

Application of Combined Optimal Strategic Generation Expansion and Transmission Expansion Planning to 400KV 8 bus system of WBSETCL

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ABSTRACT: This paper presents a short term optimal combined generation and transmission expansion planning problem solution by optimization technique. This method is a minimum cost assessment method for composite system expansion planning. First, the generation expansion planning (GEP) problem is formulated and solved by implicit enumeration technique (IET). The problem is to select the economical units with proper level of reliability under the financial and technical constraints and this will meet up the customers need at reasonable price. In this way, types, sizes and number of generating units are selected from many proposed alternatives. Then, operating level of each generating unit is found by using linear programming technique after setting up new plants. The optimal output of level of these plants are determined according to their cost. Once according to GEP, new plants are set up, next job is to select the location of connecting these new plants to the existing network subject to cost minimization capable of satisfying the future generation and load demand at each bus. So optimal transmission expansion planning (TEP) comes into picture. TEP problem is formulated as a LP problem and solved to find optimum route.

KEYWORDS: Text detection, Inpainting, Morphological operations, Connected component labelling.

Nomenclature:

c_{1i} - Capital cost of proposed line i .
 F - Total cost.
 P_{1i} - Power flow on proposed line i .
 N_1 - Number of proposed line i .
 P_i - Power flow on existing line i .
 IP_i - Injected power at bus i .
 $X1(i)$ - Set of proposed line connected to bus i .
 $X2(i)$ - Set of existing line connected to bus i .
 PM_j - Maximum power flow on existing line i .
 NLB - Number of pure load buses i.e where only load exists.
 NG - Number of generator for buses.
 NGB - Number of generator buses.
 NL - Number of pure load buses where only load exists.
 $N2$ - Number of existing lines.

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I. INTRODUCTION

To meet up the increased demand, generating capacity are to be increased. This can be done either by augmenting the existing plants or setting up new plants. The problem is to select the economical units with proper level of reliability and as such optimal generations are needed to overcome this problem. Here Generation Expansion Planning (GEP) takes vital role.

Once, according to GEP new plants are set up, next job is to select the location of connection of these new plants to the existing network subject to cost minimization while satisfying the system. So optimal transmission expansion planning (TEP) also comes into picture which can be achieved by knowing the load and generation level at each buses. Here combined GEP and TEP works have been carried out. This paper presents a minimum cost assessment method for composite system expansion planning.

In this paper combined GEP and TEP have been carried out on a real network (400 kv, 8 bus system of West Bengal Electricity Transmission Corporation Limited) which has been chosen to illustrate the proposed approach.

Such combined work is very useful in producing extra advantage with respect to total cost savings etc. as minimization is done at every stage starting from generation up to the end of Transmission planning. In this paper a real network (400 KV, 8 bus system of West Bengal Electricity Transmission Corporation Limited) has been chosen to illustrate the proposed approach.

II. BRIEF HISTORY OF PREVIOUS WORK ON GEP AND TEP

Composite GEP and TEP works have not been presented in literature. Comprehensive GEP and TEP are separately done. Optimal combined planning approach has been hardly discussed. The problem of generation expansion planning has been studied extensively using mathematical techniques. This problem has first formulated as linear programming problem by Messe and others [1]. A number of salient optimization methods have been successfully applied during past decades. Recently Fukuyama et al[2] applied genetic algorithm to solve GEP problem and showed very good results. Socio-economic and environmental developments also create a planning problem which requires the explicit treatment of uncertainty. Sanghvi et al.[3] presented a mathematical optimization model which had great uncertainty and its impact on the key variables by defining a number of possible states that are likely to occur.

Garver[4] has made very significant contribution in TEP. He used linear programming technique to determine the power flows in the loss less network. New lines are added where largest overload exists and the process continues till overload remains. Henault[5] proposed another method which uses dynamic programming technique. Kaltenbuck [6] also proposed a method using both linear programming and dynamic programming.

III. GENERATION EXPANSION PLANNING (GEP)

GEP is a strategic planning of expansion of generations to meet up the forecasted load demand over a long term period of 5 years to 25 years so that firstly this planning will be most economical and reliable under the financial and technical constraints and this will meet up the customer's need at reasonable price and reliable electric energy supply. It is a least cost capacity addition schedule i.e. selection of types and sizes and numbers of generation units among many available alternatives. GEP is modelled as an optimization problem where the objective is to minimize the total cost subject to certain constraints. The objective function of the least cost GEP problem is the sum of yearly discounted costs which incorporates the capital cost and operation cost over a planning horizon. It is composed of investment cost and expected fuel cost.

