector of India and identifying the key factors that led to reforms and restructuring processes in power sector			Discussed and analyzed major alterations done at the regulatory and policy level since the process of reforms were initiated... Discussed in brief changes in the market structure during the reform process.. Identified issues related to open access and tariff arising in this context.	Reforms separated generation, transmission and distribution sectors functionally. It also established federal as well as state regulatory bodies. It encouraged privatization in all the three sectors of the power system. It made the regulatory changes in such a way that they bring tariff rationalization, higher customer participation, and more transparency in the systems and processes. It was finally inferred that Electricity Act 2003 has immense potential for upgrading the sector.		Power Sector Reforms and restructuring	Fewer private players in Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Thakur et al. (2004)	IEEE	Impacts, policy shift, Electricity Act 2003, power generation, transmission, and distribution	To understand and discuss Electricity Act 2003 in Indian Power Sector and to assess the impact of various provisions under this Act			Discussed implication of Electricity Act 2003 for power sector of India and introduction of open access. Discussed various issues not resolved by the Act in generation (direct contract with distribution, takeover of contract by government intermediary, licensee with transmission links, scheduling of capacity, trading among gencos, and group captive capacity), transmission (redistribution of cross-subsidy surcharge & its burden on customers, impact of inadequate transmission capacity on open access and distribution, voltage definition to transmission) and distribution (network pricing, cross subsidization, impact of open access)	Electricity Act is an exemplary change introduced in the Indian power industry and has revamped the current power structure. Its complete success depends on the implementation with various uncertainties available in the sector. However, the Act leaves various issues that is not addressed along with the benefits it is going to deliver to the customers.	Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Absence of strategic planning by Govt.
Chitkara et al. (2001)	India Infrastructure Report	Indian Power Sector	To review the power sector in the context of pre-reform and post-reform era			Discussed the change in Indian Power sector during reform and restructuring.	The poor performance of SEBs in terms of financial losses can be attributed to the agency failure. To address this issue, encouraging privatization is the urgent need to improve the overall efficiency of the sector.	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Poor performance and financial health of Utilities Fewer private players in Transmission
Vivek Pandey (2007)	Electrical India	Grid Management, Transmission, Power sector	To review the transmission grid management in India			Discussed various facts of grid management in Indian Power sector (role of load dispatch centers, grid management, and various states of grid management, regional	As the complexity, uncertainties and market growth in the transmission sector are increasing, the risks associated with grid operation are also increasing. Therefore, management of the grid must be given focused attention by all the stakeholders.	Impact of each barrier on IPTS is not known Measures to eliminate the	Transmission System in India	Absence of strategic planning by Govt. Low investments in

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						electricity market, electricity trading, open access system and contribution of grid operators). Analyzed various challenges in grid management such as network complexities, changing demand, dynamic changes in system parameters, impact of natural calamities, etc.		barriers of IPTS are not known		Power Transmission Grid instability due to Renewable Energy
Singh (2010)	Science direct	Open access, Competition in power markets, India	To provide an outline of the nature and statistics related to the competition in the power sector			Discussed the details, status and the impact of programs related to open access initiated by State Regulatory Commission (SERC). Many residual issues for wholesale (pricing, capacity, transmission rights, fuel markets, market mechanisms, market power, monitoring) and competition (tariffs, supplier, procurement, renewable sources) were further highlighted.	The Electricity Act 2003 addresses the issues concerning competition in the power sector but these are not sufficient to reach the objective. The challenges in the sector involves technological and financial inefficiencies, The regulatory bodies must develop a framework that can provide road map for developing market and its mechanism.	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not knownMeasures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Absence of strategic planning by Govt. Low investments in Power Transmission Poor performance and financial health of Utilities
Pradeep et al. (2007)	Grid-Interop Forum 2007	Common Information Model, Interoperability, Inter Control Center Communication Protocol, Indian power sector	To understand the key role that interoperability plays in power sector in Indian context.	organizational interoperability, application interoperability, information interoperability and technical interoperability		The current status of interoperability in the power sector organizations has been discussed. Also, Unified Load Dispatch and Communication (ULDC) which is a recent architecture driving infrastructure of various power system organizations.	It was inferred that organizational interoperability is beneficial and crucial for the power system organization.	Interconnections among the barriers of IPTS are not known	Power Sector in India	
Singh et al. (1998)	IEEE	Competitive electricity market, Transmission congestion	To study the management of costs associated with			Discussed the economic and costs aspects associated with transmission congestion management problem and associated issues. Proposed	Nodal pricing seeks to provide the correct locational price signals but may provide opportunities for arbitrage of nodal price differences	Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
			transmission constraints			two models (Pool model and Bilateral Model) for implementing a competitive electricity market. Discussed the framework for managing congestion and discussed costs in a bilateral model	particularly if implemented with physical bilateral contracts			
Hernández et al. (2016)	Taylor & Francis	collapse mechanisms, pushover analyses, Transmission tower, wind load, ductility, over strength,	To assess the capacity and collapse mechanism of two existing transmission towers under wind loading.	Structure height, voltage, span, line angle, insulators, conductors, self-weight of tower elements, cables and insulators, mechanical tension in cable due to line deviations, wind loads acting on cables and tower body, demand/capacity ratio		Developed a nonlinear static model to assess the capacity and collapse mechanisms of two existing transmission towers. Adopted different load distribution patterns from different countries.	Analysed a damage concentration, which leads to a fragile collapse mechanism with important strength reserves and a non-uniform distribution of yielding within the tower height	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Transmission System in India	Transmission congestion
Mohapatra and Mukhopadhyay (2006)	IEEE	Life Cycle Cost, Residual Life Assessment, Asset Management, Risk, Run-Refurbish-Replacement	To identify critical problems relating to risk management and asset management in IPTS			Discussed key issues related to risk management as well as asset management (failure of equipment, rate of failures, network reliability issues and shut down of station). Discussed various strategies reduce the risk, costs and improve the life, performance and reliability of the assets (preventive maintenance practices, condition monitoring parameters, replacement decision, effective &	Managing assets when they are still operating and when they have crossed the expected life is difficult for the utilities. The life of the equipment in operation is assessed by Residual Life Assessment (RLA) through which run, refurbish and replacements decisions are made. It also helps in making decisions related to future investments required in IPTS.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission congestion Transmission Losses Delay in project execution

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						efficient utilization of existing assets, condition monitoring)				
MOP (2014)	Government of India, Ministry of Power	Transmission System	To develop a 20-year perspective transmission plan in India			The report has discussed about the transmission expansion with the growth in generation capacity. It has discussed about the evolving transmission corridors during 14th and 15th Five-year plans and beyond	There is a need to build high capacity transmission corridors to deal with the increasing problem of Right-of-Way in IPTS.	Interconnections among the barriers of IPTS are not known	Planning in Transmission System	Fewer private players in Transmission Absence of strategic planning by Govt. Transmission congestion Transmission Losses
Central Electricity Authority (CEA)	Government of India, Ministry of Power	Transmission System Planning	To develop a national transmission plan			The report has discussed transmission planning with the objectives of the growth of transmission system, optimum utilisation of resources, technology and cost optimization	The transmission requirements has been aroused by adding new generation capacities in the system due to increase in power demand.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Fewer private players in Transmission Absence of strategic planning by Govt. Transmission congestion Transmission Loss
Bhattacharyya (2007)	Science direct	India; Sustainability, Power sector reform	To understand the sustainability of the power sector reform and its execution.			Discussed the experience of introducing the power sector reform in India and assessed the reform sustainability on the basis of political accessibility, financial	The implementation rate of the reform is lower in the sector, although there is a legal framework that provides roadmap for the execution of reforms. This could be because of the lower acceptance of reform policies. The	Interconnections among the barriers of IPTS are not knownMeasures to eliminate the	Power Sector Reforms and restructuring	Poor performance and financial health of Utilities

