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Analysis of Investment Issues and Transmission Schemes for Grid Integration of Remote Renewable Energy Sources

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Abstract - Investment in the transmission sector faces a set of technical, economic and regulatory challenges. Ever rising energy demands, increased renewable energy penetration into remote grid and deregulation of power industry necessitates the need for evaluation of these challenges prior to investment in the transmission sector. The present study aims at investigating these challenges and recommends possible solutions for the development of transmission sector. A review of challenges faced by renewable energy penetration into remote grid and an analysis of case studies involving principal transmission schemes employed in various countries for evaluating these challenges are presented.

Keywords– Transmission sector, Investment, transmission schemes, renewable energy, grid integration.

1. Introduction

Global electricity demand is expected to double by 2030, growing at an annual rate of 2.4%. This growth is strongest in developing countries, where electricity demand will rise by over 4% per year, tripling by expected period. The share of global electricity demand in developing countries rises from 27% in 2000 to 43% in 2030. To meet this growth in energy demand, capital investments required for the development of power sector infrastructure is expected to be $11 trillion globally and $5 trillion in developing countries. The average annual rate of investment is expected to increase from $450 billion in the current decade to $630 billion in next decade [1]. In India, the present peak demand is about 1,35,918 MW and the peak demand met is 1,29,815 MW with a deficit of about 10% [2]. One of the major reasons for not meeting the peak demand is the lack of proper transmission infrastructure. Transmission lines play a vital role in the successful and stable operation of the power system network. The energy peak demand in 2017 and 2021 has been projected as about 200 GW and 284 GW respectively.

To meet the ever rising energy demand, the generation and transmission capacity additions are to be planned and executed simultaneously involving huge capital investment. Most of the power is generated from conventional power stations utilizing fossil and nuclear fuels, which are probably located away from the load centres due to environmental constraints. The most convenient means of transporting electrical energy in such a scenario is the use of transmission lines. The design and construction of these lines is a very complex aspect as several design parameters having complex interactions among themselves and in terms of their effect on overall system cost has to be selected [3,4]. Any delay in constructing new transmission lines will under utilize the generation facilities and investment. In this regard, the present study concentrates on the issues faced by construction of new transmission lines and possible solutions for mitigating the challenges, with emphasis on remote renewable energy integration into the grid.

2. Transmission Lines: Planning and Construction

Utilities in the present days aim at constructing the transmission lines with least capital investment and gain maximum economic efficiency. Transmission planning aims at new line installations or network expansions to meet the anticipated power demands reliably and economically. Transmission planning aims at evaluating in detail the technical data, economics and environmental impacts in constructing new lines [5]. Figure 1 shows the detailed transmission planning methodology.

