Reforms and Technology Adoption in the Electricity Transmission Companies of India

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Abstract
India's power sector has undergone a remarkable transformation, aimed at providing reliable, affordable, and sustainable energy to its people. Adoption of loss reduction technologies (LRTs) is crucial to address high transmission losses and, improve quality and reliability of supply. These, in turn, can raise consumer satisfaction and can also help distribution utilities in improving their financial performance. Although electricity transmission sector reforms, implemented through a number of policy and regulatory initiatives, emphasize distribution performance improvement, LRT adoption by transmission utilities has generally remained limited. Conceptualizing technology adoption and reforms from a new institutional economics perspective, this paper provides a systematic approach for identification and classification of barriers to LRT adoption to guide future transmission reforms. Based on literature review and stakeholders survey, thirteen barriers are identified and classified at three levels of governance – sector, utility and sector consumer interaction. Further, the Analytical Hierarchy Process (AHP) is used to rank the barriers. Results suggest that future reforms should focus on the improvement in utility-level governance, unlike the present focus on sector-level governance.

***Keywords*: Technology adoption, Barriers, Indian electricity transmission sector, transmission losses.**

Introduction: -

More than two decades since the reforms process was introduced in the Indian electricity transmission sector, transmission losses, are still higher than the desirable levels, and continue to pose challenges for the viability of the entire sector. India's power sector has undergone a remarkable transformation, aimed at providing reliable, affordable, and sustainable energy to its people. Over the last 15 years, significant strides have been made in enhancing power generation capacity, expanding access to electricity, promoting renewable energy, and implementing innovative policies. India's journey towards a greener future has gained global recognition. With the addition of over 175 GW of generation capacity in the past nine years, India has transitioned from a power deficit to a power surplus nation. The country's commitment to renewable energy sources has played a pivotal role in achieving this feat. The remarkable growth of solar and wind energy capacity has cemented India's position as a global leader in renewable energy adoption. Today, India stands 4th globally in Renewable Energy Installed Capacity, with 43% of its total installed electricity capacity coming from non-fossil energy sources.

Globally, the power sector is undergoing a major technological transition driven primarily by environmental concerns and digitalization. Electricity distribution networks should be capable of handling variable and uncertain supply of renewable energy sources, two-way electricity transaction as well as data flow. Combined with digitalization, intelligent networks will make the sector more resilient, efficient and cost-effective, and meet user expectations with reduced costs. For the Indian electricity distribution sector, technological transition of existing electricity distribution networks is crucial. This is to deal with issues of environmental sustainability and address persistent problems including high transmission and distribution (T&D) losses

(20% in 2018-19), low-reliability, limited accessibility and poor supply quality. In 2015, the third financial bailout of the distribution sector, burdened with rising financial debt, had resulted in limited success as the sector remain beset with high financial losses (Rs. 29,576 crore for 2022-23).

Despite the relevance of technology adoption, there have been limited analysis of impact of reforms on technology adoption. Jamasb and Pollitt and Pollitt (2012) raise concerns regarding lack of innovation and technology adoption under the current utility business model and suggest need for another set of distribution reform. Marino, Parrotta, and Valletta found a negative impact of reforms and deregulation on electricity sector innovations, measured by the number of patents granted, across 31 OECD countries. Analysing investments in distribution R&D projects in Brazil, Jannuzzi argues reforms and regulatory changes alone are insufficient to promote investment in energy efficiency. Such findings threaten sustainable efficiency improvement in the power industry. Inadequate understanding of technology adoption processes begets a consensus over path of distribution reforms. A focused investigation identifying barriers hindering technology adoption, can help future reforms for the distribution sector. Although poor performance of utilities has drawn attention, the specific issue of technology adoption in the distribution network (particularly LRT) remains to be thoroughly investigated. This paper intends to fill this gap by combing macro level approach of analysing reforms and its impact on investment in new technologies, with micro-level approaches that analyse technology adoption dynamics at the utility and actors level (.

