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OPTIMAL TRANSMISSION EXPANSION PLANNING: AN APPLICATION TO 400 KV SYSTEM IN WEST BENGAL

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ABSTRACT: This paper describes a computer software based method to determine where to add new circuits with minimum circuit length in an expanding transmission system. In such determination application of network simplex has been presented in this paper. 400 KV transmission network of West Bengal is used to illustrate this proposed method. Eighth Plan configuration of 400 KV System of State Electricity Board of West Bengal is taken as existing system. Based on the load and generation pattern of the ninth plan of State Electricity Board, a network with minimum circuit length is designed subject to system constraints and finally compares with the planning of State Electricity Board. It has been observed that the present approach produces a more economic configuration than those planned by the State Electricity Board. Finally, an A.C. load flow solution is made on the designed network to satisfy the load flow solution.

I. INTRODUCTION

In recent years several computers softwares based different mathematical technique have been developed to solve the expansion planning of transmission network. Many Researchers have made very important contributions in this particular area. Garver [1] is the scientist who have first made very significant works in this area. He very successfully used linear programming to determine the power flows in the loss less network and add new lines where largest overload exists and the process continues till overload remains. Henault [2] proposed another method, which utilises dynamic programming as a solution technique. Kaltenback [3] also proposed a method using both linear programming and dynamic programming. Lee and others [4] proposed a method which uses the zero-one integer programming. Serna and others [5] proposed a method using two sub-models. The first sub-model utilises Fold - Fulkerson algorithm to calculate the flows. The second sub-models used a search technique to add the best line.

In this planning approach increased peak loads and generations are considered to be a known parameter. Generations are assigned to the generator buses to balance the total load. In this paper a practical problem is considered and increased load and generation are used based on real life data. Initially, generations are reduced at some buses to balance the total load and finally, in case of load flow study it is increased to the real data in anticipation of power losses. All other datas used in this paper are actual one.

In this paper computer software has been developed using network simplex to solve transmission expansion planning problem. 400 KV transmission network in West Bengal under State Electricity Board is used as an illustrative example. This paper describes a method of finding the least cost network of a power system planning problem. Application of network simplex to determine where to add new circuits with minimum lengths in an expanding transmission system is presented.

Suppose there is an existing network of which locations and magnitudes of loads and generation are known. Now it is required to design to transmission network capable of satisfying the needs of future load and generation condition using minimum circuit lengths subject to system constraints. In this paper 400 KV transmission system of West Bengal State Electricity Board under 8th Plan is taken as existing system. Load and generation pattern of 9th Plan configuration of 400 KV transmission system of West Bengal State Electricity Board is taken as the future load and generation requirement. Using the proposed method an optimum plan system is designed which is a less costly than plan by the West Bengal State Electricity Board.

The steps, which are used for the proposed design, are -

- (1) Problem formulation as a linear minimisation problem
- (2) Solution of this problem by network simplex
- (3) Addition of circuits are made based on the location of the largest overload in this flow estimation.
- (4) If overload remains go to step 2

In this technique overload will not occur on a circuits but on a network link called overload path. This path initially provides routes for overload when they occur and later locations for new circuits. Finally, an optimum network is obtained with flows and added circuits where needed.

II. EXAMPLE SYSTEM AND DATA REQUIREMENTS

Fig.1 shows the existing example system, which is 400 KV transmission system of West Bengal State Electricity Board under 8th Plan. The future condition with increased load and generation is shown in fig. 2, which is as per the 9th Plan of West Bengal State Electricity Board. Here three new buses have been added to the existing system, which is also as per the 9th Plan of West Bengal State Electricity Board. Now the question comes how these three new buses should be connected to the existing system so that it would be more economic configuration. The present approach illustrates this method using network simplex. For the system of fig. 2, the scheduled generation and load are shown in Table-I and the other detailed datas used for this approach are given in Table-II. Table-III shows the bus data for AC load flow test. The possible route lengths are computed by plotting the buses in a particular scale. The possible routes with bus 5 are omitted because the distance from this bus to other bus except, bus 4 is not available. The guide number (GN) of Table -II is a non-electrical quantity and GN is proportional to the length and indicates relative cost. In this approach the value of GN of overload path is made five times that of parallel circuit indicating the relative cost of new circuits to be large enough to penalise overloading until all circuit capacity has been used. Experience has shown that guide number 3 to 5 times larger than those for parallel circuit produce the desired results [1].

