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Addressing Future Power Demand Through Optimized Transmission Planning Using High-Power Conductors and Partial Dynamic Line Loading

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ABSTRACT

India's power demand is increasing at a compound annual growth rate (CAGR) of 7.18% due to rapid urbanization. The paper examines the planning for the extension of transmission to suit the increased load development. Before deregulation due to the power monopoly, optimization techniques were undeveloped, contingency analyses were not conducted, resulting in inefficient transmission investments, increased transmission charges, and diminished reliability, which resulted in inferior quality and increased electricity prices for consumers. The Cost/Benefit index is formulated based on the revenue generated by the line and employed for the optimization of transmission lines. Urbanization will result in Right of Way (RoW) issues for new line installation, necessitating the usage of high-power conductors (HPCs) in these regions. Dynamic line loading (DLL) may or may not yield a "return on investment" in countries facing extreme heat conditions. Consequently, the partial DLL using ambient temperature was employed as a test model in this paper instead of explicitly implementing the complete DLL. This technique is applied to the IEEE 14 test bus system, based on the assumption of a 60% uniform load growth and non-uniform load growth rates of 18%, 21%, and 24% at various buses.

1. INTRODUCTION AND LITERATURE REVIEW

In India, following independence, the government-run public sector took over as the main source of power. Nonetheless, the power industry has encountered a number of difficulties, such as severe energy and peak demand shortages, ongoing power outages, unreliable and low-quality supplies, and higher prices for industrial consumers due to cross-subsidization. The government passed "The Electricity Regulatory Commissions Act, 1998" in response to the growing difficulties facing the power sector [1], which emphasizes the urgency of swift and decisive action and determined that the government must step aside in order to carry out meaningful reforms by concentrating on the core problems facing the electricity industry. Three previous laws—the Indian Electricity Act of 1910, the Electricity (Supply) Act of 1948, and the Electricity Regulatory Commissions Act of 1998—were superseded by the Electricity Act of 2003 [2]. Important steps were adopted by this comprehensive reform, including increasing captive power generation, unbundling State Electricity Boards, and fostering competition in distribution through an open access system. Despite the introduction of these regulations, the transmission sector in the country continues to operate as a natural monopoly, predominantly controlled by government organizations [3]. Under the traditional rate-of-return regulation model, firms are incentivized based on the amount they invest in infrastructure. Since the rate of return is generally fixed, regulated monopolies tend to prefer having more assets included in the rate base. This dynamic often creates a perverse incentive to overinvest in infrastructure, provided such investments are approved by regulators, who usually oversee and authorize capital expenditures in advance [4].

Deregulation involves altering the rules and regulations that govern the functioning of a system [4]. In any market, technological and economic reforms are essential to enhance product quality, improve system efficiency, and address consumer demands. Prior to deregulation, electricity was considered a public service, operating in a monopolistic environment with no competition [5]. The primary objective of this reform was to enhance the performance of State Electricity Boards (SEBs), improve the efficiency of electricity generation, transmission, and distribution, and encourage the participation of private entities [6]. In a deregulated context, the development of transmission optimizing techniques is crucial to preventing planned investment and overinvestment [7]. The operators' revenue increases as a result, and private parties are encouraged to participate [8].

To overcome the over investment the optimal transmission planning is developed in this paper. The Electricity (Transmission System Planning, Development and Recovery of Inter-State Transmission Charges) Rules, 2021 established the concept of General Network Access. Defined as non-discriminatory access to the Inter-State Transmission System, General Network Access (GNA) is available to Designated Inter-State Customers. In the GNA, the transmission pricing will be done based on the power flow. So, in this paper with introduction of Cost/Benefit index, the low revenue lines are removed from the planning. The Cost/Benefit index includes the income of the transmission line based on MW flow as per open access pricing and construction cost of line which includes the RoW cost, tower construction cost, conductor cost.

In order to meet growing demand, it is essential to increase the capacity of the transmission system. The present practice to improve the capacity of the transmission system by building the new transmission infrastructure. But there are difficulties in acquiring RoW [9] emphasize how important it is to maximize the use of already-existing RoW [10] in order to boost power transmission capacity within the same corridor [11]. In order to increase the capacity of the corridor with existing RoW is possible with following methods.

- The adoption of special towers, multi-circuit or multi-voltage poles.
- The upgrading of the current line to a higher voltage or several voltages within the same right-of-way.
- Maximizing the use of the current transmission lines by improving and upgrading them.
- High Performance Conductor (HPC) and certain special conductors are suitable for use with them.

When upgrading existing lines by substituting the conductors, an evaluation of the current structural capacity must be conducted. Replacing the conductors of an existing line should only be undertaken if it has been established that the structures can withstand the necessary loads for the anticipated lifespan of the new conductor system and the augmented load during the pre-tensioning phase.

The conductors, such as ACSR and AAAC, are designed to operate at maximum temperatures of 85°C and 95°C, respectively [12]. There thermal limits are constrained by the risk of annealing at elevated temperatures, which restricts their ampacity. As a result, further ampacity enhancement is not achievable with these conductors. To overcome this limitation, ampacity can be increased within the same transmission line by utilizing Cither larger conductors or High-Performance Conductors (HPC). High Performance Conductor consists of stranded combinations of annealed aluminium or aluminium alloy wires for enhanced conductivity, strengthened by core wires. HPCs are specifically designed for continuous operation at elevated temperatures of at least 150°C, with certain types capable of sustaining temperatures up to 250°C without degradation in mechanical or electrical properties. Their ability to operate at higher temperatures allows HPCs to carry substantially greater current typically 1.5 to 2 times that of ACSR, while maintaining similar size and Weight. This approach offers a cost-effective solution for capacity enhancement in some cases, with shorter installation times and reduced infrastructure requirements High-Performance Conductors (HPC) are costlier than conventional aluminum-stranded conductors [13], making them impractical for all uprating scenarios.

Reconductoring with HPC conductors is not always economically viable for capacity enhancement [14] and should be considered on a case-by-case basis [15]. In rural areas as the RoW cost and RoW issues are very low, the construction of new transmission lines is easier and this expanded corridor will be useful for future expansion also. In urban areas reconductoring with HPC conductors is cheaper where RoW cost is very high and RoW issues are present.

In most of the analysis's, the transmission line expansion planning done for normal conditions [16], load variations and generator variation [17]. But in (N-1) contingency is not analyzing. As in the deregulation environment the reliability also the important, it is necessary to perform (N-1) contingency [18]. So, in this paper the (N-1) contingency is included for the transmission expansion planning [19]. In the literature survey it is also identified that the construction cost of new transmission line is assuming the constant but in the real time it is depends on the conditions that is line is constructing on new tower or existing tower and is using HPC conductor or normal conductor [18, 19]. So, to meet real time conditions in this paper different real time conditions are assumed in the planning.

The rated ampacity of overhead current expressed as Eq. (1).

$$I = \sqrt{\frac{\pi.\bar{h}.D.(T_{cond} - T_{amb}) + \pi.\varepsilon.\sigma.D.\left(T_{cond}{}^{4} - T_{amb}{}^{4}\right) - \delta.D.a_s}{R(T_{cond})}} \quad (1)$$

where, I is the current transferred through the conductor, $R(T_{cond})$ the resistance of the conductor at a given conductor temperature $\bar{h}$ is the average heat transfer coefficient, T_{amb} is the ambient air temperature, D is the conductor diameter, σ is the Stefan-Boltzmann constant, ε is the emissivity of the conductor surface, a_s is the absorptivity of conductor surface, and δ is the incident solar radiation [19].

In steady state conditions the transmission line current limit (thermal rating) is calculated based on that yields a given maximum allowable conductor temperature and assumed it as constant as weather conditions are assumed as constant (mostly max allowable conductor temperature 75°C and weather temperature is 45°C [20], solar absorption coefficient 0.8, Solar radiation 1045 watt/sq.m., Emission constant 0.45, Wind velocity 0.56 m/sec, Effective angle of incidence of sun's rays 90°C). But the "Dynamic Rating" where the conductor temperature is calculated for an electrical current and weather conditions which vary over time in any fashion) [21].