The paper builds on insights from theories of sociotechnical systems and new institutional economics (NIE). It begins with the ‘barrier approach’ in the context of energy efficiency, renewable energy, energy conservation, technology adoption and diffusion. Distribution networks are envisaged as a type of sociotechnical system wherein technological, economic, political and social features interact through actors, institutions and governance structures. NIE provides a powerful interpretive framework that focuses on the stated elements and interactions therein. Technology adoption decisions seem to be driven predominantly by actors, the social context, institutions and governance structures. Reforms redefined role of actors by bring about change in institutions and governance structures, that govern inter-linkages in sociotechnical systems. It also influenced decision-making about technology choice. The present study is based on this conceptual understanding, and validated through insights from semi-structured interviews and surveys with utility officials, regulators and power sector experts. Thirteen barriers that influence technology adoption in Indian electricity transmission sector are identified. These are classified at three levels of governance, and ranked using the AHP method. In doing so, we derive the effect of reforms on various barriers influencing utilities decision-making for LRT adoption.

The study contributes to the understanding of inter-relationships between reforms and technology adoption by developing a theoretical framework that helps to define and identify barriers. The methodological approach, based on institutional theories, highlights the governance perspective and adds to the novelty of study. Empirically, the study adds to scarce literature analysing LRT adoption issues in the Indian electricity transmission sector. The methodological approach and findings are also relevant in the context of countries facing similar issues, and adoption of green technologies and smart-grid. The paper is structured in two sections in which one is related to the barriers in adoption of reforms and one is related to the new technologies in electricity transmission companies in India.

Reforms in the Electricity Transmission Companies: -

Advanced Transmission Technologies: - Several advanced transmission technologies exist today that can be used to improve and enhance the transmission system, spanning both grid software and grid hardware, as defined in Figure 1. Sensor and software solutions, such as dynamic line rating and topology optimization, focus on improvements in the control center, control systems, and decision-making processes. Actuator and hardware solutions, such as power flow controllers and advanced conductors and cables, focus on improvements in the physical assets and infrastructure responsible for carrying, converting, or controlling electricity. These different technologies can be used in isolation or in tandem to improve the overall efficiency and effectiveness of the transmission network. These technologies can also help increase the reliability and resilience of the entire electric power system.