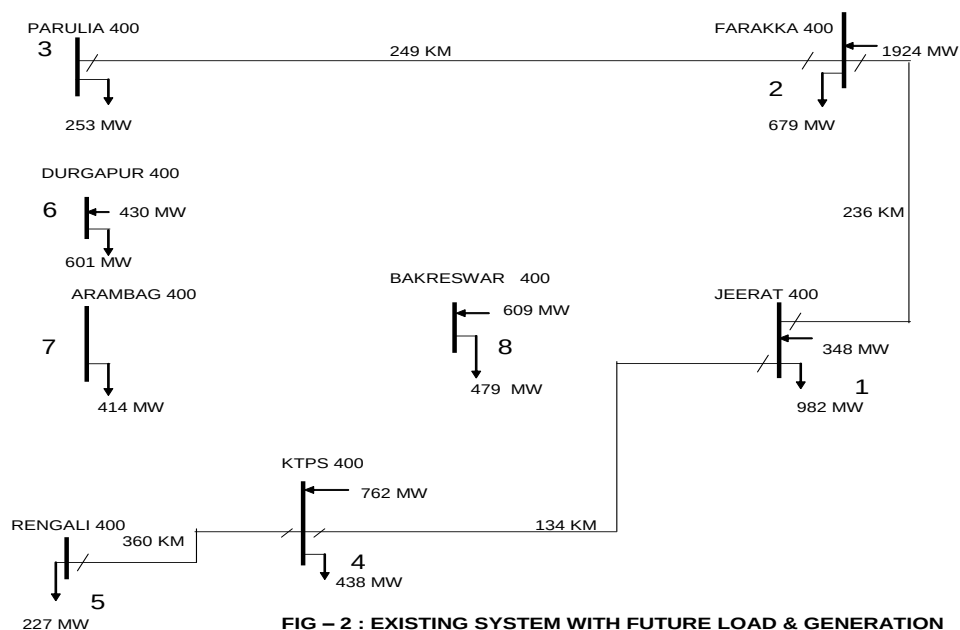
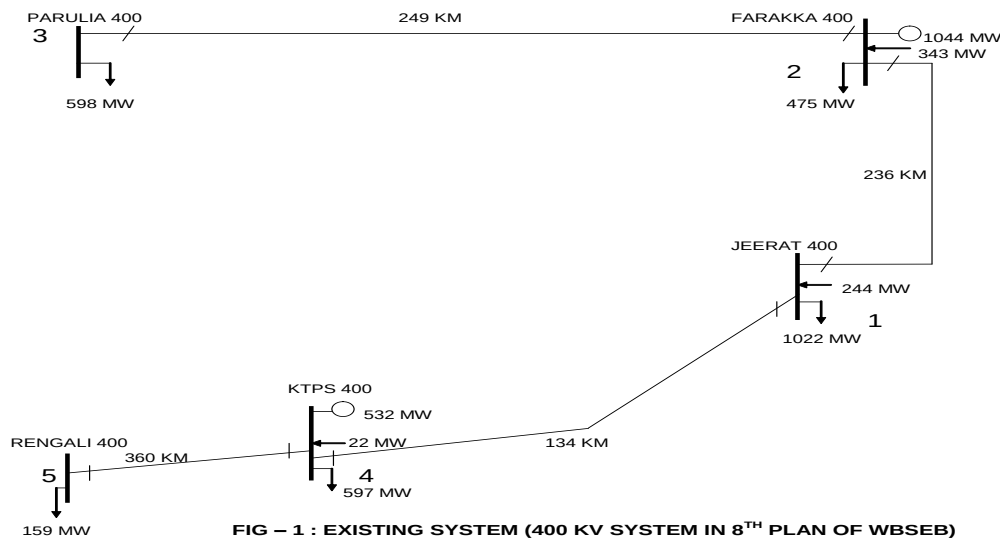


TABLE – I: Net Generation Minus Load Data

Bus	Generation	Load	Net
1	348	982	- 634
2	1924	679	1245
3	0	253	- 253
4	762	438	324
5	0	227	- 227
6	430	601	- 171
7	0	414	- 414
8	609	479	130
Totals	4073	4073	0