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						viability, subsidy issues, economic efficiency, social issues, environmental effects	sector has not witnessed performance improvement, reductions in costs and improved services.	barriers of IPTS are not known		
Thakur et al. (2006)	Science direct	Restructuring; Unbundling, Data envelopment analysis	To compare the efficiencies of state owned electric utilities in India responsible for generating, transmitting and distributing the power.	Total costs, adjusted cost, energy sold, customers, distribution line length	Data Envelopment Analysis (DEA)	Discussed the structure of the of Indian Power sector. Evaluated the performance of state owned utilities in Indian context..	The state owned utilities are inefficient and are not operating as desired. The results further indicated that restructuring and reforms in the sector may improve the performance of utilities.	Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Poor performance and financial health of Utilities
Joseph (2010)	Science direct	India, Captive power, Electricity	To analyze the impact of private sector involvement by politicians		Time series cross section, Breusch-Pagan Lagrangian Multiplier test	Three hypotheses have been formulated to test the relationships between captive power production and agricultural state, T&D losses and captive power generation and price of electricity and captive power plant	The reforms are partially adopted as industrial consumers have been exited from the state-owned system. Out of all the sectors, generation is open to both private and state where as distributors are still state run sector despite their financial crunches. Due to this they are not able to improve the infrastructural improvements and fulfill the power demand.	Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Transmission congestion Transmission Losses
Kirthikaand Balamurugan (2016)	Science direct	Transmission line power flow, FACTS, D-FACTS, Congestion management, Control algorithm	To relieve from the transmission congestion by monitoring power flow in the transmission line	Power Flow, voltage phase angle voltage, reactance	Algorithm and Simulation	Discussed the abstraction of series compensators utilized in the transmission conductors of the power system network and the concept of real power flow control	The control strategy is realized on a group of FACTS devices, which are operating in the power transmission lines.	Interconnections among the barriers of IPTS are not known	Transmission System in India	Transmission Congestion
Brian Min, Miriam Golden (2014)	Science direct	Politics, Line losses, India	To study the politics of electricity losses in Uttar Pradesh	Line losses, Electoral cycles, Power supplied		Discussed the statewide trends from 1970 to 2010 and examined electrical power distribution, billing, and line losses from 2000 to 2009. Examined data from Uttar Pradesh to demonstrate that	Provided evidence that line loss is politically correlated. line losses have become bound up with the intense electoral competition in Uttar Pradesh	Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						variations in electricity losses are related to the timings of statewide elections.				
Omer et al. (2013)	IJAREEIE	Energy Audit, Restructuring, Power Sector, Deregulation, Distributed Generation	To identify issues, challenges and opportunities for Indian Power System			Identified various issues (limited fuel, equipment shortage, land acquisition, and environmental clearances, transmission & distribution losses, aging power plant and transmission network, sharp increase in demand, inter-state disputes, delay in construction projects, erratic monsoons, less inclination to renewable. It identified various strategies (renovation & modernization of generation sector, development of national grid, strengthened role of renewable in the sector, implementation of modern techniques, institution of energy audit and adoption of innovative business model) to minimize these issues	The country is not able to make electricity available to every household. Also power reliability is also a major challenge for the country.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Incapabilities in Transmission System	Delay in project execution Transmission Losses Transmission congestion Low investments in Power Transmission Failure to upgrade Technology
Balijepalli I et al. (2010)	IEEE	Indian power sector, Smart grid	To present initiatives taken with regard to Smart Grid and their implications in the Indian power sector.			Discussed Indian power market and its current operation structure is covered. Discussed the Smart Grid vision and various initiatives in India. Discussed required focus areas and needs for an efficient power market when Smart Grids	The Smart Grid maturity model will help these utilities to identify their position and provide pointers for future transformation	Measures to eliminate the barriers of IPTS are not known	Transmission System in India	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						were introduced into the Indian power market.				
Wamukonya (2003)	Science direct	Power sector reform	To evaluate the reform implications in terms of what outcomes were expected.			Discussed various drivers of reforms in different countries such as inability of the government to meet increasing power demand, inadequate regulatory framework, macro-economic crisis, Lack of capital, Mismanagement, poor operational performance, and distorted tariff structures). Assessed the outcomes of the reforms in different countries. Proposed various alternatives to reforms.	Although there were many reasons to call for reforms, the processes adopted have neglected the crucial diversity across reformers and their peculiarities, and hence jeopardized sustainable development.		Power Sector Reforms and restructuring	
Garg (2012)	JGSEE		To analyze the current scenario related to energy consumption and its future requirement			Discussed energy scenario of world and India. Discussed various non-renewable energy and renewable energy supply options	Energy is vital for the development. The present energy scenario in India is not satisfactory.	Interconnections among the barriers of IPTS are not known	Power Sector in India	Transmission congestion
Nepal and Jamas (2015)	Science direct	Electricity restructuring, Market liberalization	To analyze the experience of implementing power reforms in developing and transition economies			Discussed the overview of reform model. Identified various drivers of restructuring the sector in developed as well as developing countries. Analyzed the reform experience of various countries like Nepal, Belarus.	The execution of the reform varies country to country on criteria such as objective, size of the sector and the context in which the reforms have been introduced. Such reforms bring socio-economic challenges across the country.		Power Sector Reforms and restructuring	Absence of strategic planning by Govt.

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Wang et al. (2015)			To evaluate performance and rank the electricity industry during economic recession	Staff costs, energy purchase, other expenses, equity capital, net income, net profit, basic EPS	Data Envelopment Analysis (DEA)(Malmquist non-radial and Malmquist radial)	Assessed the performance of the electricity firms that are listed in Bombay Stock Exchange (BSE) and National Stock Exchange (NSE)	Companies have not shown any abrupt changes during recession and are consistently good.	Impact of each barrier on IPTS is not known	Power Sector in India	
Singh (2009)	Science direct	Renewable energy credits, India, Renewable portfolio obligation	To put forward the scheme for credits of renewable energy that are tradable nationally tradable renewable energy credits scheme for achieving the targets set by the respective SERCs as renewable portfolio obligation			Broadly discussed about the features of Electricity Act 2003 to explore the regulatory framework and pertinent issues for renewable energy. Examines the provisions provided in the regulatory framework related to procurement of the power from the renewable resources. Assesses the market for the renewable energy credits that can be traded nationwide.	Trading electricity generated by renewable sources outside the state increases transmission costs and congestion	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector Reforms and restructuring	Transmission congestion
Liming (2009)	Science direct	Rural Renewable energy, Financing, China, India	To analyze the current status of renewable energy in the rural regions in India and China			Discussed about the current position of India and China in f renewable energy.. Presented a comparative study to invest in renewable energy specifically in the rural regions of India and China by assessing various financing channels and instruments available in the respective country	There are many options to invest in the renewable energy in India and China. Both the countries can be benefitted by exchanging technologies and experience between themselves to encourage renewable energy in the sector.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the	Power Sector in India	Grid instability due to Renewable Energy

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
								barriers of IPTS are not known		
Hollander and Schneider (1996)	Pergamon	Energy Efficiency	To explore the origin of the energy-efficiency and assess the roles of market, government and technological innovation in determining future progress.			Discussed the prognosis for utility energy-efficiency programs. Examined the hypothesis that huge investments in innovation and R&D is one of the key drivers to develop technologies to improve energy efficiencies.	Energy-efficient technologies promotes socio-environment benefits. It was found that technological solutions can provide energy-efficiency developments.	Interconnections among the barriers of IPTS are not known	Power Sector in India	Failure to upgrade Technology
Bhattacharyya (2008)	Journal of World Energy Law & Business	Indian Power System, Foreign Direct Investments	To assess the strategies of promotion of public-private model in electricity sector			Discussed briefly about the Indian electricity sector. Reviewed estimated power demand and matched it with the capacity available to understand capacity requirements under various growth situations. Based on capacity requirement estimated investments required. Presented regulatory priorities required to improve the current scenario.	Discussed about the capacities required to ensure availability of the reliable supply of electricity. Suggested to match the generation capacity with the transmission and distribution sector. However, there is a concern about the availability of fund that can support expansion.	Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Low investments in Power Transmission
Seddighi and Ahmadi-Javid (2015)	Science direct	Generation expansion planning, Electrical power systems, Transmission expansion planning, Sustainable development, Social responsibility, Multistage	To highlight sustainable way of expanding generation and transmission capacities.	Fixed costs of opening, operating and maintaining a new generating unit, interest rate, cost of building transmission line, CO2 emission costs, penalty cost for unserved energy,	multistage stochastic programming	Addressed the expansion planning by developing a stochastic model Carried out sensitivity analyses.	Emphasized the significant role of policies related to sustainability in the power grid.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Transmission System in India	Transmission Congestion Low investments in Power Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		stochastic programming		maximum allowable noise level at node						
Binayak Bhandari et al.(2014)	Springer	Mathematical Modelling, Renewable Energy System,	To summarize mathematical models developed for renewable energy systems such as PV, hydro, wind and various storage devices. .	PV generation efficiency, PV generator area, power conditioning efficiency, total radiation in solar cell, generator inertia, turbine damping coefficient, critical damping of shaft, modulus of rigidity, shaft length, shaft frequency	Mathematical Modelling	Presented various mathematical models developed for renewable energy systems in the power system. Further mathematical modelling for various storage devices are also presented.	The design goals for hybrid system by integrating renewable energy system are to minimize the production costs, purchase of power from the grid, emissions, and life cycle costs and maximize the reliability of power.	Interconnections among the barriers of IPTS are not known	Planning in Transmission System	
Shrimali et al. (2016)	Science direct	India, Renewable targets, Cost-effective policies and Forecasting	To analyze the cost of policy support under existing federal policies and assess the most cost-effective federal policy	Cash of support, cash flow of federal support, tax reductions, state level support	Regression analysis	Forecasted the unsubsidized electricity costs for wind, solar, and the l fossil fuel; and then examined the cost of support under existing as well as proposed debt-related policies	Assessed the costs incurred to GoI to meet its renewable energy. Compared to imported coal-based power, wind energy is already cheaper, and is expected to remain so up to 2022.	Interconnections among the barriers of IPTS are not known	Planning in Transmission System	
Wood and Dow (2011)	Science direct	RO reform Internal and external failures UK renewable energy policy	To re-examine regulatory policies for renewable energy in UK by examining the failures of mechanisms adopted			Discussed about the 2009 RO reform process. Examined whether or not the UK Government has learned from the past performance, mistakes and difficulties of renewable energy policy with particular regard to reforming the RO.	There exists a many failures that are internal and external to the systems. These failures have developed high degree of risks and uncertainties for investors due to more emphasis is given to reduce the costs, and electricity price.	Interconnections among the barriers of IPTS are not known	Planning in Transmission System	Grid instability due to Renewable Energy