A. MATHEMATICAL MODELLING OF GENERATION EXPANSION PLANNING (GEP)

In case of commissioning new plants both capital costs as well as operating costs are to be considered. While for the existing plants, the running costs are considered only. In case of augmentation of capacity at an existing plant, even though capital investment is essential, it will only be a small percentage of that when a completely new plant is set up.

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B. OBJECTIVE FUNCTION

Here in this paper total cost is assumed as the summation of the capital cost and fuel cost i.e. running cost.

Capital Cost - Let N_G be the total number of plants and N be the number of proposed plants. Then the capital cost associated with X_j^{th} unit of the proposed plant can be represented as [7]:

$$C' f_i (X_j) = \left[\frac{(1+i)^{(T_j+1)} - 1}{1+r} \right] Cc_j a o_j Gx_j (1)$$

The present worth of the above cost is represented as [7]:

$$C f_i (X_j) = \left(\frac{1+i}{1+r} \right)^t C' f_i (X_j) \tag{2}$$

Where 't' is the time in years at which the investment is made, 'i' the rate of inflation, 'r' the rate of interest, T_j the time span in year of X_j^{th} unit, $a o_j$ the cost in money units per MW capacity of j^{th} unit, Gx_j the unit capacity and Cc_j is the carrying charges of the j^{th} unit.

The total cost is represented as [7]:

$$C f (X) = \sum_{j=1}^N c f_j (X_j) \tag{3}$$

C. OPERATING COST

The total operating cost is defined as [7]:

$$C_o (P_o_j) = f_i (P_o_j) \tag{4}$$

where f_i is the cost function of j^{th} plant in MW.

P_o_j is the output of the j^{th} plant in MW.

The present worth of the cost considering interest and inflation is given by [7]:

$$C_o' (P_o_j) = \left(\frac{1+i}{1+r} \right)^t C_o (P_o_j) \tag{5}$$

The total operating cost is as follows [7]:

$$C_o' (P_o) = \sum_{j=1}^{NG} C_o' (P_o_j) \tag{6}$$

The objective function to be minimized is the sum of operating cost and capital cost and is given by [7]:

$$CT = C f (X) + C_o (P_o) \tag{7}$$

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D. CONSTRAINTS

Here two constraints can be considered. They are – (1) Physical (2) Technical limitations.

i. PHYSICAL LIMITATION:

There are upper and lower limit of generation. In case of hydel plant, lower limit is zero and in case of thermal plant this lower limit is greater than zero. The upper limits are the maximum capacity of the plants irrespective of thermal or hydel plant.

The constraints are of the form

$$P_j(\min) \leq P_{o_j} \leq P_j(\max) \quad (8)$$

Where $j = 1, 2, \dots, N_G$.

$P_j(\min)$ is the minimum output of the j^{th} plant and $P_j(\max)$ the maximum output of the j^{th} plant.

ii. POWER BALANCE AND RELIABILITY

The minimum capacity of a power plant must be equal to or greater than the peak demand. Capacity of a plant is always kept at least 20% greater than peak demand to ensure the reliability of service.

Thus, the combined power balance can be expressed as :

$$\sum P_j \text{ old} + \sum P_j \text{ new} \geq 1.2 D \quad (9)$$

where D =Demand

E. FINAL PROBLEM FORMULATION

Thus, the optimal single stage expansion planning problem can be modelled as[7]:

$$\text{Minimize : } C f(X) + C_o (P_o) \quad (10)$$

Subject to

- $P_{o_j} \geq P_j(\min)$
- $P_{o_j} \geq P_j(\max)$ and
- $\sum P_j \text{ old} + \sum P_j \text{ new} \geq 1.2 D$

F. SOLUTION TECHNIQUE

The demand D at the end of lead time should be known by load forecasting. The problem is solved in two steps. The number of plant additions required at minimum capital investment is found using implicit enumeration technique. Then, the operating points of all the plants at minimum operating cost are calculated using linear programming.

i. IMPLICIT ENUMERATION TECHNIQUE (IET)

The problem of determination of the number of plant additions required is formulated as a 0 – 1 integer programming model which is solved using implicit enumeration technique.

