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TRANSMISSION EXPANSION PLANNING WITH SOLAR AND WIND FARM IN DEREGULATED ENVIRONMENT

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ABSTRACT: *Today's electric power system has highly complex and large scale interconnected transmission systems. In order to tackle the significant power system optimization problems transmission network expansion planning (TNEP) is required. This paper proposes a novel algorithm which is applied to transmission system consisting of the combination of solar PV and wind farms in order to solve the TNEP problems efficiently by using the analytical algorithm. The proposed method has achieved solutions with good accuracy, simple implementation and satisfactory results.*

KEYWORDS: Transmission expansion planning, Distributed generation approaches, Deregulation, Planner, Unbundling, Photovoltaic (PV), wind turbine generators (WTGs)

INTRODUCTION

The reserve capacity in the transmission system has been falling due to increased electricity demand and increasing generation capacity over the last few years. This has resulted in an over-utilized transmission and distribution system with an increased level of losses and higher probability of disturbance. The conventional methods of reducing the distribution losses include load balancing, bifurcation of overloaded lines, installation of shunt capacitors, high voltage distribution system etc. In these types of distribution networks, addition of new loads becomes very difficult and practically impossible. So, the need for more efficiency in power production and delivery has led to privatization, restructuring and finally deregulation of the power sectors in several countries traditionally under control of federal and state governments [1]-[2].

Main benefits from the deregulation are cheaper electricity, efficient capacity expansion planning, more choice and better service. The deregulation of power sector provides a fair co m- petition among producers as well as more choice and better service for consumers of electricity [5]-[9]. The objective of this paper is to present a new approach for transmission expansion planning, considering new objectives and uncertainties in deregulated power systems. Combination of conventional sources, renewable energy sources in the form of solar energy and wind energy have been used for measuring the goodness of expansion plans [3]-[4].

Transmission expansion planning approaches

Restructuring and deregulation of the power industry have changed the objectives of trans- mission expansion planning and increased the uncertainties. As a result, new approaches and criteria are needed for transmission expansion planning in deregulated power system [10].

Different approaches of Trans miss ion expansion planning on the basis of uncertainty are Deterministic and Non-Deterministic Approach, On the bas is of Power System Horizon are

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Static and Dynamic Approach and on the bas is of Power System Structure are Regulated Power System and Deregulated power system [11].

In deterministic approaches the expansion planning is done without considering the probability of occurrence of the worst cases in the system. In non-deterministic approaches the expansion planning is done for all possible cases which may occur in future with considering the occurrence probability of them. Hence, Non - deterministic approaches are able to take into account the past experience and future expectations [10]. In static planning the planner only focuses on the optimal plan for one year on the planning horizon, which means he only thinks about "what" transmission facilities must be added to the network and "where" they must be installed. In dynamic planning the planner focuses on the optimal strategy along the whole planning period i.e. multi-year is considered. Also the dynamic planning is done keeping in mind about "what" and "where" in addition with "when" the trans mission facilities must be installed in planning horizon.

The regulated power system was the traditional power system called as vertically integrated market where one regulated utility was responsible for generation, transmission and distribution. In vertically integrated power systems, network expansion was intended to meet the present and future system reliability standards at a minimum investment cost [12]. So in such a system planners have complete access to the required information for planning. In these systems location of generation and loads, size of loads and generating units, availability of units, load pattern, and dispatch pattern are known. Therefore, planners can design the least cost transmission plan based on certain reliability criteria. Trans miss ion planning in regulated systems is modeled with a deterministic optimization. The objective function is cost of planning and operation, with technical and economic constraints. The deregulated power system is the one in which generation and distribution is unbundled in a view to be more economical and reliable as compared to the traditional one. The deregulation introduces the competition in generation in a view to improve the efficiency and in transmission to increase the reliability of the system resulting in transformation of traditional power system and introducing the new challenges in all aspects of generation, transmission and distribution.

Probabilistic approach and analytic algorithm

This paper proposes a probabilistic approach for transmission network expansion planning considering solar PV module output power and WTG power output fluctuations. This approach attempts to reconcile optimization over uncertain constraints. The constraints are guaranteed to be satisfied with a specified probability at the optimum solution. Probabilistic approach considers solving some case studies with various uncertainties using specified methods.

Many large scale solar PV farms and wind farms are built and connected to transmission networks directly. But, both solar power and wind power are variable and intermittent and they therefore introduce an extra factor of uncertainties for power system operation and planning [13]. The variable characteristics of solar power and wind power are similar to those of the loads; therefore both solar power and wind power are uncontrollable. The network with large proportion of wind power will have more power flow fluctuations. Therefore, the deterministic TNEP methods, which only account for one operation scenario, are unsuitable for the planning with stochastic power output from solar PV module and wind turbine generators (WTGs). Therefore probabilistic approach is most suitable in this case of transmission expansion planning.