To implement the DLL, it is necessary to build up the technical requirement are:

a. Real time data aquations (wind speed and direction, conductor temperature, solar radiation, humidity with integration with weather stations),

b. Sensor requirement at:

- Weather stations (wind speed, temp, humidity sensors),
- LiDAR / Infrared Cameras (conductor sag, clearance sensors),
- IoT Sensors (current, temperature, vibration),

c. SCADA/PMU Data (power flow, voltage, current),

d. Dynamic Line Rating (DLR) Calculation:

- IEEE 738-based thermal modelling,
- CIGRE-based conductor sag and clearance assessment.

e. Load forecasting with real-time and historical data,

f. Data communication (Fiber Optic (IEC 61850, DNP3, MODBUS, OPC UA), 5G / LTE / Private RF Networks, Satellite, SCADA/PMU Streaming),

g. Data analysis,

h. Hard ware requirement (Edge devices for local sensor data collection, Cloud/On-premise servers for computational processing High-speed communication links),

i. Software requirement:

- Backend: Python, MATLAB, or C++ for simulation models

- Cloud: AWS, Azure, or on-premise data center
- Database: SQL, NoSQL (for real-time data processing)
- Frontend: Web-based dashboard (React, Angular)

This investment cost-based regulation approaches should give good “rate of return.” In the Middle east countries like Kuwait, Iraq, and Saudi Arabia experience some of the hottest summers temperature 40℃ to 50℃, in South Asia countries like India and Pakistan frequently face heat waves with temperatures crossing 45℃, In North America counties like Southwestern U.S. [22] (e.g., Death Valley, Arizona) and parts of Mexico experience extreme heat, Central Australia (Outback) experiences some of the world's highest temperatures like 45℃ and due to the global warming these temperature may go up. Now the question is that weather the positive rate of returns comes for investment on DLL in these countries. The main benefit of DLL depends on the ambient temperatures, but in over heating countries as ambient temperature greater then equal to steady state assumed temperature, the DLL benefit may give negative “return on equity.” In this scenario the TSO does not come forward to invest on DLL. To overcome this, it is important to test the benefit of variable ambient temperature benefit in dynamic rating of overhead conductor. So, a partial DLL technique is introduced which only depends on the ambient temperature. [23].

The Eq. (1) represents the relation between max allowable current of the overhead line. In steady state loading this current is calculated at the maximum allowable conductor temperature by assuming remaining all the parameters are constant. In DLL, the maximum allowable current is calculated with real time values at maximum allowable conductor temperature. To test benefit of the partial DLL the maximum allowable current is calculated with real time temperatures at maximum allowable conductor temperature. The sensitivity analysis is carried out between maximum allowable current with respect to temperature in the study [21]. In the studies it is found that every 2℃ reduction in temperature, the capacity of the line can increase 2% to meet maximum allowable temperature and 10℃ drop in temperature can increase the capacity of the line 11% to meet maximum allowable temperature. To implement the partial DLL only weather station data (temperature) requires, load forecast, temperature forecast, DLL calculation is required.

From the above literature survey, it is summarized that the expansion of transmission infrastructure is very important to meet future load growth. Prior to deregulation the optimization of transmission expansion is not done and over investment was done but in deregulation environment this over investment reduces the revenue and increases the initial investment. In the recent studies also transmission expansion is done only based on the initial investment but not on revenue of the system. So, in this paper the transmission optimization done by introducing a new Cost/Benefit index and this index will help to eliminate the low revenue lines and keeping the high revenue lines in the system. So, the transmission operator will get high revenue.

It is also identified in many researches the development of transmission expansion planning not taken into account of the (N-1) contingencies analysis and contingency limits. The construction cost of the new lines is assumed constant in many researches but it is different for each line according to field conditions. In this paper the construction cost of each line is taken differently according to real time conditions and developed optimization transmission planning including the (N-1) contingency analysis. The HPC conductors are the alternative solution for RoW issues but the HPC are not including in the transmission optimization planning. So, in this paper the HPC conductors are included in the optimization planning to address RoW issues.

It is also identified the DLL technique and its advantages are addressed in many research papers but its feasibility studies in over heating countries is not done. In the literature survey, it is also concluded that the DLL advantage is mostly depends on the temperature but in over heating countries this temperature benefit may or may not give good results. The direct implementation of DLL in over heating countries without testing real time temperature benefits may not be suggestable because its implementation is costlier and complex. So, in this paper an alternate solution i.e. partial DLL implementation is suggested to focus on temperature benefit of DLL with very low investment and low complex and less software requirement. The partial DLL is the first step for practical analysation of temperature benefit of DLL in overheating countries.

In Section 1, the paper discussed the introduction and literature review, research gap identification is done. In Section 2, a developed methodology according to problem statement is explained. In Section 3, implementation of methodology on IEEE 14 bus system with uniform load growth and non-uniform load growth is discussed. In Section 4, case study results and discussion are done and in Section 5 the conclusion is given.

2. METHODOLOGY

1) Run the load flow solution of the base case.

2) Increase the load at all the buses as per load forecast and run the load flow solution.

3) Identify required number of new lines on 80% loading criteria (conventional technique) and use HPC conductors where the RoW issues are present in place of new lines.

4) Run the load flow analysis and repeat step 3, until all the lines are loaded less than 80% and all the bus voltages are within 10% violation [7, 9].

5) Perform (N-1) contingency analysis of the modified network with new lines.

6) Identify and add new lines on 100% loading criteria under (n-1) contingency and go to step 3 until all the lines are loaded less than 100% and all the bus voltages are within 10% of violations under (1-1) contingency [9, 18].

7) Identify the construction cost of new lines on existing tower and new tower.

8) Compare the Calculate the Cost/Benefit index as per Eq. (2) of the new transmission lines and average Cost/Benefit index using Eq. (3) of modified system.

$$C_i = \frac{Income}{Cost} = \frac{P_i * D_i * TSC}{C_x}$$
$$C_i = \frac{P_i * D_i * TSC}{C_{km} * D_i} = \frac{P_i * TSC}{CKM} \tag{2}$$

$$\text{Avg}C_i = \frac{\text{Sum of } C_i \text{ of individua llines}}{\text{total no of lines}}$$
$$\text{Avg}C_i = \sum_{\text{k=1}}^{\text{n}} \frac{C_{ik}}{\text{n}} \tag{3}$$

9) (a) Compare all the final circuits of new transmission line, remove the low Cost/Benefit index line and run the load flow

analysis and (N-1) contingency analysis, check whether all the lines in the modified network are loaded less than 80% in load flow analysis, less than 100% in contingency analysis and voltages are within 10% of violations. If satisfy then go to step 8. If not then keep the line in the planning and remove the next low Cost/Benefit index line and repeat the step 9(a). Go to step 9(b) after the consideration of all the lines.

(b) Replace the low Cost/Benefit index HPC line with the conductor used before HPC and run the load flow solution and (N-1) contingency analysis, check whether all the lines in the modified network are loaded less than 80% in load flow analysis, less than 100% in contingency analysis and voltages are within 10% of violations. If not keep the HPC back in the planning. Go to step 10.

10) To implement partial DLL, identify the peak load timing alongside the corresponding temperature, and determine the percentage of additional load that can be accommodated before meet the thermal capacity of the line. Replace the 100% of the line capacity with new increased capacity under (N-1) contingency and repeat step 10.

11) During step 10, identify which lines are loaded more than 100% and less the new limits under (N-1) contingency and these lines dynamic line capacity to be monitored on real time.

3. CASE STUDY

3.1 Case study 1

An IEEE 14 bus system with uniform load increment of 60% at all the buses are analyses for implementation of optimization technique of the Transmission expansion planning. The IEEE 14 bus system parameters are placed in Table 1 and Table 2.

Step 1: Base case load flow solution.

The N-R load flow solution done using PSSE software and results of the base case are shown in Table 3 and Table 4. Base case violations are not considered in the planning.

Step 2: Increase the load at all the buses as per forecast and run the load flow solution.