The problem statement is

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$$\text{Min } Z = C f(x) \quad (11)$$

$$\text{Subject to : } Q(L) = -1.2D + \sum_{j=1}^{NG} G_{X_j} X_j \geq 0$$

Where $L = 1, 2, \dots, M$ and $M = \text{Total number of constraints}$. $X_j = 0$ or 1 for proposed plant and $X_j = 1$ for existing plant $j = 1, 2, \dots, NG$.

The above problem can be represented as

$$\text{Min } Z = \sum_{j=1}^N C(J) * X(J) \quad (12)$$

$$\text{Subject to: } Q(I) = -B(I) + \sum_{j=1}^N A(I,j) * X(J) \geq 0$$

$$L = 1, 2, \dots, M$$

$$X(J) = 0 \text{ or } 1, J = 1, 2, \dots, N$$

Where $C(J) \geq 0, J = 1, 2, \dots, N$

The problem is solved by writing a computer program based on the implicit enumeration technique. The detail algorithmic steps of the technique are given below. If a variable in the objective function has a negative cost coefficient, simply replace the variable with another variable that is one's complement of the first variable [7].

Algorithm for Implicit Enumeration Technique

Step-1: set $FRE = (1, 2, \dots, N)$
 $NFRE = \text{empty set}$
 $ZMIN = 10^{10}$

Step-2: calculate $Z = \sum_{i \in NFRE} C(i) * X(i)$

Step-3: set $VC = \text{set of violated constraints using NFRE variables plus FRE variables set equal to zero}$.

Step-4: If VC is empty goto **step-12**, otherwise goto **step-5**.

Step-5: set $BUD = ZMIN - Z$

Step-6: set $T = \text{set of variables in FRE which have (a) an objective function coefficient } < \text{BUD and (b) a positive coefficient in some constraints in } VC$.

Step-7: If T is empty then goto **step-11**, otherwise goto **step-8**

Step-8: For each constraint in VC (a) set to 1 the FRE variables in T that have positive co-efficient in given constraint (b) set NFRE variables equal to their specified values.

Step-9: If any of the constraints are still violated then go to **step-11**, otherwise goto **step-10**

Step-10: Remove from FRE and add to NFRE the variable in T that would minimize the total distance from feasibility over all constraints a and goto **step-2**.

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Step-11: If NFRE is empty then goto step-21, otherwise no feasible completion of the partial solution represented by NFRE has a smaller value than the current ZMIN value, so goto **step-16**.

Step-12: Variables in NFRE along with the variables in FRE set equal to zero from a complete solution. Goto **step-13**.

Step-13: If $Z < ZMIN$, goto **step-14**, otherwise goto **step-15**.

Step-14: set $ZMIN = Z$, save the complete solution and goto **step-15**.

Step-15: If NFRE is empty then the feasible solution $X(l) = 0, (l=1, 2, \dots, N)$ is optimal, so goto **step-20**, otherwise goto **step-16**.

Step-16: If the last element in NFRE is negative then goto **step-18**, otherwise goto **step-17**.

Step-17: Make the last element in NFRE negative and goto **step-2**.

Step-18: If all elements in NFRE are negative then goto **step-20**, otherwise goto **step-19**.

Step-19: Make rightmost positive element in NFRE negative. Drop elements to right from NFRE and add to FRE and goto **step-2**

Step-20: The complete solution corresponding to ZMIN is optimal. If $ZMIN=10^{10}$, no feasible solution. Write results and stop.

Step-21: No feasible solutions to the problem and stop.

ii. LINEAR PROGRAMMING (LP)

In order to find out the operating level of the units of generating plants LP is used. Here in this case MATLAB LP package in optimization toolbox is used for solution.

The LP problem can be represented as:

$$\begin{aligned} \text{Min } Z &= [c][x] \\ \text{Subject to: } [A][x] &\leq b \\ x &\geq 0 \end{aligned} \tag{13}$$

IV. TRANSMISSION EXPANSION PLANNING

Transmission expansion planning is a strategic planning of expansion of transmission network capable of satisfying the needs of future generation and load demand with minimum cost subject to system constraints. Here two constraints have been considered. They are power balance equation and line loading limit. Other constraints including losses are dropped because of the effect of these constraints are not very significant as was established by Yousuf and Hackman [8]. The aim of TEP is to determine where to add new circuits with minimum cost in an expanding transmission system. In recent years several computer based mathematical techniques have been developed to solve this problem. In this paper, the TEP problem is formulated as a LP problem and solved to find optimum route by using MATLAB LP package.