In this paper, analytical algorithm for TNEP associated with large scale solar and wind farm in deregulated environment is used. Because of intermittence of the large scale solar power along with wind farm output, the power flow of transmission system becomes more difficult to predict [14]. The curve fitting tool in matlab is used to get the probability distribution of active power flow. In order to reduce the computational cost, analytic method is used. The complex probabilistic density functions (PDFs) of solar PV module and Wind Turbine Generator are obtained by writing a program in matlab [15]. Then these PDFs are used to find out probability distribution of power flow with analytical method. Unlike traditional leas t-cost TNEP model, this p a p e r takes not only cost but also expected future trans mission profit as criteria to determine which line should be chosen in final planning scheme. The proposed analytical TNEP method is applied to modified Garver s ix-bus test system [16]-[21]. The tests demonstrate that the proposed algorithm can obtain optimum transmission expansion planning scheme.

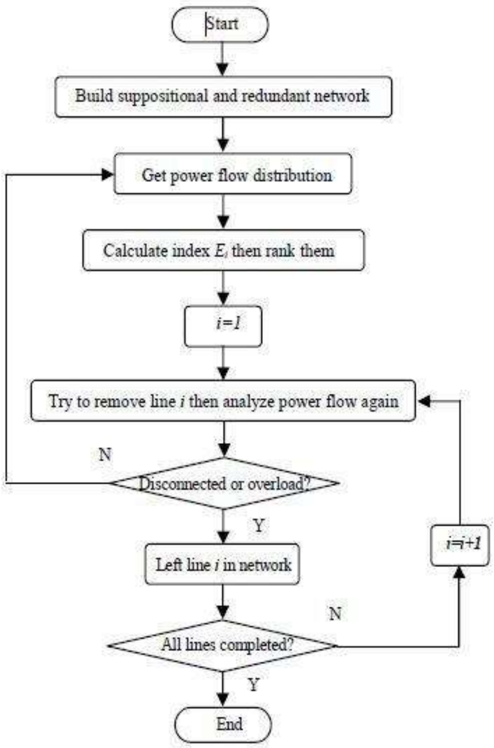

Fig.1 Flowchart of Analytic algorithm for TNEP

The main objective of TNEP is to minimize the investment. But in deregulated environment, TNEP would be rather market-oriented, in which investment and profit prospects would be equally concerned. For evaluating the economy efficiency of each alternative line, a novel index Ei is introduced which can be obtained by following equation:

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Ei = Ii / Ci = [E(Pi)* Di* ρ] / Ci………(1)

Where, **Ii** is profit prospect of alternative line **i**, **Pi** expected actual power flow, the distance **Di**, and the pre-determined unit cost ρ of each transmission line. **Ci** is the cost of transmission line **i**. If **Ei** is bigger than **Ej**, it means line **i** is more efficient in economic than line **j**. In order to get optimum expansion scheme, low efficient candidate lines should be removed from redundant network step by step until the final planning scheme is obtained. In this process, some low efficient alternative lines should be held in network for their important roles in insuring system reliability.

RESULTS

Probabilistic approach:

Probabilistic Solar PV module Output Model:

The output characteristics solar PV module I-V characteristics and solar PV module output power as shown in fig. 2 and fig. 3is obtained by writing a program based on equations 2, 2(a) to 2(b) in MATLAB.

A general mathematical description of I-V output characteristics for a PV cell has been studied so the voltage-current characteristic equation of a solar cell is given as:

$$I = I_{ph} - I_S\left[\exp\left(\frac{q(V+IR_S)}{KT_CA}\right) - 1\right] - \frac{V+IR_S}{R_{SH}}$$

……………………… (2)

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as:

$$I_{ph} = [I_{SC} + K_I(T_C - T_{Ref})]H$$

………………… 2(a)

On the other hand, the cell's saturation current varies with the cell temperature, which is described as:

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 \exp\left[\frac{qE_G(T_C - T_{Ref})}{T_{Ref}\,T_C kA}\right]$$

………………… 2(b)