TABLE – II: Circuit Data

Terminals	Overload Path		New Circuits		Existing Circuits		
	Length in Km.	GN	Capacity in MW.	GN	Length in Km.	Capacity in MW.	GN
1 – 2	236	1180	900	236	236	900	236
1 – 3	222	1110	900	222			
1 – 4	134	670	900	134	134	900	134
1 – 6	224	1120	900	224			
1 – 7	196	980	900	196			
1 – 8	170	850	900	170			
2 – 3	249	1245	900	249	249	900	249
2 – 4	296	1480	900	296			
2 – 6	264	1320	900	264			
2 – 7	338	1690	900	338			
2 – 8	388	1940	900	388			
3 – 4	140	700	900	140			
3 – 6	15	75	900	15			
3 – 7	132	660	900	132			
3 – 8	252	1260	900	252			
4 – 5	360	1800	900	360	360	900	360
4 – 6	132	660	900	132			
4 – 7	65	325	900	65			
4 – 8	112	560	900	112			
6 – 7	120	600	900	120			
6 – 8	240	1200	900	240			
7 – 8	132	660	900	132			

'R' for each new and existing circuit = 0.05517 Ohm/Km.

'X' for each new and existing circuit = 0.206 Ohm/Km.

III. PROBLEM FORMULATION

The linearised model used in this approach to obtain the optimum network is as follows:

N1

$$\text{Minimise } F = \sum_{i=1}^{N1} C1_i \cdot P1_i$$

Subject to

(a) The power balance constraints at bus i

$$\sum_{j \in X1(i)} P1_j + \sum_{j \in X2(i)} P_j = IP_i, i = 1, 2, \dots, N-1$$

(b) The line loading limit constraints for existing line j

$$P_j \leq PM_j, j = 1, 2, \dots, N2$$

Where $C1_i$ = Capital cost of proposed line 'i'

$P1_i$ = Power flow on proposed line 'i'

N1 = Number of proposed line

P_i = Power flow on existing line 'i'

IP_i = Injected power at bus 'i'

$X1(i)$ = Set of proposed lines connected to bus 'i'

$X2(i)$ = Set of existing line connected to bus 'i'

PM_i = Maximum power flow on existing line 'i'

N = Number of buses

N2 = Number of existing lines

Here the other constraints including loss are dropped because the effects of these constraints are not very significant as was established by Youssef & Hackam [6].

IV. NETWORK SIMPLEX

The network simplex algorithm for the minimum cost flow problem is a special case of the pounded variable primal simplex algorithm for linear programming. The main advantage of network simplex is that there is no need to maintain the simplex tableau explicitly. This efficiency of the algorithm is achieved by the use of tree structure of the basis. The detail steps of network simplex are given below :

- Step - 1 - Take a tree and set all non-tree overload path flow at zero and all non-tree circuit line flow at capacity or at zero.
- Step - 2 - Calculate tree line flows
- Step-3 - Calculate bus guide potential by setting one bus at zero potential using the relation (sending bus potential - receiving bus potential) = Branch guide number, for all three branches.
- Step-4 - If the optimality condition given below are met then the configuration with optimum route is obtained

Optimality conditions

Potential difference across a link - link $GN < 0$, for all links which are not at capacity.

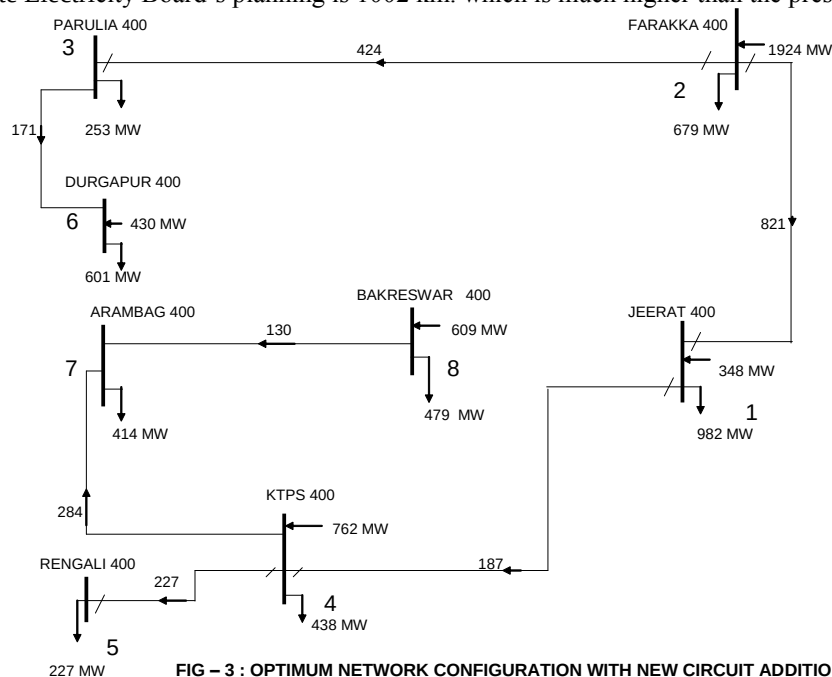
Potential difference across a link - link $GN \geq 0$, for all links which are at capacity.