A. PROBLEM FORMULATION OF TRANSMISSION EXPANSION PLANNING

The linearized model used in this approach to obtain the optimum route is as follows [4]:

$$\text{Minimize } F = \sum_{i=1}^{N1} C_{li} P_{li} \tag{14}$$

Subject to the constraints

- a) The power balance constraints at load bus i

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$$\sum_{j \in X1(i)} P1j + \sum P1j = 1Pj; \quad i = 1, 2, \dots, N_L$$

b) The power balance constraints at generator bus i

$$\sum_{j \in X1(i)} P1j + \sum_{j \in X2(i)} P_j \leq IP_i, \quad i=1, 2, \dots, NGB \quad ; \quad i=1, 2, \dots, N_G$$

c) The line loading constraints for existing line

$$P_j \leq PM_j \quad j=1, 2, \dots, N_7$$

V. LEAST COST CAPACITY ADDITION SCHEDULE – AN APPLICATION TO A REAL SYSTEM (400 KV 8 BUS SYSTEM OF WBSETCL)

The present method has been applied to 400 KV 8 bus system of WBSETCL. Considering the eighth plan of WBSEB as the existing system, this method has been applied on the system with minor assumptions as and whenever necessary to fit the problem properly and finally the results are compared with the 9th Plan System of WBSETCL. In this connection, estimated load demand of West Bengal for the future 25 years upto 2030 as shown in **Table-I**.

Fig. 1&2 shows the existing generation and transmission system of WBSETCL as per with 8th and 9th plans of WBSETCL. **Fig. 3** shows the existing network with future load and generating units, which is more or less as per with the 9th Plan of WBSETCL. At some buses of **Fig. 3** net loads are shown because of that buses some generation are coming from other sources and neglecting these generation net loads are shown to fit the problem properly. **Table-II** gives the data for generation expansion planning.

The existing and proposed generation units are shown in **Table III** where the minimum capacities are assumed. The programme developed using the Algorithm for Implicit Enumeration Technique discussed earlier have been applied to find out the economic units. The output of the programme is shown in the **Table VII**, which clearly indicates that unit 1, 2 and 6 are not required for the considered data. In **Fig.2**, net load has been considered to simplify the problem at some buses because some power is coming from other system in reality and that is why demand (D) at the end of lead time is less than the present capacity i.e. the considered 400 K.V. system is a part of a large integrated system.

A. DETERMINATION OF OPERATING LEVEL OF THE PLANTS

The operating level of the existing plants and as well as selected plants are determined using linear programming (LP) formulation. The maximum and the assumed minimum capacity of the plants are given in **Table III**. The assumed cost curve of the plants are given in **Table IV**. So, the LP problem formulation for the determination of operating level will be as follows:

$$\text{Minimize } F = (14 + 14PO_3) + (15 + 15PO_4) + (16 + 16PO_5) + (10 + 12PO_7) + (12 + 13PO_8) + (13 + 11PO_9) + (20 + 2PO_{10}) + (22 + 22PO_{11}) + (13 + 12PO_{12}) + (17 + 13PO_{13}) + (18 + 15PO_{14}) + (12 + 14PO_{15}) + (15 + 12PO_{16}) + (14 + 16PO_{17}) \quad (15)$$

Where PO_i = Output of the i^{th} plant

Subject to constraints:

(a)

$$PO_3 + PO_4 + PO_5 + PO_7 + PO_8 + PO_9 + PO_{10} + PO_{11} + PO_{12} + PO_{13} + PO_{14} + PO_{15} + PO_{16} + PO_{17} = 1.2 D$$

(b) Upper and lower limit constraints of the plants as stated in **Table-III** The above LP package and the result is shown in **Table-V**.

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VI. OPTIMUM ROUTE FINDING OF TRANSMISSION EXPANSION PLANNING

After obtaining the operating level of the existing and selected plants, the generation of each bus is known. The future load conditions are shown in **Fig. 3**. Once the load and generation pattern at each bus are known then using data of **Table- VI** a LP problem can easily be formulated as discussed above and has been solved using MATLAB LP package. The final result i.e. the final transmission system with optimum route is shown in **Fig. 4** and plant selected for commissioning shown in **Table-VII**.