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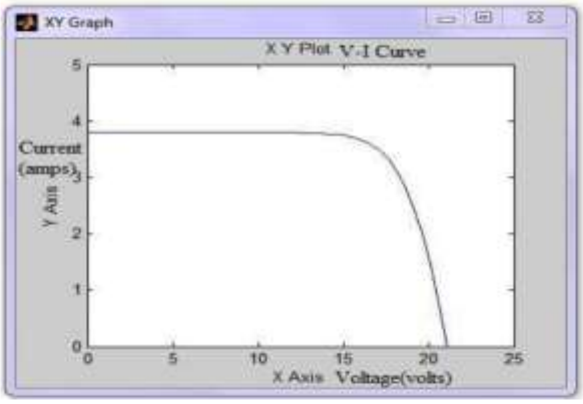


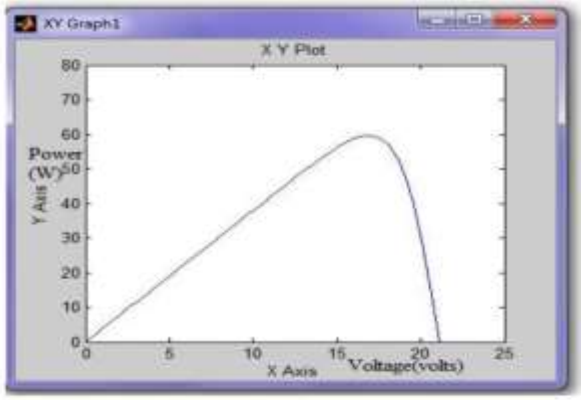


Fig.2 Relationship between solar PV module I-V characteristics Fig.3 Relationship between solar PV module output power

Probabilistic WTG Output Model

The output characteristics WTG between wind speed V and WTG output power is obtained by writing a program based on equations 2(c) to 2(e) in MATLAB.

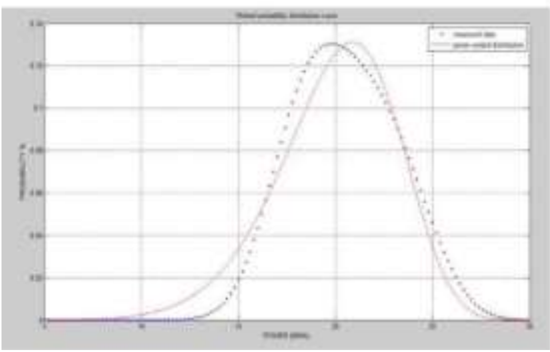
The relationship between wind s peed and WTG output can be described by the following equation: $P=0$ if $(V>= \&\& V<V_{ci})$………………. 2(c)

$P=P_{rate}*(V-V_{ci}) / (V_{rate}-V_{ci})$ if $(V>= V_{ci} \&\& V<V_{rate})$ ……………2(d)

$P=P_{rate}$ if $(V>= V_{rate} \&\& V<V_{co})$………………………………… 2(e) $P=0$ if $(V_{co}<V)$……………………………………………… …… 2(f)

Probabilistic distribution of solar power:

Probability Density Function curve for solar power is obtained with the help of program written in MATLAB and curve fitting done. Then Weibull Probability Distribution of power output of solar PV module is obtained with the help of program and curve fitting operation in MATLAB



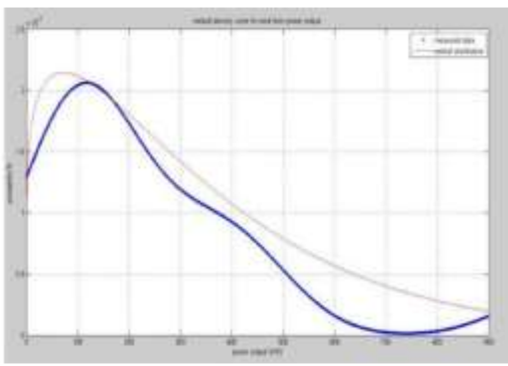


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Fig.4 Weibull Probability Distribution Curve for solar power Fig.5 Weibull Probability Distribution Curve for wind Power

Probability Distribution of Wind Power

Probability Density Function curve for wind power is obtained with the help of program written in MATLAB and curve fitting done. Then Weibull Probability Distribution of power output of WTG is obtained with the help of program and curve fitting operation in MATLAB.

Analytic approach

In analytic approach we follow the analytic algorithm for TNEP as given earlier. The results are shown in this section to demonstrate the performance of proposed analytic algorithm on the modified Garver six bus test system. Presented in Fig. 6, the original Garver six-bus test system consists of three generators at buses 1, 3 and 6. The forecasting load is 760 MW, distributed unevenly among the buses. Originally, the system has a total of 6 transmission circuits.