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Khan et al. (2014)	Science direct	Modified Kirchhoff Matrix; Transmission Pricing, Transmission Loss Allocation, Power flow tracing, Transmission Reliability Margin Allocation	To analyze transmission usage, transmission losses and transmission reliability) for both generators and consumers.		Graph Theory based	Developed a mathematical model for transmission usage, loss and reliability allocation using matrices methodology. Developed a modified Kirchhoff matrix for usage allocation and formed loss allocation matrix. Incorporated (n-1) reliability criteria, maximum flow of transmission lines is calculated. Allocated TRM of every transmission line to generators by using modified Kirchhoff matrix.	The method observed to be simpler and easier in implementation in the large power system.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Transmission System in India	Transmission Losses
Sikiru et al. (2014)	Science direct	Transmission line switching, Active power loss minimization, Linearized power flow equations, Mixed integer programming	To propose a model that accounts for both active power as well as reactive power in regards to transmission dispatch problem formulations	Active power, resistance of link, current of link, reactive power, voltage, phase angle, susceptance, conductance, incidence matrix, of load and generator buses,	Mixed Integer Programming	Proposed a transmission dispatch formulation that covers the overall spectrum of operation in a power system network using the load duration curve to overcome this limitation for multi period with an objective of minimization of loss.	Demonstrated the unacceptability of the consideration of active power alone in the linearization of load flow equations used in the formulation of transmission dispatch problems.	Interconnections among the barriers of IPTS are not known	Transmission System in India	Transmission Losses
Pagani and Aiello (2013)	Science direct	Reliability, Power Grid Infrastructure, Complex, Network Analysis Graph theory	To carry out the survey of scientific studies that are investigating various attributes of the Power Grid infrastructures	Geographical location, node degree distribution	Graph Theory, Complex Network Analysis	Discussed about the power grid and its complex system.	Both qualitative and quantitative analysis are close to each other in the real business environment.	Interconnections among the barriers of IPTS are not known	Transmission System in India	Transmission Congestion
Chen et al.(2010)	Science direct	Complex networks, Vulnerability Power, Power	To recommend a hybrid technique to understand the	Network capacity, probability of exposed line	Error and attack tolerance,	Studied the structural vulnerability of power networks by introducing a hybrid approach to	After comparing with the traditional dynamic model, the proposed model has two main improvements: (1) employ power flow distribution	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		grids, flow equations	structural vulnerability of power transmission system	tripping, load shedding, generation capacity, line flow limits	Simulation	investigate the error and attack tolerance.	instead of between distribution; (2) adopt load shedding as the measure of damage instead of efficiency loss;			Transmission Losses
Chang and Wu (2011)	Science direct	Power grids Infrastructure, Cascading failure System reliability Performance, State transition graph	To examine the reliability of transmission grids in regards of cascading failures due to external turbulences. .	Voltage phasor vector, admittance matrix, active and real power, event vector,	Matrix-based system reliability	The stability of the transmission grids is assessed using state transition graph. The reliability of the transmission system was also examined during cascading failures using the case study of China's transmission network.	Cascading failure could be triggered by an intentional disturbance and causes much severe consequences than an earthquake of magnitude 7.	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Congestion
Pagani and Aiello (2014)	Science direct	Network evolution, Complex network, Power grid Smart grid	To investigate the implications of growth models and network topologies on the efficiency and reliability of the network			Described the key characteristics of the network models. Compared the properties of the various generated graphs. The economic aspects of denser networks are evaluated	It was observed that energy exchange at local scale is fruitful in many aspects such as renewable energy sources, selling of power surplus by the customers.	Interconnections among the barriers of IPTS are not known	Transmission System in India	
Urpelainen (2014)	Science direct	Rural electrification India, Energy access, Off-grid electricity generation	To analyze how grid expansion and off-grid electrification complement each other	Separation, Integrated development, Uncoordinated integration		Analyzed the relationship between grid and off-grid expansion (competitor, complement or independent). A case study of India has been undertaken to highlight the relationship between electrification of the grid as well as for off-grid electrification. Proposed various techniques to solve the problem, some feasible in the short run (transparency of grid extension plans) and others in the medium to long run (governance reform to deal with fragmentation	Current practice fails to explicitly integrate grid extension and off-grid electrification, with particular negative consequences for entrepreneurs who plan to provide productive loads to villages.	Interconnections among the barriers of IPTS are not known	Transmission System in India	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Ravikumar et al. (2008)	Science direct	Support Vector Machine, Fault, Transmission system	To develop a process to identify causes of fault during post-fault diagnosis		Support Vector Machine (SVM)	Presented a method to achieve knowledge-base for diagnosing the faults by analyzing the line current and voltage phasor values after the detection of the faults..	The method developed Is important to diagnose the faults occurred in the operations of the relays due to the disturbance happened in the adjacent line of the same sub-station. This will be beneficial to monitor the faults, improve the coordination among relays, which will ensure the security in the power system operations.	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not known	Transmission System in India	Transmission Congestion
Dobaria et al. (2016)	Science direct	Solar PV system, Performance ratio, Performance analysis, Specific yield, Yield factor, Final yield	To study the performance and consistency of the 5.05 kWp grid tied to Photo Voltaic plant installed in one of the Indian engineering institute at Rajkot.	Final yield, reference yield and performance ratio	Performance indices	Analyzed the operating performance of the 5.05 kWp grid connected roof-top solar PV plant based on performance indices	Results indicated that the solar PV plant is technically as well as financially viable in this area and also in such a similar weather area in western part of India.	Interconnections among the barriers of IPTS are not known	Transmission System in India	
Joshi and Pathak (2014)	Science direct	Decentralized Grid connected power generation energy efficient building	To identify barriers to energy efficient building with grid connected decentralized energy generation			Identified advantages of EEB (energy saving & security, costs savings, human health, addresses climate change and green job opportunities). Identified barriers to energy efficient building getting power from independent renewable energy sources (lack of information, lack of technical guidelines, lack of availability of technology, substantial initial investments).	Infrastructural sector such as building can become secondary source of power in India. Use of energy efficient technologies and introduction of reforms can reduce the overall power demand in the country	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Losses Transmission congestion Low investments in Power Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Kasa et al. (2016)	Science direct	FACTS, Power quality Renewable energy sources, Fuzzy controller Neural networks	To improve quality of the power flowing in the grid especially in case of renewable energy sources.	Harmonic distortion of load current, active & reactive power of load, power factor of source,	MATLAB/SIMULINK	Developed a model to present use of renewable energy sources optimally and to replace the battery with solar energy components.	The proposed model efficiently help to supply power during any kind of load fluctuation.	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	
Yenneti (2016)	Science direct	Grid-connected India, Challenges, Solar energy Jawaharlal Nehru National Solar Mission (JNNSM)	To undertake a functional analysis of solar energy development between post-Independence and post-JNNSM periods; and to unpack the underlying challenges for solar development, and to offer thoughts on overcoming some of the challenges			Discussed solar energy potential and status in India, the evolution of solar energy policy governance pre and post reform. Compared the state policies for grid connected solar PV development. Discussed challenges (policy and regulatory issues, financial and market issues, technological issues, socio-environmental issues) and opportunities (policy, economic, social, technological, environmental, legal) for grid connected solar energy development	India would dominantly become solar powered country by the year 2030, if it mandatorily replaces conventional sources with solar energy	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Grid instability due to Renewable Integration

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Cupac et al.(2013)	Science direct	Cascading failures Vulnerability of infrastructure Power grids	To anlalyse the underlying drivers of subsequent grid failures by developing mathematical model and to suggest preventive measures to minimize the risk of blackouts.	average path efficiency, network efficiency, total load shed, transmission capacity, average network damage	Power Flow Model and Complex networks model	Directly compared the critical behavior and the overall distribution of the damage across the transmission grids	Analysis indicated that the mathematical model exhibited properties that are close to the real world despite having certain assumptions	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Transmission System in India	Transmission congestion
Viebahn et al. (2014)	Science direct	Power sector, CCS, India, Integrated assessment, CO2 storage potential	To assess the capability of CCS technology in reducing future CO_2 emissions in India			An integrated approach covering five assessment dimensions (commercial availability, usable CO2 storage potential, economic assessment, environmental assessment, stakeholders) has been chosen.	The storage capacity has been assess using geological data of the sites as currently the exact data related to capacity is not available.	Impact of each barrier on IPTS is not known	Planning in Transmission System	
Bhattacharya (2007)	Science direct	India, Electricity Act, Restructuring	To review the Electricity Act2003 to analyze the economic rationale of certainimportant provisions and to see whether it has thepotential of creating a viable electricity sector in India	Trading, distribution & retail supply, unregulated rural markets, SEB restructuring, autonomy & accountability of regulatory bodies, policy directions, tariff policy & principles, subsidy & cross subsidy, supply through meters, time limit for release of new		This paper has analyzed sustainability aspects of reforms introduced in the power sector in India by analyzing a framework that comprises of six key factors (Industry structure, regulatory framework, tariff determination, licensing, electricity theft and penalty)	The new act has introduced significant changes to the industry structure (generation, transmission and distribution) and has provided more flexible regulatory regime and stricter penal provisions for misuse of electricity		Power Sector Reforms and restructuring	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
				connections, default in payments, theft and penalty						
KPMG (2010)	Indian Power Sector		To identify various bottlenecks and challenges existing in the power sector of India			Discussed the challenges of Power Sector in India (delay in project execution, fuel availability, equipment shortage, land acquisition & environmental clearance, manpower shortage and schedule dependency on transmission lines). Proposed project management framework to overcome challenges of Power system.	Power deficit is one of the key challenges, which country is facing. This has huge impact on the Indian economy. Many projects are being carried out in generation, transmission and distribution sectors. It is important to review each project and improve their execution efficiencies so that targets set by the policy makers can be met.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Delay in project execution Transmission Congestion
Kunz and Zerrahn (2015)	Science direct	Electricity economics, Generalized nash, Congestion management, equilibrium, Re-dispatch Renewable energy generation, Game theory, Transmission system operators	To analyze the process of managing congestion happening in the power grid		Generalized Nash Equilibrium Model	Developed a model to analyze the benefits of coordinating re-dispatch among the operators of transmission system With the objective of providing a cost-minimal re-dispatch to eliminate line overflow. For the study, Germany was considered, where the entire network of the four different regions were managed by four different transmissions operators allocated to each region.	The model developed in the study helped in identifying the grid with maximum congestions. One of the advantages of this model is that it can be applied to other congestion management situation that require coordination.	Interconnections among the barriers of IPTS are not known	Transmission System in India	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Gupta et al. (2012)	Science direct	Power system reliability, Monte Carlo simulation, Roulette wheel selection, Power transmission planning	To propose a mathematical model for the expansion planning of transmission systems where the priory information related to transmission capacity is not needed.	time , expected outage of generators, length of transmission line, number of transmission lines, proposed expected generation capacity, pre-specified expected generation capacity of generators, capital costs of facility, operating and maintenance costs	Monte Carlo simulation, Genetic Algorithm	The model proposed in this study focusses on minimizing the investments, unfulfilled demand, unserved generated power, losses related to wheeling, operational costs with the objective of determining the capacity of the transmission lines optimally.	Adding a new transmission lines to fulfil the increasing power demand is not the only solution. Upgrading the capacity of existing transmission lines would also help in fulfilling the demand.	Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion
Andrés et al. (2004)	CIGRE	Transmission Bottlenecks	To identify and minimize bottlenecks in transmission efficiency			Identified various bottlenecks in Transmission efficiency. Discussed about benefits of Light Triggered Thyristors (LTT) for HVDC and FACTS to improve performance of transmission line. Utilization of Power Electronics (power flow controller) in eliminating bottlenecks	The power system will further face increase in loads that will leads to further increase in bottlenecks and power reliability issues. Use of devices related to FACTS and HVDC in the power system will improve the situations	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission Congestion
Kumar et a.l (2014)	Science direct	Smart grid India, Cyber security regulations, Indian Power Sector	To address the threats related to the cyber security in the entire power sector			Discussed key challenges in preventing cyber-attacks (impact of cyber threat, discovery of threat, source of threat, appropriate response to threat, sharing the pertinent information,	Smart Grid seems to be the solution of most of the challenges faced by the power sector in India. . Use of ICT-related technologies in the power system grids without addressing the issues related cyber security would add further misery into the system.	Interconnections among the barriers of IPTS are not known	Planning in Transmission System	