VII. RESULTS OBTAINED

The results show that the additional line length required in this present approach is 212 KW which is 1002 KM for WBSETCL planned system. However the planned network is radial one. The details of tower used in eighth and ninth plan of WBSETCL and the proposed planned system are given in **Table VIII**. The cost of towers are also shown in the same Table and estimated by considering cost of A Type tower is 1 money unit MU, for B type is 2 money unit MU, for B type 3 money unit MU, for D type 4 money unit MU, for DA type 5, for DB type 6 money unit, for DC type 7 money unit, for DD type 8 money unit, for Special type 9 money unit,. Except cost all the datas in the **Table VIII** are actual one. This table indicates that regarding tower a saving of 2475 MU is possible, regarding line length, if we consider cost of 1 KM of line is 1 MU then it is possible to save 790 MU that is total saving of 3265 MU for both tower and line length which clearly indicates that the proposed planned system is much cheaper than WBSETCL planned system. It is estimated that the surface coverage area for WBSETCL is to be 77.012 Square KM where surface coverage area of proposed planned system is only 61.932 Sq. Km. As the obtained network is radial one, a.c. load flow test is not necessary. However as usual a load flow test has been done which indicates that the proposed planned system is capable of power movement.

VIII. CONCLUSION

This paper presents an approach for short term optimal generation expansion planning. The approach uses mathematical optimization techniques for optimal solution. The method proposed in this paper finds the number of plants to be selected from a possible new addition and the generation levels of the existing as well as proposed plants. The proposed method also shows how to find the minimum additional transmission routes. The present method provides a simple and flexible approach to combine generation-transmission expansion planning so that new variables and constraints can easily be incorporated in to the mathematical model. The main limitation is the assumption of some data due to either the non-availability of these data or the proper authority failed to supply such data.

Regarding generation, economic selection of units are possible. Here comparison with real system indicates that plant number 1 and 2 at Bakreswar and plant number 6 at Farakka are not necessary for the load pattern and this is true for the considered data only. Power utilities will be benefited for selection of economic unit with this method. Regarding optimum route finding, power utilities are normally following arbitrary procedure. The proposed approach could be a better method for them for this purpose. This approach will help the power utilities to get uninterrupted power supply with large amount of cost saving which in turn helps the nation. Regarding optimum route finding, not only economic consideration is important, reliability and stability analysis of route are also equally important, but discussion of that is beyond the scope of the present paper.

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Table-I: Estimated Load Demand of West Bengal

Year	Demand in MW
2007	5581
2012	7441
2020	8937
2025	11120
2030	13589

Table-II: Data for generation expansion planning

Present capacity of generating units	2860 M.W.
Lead time	5 years
The Demand D at the end of lead time	2803 M.W.
Life span of the unit	20 years
Rate of inflation	10%
Rate of interest	10%
Cost in money unit for M.W capacity	2
Carrying charges	20%

TABLE-III : Upper and lower limit constraints Existing and Proposed Generation Units

Existing System				Proposed System			
Plant No.	Type	Minimum Capacity (MW)	Maximum Capacity(MW)	Plant No.	Type	Minimum Capacity(MW)	Maximum Capacity(MW)
7	Thermal	50	200	1	Thermal	50	210
8	"	50	200	2	"	50	210
9	"	60	200	3	"	70	210
10	"	150	500	4	"	60	210
11	"	180	500	5	"	60	210
12	"	70	210	6	"	150	500
13	"	60	210				
14	"	50	210				
15	"	60	210				
16	"	50	210				
17	"	70	210				

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Plant No.	Cost Curve
1	--
2	--
3	14+ , 14 PO ₃
4	15+ , 15 PO ₄
5	16+ , 16 PO ₅
6	--
7	10+ , 12 PO ₇
8	12+ , 13 PO ₈
9	13+ , 11 PO ₉
10	20+ , 2 PO ₁₀
11	22+ , 22 PO ₁₁
12	13+ , 12 PO ₁₂
13	17+ , 13 PO ₁₃
14	18+ , 15 PO ₁₄
15	12+ , 14 PO ₁₅
16	15+ , 12 PO ₁₆
17	14+ , 16 PO ₁₇