It is assumed that a uniform load growth of 60% at all the busses and the N-R load flow solutions are performed using PSSE software. The results of the load flow solutions are shown in Table 5 and Table 6.

Table 1. IEEE 14 bus system bus and generation data [24-26]

Bus Number	Voltage (p.u.)	V_{max} (p.u.)	V_{min} (p.u.)	Susceptance (p.u.)	P_{gen} (MW)	P_{max}	P_{min}	Q_{max}	Q_{min}
1	1.06	1.1	0.9	NA	0	500	80	NA	NA
2	1.045	1.1	0.9	NA	40	100	40	50	-40
3	1.01	1.1	0.9	NA	NA	NA	NA	40	0.0
4	1	1.1	0.9	NA	NA	NA	NA	NA	NA
5	1	1.1	0.9	NA	NA	NA	NA	NA	NA
6	1.07	1.1	0.9	NA	NA	NA	NA	24	-6.0
7	1	1.1	0.9	NA	NA	NA	NA	NA	NA
8	1.09	1.1	0.9	NA	NA	NA	NA	24	-6.0
9	1	1.1	0.9	0.19	NA	NA	NA	NA	NA
10	1	1.1	0.9	NA	NA	NA	NA	NA	NA
11	1	1.1	0.9	NA	NA	NA	NA	NA	NA
12	1	1.1	0.9	NA	NA	NA	NA	NA	NA
13	1	1.1	0.9	NA	NA	NA	NA	NA	NA
14	1	1.1	0.9	NA	NA	NA	NA	NA	NA

Table 2. IEEE 14 bus system bus line data

Line No.	From Bus	To Bus	Line Impedance (p.u.)		Half Line Charging Susceptance (p.u.)	MVA Rating	Tap Setting
			Resistance	Reactance			
1	1	2	0.01938	0.05917	0.02640	120	NA
2	1	5	0.05403	0.22304	0.02190	65	NA
3	2	3	0.04699	0.19797	0.01870	36	NA
4	2	4	0.05811	0.17632	0.02460	65	NA
5	2	5	0.05695	0.17388	0.01700	50	NA
6	3	4	0.06701	0.17103	0.01730	65	NA
7	4	5	0.01335	0.04211	0.00640	45	NA
8	4	7	0	0.20912	0	55	0.978
9	4	9	0	0.55618	0	32	0.969
10	5	6	0	0.25202	0	45	0.932
11	6	11	0.09498	0.1989	0	18	NA
12	6	12	0.12291	0.25581	0	32	NA
13	6	13	0.06615	0.13027	0	32	NA
14	7	8	0	0.17615	0	32	NA
15	7	9	0	0.11001	0	32	NA
16	9	10	0.03181	0.0845	0	32	NA
17	9	14	0.12711	0.27038	0	32	NA
18	10	11	0.08205	0.19207	0	12	NA
19	12	13	0.22092	0.19988	0	12	NA
20	13	14	0.17093	0.34802	0	12	NA

Table 3. IEEE 14 bus system base case line loading results

Line	Line Limits (MVA)	% Loading
1-2	120	124.00%
1-5	65	110.00%
2-3	36	195.00%
2-4	65	83.00%
2-5	50	79.00%
3-4	65	36.00%
4-5	45	138.00%
4-7	55	54.00%
4-9	32	50.00%
5-6	45	102.00%
6-11	18	42.00%
6-12	32	24.00%
6-13	32	56.00%
7-8	32	50.00%
7-9	32	84.00%
9-10	32	20.00%
9-14	32	30.00%
10-11	12	32.00%
12-13	12	14.00%
13-14	12	47.00%

Table 4. IEEE 14 bus system base case results

Bus No.	Voltage (p.u.)	Angle (Degree)	P_{gen} (MW)	Q_{gen} (MVAR)
1	1.0600	0.00	232.40	-16.90
2	1.0450	-4.98	40.00	42.40
3	1.0100	-12.72	0.00	23.40
4	1.0186	-12.72	NA	NA
5	1.0203	-10.32	NA	NA
6	1.0700	-14.22	NA	12.24
7	1.0620	-13.37	NA	NA
8	1.0900	-13.37	NA	17.35
9	1.0560	-14.95	NA	NA
10	1.0513	-15.10	NA	NA
11	1.0571	-14.80	NA	NA
12	1.0552	-15.08	NA	NA
13	1.0504	-15.16	NA	NA
14	1.0358	-16.04	NA	NA

Table 5. IEEE 14 bus system line loading results after load enhancement

Line	Line Limits (MVA)	% Loading
1-2	120	236.00%
1-5	65	204.00%
2-3	36	353.00%
2-4	65	148.00%
2-5	50	142.00%
3-4	65	68.00%
4-5	45	247.00%
4-7	55	83.00%
4-9	32	84.00%
5-6	45	171.00%
6-11	18	84.00%
6-12	32	46.00%
6-13	32	108.00%
7-8	32	78.00%
7-9	32	172.00%
9-10	32	35.00%
9-14	32	37.00%
10-11	12	68.00%
12-13	12	28.00%
13-14	12	94.00%

Table 6. IEEE 14 bus system bus voltages, load angles and power generated results after load enhancement

Bus No.	Voltage (p.u.)	Angle (Degree)	P_{gen} (MW)	Q_{gen} (MVAR)
1	1.0600	0.00	420.68	128.46
2	0.9745	-8.73	40.00	50.00
3	0.8854	-23.83	0.00	40.00
4	0.8970	-18.66	NA	NA
5	0.9096	-15.65	NA	NA
6	0.9207	-27.23	NA	24.00
7	0.9126	-25.14	NA	NA
8	0.9568	-25.14	NA	24.00
9	0.8874	-28.66	NA	NA
10	0.8790	-29.04	NA	NA
11	0.8930	-28.41	NA	NA
12	0.8916	-29.11	NA	NA
13	0.8817	-29.28	NA	NA
14	0.8494	-31.25	NA	NA

Step 3: Identify required number of new lines on 80% loading criteria (conventional technique) and use HPC conductors where the RoW issues are present in place of new lines.

Calculated number new lines required based on 80% loading criteria of the respected lines and results are shown in Table 7 without and with consideration of the RoW issues.

Step 4: Run the load flow analysis and repeat step 3, until all the lines are loaded less than 80% and all the bus.

After addition of lines as per Table 7, the new transmission lines are added, the new lines with RoW issues are replaced with HPC conductors in the planning and load flow results are shown in Table 8 and Table 9. Due to the HPC conductor the capacity of the line increased to new limits as shown in Table 8.

As per Tables 8 and 9, it concluded that all the voltages are within normal limits and lines 2-3, 10-11 loaded more than 80%. So, one more line added between these busses and step 3 is repeated. This process continued and final number of lines are shown in Table 10. In conventional method the number of transmissions required is 43 before consideration of RoW issues.

Step 5: Perform (N-1) contingency analysis of the modified network with new lines.

As per the Table 10, the modified system (N-1) contingency analysis is performed using PSSE software and the lines loading more than 100% are shown Table 11.

Step 6: Identify and add new lines on 100% loading criteria under (N-1) contingency and go to step 3 until all the lines are loaded less than 100% and all the bus voltages are within 10% of violations under (N-1) contingency.

As per Table 11, the lines 10-11 and 13-14 lines are loading more than 100%. So, lines 10-11, 13-14 are added to the network with existing lines as per Table 10 and step 3 repeated. This process continued and the final number of added lines are shown in Table 12. As per conventional method total number of required lines increased to 45.

Step 7: Identify the construction cost of new lines on existing tower and new tower.

To match the real time conditions, new line constructions cost on existing and new tower are placed in Table 13, which are taken reference from different transmission organization. With the help of this data construction cost in cr. of every line is placed in Table 14. The construction cost of the lines included the RoW cost, tower cost, conductor cost and service charges. These rates are revised on every year.