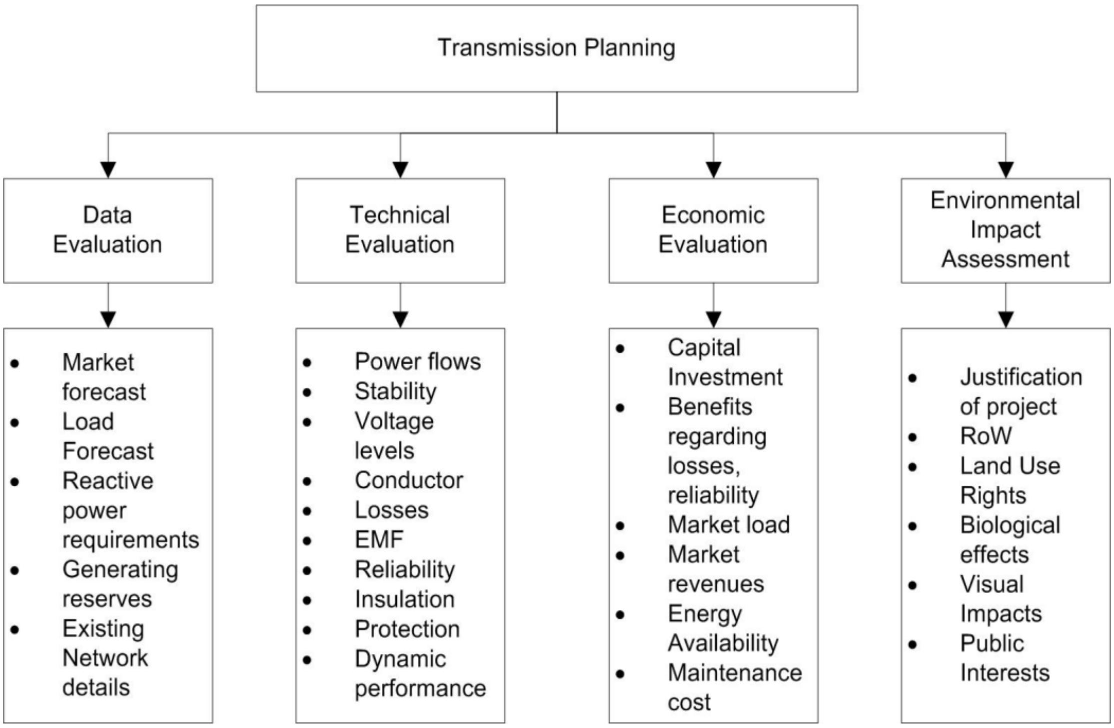

Figure 1. Transmission planning methodology

The construction of a transmission line is a difficult task which requires coordinating the execution plan at many individual sites concurrently, as construction methodology is not unique throughout and changes from site to site depending on the terrain [6]. Transmission lines construction involves heavy capital investments which are dependent on several technical, geographical, regulatory and other factors. Reliability and security levels also enhance the total cost. Right of Way (RoW) and land purchase cost which are highly volatile and dependent on the market conditions. Variations in labour cost, raw material costs and economic parameters introduce uncertainty in estimating the capital investment required for construction of transmission lines [7, 8]. Figure 2 shows the flowchart for constructing the transmission lines.

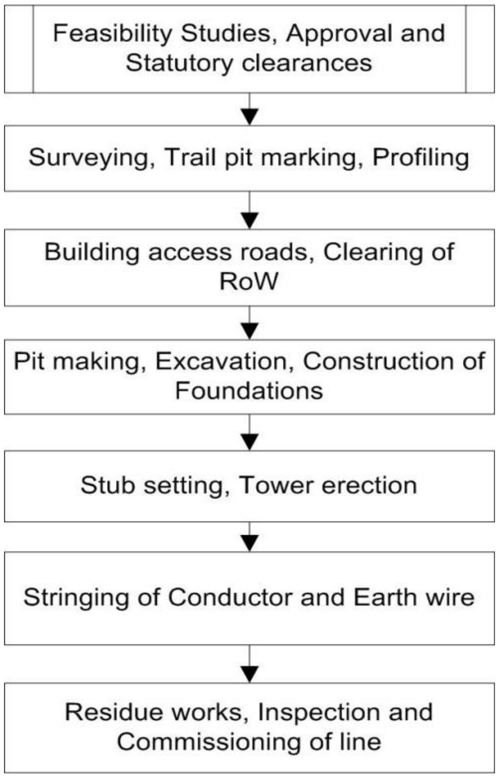

Figure 2. Flowchart for transmission line construction process

3. General Issues and Solutions

In order to meet the rising energy needs, the global transmission industry has seen rapid developments, but with simultaneous increase in limitations over several issues in the area of transmission lines. Issues arising from technical bottlenecks, environment impacts, institutional/government policies and regulatory authorities are inherent and requires careful analysis and efficient mitigation plans for successful development of transmission lines.