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						jurisdiction, dearth of legal framework from other nations). Discussed various threat exposure in generation, transmission and distribution. Assessed the adequacy of frameworks and standards related to the cyber security proposed by the regulators	The sector must utilize technologies that can address the cyber related risks.			
Beckman (2013)	Science direct	Indian power System, Cost Allocation, Inter-StateTransmission	To analyze cost allocation for India's inter-state transmission system and examines the impacts of the shift from a regional postage stamp method to a flow-based cost allocation charging method			Discussed about the Regional Postage Stamp Method and its shortcomings. Discussed the advantages of using point of connection charging method and its impact on generation, transmission and distribution. Compared the situation on international context.	The new cost allocation method has eliminated the obstacle to long-distance power transactions on the ISTS. The new system will also likely encourage transmission customers to make power purchase and sale decisions in a way that reduces congestion on existing lines. Encourage generators to locate future capacity additions in places that create less congestion on the grid	Interconnections among the barriers of IPTS are not knownImpact of each barrier on IPTS is not known	Incapabilities in Transmission System	Transmission congestion
Haller et al. (2012)	Science direct	Transmission planning, Power storage, Renewable power generation, Power system planning, CO_2 abatement, Integration of renewables, Long-term scenario	To understand the challenges that can come by integrating renewable energy at a larger scale in the next decades.	Emissions costs, fuel costs, capital costs (generation, transmission, distribution), transmission losses, power demand, stored energy, transmitted costs, interest rate, voltage angle, transmitted year	Mathematical Modelling	Developed a mathematical framework that focuses on the investments related to renewable energy supply in the entire power system.	To integrate the renewable energy supply, transmission at larger distance and storage of electricity are crucial. The investments on the transmission side are inadequate as compared at the generation end.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Low investments in Power Transmission Absence of strategic planning by Govt. Fewer private players in Transmission

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Aleksandra Kanevce, Igor Mishkovski and Ljupco Kocarev (2013)	Science direct	Network long-term evolution modeling, Southeast European power transmission system, Power transmission reliability, OPA model	To model the transmission line overload and systematic upgradation of production and transmission capacities	generation cost, power produced, transmission cost	Linear programming model	Modeled the electric transmission system with n nodes interconnected by m transmission lines	OPA model gives a real opportunity for long-term planning of the development of a complex electric power network. Power network. The applied model answers the question to what extent the network and the production facilities should be upgraded to meet the growing demand in electricity	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Transmission System in India	Transmission Congestion Failure to upgrade Technology
PWC, BHEl, ONGC, NTPC, PFC, Indian Oil, Gail, REC and World Energy Council(2012)	PWC		To analyze the current issues and barriers existing in the power sector as a whole.			Discussed the challenges of Indian Power Sector (securing fuel, erratic gas supply, securing land and clearances, competitive bidding, project execution, change in regulation). Discussed various opportunities (alternate sources of energy, investment in clean technology, power evacuation)	The power industry is focusing more on open markets and competition rather than on guaranteed and negotiated arrangements	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Incapabilities in Transmission System	Delay in project execution
Gaur and Gupta	Science direct	T&D losses, Electricity theft, Indian state	To examine the role of regulatory factors that determine the	T&D Losses and government indicators, Theft-loss ratio, Theft Loss per	Feasible Generalized Least Square Method	Determine the extent of power thefts in various parts of Indian. Discussed the role of regulatory factors that determine the thefts of	The regulatory framework has significantly negative impact. Policies focusing on lowering the degree of corruption, better compliance and management are the need of the hour.	Interconnections among the barriers of IPTS are not known	Transmission System in India	Transmission Losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
(2016)			theft in electricity in the states of India	capita, Illegal Electricity Use, political party, geographic region and the occurrence of terrorist events		electricity in many Indian states.	The study also revealed that the T&D losses are decreasing with the increase in the participation of private players.	Impact of each barrier on IPTS is not known		
Zhang et al. (2013)	Science direct	Complex networks, Cascading failures, Modeling, Active and reactive loads, Power grids, Tolerance parameter	To propose novel mathematical problem for power grid that involve both active as well as reactive loads and to use the model to analyze any kind of grid failure a new model of a power grid involving the active and reactive power loads is proposed and then used to analyze the cascading behavior of power grids	Cascading failures, Complex networks Modeling, Active and reactive loads Tolerance parameter, Power grids	Mathematical Modelling	Discussed about two Indian blackouts based on regions transmission. Developed a model involving active (P) and reactive (Q) power loads, in which a node will fail if any kind of loads on the node exceeds its capacity, and the active and reactive power loads will both be redistributed.	With the growth of the tunable parameter α, the probability of large cascading failures increases, but that of medium and small cascading failures decreases.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Incapabilities in Transmission System	Transmission Congestion
Wang and Rong (2011)	Science direct	Attack strategy Load, Critical threshold, Cascading failure, Power grid	To analyze cascading failures on power grids	Cascading failures, capacity of edge, initial load	Edge load model	Discussed about large scale black outs due to the malfunction of transmission lines. Analyzed three attack strategies (attack on edge with the lowest load, attack on edge with the smallest proportion between the total	Maximizing robustness and minimizing cost are common objectives in the design of power grid network. Some of the failures that have cascading effect on the grid are intentionally induced attacks on the power grid.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Incapabilities in Transmission System	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
						capacities of the neighboring edges of and the capacity of the attacked edge and attack on edge with the highest load)				
Sharan and Balasubramanian (2012)	Science direct	Fuel transportation, Generation expansion planning, Transmission network planning	To provide an expansion model for generation and transmission sector	set of new generating units, set of newtransmission lines, capacity of new generating unit, annualized cost per MW of new generating unit, length of transmission line, distance of fuel source from generating units.	Mathematical Modelling	The objective of the study is to minimize capital cost incurred during the construction of new transmission lines. The objective is limited by various constraints such as availability of fuel at the generation side, fuel transportation limitation from suppliers to the generation units, generating capacity and limitation in the transmission capacity of transmission line	A significant change in the power flow is observed at the time of optimization	Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Low investments in Power Transmission Transmission congestion
Verma et al. (2001)	Science direct	Sensitivity analysis; Unified power flow controller; UPFC location; Congestion management	To develop a simple and efficient model for congestion management	Voltage, current, active and reactive power	Simulation, Sensitivity Analyses	An approach has been developed to minimize the transmission congestion.	New sensitivity factors could be effectively used for loss minimization. In a congested system, the UPFC can be effectively decided based on the sensitivity factors	Interconnections among the barriers of IPTS are not known	Incapabilities in Transmission System	Transmission congestion
Samantaray (2014)	Taylor & Francis	Indian power sector, wide area monitoring, Smart grid	To minimize the issues of power sector by bringing smart grid initiatives in India			Discussed about the current Indian Power sector status. Discussed smart grid vision for India, policies and programs to initiate the smart grid plan. Discussed detailed plan for smart grid milestones, initiatives and infrastructure required to develop smart grid	Indian smart grid initiatives are remarkable developments to parallel the Indian power sector with international standard	Measures to eliminate the barriers of IPTS are not known	Incapabilities in Transmission System	Low investments in Power Transmission Failure to upgrade Technology
Rahman and	IEEE	Simultaneous ac–dc power transmission,	To enhance the strength and minimize the			Examined the possibility of converting double circuit ac line to composite ac–dc line.	A significant increase in the line capacity has been observed by converting ac line into ac-dc line		Incapabilities in	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Khan (2007)		Extra high voltage (EHV) transmission	oscillations of Transmission system			The conversion must not alter the line conductors, tower and insulators that are originally installed			Transmission System	
Jazi et al. (2015)	European Journal of Academic Essays	Ranking, Multiple-Attribute Decision Making (MADM), Risk, Project Risk Management, overhead power lines	To identify, assess and ranking of key risks of overhead power lines project		TOPSIS	Identified key risks of overhead lines project(less experienced supervisors, Regulate the bidding documents, Lack of skilled personnel, Failure to observe proper schedule, Lack of appropriate insurance, Failure to submit project progress, Inconsistency in allocations of the budget, undefined job roles of employees and employers, Lack of funding, Lack of timely presence of legal experts, alterations in contractors' system, inappropriate assessment of contractors, employing illegal personnel, absence of coordination. Ranked the identified risks	A well risk management system helps in identifying the risks, its consequences, and evaluating the preventive actions to minimize the risks.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Incapabilities in Transmission System	Delay in project execution Transmission congestion Transmission Losses Low investments in Power Transmission
Moreira et al. (2017)	IEEE Xplore Digital Library	Renewable generation and transmission expansion planning, Generation and transmission security criterion, renewable targets, reserve deliverability and siting, wind curtailment	To develop a model that can co-optimize the expansion of the transmission system and renewable generation capacity	Maximum level of system power in balance, cost per MW of candidate lines, construction cost of new nodes, cost of imbalance, construction of candidate line, production cost of generator, reserve-down/up cost of	Two-stage min-max-min model	Acknowledged that transmission capacity expansion planning has not kept paced with generation capacity expansion. In this context, the study has presented a model that can co-optimize the transmission expansion and renewable energy generation. The applicability of the model has been tested using a real case study using a realistic data of Chilean system.	Claimed that the growth of the renewable penetration in a power system should be coordinated with the transmission expansion planning	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Grid instability due to Renewable Integration