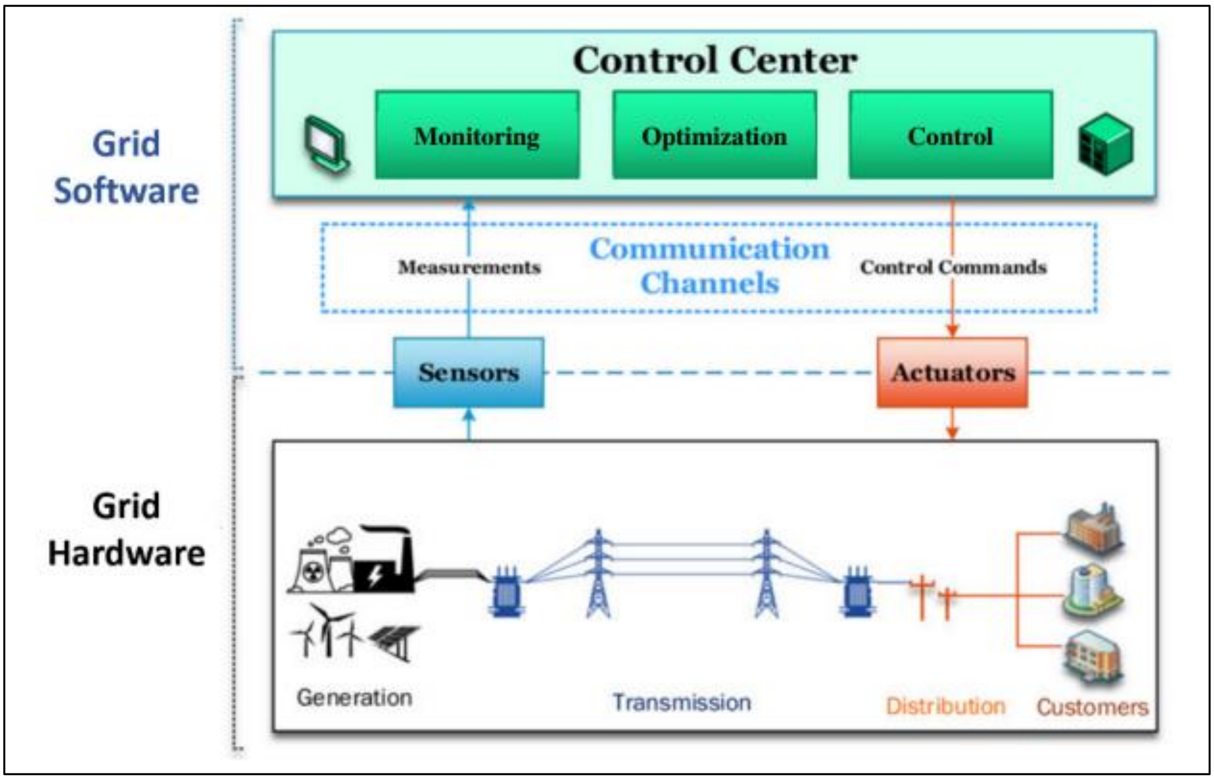

Figure 1. The modern grid: An integrated system in Electricity Transmission Companies in India

Sensors and Software Solutions: - Sensors and software solutions focus on improving the operations and planning of the grid while working within the constraints of the physical hardware. These technologies generally improve upon a short-term system outlook, such as day-ahead or real-time applications, rather than a longer-term planning horizon. Long-term system planning seeks to find an optimal transmission expansion plan with optimum aggregate benefits over the planning horizon. A well-planned network can still benefit from these solutions in the short-term since real-time network conditions will frequently differ from assumptions used in long-term planning.

Dynamic Line Rating: - Line ratings have been an important tool in determining the current-carrying capacity of transmission lines for over 80 years. More refined approaches using data on environmental conditions have given operators greater ability to fully utilize capacity on transmission networks. Dynamic line ratings (DLRs)—the latest iteration—provide system operators with real-time data to aid decision making, helping to manage congestion and improve situational awareness.

Improve Situational Awareness: - DLR provides more accurate information on line conditions to support system operator decision making. This improvement can be critical in situations where lines may sag below clearances and make the system vulnerable to faults and safety hazards. For example, DLR can detect when actual line ratings are lower than ratings calculated from static methods.

Proactive Asset Health Monitoring: - DLR can provide greater insight into the performance of a line over time. Rather than relying on engineering assumptions and maintenance schedules, real-time status of the line can be used in decision making to mitigate component failures, boosting reliability. Mining the sensor data with enhanced analytics can help detect anomalies and deliver alerts when conditions are observed that indicate a risk to reliability or public safety.

Increased Operational Flexibility: - Transmission owners occasionally increase the static rating of a transmission line if requested by an ISO/RTO under unique circumstances. DLRs that support more power to be imported into a region during an outage event can increase grid reliability and resilience. The increased operational flexibility would be beneficial during certain extreme weather conditions, such as the 2018 “bomb cyclone” and the 2014 “polar vortex” events. During these events, extremely low temperatures and wind chill caused high electricity demand, equipment failures and fuel supply constraints that resulted in generators being taken out of service. DLR would provide grid operators the option and ability to take advantage of the fact that colder temperatures and high winds allow for increased capacity on transmission lines.

Advanced Conductors and Cables: - New conductors offering enhanced performance, such as extended high-temperature operation without loss of tensile strength; reduced mechanical, chemical, and electrical deterioration; less elongation; and improved current-carrying capacity, emerged in the middle of the 20th century. These advanced designs include Aluminum Conductor Steel Supported (ACSS), All Aluminum Alloy Conductor (AAAC), Aluminum Conductor Alloy Reinforced (ACAR), and Thermal-Resistant Aluminum Alloy Conductor Steel Reinforced (TACSR) types.