3.1 Technical

The growth of transmission lines, especially in the EHV and UHV range, are generally faced with many technical challenges. The most important issue regarding the development of transmission lines is the minimization of RoW. Increased system interconnections results in reducing the technical and economical advantages by posing problems due to load flows and inter area power oscillations. The power transfer along a specified path in the system cannot be controlled by the system operator. Also, variations in power demand necessitate the need to regulate power flow on the transmission lines by flexible line loading for grid security and optimization. The EHV and UHV lines, due to their high level of reactive power generation are generally sub-optimally utilized which is a clear indication of under utilization of the transmission investment. With the widespread use of renewable energy sources, integration of renewable energy generation to the grid, especially through weak AC links and when there is no sufficient reserve capacity available in the neighbouring networks is a big challenge. A similar kind of problem is encountered in planning and stable operation of the transmission systems when dispersed generation is connected to the distribution system. The ever rising concern for environment poses the burden of reducing the biological effects due to electromagnetic fields and environmental impacts due to development of transmission lines [9].

Majority of the technical issues need optimal planning strategies and measures, induction of new technologies and innovative designs. RoW concerns can be addressed through the development of high power intensity transmission corridors by increasing the transmission voltage. The usage of multi-circuit/bundle conductor lines on HV and EHV lines increases the power transfer per unit RoW available. Power transfer can be done using compact transmission towers employing delta configuration and narrow base towers which require less area when compared to normal towers. Also, upgradation of transmission lines to next higher voltage levels is to be considered for increasing power transfer capability of the existing transmission corridor with minor increase in RoW. The loadability limits and conductor current ratings can be increased by employing High Surge Impedance Loading (HSIL) lines and High Temperature Low Sag (HTLS) conductors respectively. In some cases, reconductoring of existing lines proves to be an economic choice considering the useful life of the system. The use of composite materials like glass fibre can be used for replacing steel core in conductors for enhancing current carrying capability without increasing weight. Advanced conductor technologies such as cryogenic technology can be considered as a future option for development and operation of transmission lines with cryogenic conductors. Innovative technologies such as “Green towers” which involves designing towers with least amount of steel and other metals aiding in lesser carbon emissions and resulting in lower carbon footprint can address environmental concerns. Development of hybrid transmissions consisting of DC and AC interconnections increases the operational flexibility while meeting the energy needs optimally [10].

3.2 Operational

Apart from the above mentioned technical challenges, the construction of new transmission lines and uprating and upgrading of existing transmission lines are encountering many operational challenges. Some of the major issues include overloading of transmission line due to open access and free flow policies, loading of lines up to thermal limits due to deregulation and privatization and increasing congestion due to power trading with fast varying load patterns. Lack of timely information and inability to accommodate residual uncertainties for dealing with operational uncertainties increases the risk of outages [11].

The areas signifying scope for improvement in operational activities of line include condition based monitoring to improve reliability, availability, life extension and operational efficiency. Preventive maintenance strategies are helpful in avoiding forced outages to some extent. New technologies can enhance the power handling capacity, provide better dynamic reactive power support and minimize the construction of new transmission lines by reinforcing them into the existing grid. Effective grid management is essential for managing transmission assets, operating methods and recognizing and evaluating alternatives for meeting transmission needs. The development of probabilistic, cost and risk management models helps in dealing with uncertainties in resource allocation, quantifying and analyzing contingencies impact on the system and for optimum utilization of the system required level of reliability respectively, while providing system operators with better information regarding system operational limits [12].