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
				generator, nominal demand						
Hajebrahimi and Rashidinejad (2017)	IEEE Xplore Digital Library	Demand response programs (DRPs), realistic achievable potential (RAP), smart grid, transmission expansion planning associated with DRPs (PMO-TEPDRPs), wind farms, Consumer economic model	To develop a nonlinear economic model of responsive loads is presented based on price elasticity of demand and customers benefit function	Congestion cost, total incentive cost, investment cost of new lines, risk costs, number of new line added, duration of load curtailment, active power flow in branch, wind speed, vector of variable load, wind farm production, production of generator, branches added in corridor		Acknowledged that the transmission expansion plan is a critical challenge under smart grid environment. The authors have developed a non-linear economic model to investigate the impact of demand response resource. The model was developed using genetic algorithm II. The capability of the proposed framework has been confirmed by carrying a several analyses.	It was observed that the total costs were decreased throughout the optimization procedure. Thus, there is no need of further investments.	Interconnections among the barriers of IPTS are not known Impact of each barrier on IPTS is not known	Planning in Transmission System	Grid instability due to Renewable Integration
Khan and Siddiqui (2017)	Springer	TCSC, Deregulated power system, FACTS, Sensitivity analysis,	To reduce the transmission congestion using FACTS devices	Voltage Bus, impedance, shunt susceptance, compensate reactive power	Mathematical model	Identified an optimal location of FACTS device by minimizing installation costs in a decontrolled power system to remove the congestion in the transmission grid. To increase	When the FACTS devices are connected to the congested line, the congestion of the lines had been solved.	Impact of each barrier on IPTS is not known Measures to eliminate the	Transmission System in India	Transmission Congestion Failure to upgrade Technology

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		Congestion management				the power transfer capability of transmission network, the study has considered thyristor-controlled series capacitor. The placement of capacitor in the congested transmission line is determined using sensitivity analysis of the power flow.		barriers of IPTS are not known		
Rajkumari and Gayithri (2018)	Science direct	Performance Indicators, Power sector reform, Karnataka Power Sector, Power Sector Performance Index	To assess the performance of power sector after reforms were introduced in the Indian state of Karnataka on various technical and financial indicators in terms of	Installed capacity, growth in total generation, capacity utilization rate, energy deficit, peak deficit, T&D loss, average utilization rate, commercial loss	Case Study	Assessed the power sector performance after the introduction of Karnataka Electricity Reforms Act (KERA), 1999. A quantitative performance index was computed using technical and financial indicators. It was observed that indicators like peak deficits, installed capacity, revenue realization rate and energy consumption have exhibited development as compared to other states. Also, T&D losses have also reduced tremendously.	The overall ranking of the state after the reforms has been improved from 8th to 3rd position.	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Restructuring of Power sector	Transmission Losses
Saha and Bhattacharya (2019)	Science direct	Power sector reliability, Welfare implications, restructuring of power utility	To examine the consequences of power sector reforms in the state of West Bengal in a situation where public sector and private sector co-exists.	Consumption of electricity by consumer, electricity tariff, consumption of electricity, electricity tariff, elasticity of electricity demand, estimated welfare,	Panel data Regression	The study assessed the impact of reforms on the capacity to meet power surplus of the state. It was observed that the performance of the sector has been diminished. Due to de-integration of the sector into public and private.	The primary findings of the study indicated the negative impact of de-integration of the power supply network on welfare, involving both consumer and producer surplus	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Restructuring of Power sector	Transmission Losses

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Veluchamy et al. (2018)	Research India Publications	DISCOM, power sector reform, Financial viability, power distribution companies, Aggregate Technical and Commercial (AT&C) Loss	To study determines the factors significantly contributing to the sustained losses of DISCOMs from the detailed literature survey		Qualitative study	Discussed that series of reforms in the sector have bought improvements in the sector but the financial crisis of the distribution companies in India still sustained. The study has identified various factors that leads to the financial losses to the distribution companies. It discusses various policy initiatives required to reform the distribution sector of India.	The state power utilities are unable to sustain its business without the government subsidy support. There is a dire need to rationalize the present tariff structure to achieve financial viability of state-run DISCOMs.	Interconnections among the barriers of IPTS are not known	Restructuring of Power sector	Poor performance and financial health of Utilities Transmission Losses Absence of strategic planning by Govt.
Agrawal et al. (2017)	Science direct	Electricity Amendment Bill 2014, Electricity Act 2003, Distribution, Carriage, Content	To review the Electricity Amendment Bill 2014		Qualitative study	Critically evaluated various key features of Electricity Act 2003 with special emphasis has been given to the losses in the distribution sector. The study also discusses the Electricity Amendment Bill 2014. The study also emphasizes requirement of third generation reforms in the sector.	Exclusion of content from carriage has been widely accepted to increase the competition to fulfil the consumer interest.	Interconnections among the barriers of IPTS are not known	Restructuring of Power sector	Poor performance and financial health of Utilities Grid instability due to Renewable Integration
Sunita Saini (2018)	National journals	Generation capacity, Power sector, SEBs	focuses on the present status of Indian power sector along with its evolution		Qualitative study	Discussed about the evolution of the power sector considering all the three sectors of power system. The author discussed that the power sector is mostly dominated by public sector. It was further concluded that the power sector requires more development to boost the economic development.	Power sector needs more advancement & development to thrive further boosting the economic development of the country	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power sector in India	Poor performance and financial health of Utilities

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Kovendan and Sridharan (2017)	Springer	Remote monitoring, Data aggregation, electrical grid, Smart grids,	To survey the literature related to power grid, wireless communication and smart grid		Qualitative study	The study presents the survey related to the recent position of the Indian power grid. It also presents the necessity of the smart grid. The study summarizes the importance of the ICTs in the smart grid.	Many components related to smart grids are yet to achieve higher degree of reliability. Integrating renewable energy and improving reliability of the power seems to be challenging.	Impact of each barrier on IPTS is not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion Failure to upgrade Technology
Verma (2016)	National Journals	transmission, market splitting, electricity price, Congestion management	To minimize the congestion of transmission lines		Qualitative study	Congestion can be manage using market splitting method that has the capability of controlling prices effectively. Nodal pricing can also assist in addressing congestion charges	Congestion in the transmission lines cannot be avoided but can be controlled using various techniques and tools.	Interconnections among the barriers of IPTS are not known	Incapabilites in power transmission system	Transmission Congestion
enggren et al. (2016)	Science direct	Renewable, Decarbonization, Multilevel perspective, MLP, Nordic power systems, European integration, Governance	To address this gap and examines institutional barriers for developing the grid towards a decarbonized Nordic power system by 2050		Qualitative study	The study identified various drivers (EU drivers, Nordic drivers, National drivers, technology drivers,) and various barriers (regime, concession, planning barriers) to decarbonized power system	overcoming uncertainties in the concession procedure and stronger collaboration across countries to overcome uncertainties in planning practices would make Sweden's transmission grid truly fit for this purpose	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Incapabilites in power transmission system	Grid instability due to Renewable Integration Absence of strategic planning by Govt.
Rampurkar et al. (2016)	IEEE	Voltage collapse, System Simulator for Engineering (PSS/E), hopf bifurcation,	To analyse the blackouts happened in the power grids of India	North region load, damping, frequency	Simulation	It has been revealed that insignificant upsurge in the NR load brings oscillations in the system. Further anlaysis is done using Prony analysis, which measure frequency of the oscillations.	It is suggested to track oscillations system that disturbs the stability of the system and brings cascading failures that results in blackout. The study also highlights PMU assessment in real-time to track the oscillations.	Interconnections among the barriers of IPTS are not known Measures to eliminate the	Transmission System in India	Transmission Congestion

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		Blackout, cascading failure, power system modelling						barriers of IPTS are not known		
Ahmad(2018)	Springer	Indian power market, DISCOM, Power exchange, day-ahead market, Smart micro-grid, Bilateral trading	To provide a comprehensive framework of power exchanges based on Indian power trading market	Average energy, average demand, peak demand, load factor		With the commencement of market for power exchanges in the year 2008 has improved the efficiency and competition in the power system and decreased the volatility in the sector.	The introduction of power trading in the sector has reduced the net amount	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion Grid instability due to Renewable Integration Failure to upgrade Technology
CEA (2018)	Ministry of Power, Government of India	Generation, transmission, distribution, Indian Power Sector	To analyze the evolution of the Power sector since 1947	Installed capacity, electrical energy generation, transmission & distribution network, T&D losses, captive power plants, pattern of electricity consumption	Qualitative study	The study analyses the evolution of the Indian Power sector according to the five-year plan. There is substantial increase in the capacity of generation. The power shortage has been also reduced. Some of the generation capacities have remained unutilized due to constraints in transmission and distribution sector	Power Sector in India has evolved significantly in terms of generation, transmission and distribution capacities	Impact of each barrier on IPTS is not known Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Transmission Losses
MOP (2017a)	Tarang, Ministry of Power, Government of India	Competitive bidding , Indian Transmission sector, , green energy corridors, transmission projects	To establish an IT based platform in the IPTS		Qualitative study	The app provided by the Tarang provides information related to on-going bidding process through Tariff-based Competitive Bidding (TBCB)	The overall growth of the Transmission sector can be monitored using Tarang app.	Impact of each barrier on IPTS is not known Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Planning in Transmission Sector	Grid instability due to Renewable Integration Failure to upgrade Technology