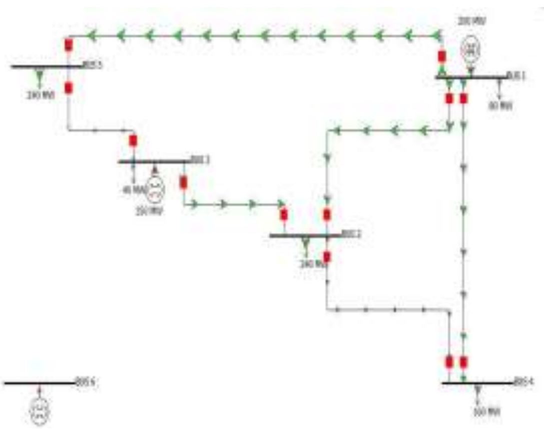

Fig.6 Initial configuration of Garver's six bus test system

Some modifications are carried out to this famous test system. Firstly generator connected to bus 6 is assumed to be a large-scale wind farm, which is consisted of several WTGs subjected to the same wind regime. The generator at bus 3 is assumed to be solar PV module. Then generator connected to bus 1 is assumed to be thermal unit. The parameters of generators are shown in Table.1.

Table.1. capacity of different generators in Garver bus system

S. No.	Gen. No.	Capacity(MW)
1	1	200
2	3	150
3	6	600

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Here we consider two different cases for different loading conditions. In each case we calculate the economic efficiency for each transmission line of modified network and also calculate the economic efficiencies for removal of each transmission line one by one in order to obtain redundant network. Also comparison has also been made between the economic efficiencies graphically. A MATLAB program is made for calculating the economic efficiency for each transmission line.

CASE 1:

Load 1: 100MW *Load 2: 160MW* *Load 3: 100MW*

Load 4: 150MW *Load 5: 120MW* *Load 6: 110MW*

Table2: Data for Redundant network

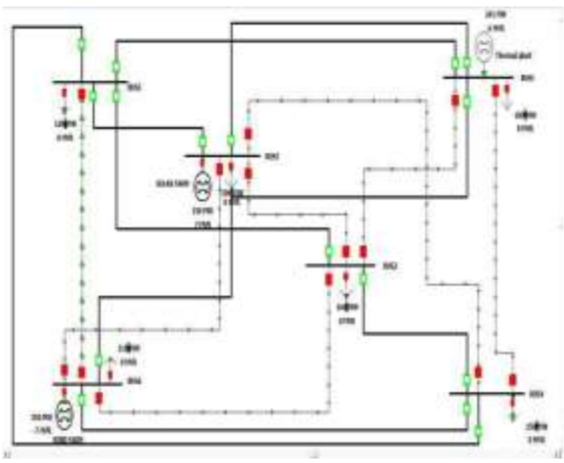

Fig 7: The Redundant network for Garver's Six bus system showing dark black lines as Less efficient lines.

Circuit	**Power (MW)**	**Percentage Loading**	**Economic Efficiency**
5-6	120.15	80.19	120.15
1-4	96.00	64.07	96.00
2-6	69.30	46.27	83.16
3-4	54.05	36.12	69.49

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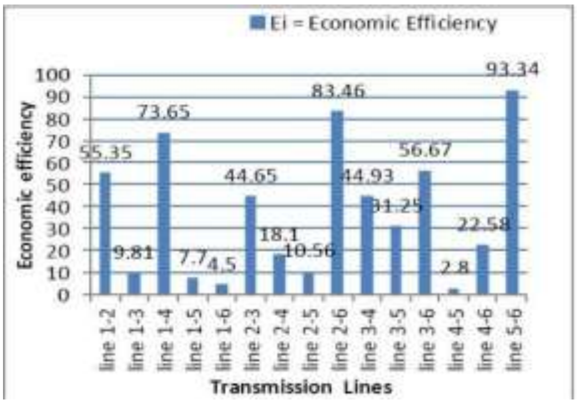
3-6	50.35	39.05	54.92
2-3	46.05	41.96	46.05
1-2	44.7	29.97	44.7

Now the comparison has been made between the economic efficiency of each transmission line calculated for the modified network and the economic efficiency of each transmission line forming a redundant network with the help of bar graphs.