3.3 Government/legal/policy

The role of governments, legal policies and regulatory bodies are vital in determining the growth of the transmission industry. Most of the issues dealing with these entities, from acquiring the license to redressal mechanisms are highly time consuming, delaying the construction of new transmission lines and in providing solutions for the difficulties encountered by stakeholders in the transmission industry. Acquisition of land, high capital investments in construction of new EHVAC, UHVAC and HVDC lines, sub-optimal planning leading to under-utilization of resources and insufficient focus on upgradation of existing transmission lines are the major administrative issues faced by the transmission industry. New RoW for transmission lines are environmentally interfering, complicated to route and subject to a very slow approval process as regulatory authorities are more and more disinclined to approve projects that do not address local needs posed by government policies. Lack of public policy addressing how costs and benefits are allocated, redressal methods for unanticipated events, targeted planning for short, medium & long term energy transfers and incentives that supports the required level of transmission investments are the major drawbacks in the policy matters hampering the construction of transmission lines. Inability to generate participation from established global players and participation from inexperienced players make the concept to commissioning time significantly high. Above all, the uncertainties posed by electricity deregulation increase the gap between new technology developed and its actual employment for operational use [5].

As transmission industry is fast growing and more and more capital investments are necessary for meeting the transmission needs, government provisions and regulatory policies should attract private investment in the transmission sector. Reforms in the transmission sector must be initiated by the institutional bodies for addressing the present issues, private and public sector transmission utilities are encountering. In this regard, incentives may be provided for public and private investors for investing in the transmission sector along with policies for faster land acquisitions and environmental clearances. Incentives may also be provided for early commissioning and faster execution of transmission lines. Policies should encourage investment in transmission R&D especially for development of cost efficient technologies which will enhance power transfer capacities in existing RoW. Institutional bodies must develop performance metrics to determine minimum planning and operational standards for transmission grid and apply stringent selection processes for filtering inexperienced participants. Governments should take the lead responsibility in educating consumers to manage their distributed energy resources for reducing the dependence on conventional energy and encourage renewable energy growth, while providing redressal mechanism for unforeseen events. The policies should aim in providing system information needs to all market participants for making superior knowledgeable decisions regarding transmission system investments and also provide simplified exit norms which aid in asset churning [8].

4. Remote Renewable Energy Integration

The electric utilities worldwide experienced a shifting trend in generation and real time dispatch due to the combined effects of deregulation and environmental concerns. Development of sufficient transmission infrastructure and an appropriate investment scheme is necessary to meet the above changes. However, the generation shift and transmission investment pose many challenges for electric utilities especially with remote renewable energy integration to the grid .

4.1 Challenges

Remote renewable energy penetration is faced with a number of challenges in the present deregulation scenario of the electricity industry. The technical challenges are power fluctuations, energy storage, protection schemes, optimal placement of renewable sources, islanding, power quality issues, network topology (spaghetti or hub) and transmission technology (HVAC or HVDC). Figure 3 shows the various topologies adopted for remote renewable energy integration to grid. Some of the inherent challenges with integrated renewable are uncertainties and balance between generation and demand and open access. Generator investment needs assurance regarding availability of transmission lines for evacuation of power and transmission investment needs assurance of firm power generation which causes a dilemma of what comes first – generation or transmission.

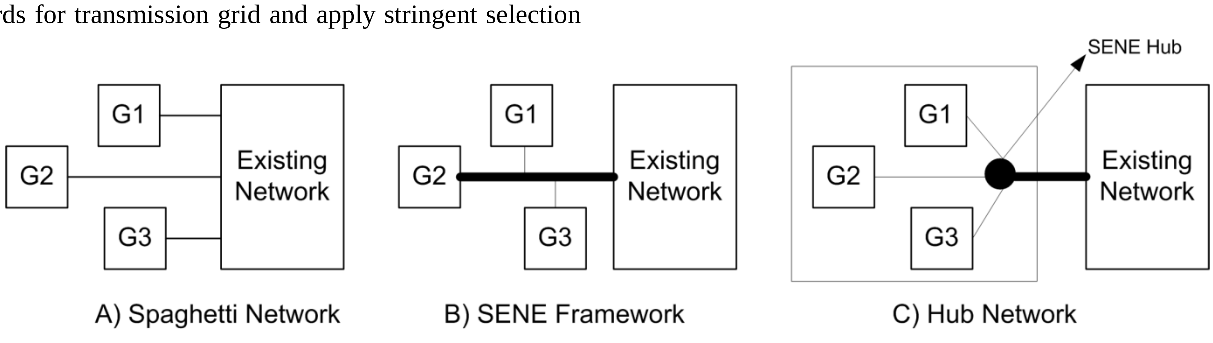

Figure 3. Transmission topologies for remote renewable energy integration [15]