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
Paramanik et al. (2019)	IEEE	Power harmonic filters, power system stability, integrated circuits, harmonic analysis, power quality	To minimize harmonics generated by devices unified power quality conditioners in a Smart Grid system		Biogeography based optimization (BBO)	The study has used to modified UPQCs to eliminate the lower order harmonics after the injection of harmonics of same order. The higher order harmonics are further suppressed by injecting same order harmincs having equal magnitude but the phase of the harmoincs are opposite	The devices that are said to eliminate the harmonics in the smart grid system also generates some harmonics that impacts the system stability	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion Grid instability due to Renewable Integration Failure to upgrade Technology
Bansal et al. (2018)	Springer	Solar energy, polcies, green house gas emissions, policies	To reduce the green house gas emissions by increase the share of renewable energy in the power sector		Qualitative study	The power demand of the country are mostly met through fossil fuels. Indian government are focusing on increasing the contribution of renewable energy.	Some states in the country are actively involved in increasing the share of their states in renewable energy.	Impact of each barrier on IPTS is not known Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Planning in Transmission Sector	Grid instability due to Renewable Integration Failure to upgrade Technology
Singh and Vashishtha (2019)	Global research network	Transmission and Distribution Losses (T&D), Power supply Position, Initiative Policies, Power Sector, Plant Load Factor	To discuss the trends of T&D losses, plant load factor, policy initiatives, deficit in power supply position		Qualitative study	Power deficit is one of the key challenges in the Indian power system due to various issues such as power theft, line spillages, misuse of power.	There is huge opportunity in the improvements of power quality, power generation using non-conventional resources such as solar, wind etc.	Impact of each barrier on IPTS is not known Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Power Sector in India	Transmission Losses
Irfan et al. (2019)	Elseivier	Grid construction, wind energy, India, wind	To identify critical factors for the development		Diamond model approach	The factors identified include , firm strategy, rivalry, demand condition, chance, factor condition, related and	The factors identified in the study must be strengthened to establish the wind energy industry in the country	Impact of each barrier on IPTS is not known	Planning in Transmission Sector	Grid instability due to Renewable Integration

Author & Year	Source	Keywords	Objective	Variables	Tools	Findings	Inference	Research Gap	Themes emerged from LR	Barriers Identified
		turbine, policies, diamond model	and competitiveness of wind industry in India			support industry, government, and structure		Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known		Failure to upgrade Technology
Ahmad et al. (2019)	IEEE	Batteries, energy management, electric vehicles, optimization, microgrids	To proposes a framework to optimally manage energy systems in case of electric vehicles charging stations		Mixed Integer, non-linear optimization model	The study utilized the optimization model to minimize the energy cost in charging the vehicle at the same time maximize the cost of selling surplus energy generated by photo voltaic system.	Th eproposed framework helped in optimally manage the charging stations for electric vehicles	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion Grid instability due to Renewable Integration Failure to upgrade Technology
Rathore et al. (2019)	Elseivier	Rooftop, energy, solar, India	The study discusses the decentralized solar rooftop PVs initiatives adopted in India		Qualitative study	The study has discussed several factors that act as a motivator for investing on solar rooftop by the end customers. The study also discusses barriers of its growth in the India.	The development of solar roof tops are not up to the standard in India despite the policy makers have targeted to install 40GW of decentralized slor roof tops by the year 2022	Interconnections among the barriers of IPTS are not known Measures to eliminate the barriers of IPTS are not known	Transmission System in India	Transmission Congestion Grid instability due to Renewable Integration Failure to upgrade Technology

Table A3 Literature on *Theory of Constraints*

Authors	Tools Used	Variables considered	Inference	Industry
Arijit Bhattacharya, PandianVasant, BijanSarkar, Sanat Kumar Mukharjee (2007)	Fuzzy Linear Programming	Profit Throughput per unit Capacity per unit of resources	Make the traditional product-mix decision under TOC more explicit when multiple constrained resources exist Find fuzziness (i.e. some sort of vagueness) patterns of the product-mix decision under TOC with disparate level of satisfaction of the DM.	Product-Mix decision problem
Panayiotis Ifandoudas& Ross Chapman (2010)	Case Study of Electrical component manufacturing SME	Order processing time	Adoption of agility in manufacturing using TOC and Resource Based View (RBV) to attain sustained competitive advantage Combination of three theories: TOC, RBV and Agility Created a flexible manufacturing system	Agility in Manufacturing (SMEs)
Robin Cooper and RegineSlagmulder (1999)	Application of Theory	Revenue Material Labor Machining Inspection Profit Throughput	Integrating Activity-Based Costing with TOC Decision on producing ABC products based on total throughput and profit	Optimal short term mix of products
John H. Blakstone	Review article	Market Demand Capacity of resources Profit Holding costs of inventory Stock out Sales Volume Product Margin	Benefits realized using TOC in different areas such as Manufacturing. Product –mix decisions, Sales, Managing People, Supply Chain, Operations, project Management etc.	General
C. Carl Pegels and Craig Watrous (2005)	Case Study	No. of customers' orders Set up time of assembly	Utilized TOC management principles to improve the performance of manufacturing facility	Manufacturing
Kuo-JungYuany, Sheng-Hung Changz and Rong-Kwei Li (2003)	Application of Theory	Throughput Inventory level Operating expenses	Explains buffer management process of Theory of Constraints, where in key focus is towards monitoring and adjusting the size of the buffer.	Distribution System
José Costas Borja Ponte, David de la Fuente, RaúlPino, Julio Puche (2015)	KAOS	Net Profit Cash Flow Return on Investment	Minimizes bullwhip effect by employing TOC Each level of supply chain exhibited improvement by removing the bottleneck.	Supply Chain Management
Victoria J. Mabin, Steve Forgeson and Lawrence Green	Case Study	Resistance to change Certainty about the future Promotion of change programs	Mentioned different kinds of resistance to change and explained the process to counter them using Thinking Process of TOC.	Change Management
Mahesh Gupta and Joseph Kline	Application of Theory	Throughput Inventory Operating Expenses	Demonstrated the applicability of TOC to an outpatient unit in a one of the community health center	Community Mental Health Agency
Seonmin Kim Victoria Jane Mabin and John Davies	Review article (1994-2006)	Thinking Process Tool	Reviewed the literature related to Thinking Process and categorized the literature based on various research issues of the studies undertaken	General

Authors	Tools Used	Variables considered	Inference	Industry
Kevin J. Watson, John H. Blackstone and Stanley C. Gardiner (2007)	Review article		Identified literature from more than 400 articles, books, thesis, conferences, white reports, etc. that have contributed to the TOC. The literature was divided into five different eras and discussed the limitations existing in the TOC literature	General
J. Davies, V.J. Mabin and S.J. Balderstone	Thinking Process tool		Compared the TOC techniques with the operation research techniques. Put more emphasis on continuing the usage of multi-methodological techniques	General
Mahesh C. Gupta and Lynn H. Boyd (2008)	Empirical study	Throughput Inventory Operating Expenses ROI Productivity Turnover	Examined the links between TOC and core concepts of operations management. Revealed that both the domains can be integrated. Further showed that TOC has an essential properties to treat it as a good theory	General
Ike Ehie and Chwen Sheu (2003)	Case- Study	Productivity improvement Number of defects Variability of the process	Examined the integration of TOC with six sigma to improve the performance of production processes.	Six Sigma
JAYDEEP BALAKRISHNAN and CHUN HUNG CHENG (2000)	Linear Programming	Types of the products Demand of products Export market	Matched TOC with linear programming (LP) using step improvement process in TOC. Observed a greater profit by employing LP at various steps of TOC.	Manufacturing
Viera Šukalová, Pavel Ceniga (2015)	Empirical study	Lead time Reliability of supplies Delivery Time Defect free deliveries	Applied TOC in the context of supply chain management to help the supply chain members understand the benefits to coordinate with each other	Enterprise Distribution System
Katrin Fekri, Dr. Abdollah Shafiabady, Dr. Rahmatollah Nooranipour and Dr. Ghodsy Ahghar	Statistical	Entrepreneur skills	Compare the effectiveness of Shafiabady's multi - axial model with TOC and focuses on improving the entrepreneurship skills of students of Islamic Azad university at Tehran	Entrepreneurship education
G. Ioannou & C. Papadoyiannis (2007)	Case Study	Code development Business requirements (Business critical & Legal)	Explains the reason behind long time taken to implement the ERP and various resistance at the organizational level while implementing ERP. Using TOC in this context helped to identified various bottlenecks and develop a plan to overcome the bottlenecks.	Enterprise Resource Planning (ERP) Implementation
Michael Umble & Elisabeth Umble (2001)	Case Study	Labor requirement planning Replenishment system Work-in-Process inventory (WIP) inventory	Argued through a case study that ERP and TOC are complementary system that can generate a powerful synergy	ERP implementation in Manufacturing Plant
Zinovy D. Radovilsky (1997)	1. Mathematical Modelling 2. Sensitivity Analysis	Time Buffer Throughput Operating Expenses Net Profit	Described a new method to deal with any kind of disturbances occurring in the production processes. The approach also has the capability to maximize the productivity of resources that have limited capacities.	Manufacturing