Table 7. Number of lines requirement with and without row issues

Line	Line Limits	% Loading	No of Lines Required	New Lines Required	RoW Issues	New Lines to be Added After RoW Issues Consideration
1-2	120	236.00%	3	2	Not available	2
1-5	65	204.00%	3	2	Not available	2
2-3	36	353.00%	5	4	Not available	4
2-4	65	148.00%	2	1	Present	0
2-5	50	142.00%	2	1	Present	0
3-4	65	68.00%	1	0	Not available	0
4-5	45	247.00%	4	3	Present	0
4-7	55	83.00%	2	1	Not available	1
4-9	32	84.00%	2	1	Not available	1
5-6	45	171.00%	3	2	Not available	2
6-11	18	84.00%	2	1	Not available	1
6-12	32	46.00%	1	0	Not available	0
6-13	32	108.00%	2	1	Not available	1
7-8	32	78.00%	1	0	Not available	0
7-9	32	172.00%	3	2	Not available	2
9-10	32	35.00%	1	0	Not available	0
9-14	32	37.00%	1	0	Not available	0
10-11	12	68.00%	1	0	Not available	0
12-13	12	28.00%	1	0	Not available	0
13-14	12	94.00%	2	1	Not available	1

Table 8. Line loading after addition of new transmission lines after consideration of RoW issues

Line	Total No. of Lines Required	New Lines Added	Line Limits (MVA)	% Loading
1-2	3	2	120	64
1-5	3	2	65	69
2-3	5	4	36	89
2-4	1	0	130	28
2-5	1	0	130	31
3-4	1	0	65	20
4-5	1	0	130	57
4-7	2	1	55	36
4-9	2	1	32	31
5-6	3	2	45	66
6-11	2	1	18	47
6-12	1	0	32	31
6-13	2	1	32	60
7-8	1	0	32	69
7-9	3	2	32	41
9-10	1	0	32	19
9-14	1	0	32	25
10-11	1	0	12	90
12-13	1	0	12	5
13-14	2	1	12	69

Table 9. Bus voltages, angles and generator outputs after addition of new transmission lines

Bus No.	Voltage (p.u.)	Angle (Degree)	P_{gen} (MW)	Q_{gen} (MVAR)
1	1.0600	0.00	387.52	15.74
2	1.0450	-2.49	40.00	34.19
3	1.0221	-5.89	0.00	0.00
4	1.0164	-7.15	NA	NA
5	1.0210	-5.32	NA	NA
6	1.0700	-8.70	NA	8.45
7	1.0486	-9.31	NA	NA
8	1.0875	-9.31	NA	24.00
9	1.0441	-10.06	NA	NA
10	1.0390	-10.16	NA	NA
11	1.0556	-9.33	NA	NA
12	1.0505	-9.79	NA	NA
13	1.0491	-9.72	NA	NA
14	1.0268	-10.98	NA	NA

Table 10. Final number of new lines required as per 80% loading criteria and line loadings after consideration of RoW issues

Line	Total No of Lines Required	New Lines Added	Line Limits (MVA)	% Loading
1-2	3	2	120	65
1-5	3	2	65	68
2-3	6	5	36	75
2-4	1	0	130	35
2-5	1	0	130	24
3-4	1	0	65	26
4-5	1	0	130	55
4-7	2	1	55	36
4-9	2	1	32	31
5-6	3	2	45	68
6-11	2	1	18	53
6-12	1	0	32	31
6-13	2	1	32	59
7-8	1	0	32	69
7-9	3	2	32	40
9-10	1	0	32	12
9-14	1	0	32	28
10-11	2	1	12	54
12-13	1	0	12	5
13-14	2	1	12	65

Table 11. Overloaded lines in (N-1) contingency after addition of new lines

Monitored Branch	Contingency Label	Rating	% Loading
10-11 circuit 1	Circuit 1of Line 4-5 open	12	111.1
10-11 circuit 2	Circuit 1of Line 4-5 open	12	111.1
13-14 circuit 1	Circuit 1 of Line 9-14 open	12	103.7
13-14 circuit 2	Circuit 1 of Line 9-14 open	12	103.7
13-14 circuit 2	Circuit 1 of Line 13-14 open	12	101.8
13-14 circuit 1	Circuit 2 of Line 13-14 open	12	101.8

Step 8: Calculate the Cost/Benefit index as per Eq. (2) of the new transmission lines and average Cost/Benefit index using Eq. (3) of modified system.

The Cost/Benefit index is calculated as per Eq. (2) and calculated and placed in Table 15.

Step 9(a): Remove the low Cost/Benefit index line and run the N-R load flow analysis and (N-1) contingency analysis, check whether all the lines in the modified network are loaded less than 80% in load flow analysis, less than 100% in contingency analysis and voltages are within 10% of violations. If satisfy then go to step 8. If not then keep the line in the planning and remove the next low Cost/Benefit index line and repeat the step 9(a). Go to step 9(b) after the consideration of all the lines.

Step 9(b): Replace the low Cost/Benefit index HPC line with the conductor used before HPC and run the load flow solution and (N-1) contingency analysis, check whether all the lines in the modified network are loaded less than 80% in load flow analysis, less than 100% in contingency analysis and voltages are within 10% of violations. If not keep the HPC back in the planning. Go to step 10.

Table 12. Final number of new lines required as per 80% loading and (N-1) contingency criteria and line loadings after RoW issues

Line	Total No of Lines Required	New Lines added	Line Limits (MVA)	% Loading
1-2	3	2	120	65
1-5	3	2	65	68
2-3	6	5	36	75
2-4	1	0	130	35
2-5	1	0	130	23
3-4	1	0	65	25
4-5	1	0	130	53
4-7	2	1	55	35
4-9	2	1	32	29
5-6	3	2	45	69
6-11	2	1	18	53
6-12	1	0	32	27
6-13	3	2	32	43
7-8	1	0	32	66
7-9	3	2	32	38
9-10	1	0	32	11
9-14	1	0	32	18
10-11	3	2	12	36
12-13	1	0	12	11
13-14	3	2	12	51

Table 13. The construction cost of transmission lines and assumption near to real time conditions [27, 28]

Line	Existing Line Construction Cost/kM	New Line Construction Cost/kM (New Tower)	New Line Construction Cost/kM (Existing Tower)	Remarks
1-2	0.7	0.7	0.15	Existing tower circuit 2 vacate
1-5	0.65	0.65	0.14	Existing tower circuit 2 vacate
2-3	0.58	0.58	0.11	Existing tower circuit 2 vacate
2-4	0.65	0.81	Due to RoW issues existing tower utilised with HPC conductor	Combination of 2-4, 2-5 and 2-5,4-5 lines used single tower
2-5	0.62	0.81	Due to RoW issues existing tower utilised with HPC conductor.	Combination of 2-4, 2-5 and 2-5,4-5 lines used single tower
3-4	0.65	0.65	0.14	Existing tower circuit 2 vacate
4-5	0.61	0.81	Due to RoW issues existing tower utilised with HPC conductor	Combination of 2-4, 2-5 and 2-5,4-5 lines used single tower
4-7	0.65	0.65	0.14	Existing tower circuit 2 vacate
4-9	0.59	0.59	0.12	Existing tower circuit 2 vacate
5-6	0.62	0.62	0.13	Existing tower circuit 2 vacate
6-11	0.54	0.54	0.1	Existing tower circuit 2 vacate
6-12	0.29	0.57	0.1	Combination of 6-12, 6-12 and 6-13,12-13 lines used single tower
6-13	0.29	0.57	0.1	Combination of 6-12, 6-12 and 6-13,12-13 lines used single tower
7-8	0.57	0.57	0.1	Existing tower circuit 2 vacate
7-9	0.57	0.57	0.1	Existing tower circuit 2 vacate
9-10	0.57	0.57	0.1	Existing tower circuit 2 vacate
9-14	0.57	0.57	0.1	Existing tower circuit 2 vacate
10-11	0.53	0.53	0.08	Existing tower circuit 2 vacate
12-13	0.24	0.53	0.08	Combination of 6-12, 6-12 and 6-13,12-13 lines used single tower
13-14	0.53	0.53	0.08	Existing tower circuit 2 vacate

From Table 14, it is identified that between two busses the added new lines are 0 to 5. During analysis the new line leading to installation of new tower construction cost is high compare to new line not leading to installation of new tower. Example the line 2-3 consist of 6 lines, the circuit 5 constructed leads to establishment of new tower circuit 6 constructed on the same tower used for circuit 5. So, the construction cost of the circuit 5 is high compare to circuit 6 and Cost/Benefit index is reverse as both lines carry same current. So, during optimal transmission planning circuit 5 removal should not analyses when circuit 6 exists., To overcome these difficulties the last circuits of the transmission line Cost/Benefit index compared in this paper and Cost/Benefit index values are placed in Table 16. From the Table 16, the circuit 3 of line 10-11 has low Cost/Benefit index valtableue compare to last circuits of all the new lines. So, circuit 3 of line 10-11 removed from the planning and the load flow and (N-1) contingency limits are not violating. So, line 10-11 circuit 3 permanently removed from the planning. The Cost/Benefit index Table after removing circuit 3 of line 10-11 is shown in Table 16.