- Step - 5 - If the optimality conditions are not met then take the link in the tree which do not met the optimality condition.
- Step-6 - Find the loop formed by the link taken with the tree lines.
- Step-7 - Drop a line from this loop based on whether the link taken belongs to a lower limit condition or at upper limit condition.
- Step-8 - Go to step 2.

In the above algorithm it is assumed that the overload paths existing as given in Table-II and overload path have unlimited capacity and these paths will indicate the possible location of new circuits. These overload paths resist power flow as they have high Guide number. For larger system the number of overload paths may be restricted to a smaller number.

V. RESULTS OBTAINED

Using the steps of network of network simplex as discussed above, a computer program has been developed and by running the program a configuration with optimum route is obtained. New circuit addition is made in this configuration based on the largest overload. After adding new circuits a new flow estimation is carried out to obtain the final network configuration with flow patterns. The final plan network obtained in this approach is shown in fig. 3, The West Bengal State Electricity Boards planned system is shown in fig.4. The result shows that the additional line length required in this present approach is 212 km. The additional line length required for West Bengal State Electricity Board's planning is 1002 km. which is much higher than the present approach.



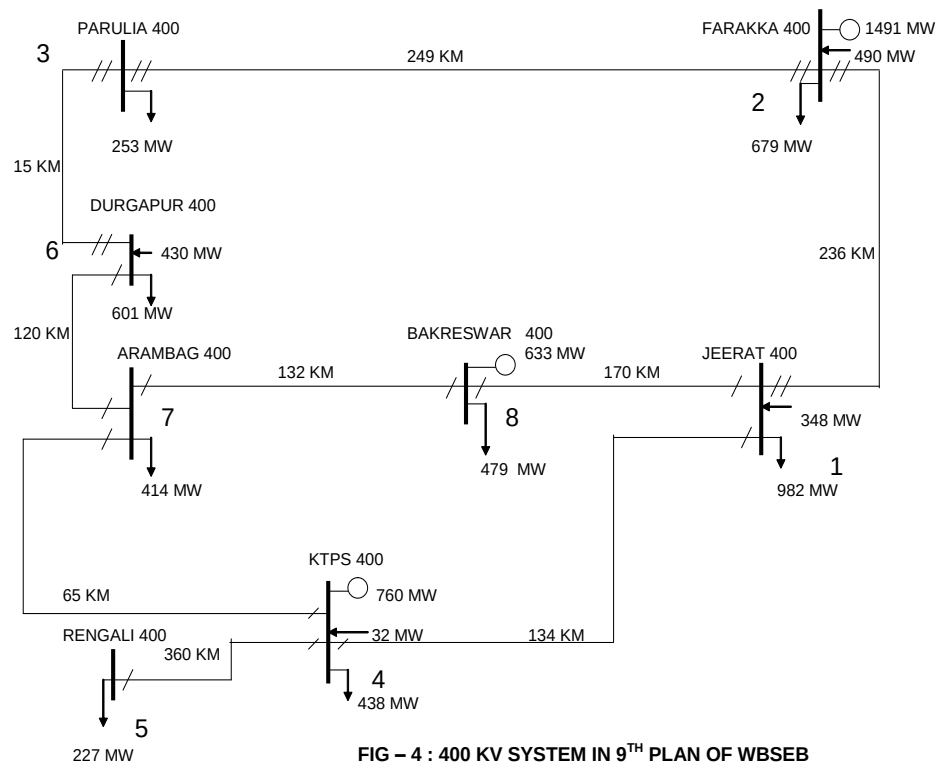


FIG – 4 : 400 KV SYSTEM IN 9TH PLAN OF WBSEB

VI. A.C. LOAD FLOW TEST

An A.C. Load Flow Test is made on the design network of fig. 3 to ensure that the designed network is capable of supporting the power movement. For load flow test the generation at generator buses are increased as per the 9th Plan of West Bengal State Electricity Board in anticipation of power losses. In this particular approach load flow test is not necessary, as the obtained network is a radial one. The load flow test result is shown in fig. 5 . The arrow with a bar indicates the reactive power flow.