Table-IV : Assumed Cost Curve of the Plants

Table -V: Operating Level of the Plants

Plant No.	Output(MW)
3	210
4	210
5	210
7	200
8	200
9	200
10	500
11	374
12	210
13	210
14	210
15	210
16	210
17	210

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Table VI: Proposed Route Cost Parameter and Existing Line Capacity

Proposed Route	Length(Km)	Cost Parameter	Existing line Capacity (MW)
1 -2	236	1180	900
1 -3	222	1110	
1 -4	134	670	900
1 -6	224	1120	
1 -7	196	980	
1 -8	170	850	
2 -3	249	1245	900
2 -4	296	1480	
2 -6	264	1320	
2 -7	338	1690	
2 -8	388	1940	
3 -4	140	700	
3 -6	15	75	
3 -7	132	660	
3 -8	252	1260	
4 -5	360	1800	900
4 -6	132	660	
4 -7	65	325	
4 -8	112	560	
6 -7	120	600	
6 -8	240	1200	
7 -8	132	660	

Table-VII: Plants Selected for Commissioning

Plant No.	Commissioning Yes / No	Type	Generation (MW)
1	No	Thermal	Nil
2	No	-do-	Nil
3	Yes	-do-	210
4	Yes	-do-	210
5	Yes	-do-	210
6	No	-do-	Nil

Table VIII: Tower comparison

Tower Type	No. of towers in WBSETCL Existing system	No. of towers in WBSETCL Planned system	Estimated No. of towers in the proposed planned system	Additional No. of towers required for WBSETCL planned system	Estimated Additional No. of towers required for proposed planned system	Cost of extra towers required for WBSETCL planned system	Cost of extra towers required for proposed planned system
A	1378	3235	1793	1857	415	1857	415
B	136	279	161	143	25	286	50
C	116	230	143	114	27	342	81
D	101	286	169	185	68	740	272
DA	01	19	19	18	18	90	90
DB	0	01	01	01	01	06	06
DC	0	03	03	03	03	21	21
DD	12	22	18	10	06	80	48
Special	08	14	10	06	02	54	18
					Total =	3476	1001

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Table IX: Cost of Tower in MU

Tower Type	A	B	C	D	DA	DB	DC	DD	Special
	1	2	3	4	5	6	7	8	9

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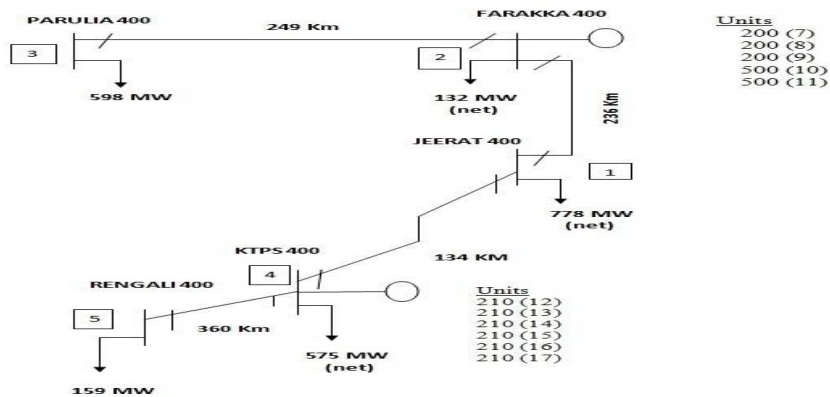


Fig 1: Existing Generation and Transmission System.