As per Table 16 the next low Cost/Benefit indexed new line is 13-14 circuit 3. In the post removing (N-1) contingency conditions are not satisfying. Next low Cost/Benefit index line circuit 3 of 7-9. Post removal of circuit 3 of line 7-9 the normal and contingency conditions are satisfying. The Cost/ Benefit index Table after removing circuit 3 of line 7-9 is shown in Table 17.

Table 14. The construction cost of each line and tower utilization

Line	ID	New Circuit Tower	Construction Cost/kM in Cr
1-2	1	Existing Tower circuit 1	0.7
1-2	2	Existing Tower circuit 2	0.15
1-2	3	New Tower 1-circuit 1	0.7
1-5	1	Existing Tower circuit 1	0.65
1-5	2	Existing Tower circuit 2	0.14
1-5	3	New Tower 1-circuit 1	0.65
2-3	1	Existing Tower circuit 1	0.58
2-3	2	Existing Tower circuit 2	0.11
2-3	3	New Tower 1-circuit 1	0.58
2-3	4	New Tower 1-circuit 2	0.11
2-3	5	New Tower 2--circuit 1	0.58
2-3	6	New Tower 2-circuit 2	0.11
2-4	1	Existing Tower sharing with 2-5,4-5 and HPC conductor	0.81
2-5	1	Existing Tower sharing with 2-4,4-5 and HPC conductor	0.81
3-4	1	Existing Tower circuit 1	0.65
4-5	1	Existing Tower sharing with 2-4, 2-5 and HPC conductor	0.81
4-7	1	Existing Tower circuit 1	0.65
4-7	2	Existing Tower circuit 2	0.14
4-9	1	Existing Tower circuit 1	0.59
4-9	2	Existing Tower circuit 2	0.12
5-6	1	Existing Tower circuit 1	0.62
5-6	2	Existing Tower circuit 2	0.13
5-6	3	New Tower 1-circuit 1	0.62
6-11	1	Existing Tower circuit 1	0.54
6-11	2	Existing Tower circuit 2	0.1
6-12	1	Existing Towers sharing with 6-13,12-13 lines	0.29
6-13	1	Existing Towers sharing with 6-12,12-13 lines	0.29
6-13	2	New Tower 1-circuit 1	0.57
6-13	3	New Tower 1-circuit 2	0.1
7-8	1	Existing Tower circuit 1	0.57
7-9	1	Existing Tower circuit 1	0.57
7-9	2	Existing Tower circuit 2	0.1
7-9	3	New Tower 1-circuit 1	0.57
9-10	1	Existing Tower circuit 1	0.57
9-14	1	Existing Tower circuit 1	0.57
10-11	1	Existing Tower circuit 1	0.53
12-13	1	Existing Towers sharing with 6-12,6-13 lines	0.24
13-14	1	Existing Tower circuit 1	0.53
13-14	2	Existing Tower circuit 2	0.08
13-14	3	New Tower 1-circuit 1	0.53

Table 15. Cost/benefit index table after addition of new lines

Line	ID	P Flow	Income in Cr/Year	Construction Cost/kM	C_i of Line	C_i Ranking
1-2	3	82.1	29.9665	0.7	42.81	4
1-5	3	46.7	17.0455	0.65	26.22	7
2-3	6	28.2	10.293	0.11	93.57	1
4-7	2	18.4	6.716	0.14	47.97	3
4-9	2	9.4	3.431	0.12	28.59	6
5-6	3	28.6	10.439	0.62	16.84	8
6-11	2	8.9	3.2485	0.1	32.48	5
6-13	3	13.8	5.037	0.1	50.37	2
7-9	3	12.4	4.526	0.57	7.94	9
10-11	3	4	1.46	0.53	2.75	11
13-14	3	6.1	2.2265	0.53	4.20	10
Average Cost/Benefit index					31.60	

Table 16. Cost/benefit index table after removing circuit 3 of line 10-11

Line	ID	P Flow	Income for Cr/Year	Construction Cost/kM	C_i of Line	C_i Ranking
1-2	3	82.2	30.003	0.7	42.86	4
1-5	3	46.7	17.0455	0.65	26.22	7
2-3	6	28.2	10.293	0.11	93.57	1
4-7	2	18.6	6.789	0.14	48.49	3
4-9	2	9.5	3.4675	0.12	28.90	6
5-6	3	28.4	10.366	0.62	16.72	9
6-11	2	8.4	3.066	0.1	30.66	5
6-13	3	13.9	5.0735	0.1	50.74	2
7-9	3	12.4	4.526	0.57	7.94	10
10-11	2	5.5	2.0075	0.08	25.09	8
Average Cost/Benefit index					32.58	

Table 17. Cost/benefit index table after removing circuit 3 of lines 10-11 and 7-9

Line	ID	P Flow	Income for Cr/Year	Construction Cost/KM	C_i of Line	C_i Ranking
1-2	3	82.1	29.97	0.7	42.81	5
1-5	3	46.8	17.08	0.65	26.28	9
2-3	6	28.2	10.29	0.11	93.57	1
4-7	2	17.5	6.39	0.14	45.63	4
4-9	2	10	3.65	0.12	30.42	7
5-6	3	28.8	10.51	0.62	16.95	10
6-11	2	8.8	3.21	0.1	32.12	6
6-13	3	14.1	5.15	0.1	51.47	3
7-9	2	17.5	6.39	0.1	63.88	2
10-11	2	5.9	2.15	0.08	26.92	8
13-14	3	6.3	2.30	0.53	4.34	11
Average Cost/ Benefit inde					33.86	

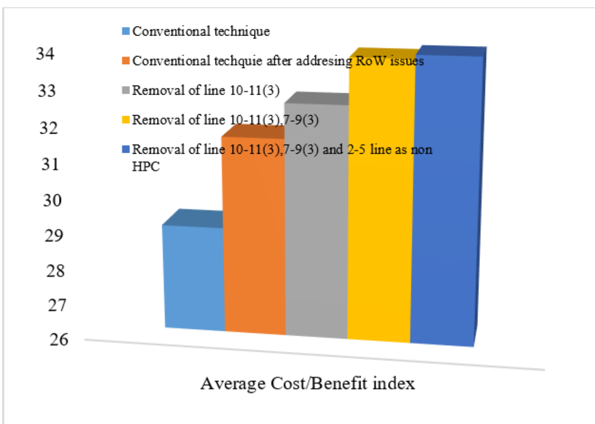

Figure 1. Average cost/benefit index growth using optimization technique

Table 18. The optimal transmission planning steps after removing circuit 3 of lines 10-11 and 7-9