Economic and regulatory challenges include compliance to investment tests and cost benefit assessment policies. Growth of strategic benefits of transmission expansion is essential to overcome the problem of discarding grid integration caused due to heavy investment inconsistent to quantified benefits. Economies of scale, competition with other conventional power generating sources, transmission cost allocation and recoveries are some of the major issues. Transmission investment necessary for renewable generation integration with grid is considerable compared to conventional generation. Risk of asset stranding, quantification of strategic benefits and transmission cost allocation to renewable generators are emerging issues which are crucial in promoting remote renewable sources [13, 14].

4.2 Case studies

The following case studies aims at reviewing the principal renewable energy development and transmission expansion planning schemes implemented/proposed in various countries for integrating high concentrations of renewable energy generation into the grid. Fig. 4 shows the block diagrams for the various schemes reviewed in the following sections.

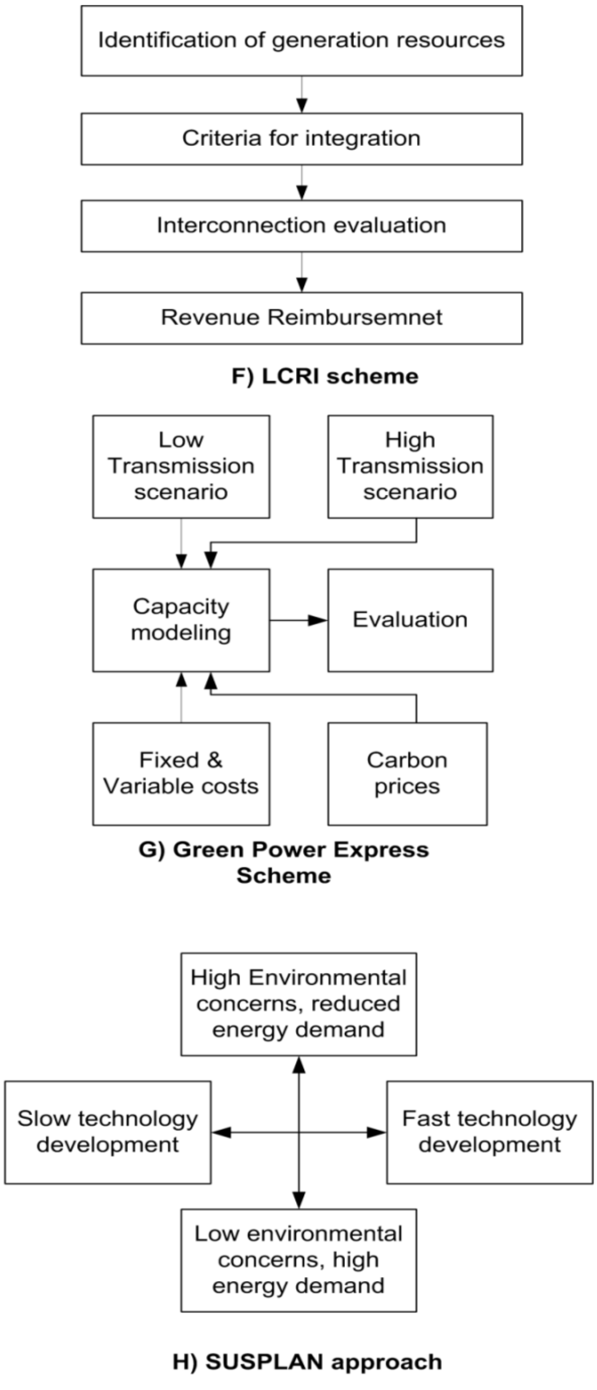

Figure 4. Block diagrams of various schemes [15, 22, 24]