Authors	Tools Used	Variables considered	Inference	Industry
Ercüment Okutmus, Ata Kahveci, Jekaterina Kartašova (2015)	Case Study	Capacity Usage rate Demand Operating Expenses	Provided a roadmap to manage the constraints effectively to increase the profitability of the organization by identifying the constraints limiting to achieve the targets.	Furniture sector
Godfrey C. Onwubolu and Michael Mutingi (2010)	Linear programming Genetic Algorithm	Throughput	This product has used Genetic Algorithm and TOC to deal with large problems typically in manufacturing firms It has used TOC to optimally decide on product mix	Manufacturing
Azar Izmailov (2014)	Description of Theory	Throughput Operating Expenses Inventory	The paper has described the TOC in detail and its various steps involved	General
Jaideep Motwani, Donald Klein and Raanan Harowitz (1996)	Application of Theory	Medical services revenue Enrolled patients Not enrolled but in-need patients Operating Expenses such as capital, facilities, training, promotion and insurance	The paper has illustrated the application of TOC to service and not-for-profit organizations	Healthcare sector
Pi-Fang Hsu and Miao-Hsueh Sun (2005)	Application of theory	System constraints Bottleneck resources Non-bottleneck resources	The paper has described the TOC in detail and its various steps involved. It has also explained various techniques and general problem-solving tools dealing with constraints	General
Seung-Hyun Rhee, Nam Wook Cho & Hyerim Bae (2010)	Case Study and Simulation experiments	Workload Expected Execution of task Task arrival rate of task Task assignment probability of task Average service rate of agent Number of agents Expected processing time Process instance release rate	Drum-Buffer-Rope (DBR) of TOC has been used to improve the business processes	Business Process Management System
Nitza Geri and Niv Ahituv (2008)	Chi-Square tests	Economic, Organizational, technological Infeasibilities Risks Inadequate Financial resources Industry IOS status	A model for inter-organizational system feasibility based on TOC has been developed Data has been collected from 139 Israeli medium and large organizations TOC will help in overcoming barriers that hinders the adoption of IOS in organizations	Inter-Organizational systems (IOS)
M. Umble , E. Umble & S. Murakami	Case Study	Work-in–process inventory Production lead time On-time delivery Productive capacity Inventory turnover Product quality Sales volume Profitability	Following the TOC approach process tools of thinking process obstacles encountered during the implementation process has been resolved.	Manufacturing

Authors	Tools Used	Variables considered	Inference	Industry
Bih-Ru Lea and Hokey Min (2010)	Linear Programming	Profitability Customer service Work-in-process inventory	Assessed the impact of time and management accounting and control on the performance of manufacturing processes in the context of ERP using TOC. TOS has been adopted in JIT-based manufacturing systems.	Just-In-Time (JIT) Manufacturing
Davood Golmohammadi (2015)	Case Study	Processing Time Set-up time Product routing	The paper has implemented TOC for the development of aster production schedule for job-shop systems	Master Production Schedule (MPS) (Automotive Industry)
Glenn Reimer (1991)	Case Study	Throughput Earnings Inventory Turns Due Date Performance Average days delayed	The paper has investigated whether material requirement planning and TOC can co-exist.	Material Requirement Planning
E. T. Kirche , S. N. Kadipasaoglu and B. M. Khumawala (2007)	Mixed-Integer Programming (MIP)	Profitability Quantity of resource Unit level cost Batch level cost Holding cost Order level cost Processing time Set up time Order processing time	The paper has integrated TOC and activity based costing to maximize profitability of firm by developing efficient order management model	Supply Chain Management
Víctor-G. Aguilar-Escobar, Pedro Garrido-Vega, María-del-Mar González-Zamora	Case Study	Medical Records Productivity Record Accuracy Personnel	Analyze the benefits of TOC in the logistics of medical records in the context of healthcare.	Healthcare
W.-H. Tsai , C.-W. Lai and J. C. Chang (2007)	Case Study	Available capacity of resources Market Demand Processing time	Proposed an algorithm using TOC to optimize joint products in the manufacturing context	Manufacturing
M. B. Aryanezhad Professor and A. R. Komijan (2007)	Linear Programming	Demand Selling Price Raw Material costs Available and required capacity	The paper has determined the optimal product mix in such a way that the output of the system is to be maximized. Discussed the limitations of TOC and proposed an improved algorithm and integer linear programming method	Product mix
Terry Nels Lee and Gerhard Plenert (1993)	Linear-Integer Programming	Number of optimal product Throughput	The paper has demonstrated that linear programming technique of product mix optimization can be used to solve the problem of TOC profit maximization Illustrated the advantages of using Linear integer programming as a tool as its results brings TOC benefits in increasing the throughput of the system.	Manufacturing
James L. WahlerP*, James F. Cox, III (1994)	Case Study	Throughput Inventory Operating expenses	Described that modifying the performance management system of the firm and selecting the appropriate competitive factors can assist in coordinating, controlling and communicating the product flow in the manufacturing process starting from receipt of order till they are shipped. Utilized TOC principles to reduce lead time and improve delivery performance	Performance Measurement System

Authors	Tools Used	Variables considered	Inference	Industry
C. V. Chaudhari and S. K. Mukhopadhyay (2003)	Case Study	Sales Price Variable Cost Yield Product mix decision Storage Forecast	The paper has identified and overcome the policy constraints using TOC in the poultry business.	Poultry Industry
Marjorie J. Cooper and Terry W. Loe (2000)	Application of theory	Customer satisfaction Customer feedback	This paper has used TOC and implemented these tools in marketing. It offers tools that instill problem identification and situation analysis skills in students	Marketing
A. Lockamy III and M. S. Spencer (1998)	Case Study	Throughput Operating expenses Inventory	The paper has examined the use of TOC performance measures in an actual operating environment Hypotheses have been developed and validated. Explained areas where theory and practice diverge.	Performance Management System
Alex Coman and Boaz Ronen (2000)	Linear programming	Operating Expenses Number of resources Number of Products Market Price of products Marker Demand	The paper has explained and analyze outsourcing problem. A linear programming model has been developed for outsourcing problem and identified analytical solution The paper has further compared the results obtained using Linear Programming model with the standard cost accounting and TOC	Production Outsourcing
R Verma (1997)	Anova Statistical tool	Throughput Operating expenses Inventory	Compared three different domains i.e. Management Science, TOC and Local optimization (LO) techniques used in the production planning.	Production Planning
Graham K. Rand (2000)	Application of Theory	Buffer Time of completion	This paper has explored linkages between TOC and CPM/PERT approaches. the relationship between the ideas developed in the TOC approach and the CPM/PERT approach. TOC approach has helped in avoiding milestones so as to put more emphasis on the critical areas. This can be done by identifying the most pertinent chain and then by inserting buffers at accurate points in the project.	Project Management
John H. Blackstone Jr , James F. Cox III and John G. Schleier Jr (2009)	Application of Theory	Project completion time Resources Time of Processing	The paper has examined various causes that lead to project lateness. It has further illustrated the completion of projects using both traditional and critical chain project techniques. The impact of critical chain technique on the completion time of project has been observed by conducting three different simulations based on uniform, exponential and triangular distributions.	Project Management
H. William Dettmer (1995)	Application of Theory	Throughput Inventory Operating costs	Applied TOC approach in achieving quality philosophy	Total Quality Management (TQM)
H. Steyn (2002)	Application of Theory	Cost of delays Constrained and Non-constrained resources buffer	The paper has applied TOC in managing resources that are shared by many projects running simultaneously. The paper also proposed the application of TOC in many other contexts like costs and risks related to project management	Project Management
Michael S. Spencer (2000)	Case Study	Throughput Waste Profits	The paper has examined the application of TOC in the area of production planning and control	Service Organization

Authors	Tools Used	Variables considered	Inference	Industry
David Kayton, Tim Teyner, Christopher Schwartz, Reha Uzsoy (1997)	Application of Theory	Cycle time of lots Mean time of failure Mean time of repair	This study has utilized a systematic approach of TOC to identify the bottleneck or constraint in the production system of wafer fabrication facility	Wafer Fabrication Facility
Hilma Raimona Zadry & Sha'ri Mohd Yusof (2006)	Hypotheses and t-test approach	Leadership Resource Management Performance Measurement Feedback Continuous Improvement Quality Management	This paper has applied TOC in the TOM area to assist the implementation of TQM processes. Surveys were carried out to understand the degree of both TOC and TQ implementation in automotive suppliers.	Total Quality Management
Samia Siha (1999)	Application of theory	Throughput Inventory Operating costs	Applied principles of TOC for improving the performance of the service firms. The paper has identified four types of service organizations and tried to adopt TOC vocabulary into these service organizations	Service Organizations
Clay Rippenhagen Shekar Krishnaswamy (1998)	Application of theory	Work-in-progress inventory	This paper has described a straightforward method of TOC to avoid starvation of possibly reoccurring bottleneck equipment.	Semiconductor industry
John F. Tanner, Jr., Earl D. Honeycutt, Jr. (1996)	Case Study	Productivity	This article has discussed the TOC as a technique to analyze the process and identifying and minimizing the bottlenecks	Re-engineering
L. Louw and D. C. Page (2004)	Mathematical modelling and simulation experiment	Bill of material Mean time to repair Mean arrival rate Waiting times Average demand rate Mean time between failures at workstation	Described modelling approach related to queuing network in the context of production for the estimation of buffer time using TOC philosophy	Queuing Network Analysis
Dave Nave (2002)	Comparative Analysis	Guidelines, Primary effect, Secondary effects Criticisms	The paper has compared Six Sigma, Lean and TOC approaches on various criteria such as focus, primary as well as secondary effects and limitations of each approaches. The paper has further provided various approach to identify the selection procedure for these three improvement models	Six Sigma, Lean
Togar M. Simatupang, Alan C. Wright and Ramaswami Sridharan (2004)	Application of Theory	Net profit Productivity Return-on-investments Cash Flow Sales per unit Truly variable costs Inventory	Applied the principles of TOC in the context of supply chain collaboration. TOC has exposed various collaboration dilemma existing inherent to the supply chain, devised collaborative replenishment strategy and established performance metrics.	Supply Chain collaboration