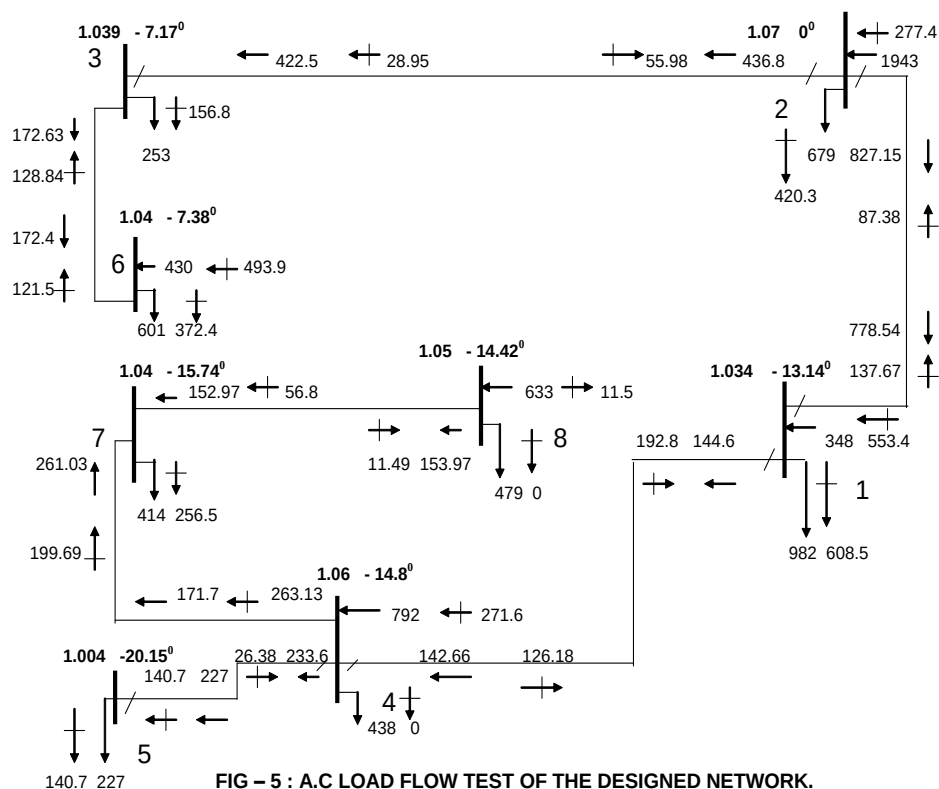


FIG – 5 : A.C LOAD FLOW TEST OF THE DESIGNED NETWORK.

TABLE – III: Bus Data for A. C. Load Flow

Bus	P (MW)	Q (MW)	Voltage (p.u.)	Remarks
1	- 634	*	1.04	Swing Bus Load Generator holds Voltage Load Load Generator holds Voltage
2	*	*	1.07	
3	- 253	- 156.8	* *	
4	354	*	1.06 *	
5	- 227	- 140.7	* *	
6	- 171	*	1.04 *	
7	- 414	- 256.5	* *	
8	154	*	1.05 *	

* Quantities to be determined by a.c load flow

VII.CONCLUSION

The total extra conductor length required for West Bengal State Electricity Board's plan is 1002 km. Total extra conductor length required for this approach is 212 km. which is only 21.1% of that actually used by West Bengal State Electricity Board in 9th Plan. This means if this type of organisation use this type of method for expansion planning of transmission network, they will be benefited much in saving conductor and thus reducing the overall cost . Now there is one very important point i.e. whether this amount varies subject to some condition, which may arise in actual practice. Now let us discuss some of such conditions, which may be encountered in actual practice. These are -

(1) The suggested route of transmission line may go through wide river or high mountain. So, in this case route length will be increased accordingly to bypass this obstructions.

(2) Accurate distance between bus to bus are not available readily. We have to work out with approximate distances. This factor definitely affected the calculations. So, the actual reduction in conductor length may vary here.

(3) In this computation all possible routes with bus No. 5 to other buses are not considered except with bus No. 4 due to want of some practical data. This may affect the final design.

In spite of the above-mentioned facts definitely the route length of the conductor will be reduced if the expansion planning of transmission network is done according to this present approach. Another important point to note that if such methods are utilised for expansion planning of transmission network in our country, huge capital cost will be reduced. So, in this way not only corers of rupees will be saved, manpower as well as time will also be saved.

Last point to mention here is that the designed network is a radial one. As the radial network is not suitable with respect to the reliability point of view, this network needs some modification to improve reliability. In the next paper reliability analysis of this planned system will be discussed.

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