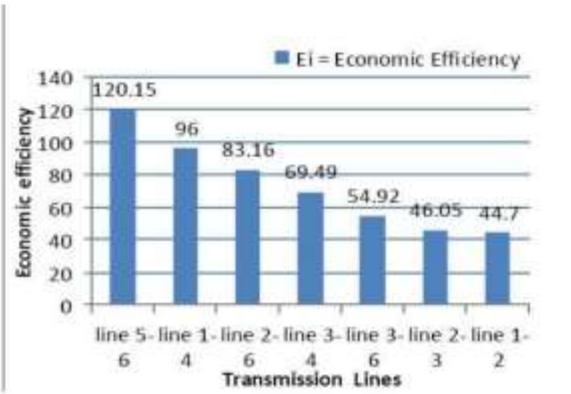


Fig 8: Economic efficiency for Modified network in case 1 Fig 9: Economic efficiency of redundant network in Descending order for case 1

CASE 2:Load 1: 100MW Load 2:184MW Lo ad 3: 118MW Load 4: 168MW Load 5:144MW Load 6: 162MW

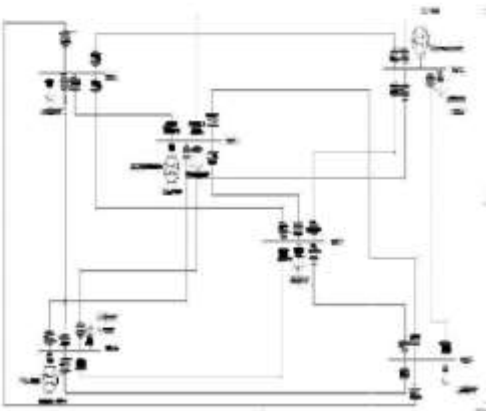


Fig.10 the redundant network obtained showing the dark black lines which are less efficient are removed.

The redundant network is obtained by removing the less efficient transmission lines fro m the modified Garver's six bus system. In redundant network t he lines are transmitting power more efficiently and w ith less losses as the length of the lines is short. The dark black lines are the less efficient lines which are removed to obtain an efficient system.

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Circuit	Power (MW)	Percentage Loading	Economic Efficiency
1-2	101.9	68.02	101.9
1-3	47.30	79.48	51.60
1-4	110.7	73.88	110.7
1-5	16.55	33.41	18.20
1-6	00.20	00.49	00.20
2-3	45.40	41.35	45.40
2-4	08.80	12.56	08.80
2-5	01.00	02.36	01.20
2-6	44.60	29.76	53.52
3-4	30.00	20.18	38.57
3-5	43.95	40.07	43.95
3-6	40.20	31.19	43.85
4-5	00.90	02.20	00.94
4-6	17.80	14.96	19.58
5-6	85.50	57.06	85.50

Now the comparison has been ma de between the economic efficiency of each transmission line calculated for the modified network and the economic efficiency of each transmission line forming a redundant network with the help of bar graphs.

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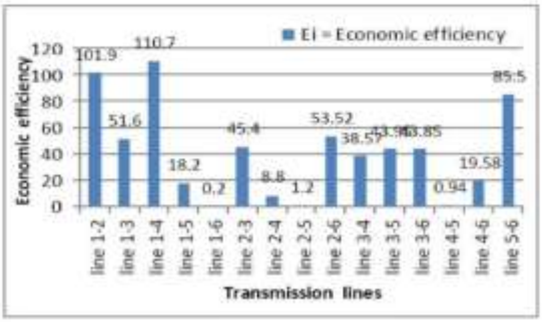

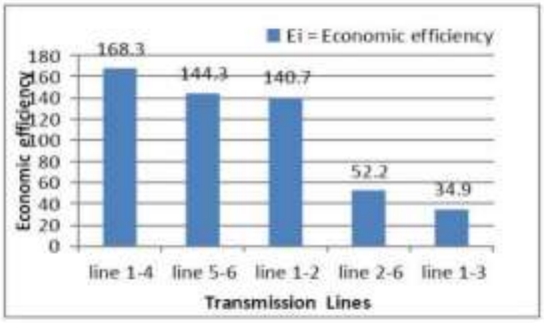

Fig 11: Economic efficiency for Modified network in case 2 Fig 13: Economic efficiency for the redundant network.

CONCLUSION

The Renewable sources of energy such as solar and Wind power increases the uncertainty in future generation. . A probabilistic approach that takes into consideration the correlation between the renewable (solar and wind farms) and the conventional sources has been performed. Analytical approach has been performed in order to obtain the efficient and effective transmission system. This paper has proposed a novel algorithm for TNEP formulation with consideration of the uncertainties in WTG and solar PV module power output. First of all the power flow distribution of network is calculated based on WTG and solar PV module output distribution. On this basis, economic efficiency index is used to evaluate the economic efficiency of all transmission lines of the network. Then low efficient lines are removed from the network until an optimum expansion scheme is obtained. All this work of developing Garver's six bus system and removing low efficient transmission lines is carried out in POWER WORLD SIMULATOR.

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