4.2.1 Regulatory Invest test for Transmission (RIT-T)

RIT-T is a cost benefit test for including all transmission additions or upgradation to the existing transmission network in Australia and New Zealand. The test aims at reducing the capital costs, operation and maintenance cost and improves reliability by comparing the benefits to costs of transmission. The net economic benefits are equal to benefits less costs. Spaghetti model is best suited for this approach as each addition is treated separately. The disadvantage with this scheme is that it does not consider economies of scale and risk of asset stranding [15, 16].

4.2.2 Scale efficient network extension (SENE)

SENE promotes integration of large scale renewable energy generation to the grid considering future generation also. Due to this the method is able to take advantage of addressing economies of scale but asset stranding risk still persists. Unlike the government electric utilities taking care of promoting and funding network additions, SENE proposes transmission providers to develop new additions for the existing network and charge the generators for using the network and if required, the customers also if expected revenue is not impending from generators [15, 17].

4.2.3 Victorian generators clusters connection (VGCC)

In this scheme all the renewable energy generations are connected first to a hub and then the hub is connected to the existing transmission network through a high voltage transmission line. Further, this scheme has to pass the RIT-T test and is assessed for cost and benefits. The location of the hub depends on concentration of generating sources, nearness to the transmission corridor, ease of access for constructing infrastructure, overall cost and environmental impacts. Due to clustering of many generators to the hub and use of high voltage transmission line to connect to the grid, the risk of interruptions is reduced [15, 18].

4.2.4 Transmission investment incentives

The Office of Gas and Electricity Markets (OFGEM), UK provides incentives to promote renewable energy integration to grid basing on available renewable generating sources, constraint costs and required investments. The incentives are offered to three classes of projects by way of baseline investment projects, incremental investment projects and additional investment projects. Constraint costs are more than investment costs for baseline projects, uncertainty is present as to whether constraint costs are more than investment in incremental projects and constraint cost are less than investment in additional investment projects indicating risk of asset stranding. Even though incentive schemes do not address the type of topology and technology to be employed, they address the issues of economies of scale and stranding risk assets [15, 19].

4.2.5 Strategic transmission investment plan

Two probable paths were selected by California Energy Commission (CEC) for resolving the problems of long distance renewable power transmission. The first one comprises of developing a dedicated transmission line, named renewable-resource trunk line, for connecting enormous amount of renewable power to the existing grid, the cost of which is recovered through general transmission rates. The second one is forming renewable energy clusters for building transmission lines. However, the present markets do not support this framework and necessary regulatory changes are recommended. A new type of transmission network expansion tariff namely environmentally driven tariff was proposed in addition to economically and reliability driven tariffs [15, 20].

4.2.6 Location constrained resource interconnection (LCRI)

The scheme was implemented by California independent system operator (CAISO) which provides a high voltage transmission line complying with reliability requirements and grid standards and a minimum commitment of 25% of line capacity. The costs of constructing the line have to be paid by generators of LCRI basing on their capacity with respect to capacity of LCRI facility, apart from evaluating the comprehensive cost-benefit analysis. However, the issues of asset stranding, connection topology and transmission technology are not addressed [15, 21].

4.2.7 Net market benefit evaluation

The net market benefit evaluation approach was proposed for Australia National Electricity Market which is a multi-year transmission investment model incorporating environmental benefits for assessment of transmission projects accommodating remote renewable generation. Environmental benefit is assessed based on emission pricing and the large scale renewable energy target scheme. The objective is to maximize the market benefits considering producer surplus, consumer surplus, merchandizing surplus, emission tax and large scale renewable energy target surplus. The method aims at long term benefit for maximum social gains and justifies transmission investment and cost allocation. Risk of stranding assets is present due to transmission addition, the cost of which is to borne by consumers as they are the beneficiaries of expansion [15].