Table A4: **Aggregated priority vectors and ranking of barriers of IPTS**

Barriers	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	Expert 11
Absence of strategic planning by Govt. (B1)	0.211	0.277	0.217	0.218	0.213	0.262	0.266	0.287	0.277	0.273	0.271
Low investments in Power Transmission (B2)	0.292	0.224	0.253	0.289	0.289	0.239	0.230	0.233	0.239	0.247	0.237
Fewer Private Players in Transmission (B3)	0.114	0.121	0.130	0.141	0.127	0.135	0.118	0.124	0.138	0.138	0.113
Transmission Congestion (B4)	0.082	0.078	0.083	0.073	0.079	0.094	0.089	0.078	0.094	0.070	0.083
Transmission Losses (B5)	0.047	0.042	0.044	0.039	0.039	0.044	0.041	0.037	0.050	0.042	0.022
Failure to upgrade Technology (B6)	0.051	0.049	0.048	0.047	0.045	0.043	0.049	0.048	0.052	0.053	0.051
Delays in project execution (B7)	0.157	0.160	0.144	0.143	0.137	0.116	0.134	0.119	0.100	0.124	0.139
Grid instability due to RE (B8)	0.015	0.015	0.016	0.014	0.013	0.016	0.016	0.018	0.027	0.021	0.033
Poor performance and financial health of Utilities (B9)	0.016	0.021	0.025	0.022	0.022	0.021	0.025	0.029	0.031	0.020	0.021

Barriers	Expert 12	Expert 13	Expert 14	Expert 15	Expert 16	Expert 17	Expert 18	Expert 19	Expert 20	Expert 21	Expert 22	Expert 23	Expert 24	Expert 25	Expert 26	Expert 27
B1	0.280	0.221	0.276	0.265	0.109	0.075	0.076	0.275	0.283	0.292	0.267	0.297	0.278	0.284	0.264	0.272
B2	0.237	0.266	0.237	0.234	0.152	0.041	0.132	0.242	0.248	0.222	0.226	0.196	0.218	0.228	0.260	0.219
B3	0.122	0.126	0.121	0.135	0.069	0.036	0.083	0.118	0.124	0.123	0.122	0.152	0.143	0.130	0.124	0.143
B4	0.077	0.051	0.068	0.079	0.051	0.033	0.096	0.092	0.074	0.072	0.073	0.073	0.082	0.088	0.071	0.052
B5	0.021	0.045	0.020	0.052	0.052	0.024	0.076	0.050	0.018	0.034	0.022	0.053	0.040	0.047	0.023	0.049
B6	0.046	0.067	0.055	0.035	0.072	0.239	0.162	0.047	0.044	0.045	0.062	0.039	0.050	0.049	0.059	0.068
B7	0.119	0.151	0.121	0.136	0.224	0.288	0.289	0.120	0.113	0.118	0.119	0.120	0.129	0.096	0.122	0.128
B8	0.036	0.035	0.037	0.014	0.029	0.017	0.028	0.016	0.032	0.019	0.039	0.015	0.015	0.027	0.037	0.039
B9	0.024	0.024	0.024	0.023	0.141	0.248	0.041	0.020	0.023	0.026	0.024	0.025	0.024	0.030	0.029	0.030

Barriers	Expert 28	Expert 29	Expert 30	Expert 31	Expert 32	Expert 33	Expert 34	Expert 35	Expert 36	Expert 37	Expert 38	Expert 39	Expert 40	Expert 41	Expert 42	Expert 43
B1	0.303	0.273	0.277	0.302	0.275	0.299	0.257	0.284	0.278	0.259	0.305	0.276	0.280	0.261	0.271	0.296
B2	0.220	0.244	0.231	0.231	0.227	0.224	0.242	0.224	0.221	0.238	0.210	0.198	0.214	0.189	0.243	0.196
B3	0.155	0.144	0.121	0.128	0.134	0.142	0.137	0.156	0.152	0.155	0.161	0.138	0.149	0.147	0.163	0.155
B4	0.081	0.070	0.080	0.074	0.095	0.075	0.097	0.084	0.068	0.081	0.088	0.089	0.091	0.045	0.074	0.076
B5	0.023	0.043	0.043	0.021	0.051	0.023	0.053	0.044	0.035	0.054	0.050	0.047	0.048	0.053	0.044	0.050
B6	0.050	0.053	0.048	0.059	0.052	0.051	0.051	0.044	0.044	0.036	0.049	0.054	0.046	0.076	0.053	0.043
B7	0.095	0.117	0.152	0.115	0.097	0.076	0.115	0.108	0.090	0.111	0.077	0.121	0.118	0.146	0.097	0.126
B8	0.038	0.022	0.016	0.039	0.029	0.033	0.018	0.019	0.021	0.016	0.028	0.016	0.018	0.055	0.022	0.022
B9	0.025	0.021	0.021	0.031	0.031	0.019	0.022	0.023	0.027	0.024	0.028	0.025	0.023	0.029	0.019	0.022

Barriers	Expert 44	Expert 45	Expert 46	Expert 47	Expert 48	Expert 49	Expert 50	Expert 51	Expert 52	Expert 53	Expert 54	Expert 55	Expert 56	Expert 57	Expert 58	Expert 59
B1	0.267	0.272	0.280	0.297	0.298	0.174	0.119	0.087	0.227	0.041	0.143	0.139	0.062	0.325	0.331	0.097
B2	0.243	0.229	0.222	0.227	0.220	0.136	0.123	0.112	0.125	0.102	0.246	0.255	0.083	0.055	0.054	0.089
B3	0.157	0.139	0.153	0.156	0.154	0.083	0.156	0.034	0.108	0.027	0.073	0.082	0.074	0.022	0.095	0.031
B4	0.083	0.081	0.067	0.083	0.071	0.042	0.086	0.057	0.039	0.153	0.034	0.033	0.113	0.106	0.142	0.059
B5	0.042	0.048	0.021	0.045	0.024	0.028	0.077	0.260	0.210	0.169	0.204	0.170	0.196	0.030	0.045	0.300
B6	0.048	0.053	0.064	0.048	0.068	0.094	0.025	0.141	0.042	0.044	0.070	0.071	0.093	0.144	0.032	0.195
B7	0.107	0.124	0.082	0.076	0.100	0.289	0.100	0.121	0.066	0.083	0.121	0.149	0.139	0.076	0.197	0.088
B8	0.019	0.017	0.036	0.022	0.042	0.061	0.087	0.037	0.041	0.147	0.027	0.032	0.093	0.040	0.029	0.026
B9	0.023	0.020	0.023	0.030	0.030	0.095	0.208	0.127	0.136	0.227	0.052	0.051	0.122	0.202	0.070	0.124

Barriers	Expert 60	Expert 61	Expert 62	Expert 63	Expert 64	Expert 65	Expert 66	Expert 67	Expert 68	Expert 69	Expert 70	Expert 71	Expert 72	Expert 73	Expert 74	Expert 75
B1	0.219	0.130	0.255	0.325	0.155	0.169	0.127	0.224	0.224	0.230	0.259	0.051	0.051	0.150	0.051	0.076
B2	0.149	0.158	0.201	0.029	0.108	0.076	0.115	0.202	0.202	0.097	0.122	0.066	0.066	0.158	0.066	0.047
B3	0.074	0.101	0.038	0.032	0.070	0.048	0.050	0.030	0.030	0.043	0.067	0.118	0.118	0.101	0.118	0.106
B4	0.097	0.061	0.055	0.099	0.078	0.095	0.043	0.077	0.077	0.062	0.034	0.112	0.112	0.061	0.112	0.112
B5	0.089	0.193	0.101	0.086	0.133	0.057	0.196	0.041	0.041	0.024	0.038	0.091	0.091	0.193	0.091	0.155
B6	0.104	0.043	0.061	0.096	0.026	0.080	0.122	0.067	0.067	0.085	0.111	0.205	0.205	0.042	0.205	0.127
B7	0.104	0.194	0.195	0.185	0.325	0.326	0.232	0.233	0.233	0.238	0.259	0.305	0.305	0.194	0.305	0.325
B8	0.024	0.027	0.022	0.032	0.054	0.051	0.025	0.022	0.022	0.029	0.035	0.024	0.024	0.029	0.024	0.029
B9	0.098	0.079	0.076	0.118	0.051	0.099	0.109	0.109	0.109	0.191	0.073	0.029	0.029	0.071	0.029	0.023

Barriers	Expert 76	Expert 77	Expert 78	Expert 79	Expert 80	Expert 81	Expert 82	Expert 83	Expert 84	Expert 85	Expert 86	Expert 87	Expert 88	GM	Rank/Criticality
B1	0.041	0.042	0.041	0.223	0.076	0.112	0.167	0.098	0.027	0.259	0.259	0.268	0.289	**0.186**	**1**
B2	0.066	0.066	0.066	0.133	0.137	0.096	0.195	0.078	0.232	0.197	0.109	0.116	0.051	**0.157**	**2**
B3	0.103	0.103	0.103	0.093	0.025	0.114	0.108	0.044	0.117	0.204	0.088	0.051	0.070	**0.097**	**4**
B4	0.126	0.126	0.126	0.075	0.137	0.098	0.067	0.056	0.138	0.095	0.034	0.061	0.051	**0.076**	**5**
B5	0.096	0.096	0.096	0.045	0.047	0.112	0.148	0.279	0.114	0.071	0.038	0.050	0.171	**0.058**	**7**
B6	0.251	0.251	0.251	0.118	0.076	0.112	0.043	0.213	0.075	0.051	0.114	0.082	0.175	**0.068**	**6**
B7	0.259	0.259	0.259	0.203	0.381	0.140	0.151	0.091	0.169	0.038	0.255	0.259	0.101	**0.144**	**3**
B8	0.024	0.023	0.024	0.022	0.034	0.112	0.034	0.025	0.029	0.028	0.034	0.026	0.022	**0.027**	**9**
B9	0.033	0.034	0.033	0.091	0.087	0.112	0.109	0.133	0.088	0.051	0.070	0.086	0.071	**0.044**	**8**