Barriers in Adoption of Reforms and Technology:-

Government Ownership: - Significant literature analyses the effects of ownership on a firm’s overall economic performance, however, its impacts on technology adoption is less studied. Even so, such studies examine indirectly the changes in firms’ technology choices, by considering changes in parameters such as employment and capital investment for technological changes. Specific to the electricity distribution sector, there appears consensus that ownership of utilities affects technology adoption decisions, however, the predicted effect remains ambiguous found that ownership may influence adoption of advanced technologies both in direct and indirect ways. They analysed government-owned generation utilities in India, and found direct influences including distortions in the incentive structures of managers. Reforms led to unbundling and, privatization of selected distribution utilities, expecting private ownership to enhance operational and technical performance through measures including adoption of technological solutions. Yet, most of the distribution utilities remain government-owned, and technical performance has not improved

Partial Unbundling: - Structure of the electricity value chain influences technology choice differentiating between vertically integrated and partially unbundled or fully unbundled utilities. Künneke highlights the technological interconnectedness between different segments of the electricity value chain and, hence, the significance of unbundling in technology adoption decisions. After unbundling, technology adoption by a distribution utility is likely to require much coordination with upstream segments, thereby potentially causing delays in adoption.

Regulations and Incentives: - Technology adoption in distribution networks is influenced by regulatory framework particularly through incentives. Approval of such investments, setting allowable rates of return, and stipulating allowable tariffs by the regulators influence a utility’s take on costs and benefits of an investment. Lack of such regulatory framework can thus hinder adoption of LRT.

Complex Regulatory Processes for Investment Approval: - Post-reform, utilities should follow complex investment approval and tariff determination procedures setup by the SERCs. As revealed during the interviews with the officials of the distribution utilities, such procedures are perceived as a hurdle, as these form an additional layer of approval over and above the program-specific government approvals.

Poor Compliance of Regulatory Framework: - At times, regulators on the other hand, condone and approve such non-compliance. These include delay or non-issue of tariff orders, relaxed compliance monitoring, and non-imposition of penalties for non-compliance hereby influencing LRT adoption. Altogether, such practices reduce effectiveness of the regulatory framework, which incentivizes investment in conventional technologies.

Technological Issues: - Various technology-related issues, such as low reliability and immaturity of new technology, mismatch with existing technologies, and underutilization of existing distribution assets, may often inhibit new technology adoption. For example, in the industrial sector of the United Kingdom, lack of maturity of new technology was found to be a key barrier.

Cost of Technology and Availability of Funds: - The high costs and unwillingness of funding agencies to finance new technology, even the commercially viable ones, pose a serious challenge to their adoption., The adoption behavior of utilities towards efficient distribution transformers under the Spanish Distribution Regulation and European Environmental Regulation, found high cost of efficient transformers adversely influenced adoption.

Organizational Inertia: - In a qualitative case study of 18 distribution utilities, Newbury (2013) found organizational rigidities and routinized capabilities are major factors determining adoption of renewable technologies. Organizational capabilities include the level of knowledge and expertise of a firm regarding a new technology, that influence firms' investment decisions

Financial Health of the Utility: - Analysing decline in performance of diesel-based generation utilities across developing countries Jhirad (1990) revealed it is a cyclic process whereby poor performance hampered investment in new technologies. Under cash constrained scenario whereby most of the utilities are loss-making and financially starved, costly but economic investments are side-lined. Lack of financial resources limits the ability of distribution utilities to invest scarce resources in LRT.

Lack of Information: - Lack of reliable information on technology, its deployment and impact plays an important role in the adoption processes of new technologies.

Political Influence: - Consumers can also affect the technology adoption decisions of utilities indirectly by influencing other key actors, including government/politicians and regulators. In addition to informal channels, consumers can influence the government through political processes, and the regulators via participation in regulatory functioning. Moreover, a weak institutional environment further strengthens such influence. Various actions of government and regulators are ultimately driven by consumer preferences. Political preferences generally tilt in favor of existing technologies, due to possible vested interests shared with existing technology suppliers and manufacturers.

Conclusion

Electricity transmission sector reforms were initiated to address persistent problems of high network losses, mounting financial losses and escalating debt amidst the need to improve access and availability of electricity. High network losses can be reduced through improved operational practices along with technological solutions. The paper aimed to identify key barriers to LRT adoption so as to understand the role of reforms in addressing the same. Building on insights from sociotechnical system and NIE theories of technology adoption, an analytical framework to identify and classify barriers at three levels of governance was developed. Consequently, thirteen barriers influencing LRT adoption were identified and ranked using AHP. In line with the evolutionary theory of technical change, organizational inertia was found to be the most significant barrier.

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