4.2.8 Green Power Express Scheme

The Green Power Express scheme was proposed for Midwest region of the USA for identifying and quantifying the benefits of extra high voltage transmission line addition for reaching renewable energy at remote locations. The EHV transmission was evaluated against Low Transmission (incremental additions) using a simulation model using least cost generation mix basing on generation costs. The model evaluated fuel used for electricity generation in both scenarios and quantified environmental benefits of EHV transmission. The EHV Transmission, apart from meeting the transmission requirement of future renewable energy generation, provides other system benefits such as economies of scale, reliability, diversity and market liquidity [22].

4.2.9 Investment cost related pricing (ICRP) methodology

The ICRP method was proposed for calculating the transmission charges in Great Britain basing on marginal investment cost of additional demand or generation. The model was evaluated for four Supergen FutureNet Scenarios namely, continuing prosperity, environmental awakening, supportive regulation and economic concern. The objective of these four scenarios include growth of renewable generation, post industrial and service oriented economy, implementing demand side and efficiency measures, reducing conventional and nuclear generations. ICRP starts from the baseline principle of allocating the full costs of all transmission facilities and does not suffer from the revenue reconciliation problem of generation marginal pricing methods [23].

4.2.10 Planning for Sustainability Approach (SUSPLAN)

The SUSPLAN model is national and transnational method proposed for Europe which economically optimizes energy infrastructure for various scenarios. The model identifies the long term technical potential of different RES technologies, barriers and constraints against deployment of RES technologies and development of grid and computes grid infrastructure costs for various RES penetrations. Uncertainties created by interdependencies between goals of various planning strategies such as energy, environment etc., more number of players in energy infrastructure development, lack of integration between RES and conventional energy planning, public opposition to grid extensions, difficulty in attributing cost and benefits for infrastructure development, poor financing mechanism for transmission capacity expansions and high congestion management costs are the major barriers identified by SUSPLAN approach. The need for standardized planning, well structured and focussed development process is stressed for high RES penetration into the grid [24]. Table 1 presents the overall performance scenario of the various methodologies proposed for mitigating the challenges of integrating renewable energy sources to the grid.

Table 1. Overview of methodologies in meeting the grid integration challenges [15-24].

Parameter/ Schemes	1	2	3	4	5	6	7	8	9	10
Generation-load uncertainty	√	√	√	√	√	√	√	√	√	√
Generation-load balance	√	√	√	√	√	√	√	√	√	√
First mover disadvantages	×	√	×	×	√	√	√	×	√	√
Free rider problem	×	√	×	×	×	√	×	×	×	×
Cost–benefit analysis	√	√	√	√	√	√	√	√	√	√
Economies of scale	×	√	×	√	√	√	√	√	×	√
Strategic benefits	×	√	×	×	√	√	√	√	√	√
Environmental benefit	×	√	×	√	×	√	√	√	×	√
Stranding asset risk	×	√	×	√	√	×	×	×	×	√
Investment & cost allocation	√	×	√	√	√	√	√	√	√	√
Transmission topology	×	√	√	×	√	×	√	×	×	×
Transmission technology	×	√	√	×	√	×	√	×	×	√

5. Conclusions

In this paper, issues and possible solutions related to general transmission planning and construction are presented in detail. It is observed that in the present power systems, apart from the technical and O&M challenges, the regulatory and environmental challenges are playing a significant role in the development of extra and ultra high voltage transmission lines involving heavy investments. Due to environmental concerns and renewable power obligations by regulatory bodies, remote renewable power penetration is increasing day by day, further augmenting the challenges faced by the transmission sector. In this scenario, an analysis of schemes which aid in the development of transmission sector and encourage renewable power integration to the grid are presented. The transmission cost allocation and recoveries, investment security and other critical issues focussed by the schemes, their relative merits and demerits are discussed.

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