Removing Line		Ranking	Remarks
Line	Circuit		
13-14	3	11	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 3 of line 5-6 is removed from the planning.
5-6	3	10	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 3 of line 1-5 is removed from the planning.
1-5	3	9	Limits in the normal load flow are violating, Line kept back in the planning. The next low C_i line circuit 2 of line 10-11 is removed from the planning.
10-11	2	8	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 2 of line 4-9 is removed from the planning.
4-9	2	7	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 2 of line 6-11 is removed from the planning.
6-11	2	6	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 3 of line 1-2 is removed from the planning.
1-2	3	5	Limits in the normal load flow are violating, Line kept back in the planning. The next low C_i line circuit 2 of line 4-7 is removed from the planning.
4-7	2	4	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 3 of line 6-13 is removed from the planning.
6-13	3	3	(N-1) contingency limits are violating, Line kept back in the planning. The next low C_i line circuit 2 of line 7-9 is removed from the planning.
7-9	2	2	Limits in the normal load flow are violating, Line kept back in the planning. The next low C_i line circuit 6 of line 2-3 is removed from the planning.
2-3	6	1	Limits in the normal case are violating, Line kept back in the planning. As the consideration of the new lines completed, need to check the HPC requirement. Low C_i HPC line i.e. line 2-5 requirement of HPC conductor will be checked by replacing HPC conductor with the conductor used before HPC.
2-5 with non HPC conductor			The normal load flow results are within limits and in (N-1) contingency results are within limits and average C_i increased to 33.97. Next Low C_i HPC line i.e. line 2-4 requirement of HPC conductor will be checked by replacing HPC conductor with the conductor used before HPC.
2-4 with non HPC conductor			(N-1) contingency limits are violating, Line kept back with HPC conductor in the planning. Low C_i HPC line i.e. line 4-5 requirement of HPC conductor will be checked by replacing HPC conductor HPC conductor with the conductor used before HPC.
4-5 with non HPC conductor			Limits in the normal load flow are violating, Line kept back with HPC conductor in the planning.

This analysis is continued and final report is shown in Table 18 and Figure 1 shows the average Ci value improvement after each removal.

Step 10: To implement the partial DLL, identify the peak load timing alongside the corresponding temperature, and determine the percentage of additional load that can be accommodated before meet the thermal capacity of the line.

As per discussion in introduction the ACSR transmission line limits decided on 45℃ ambient temperatures but in the real time it varies. The DLL benefits mostly depend on the ambient temperature but the direct implementation of DLL may or may not give "Return on Equity" because the peak temperatures in India around 45℃. But peak load and peak temperature may not be simultaneous. As per real time data, In India the peak load occurred on 1st September from 08:00 hrs to 12:00 hrs [29, 30] and the peak temperature at same time is 30℃ [31, 32]. So, in this case at least 17% of the line loading margin is added for each line. In the month of September and August the same trend continued. The next max loads (90% of peak load) [33, 34] occurred in India on 25th January 2024 at 10:00 hrs and peak temperature is 25℃ [35, 36] at these conditions at least 25% (10% for max load is 90% of the peak load and 11% as temperature benefit) of the line loading margin are added to each line compare to peak load conditions. The peak temperatures around 45℃ in India occurred in the month of May and the max load is 80% of the peak load, in this case at least 22% of loading margin are added compare to peak load conditions. From this analysis, it may conclude that at least 17% of the more margin can be used in every case compare to line loading at peak load timings [37, 38].

In this paper this 17% margin utilised under (N-1) contingency to reduce number of require lines. The results of the results are shown in Table 19 and average Ci improvement is shown in Figure 2.

Step 11: During step 10, identify which lines are loaded more than 100% and less the new limits under (N-1) contingency and these lines dynamic line capacity to be monitored on real time.

Table 20, the line loaded more than 100% and less than 117% under different contingencies are given.

Table 19. The optimal transmission planning steps with partial DLL utilization in (N-1) contingency

Removing Line		Avg C_i	Avg C_i	Remarks
Line	Circuit	(Before)	(After)	
10-11	3	31.60	32.58	The low Cost/Benefit index line is circuit 3 of line10-11. After removal of circuit 3 of line 10-11, the normal load flow results are within limits and all the lines in (N-1) contingency loaded within 117% and voltages are within limits.
13-14	3	32.58	33.68	After removing the circuit 3 of line 10-11, the Cost/Benefit index recalculated as per new line flows. The low C_i circuit 3 of line 13-14 is removed from the planning, the normal load flow results are within limits and all the lines in (N-1) contingency are within 117% and voltages are within limits.
7-9	3	33.68	35.00	After removing the circuit 3 of line 13-14, the Cost/Benefit index recalculated as per new line flows. The low C_i circuit 3 of line is removed from the planning, the normal load flow results are within limits and all the lines in (N-1) contingency are within 117% and voltages are within limits.
5-6	3	35.00	35.00	After removing the circuit 3 of line 7-9, the Cost/Benefit index recalculated as per new line flows. The low C_i is circuit 3 of line 5-6 is removed from the planning, the normal load flow limits are violating. So, circuit 3 of line 5-6 kept back in the planning and next low C_i line is circuit 2 of line 10-11 is removed from the planning for further analysis.
1-5	3	35.00	35.00	After kept back the circuit 3 of the line 5-6, the next low C_i line circuit 3 of 1-5 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 3 of line 5-6 kept back in the planning and next low C_i line is circuit 2 of line 10-11 is removed from the planning for further analysis.
10-11	2	35.00	35.00	After kept back the circuit 3 of the line 1-5, the next low C_i line circuit 2 of 10-11 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 2 of line 10-11 kept back in the planning and next low C_i line is circuit 2 of line 4-9 is removed from the planning for further analysis.
4-9	2	35.00	36.09	After kept back the circuit 3 of the line 10-11, the next low C_i line circuit 2 of 4-9 line removed from the planning. After removal the normal load flow results are within limits and all the lines in (N-1) contingency is within 117% and voltages are within limits.
6-11	2	36.09	36.09	After removing the circuit 2 of line 4-9, the Cost/Benefit index recalculated as per new line flows. The low C_i line is circuit 2 of line 6-11 is removed from the planning, the normal load flow limits are violating. So, circuit 2 of line 6-11 kept back in the planning and next low C_i line is circuit 3 of line 1-2 is removed from the planning for further analysis.
1-2	3	36.09	36.09	After kept back the circuit 2 of the line 6-11, the next low C_i line circuit 3 of 1-2 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 2 of line 1-2 kept back in the planning and next low C_i line is circuit 3 of line 6-13 is removed from the planning for further analysis.
6-13	3	36.09	36.10	After kept back the circuit 3 of the line 1-2, the next low C_i line circuit 3 of 6-13 line removed from the planning. After removal the normal load flow results are within limits and all the lines in (N-1) contingency is within 117% and voltages are within limits.
6-13	2	36.10	36.10	After removing the circuit 3 of line 6-13, the Cost/Benefit index recalculated as per new line flows. The low C_i circuit 2 of line 6-13 is removed from the planning, the normal load flow results are within limits and some of the lines in (N-1) contingency are loaded more than 117%. So, circuit 2 of line 6-13 kept back in the planning and next low C_i line is circuit 2 of line 13-14 is removed from the planning for further analysis.
13-14	2	36.10	36.10	After kept back the circuit 2 of the line 6-13, the next low C_i line circuit 2 of 13-14 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 2 of line 13-14 kept back in the planning and next low C_i line is circuit 2 of line 4-7 is removed from the planning for further analysis.
4-7	2	36.10	36.10	After kept back the circuit 2 of the line 4-7, the next low C_i line circuit 3 of 6-13 line removed from the planning. the normal load flow results are within limits and some of the lines in (N-1) contingency is loaded more than 117%. So, circuit 2 of line 4-7 kept back in the planning and next low C_i line is circuit 2 of line 7-9 is removed from the planning for further analysis.
7-9	2	36.10	36.10	After kept back the circuit 2 of the line 4-7, the next low C_i line circuit 2 of 7-9 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 2 of line 7-9 kept back in the planning and next low C_i line is circuit 6 of line 2-3 is removed from the planning for further analysis.
2-3	6	36.10	36.10	After kept back the circuit 2 of the line 7-9, the next low C_i line circuit 6 of 2-3 line removed from the planning. After removal the normal load flow limits are violating. So, circuit 6 of line 2-3 kept back in the planning.
2-5 with non HPC conductor		36.10	36.19	The normal load flow results are within limits and in (N-1) contingency results are within limits. Next Low C_i HPC line i.e. line 2-4 requirement of HPC conductor will be checked by replacing HPC conductor with the conductor used before HPC.
2-4 with non HPC conductor		36.19	36.64	the normal load flow results are within limits and all the lines in (N-1) contingency is within 117% and voltages are within limits. The next Low C_i i HPC line i.e. line 4-5 requirement of HPC conductor will be checked by replacing HPC conductor HPC conductor with the conductor used before HPC.
4-5 with non HPC conductor		36.64	36.64	Limits in the normal load flow are violating, Line kept back with HPC conductor in the planning.