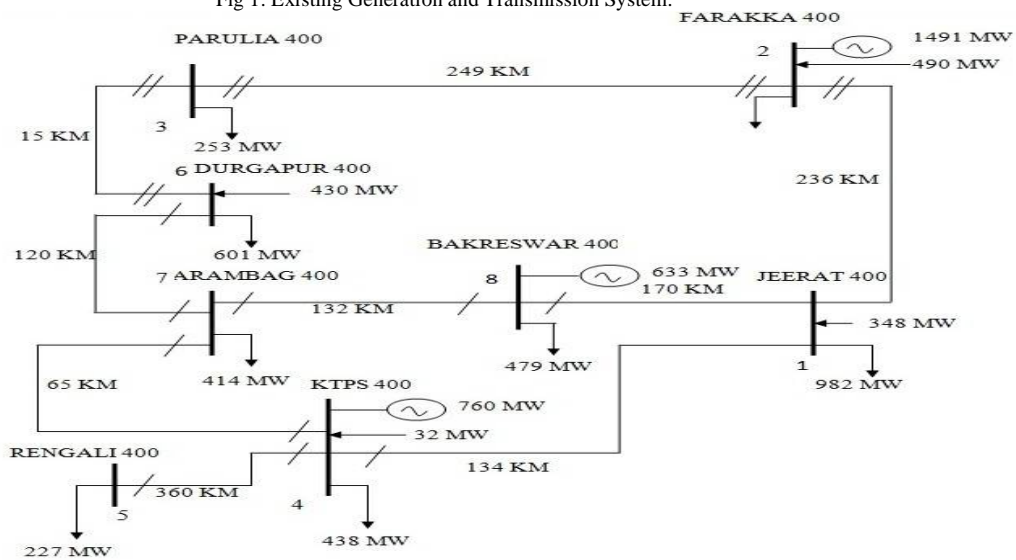


Fig.2 : 400 KV System in 9th Plan of WBSEB

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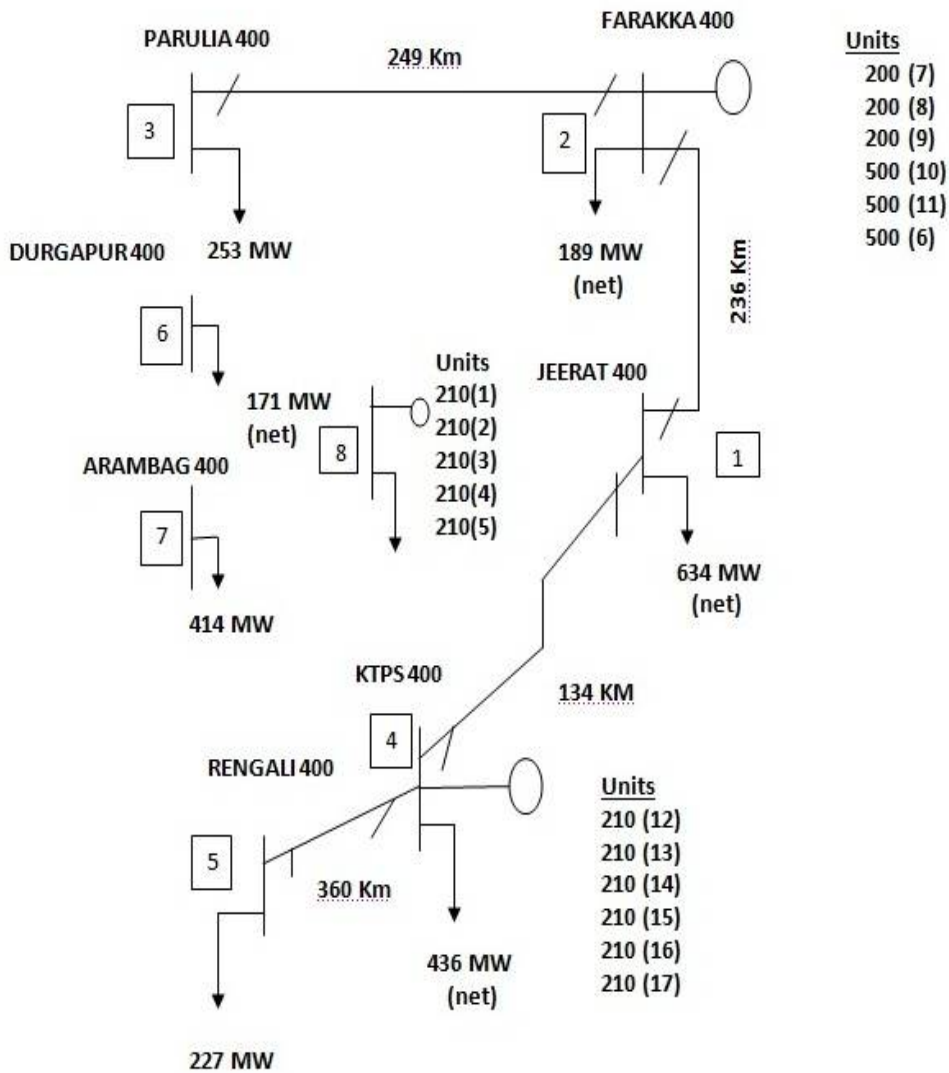


Fig. 3 :Existing Network with future load and generating units