Table 20. Lines to be monitored for partial DLL implementation

Monitoring Branch	Contingency Label	Rating (MVA)	% Loading
4-5 Circuit 1	Circuit 1of Line 2-4 open	90	106.1
2-4 Circuit 1	Circuit 1of Line 4-5 open	65	109.8
10-11 Circuit 1	Circuit 1of Line 4-5 open	12	116.5
10-11 Circuit 2	Circuit 1of Line 4-5 open	12	116.5
6-13 Circuit 2	Circuit 1 of Line 6-13open	32	102.9
6-13 Circuit1	Circuit 2 of Line 6-13open	32	102.9
7-9 Circuit 2	Circuit 1 of Line 7-9 open	32	113.1
7-9 Circuit1	Circuit 2 of Line 7-9 open	32	113.1
13-14 Circuit 1	Circuit 1 of Line 9-14 open	12	103.7
13-14 Circuit 2	Circuit 1 of Line 9-14 open	12	103.7
10-11 Circuit 2	Circuit 1 of Line 10-11 open	12	105.2
10-11 Circuit 1	Circuit 2 of Line 10-11 open	12	105.2
13-14 Circuit 2	Circuit 1 of Line 13-14 open	12	111.4
13-14 Circuit 1	Circuit 2 of Line 13-14 open	12	111.4

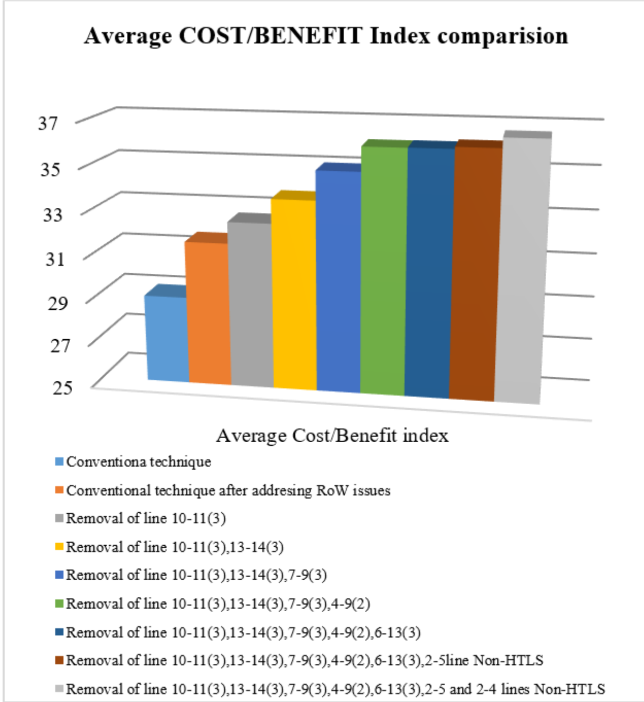

Figure 2. Average Cost/Benefit index growth using partial DLL along with optimization technique

Table 21. The optimal transmission planning steps on IEEE 14 bus with non-uniform load growth after consideration of RoW issues

Removing Line		Ranking	Remarks
Line	Circuit		
12-13	2	10	Normal Load flow and (N-1) conditions limits are not violating. So, C_i is calculated after removing circuit 2 of line 12-13's. Average C_i increased to 28.33. Circuit 2 of line 6-13's subsequent low C_i line is eliminated from the planning.
6-13	2	9	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 5 of line 2-3's subsequent low C_i line is eliminated from the planning.
2-3	5	8	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 3 of line 5-6's subsequent low C_i line is eliminated from the planning.
5-6	3	7	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 2 of line 10-11, the following low Ci line, is eliminated from the planned.
10-11	2	6	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 13-14's subsequent low C_i line is eliminated from the planning.
13-14	2	5	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 4 of line 6-11, the following low C_i line, is eliminated from the planned.
6-11	2	4	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 3 of line 1-2's subsequent low C_i line is eliminated from the planning.
1-2	3	9	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 7-9's subsequent low C_i line is eliminated from the planning.
7-9	2	2	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 1-5's subsequent low C_i line is eliminated from the planning.
1-5	2	1	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 2 of line 10-11, need. The low C_i HPC line, i.e. lines 2-5, will have its HPC conductor requirements tested by exchanging the HPC conductor with the conductor used prior to HPC.
2-5 with non HPC conductor			The standard load flow results are acceptable, and the (N-1) contingency results also fall within acceptable limits, with the average C_i rising to 28.68. The requirement for the next Low Ci HPC line, specifically line 4-5, will be assessed by substituting the HPC conductor with the conductor that was utilized prior to HPC.
4-5 with non HPC conductor			(N-1) contingency limits are being violated; the line has been held back with the HPC conductor during the planning phase. The requirement for the Low C_i HPC line, specifically line 2-4, will be assessed by substituting the HPC conductor with the previously used conductor.
2-4 with non HPC conductor			The standard load flow results are within acceptable limits, and the (N-1) contingency results also fall within those limits, with the average C_i rising to 28.82.

Table 22. The optimal transmission planning steps on IEEE 14 bus with non-uniform load growth after consideration of RoW issues using partial DLL

Removing Line		Remarks
Line	Circuit	
12-13	2	Normal Load flow and (N-1) conditions limits are not violating. So, C_i is calculated after removing circuit 2 of line 12-13's. Average C_i increased to 28.33. Circuit 2 of line 6-13's subsequent low C_i line is eliminated from the planning.
6-13	2	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 5 of line 2-3's subsequent low Ci line is eliminated from the planning.
2-3	5	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 3 of line 5-6's subsequent low C_i line is eliminated from the planning.
5-6	3	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 2 of line 10-11, the following low C_i line, is eliminated from the planned.
10-11	2	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 13-14's subsequent low C_i line is eliminated from the planning.
13-14	2	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 4 of line 6-11, the following low C_i line, is eliminated from the planned.
6-11	2	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 3 of line 1-2's subsequent low C_i line is eliminated from the planning.
1-2	3	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 7-9's subsequent low C_i line is eliminated from the planning.
7-9	2	Line is kept back in the planning, as (N-1) contingency restrictions are being violated. Circuit 2 of line 1-5's subsequent low C_i line is eliminated from the planning.
1-5	2	Normal load flow limits are being violated. Hence the line was retained in the planning. Circuit 2 of line 10-11, need. The low C_i HPC line, i.e. lines 2-5, will have its HPC conductor requirements tested by exchanging the HPC conductor with the conductor used prior to HPC.
2-5 with non HPC conductor		The standard load flow results are acceptable, and the (N-1) contingency results also fall within acceptable limits, with the average C_i rising to 28.64. The requirement for the next Low C_i HPC line, specifically line 4-5, will be assessed by substituting the HPC conductor with the conductor that was utilized prior to HPC.
4-5 with non HPC conductor		(N-1) contingency limits are being violated; the line has been held back with the HPC conductor during the planning phase. The requirement for the Low C_i HPC line, specifically line 2-4, will be assessed by substituting the HPC conductor with the previously used conductor.
2-4 with non HPC conductor		The standard load flow results are within acceptable limits, and the (N-1) contingency results also fall within those limits, with the average C_i rising to 29.69.

3.2 Case study 2

It is predicated that the buses 2, 3, 6, 8, and 24 will experience a load growth of 18%, while buses 4, 9, 11, and 13 will experience a 21% load growth. Buses 5, 10, 12, and 24 are expected to experience a 24% load growth. The methodology is applied and results are shown in Table 21 to Table 23. In conventional method the number of lines requirement is 39. In Table 21, the optimization planning steps after consideration of RoW issues is explained. In Table 22, the optimization planning steps using partial DLL technique is explained. In Table 23, lines to be monitored to implement the partial DLL technique is explained.

Table 23. The lines to be monitored to implement partial DLL

Monitored Branch	Contingency Label	Rating (Mva)	% Loading
10-11 circuit 1	Circuit 1of Line 4-5 open	12	102.7
10-11 circuit 2	Circuit 1of Line 4-5 open	12	102.7

4. RESULTS AND DISCUSSION

In this paper the transmission expansion planning done in deregulation environment. So, in deregulation environment is necessary to perform the (N-1) contingency analysis to maintain reliable supply. Case study done on IEEE 14 bus system and this system had 3 number transformers branches and 17 number of transmissions lines. It is assumed that load forecast is 60%, load flow analysis is performed with new load conditions, number of transmission lines required is calculated based on 80% loading conditions. The new line constructions are not possible for the line 2-4, 2-5 and 4-5 due to RoW issues, in this paper the alternative solution is use of HPC conductor in place of old conductor is provided and the capacity of the line increased to 130 MVA by utilising existing infrastructure. As per the conventional techniques the new transformer branches require is 4, new transmission lines required is 18 based on 80% loading criteria after using HPC conductor and average Ci of the system is further increased. The results of the optimization technique are shown from the Table 15 to Table 18 and Table 21, from this Tables it is concluded that the number of lines required is reduced, HPC conductor requirement also reduced., the comparison between these two-method given in Table 24.

The next advancement is using the partial DLL and the process of planning is explained in Table 19 and Table 22. From this Table 22. it is concluded that the number of lines requirement is further reduced. With the usage of partial DLL the average C_i is increased is further increased. In this paper transmission planning done in three methods to meet future load growth and comparison between these three methods are shown in Table 24 and Table 25.

Mostly the ACSR conductors used for overhead transmission lines and these conductors are manufacture for environment temperature at 45°C, conductor temperature 75°C, Solar absorption coefficient 0.8, Solar radiation 1045 watt/sq.

m., Emission constant 0.45, Wind velocity 0.56 m/sec, effective angle of incidence of sun's rays 90°. In the real time all these values are varies. To implement the DLL all these parameters to be monitored with sensor's, strong programming and forecast of all these parameters are required. The temperature reduction places a key load for the increase of ampere and MVA capacity of the transmission line but in the overhearing countries the 45℃ temperature occurs most commonly. So, after investing huge in DLL, if the benefit is low return on equity is reduced and private parties may not show interest for investment. So, as the major part of the DLL with the temperature, from the history of temperature and peak load timings the 17% extra loading benefit utilised in the expansion planning. If this experiment gets succeeded then step by step process the DLL can be implemented. The comparison between Full DLL and partial DLL is explained in Table 26.

Table 24. Comparison between optimization technique and conventional technique

Description	Conventional Method	Using Optimization Technique	Improvement
Alternate solution for RoW issues	Not addressed	Addressed	RoW issues are successfully addressed.
Number of total lines required with 60% uniform load growth	45	40	Five number of lines requirement reduced.
Number of total lines required with non-uniform load growth	37	34	Five number of lines requirement reduced.
Number of new lines required with 60% uniform load growth	25	20	20%-new line requirement reduced.
Number of new lines required with non-uniform load growth	17	14	17.6%-new line requirement reduced.
Average C_i with 60% uniform load growth	29.23	33.97	16.22% revenue of the system increased.
Average C_i with non-uniform load growth	25.72	28.82	12% revenue of the system increased.
Cumulative Construction Cost/KM in Cr with 60% uniform load growth	20	17.08	14.6% of the construction cost reduced for KM.
Cumulative Construction Cost/KM in Cr with non-uniform load growth	16.60	15.62	6% of the construction cost reduced for KM.

Table 25. Comparison between partial DLL along with optimization technique and optimization technique

Description	Conventional Method	Partial DLL along with Optimization Technique	Improvement
Alternate solution for RoW issues	Not addressed	Addressed	RoW issues are successfully addressed.
Number of total lines required with 60% uniform load growth	45	37	Eight number of lines requirement reduced.
Number of total lines required with non-uniform load growth	37	33	Four number of lines requirement reduced.
Number of new lines required with 60% uniform load growth	25	17	32%-new line requirement reduced.
Number of new lines required with non-uniform load growth	17	13	23.5%-new line requirement reduced.
Average C_i with 60% uniform load growth	29.23	36.34	24.32% revenue of the system increased.
Average C_i with non-uniform load growth	25.72	29.69	15.43% revenue of the system increased.
Cumulative Construction Cost/KM in Cr with 60% uniform load growth	20	16.17	19.15% of the construction cost reduced for KM.
Cumulative Construction Cost/KM in Cr with non-uniform load growth	16.60	15.00	9.64% of the construction cost reduced for KM.

Table 26. Comparison between full DLL and partial DLL

Description	Full DLL	Partial DLL
Sensor Installation	Require high number	Only temperature sensor is sufficient. (Without sensors also this data may be collected with coordinating with "Weather stations").
Data communication	Huge data communication is required.	Low data communication is enough.
Temperature forecasting	Required	Only temperature forecast is sufficient. (Without sensors also this data may be collected with coordinating with "Weather stations").
Whether conditions forecast	Required	Not required
Lines to be monitored	All the lines	Only lines loaded more than 100% to new capacity under (n-1) contingency.
Data to be monitored	Multiple	Single

5. CONCLUSION

People are demanding more power as a result of the rapid urbanization. Planning for transmission expansion is necessary to satisfy this demand. Prior to deregulation, excessive investment was made in the transmission system because of the monopoly's nature, and the supply's dependability was low since (N-1) contingencies were not taken into account. Some studies developed optimization transmission planning based on the removal of low-revenue lines; however, these studies do not take into account many real-time conditions, the construction cost of the transmission line is assumed to be constant, and the RoW issues are not taken into account. Fruitfulness gains and a good return on equity were generated for countries such as France and Italy once DLL was implemented. However, the use of DLL may or may not provide "Return on Equity" in hotter nations like Saudi Arabia, Kuwait, Iraq, Arizona, India, Pakistan, and Death Valley. These temperatures could rise even further as a result of global warming.

This work develops a reliable supply by taking into account the (N-1) contingency in the transmission expansion planning. A cost/benefit index is created during this expansion planning process, and low revenue lines are first eliminated in order to lower the number of transmission lines needed. Using HPC conductors, RoW difficulties are successfully resolved with this optimization technique, which assumes all real-time conditions. Therefore, fewer lines are needed, the system's average revenue is higher, and the construction cost per kM is also lower thanks to the optimization technique that was devised. In (N-1) contingency, a partial DLL technique is employed in conjunction with optimization techniques to further reduce the number of lines needed and enhance system revenue. In comparison to DLL, the implementation cost for partial DLL is likewise quite inexpensive. The optimal, realistic, and high-revenue transmission planning was finally produced in this study using a partial DLL technique, accounting for RoW challenges, contingency analysis, and real-time field conditions.

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NOMENCLATURE

C_x	Cost of alternative line in Cr
C_{KM}	Construction cost of line per km in Cr
C_i	Cost/Benefit Index
D_i	Length of transmission line in km
HTLS	High tension low sag conductor
MW-KM	Mega watt per Killo meter
P_i	Real power flow in MW or p.u.
TSC	Transmission service charges in Rs./KW/kM/hour
n	Total no of Transmission line
P_g	Generated active power at generating plant in MW or p.u.

P_{max}	Maximum Generator Active Power limit in MW or p.u.
P_{min}	Minimum Generator active power limit in MW or p.u.
Q_g	Generated reactive power at generating plant in MVAr or p.u.
Q_{max}	Maximum Generator Reactive Power limit in MVAr or p.u.
Q_{min}	Minimum Generator Reactive power limit in MVAr or p.u.