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Capacitor Placement and Reconfiguration of Distribution System with hybrid Fuzzy-Opposition based Differential Evolution Algorithm

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Abstract: *Distribution system reconfiguration and optimal capacitor placement are the two techniques adapted for the control of power loss. These techniques not only control the power loss but also control volt/var of the distribution system, and improve the system reliability and security. This paper proposes a method to handle reconfiguration and capacitor placement simultaneously for the effective optimization. In order to consider the constraints along with the objective, heuristic fuzzy has been integrated with ODE. The effectiveness of the proposed approach is demonstrated by employing the feeder switching operation scheme to IEEE-33 bus Power Distribution systems. The proposed algorithm reduces the transmission loss and controls volt/var while satisfying power flow constraints.*
Keywords *-Capacitor placement, Differential evolution, Distribution network reconfiguration, Loss reduction, Switching operation*

I. Introduction

Development of electrical power distribution system performance requires proper plans for increasing utilities efficiency, for instance, losses reduction. Different approaches are used to reduce losses such as optimal use of electrical equipments, optimal use of loading at the transformers, reconfiguration, and optimal capacitor placement, optimal placement of DG (Distributed Generation) and removal of harmonics. Amongst all, reconfiguration and capacitor placement are comparatively lesser operating cost. The reconfiguration of a distribution system is a process, which alters the feeder topological structure by changing the open/close status of the switches in the distribution system. The presence of high number of switching elements in a radial distribution system makes the network reconfiguration a highly complex combinatorial, non-differentiable and constrained non-linear mixed integer optimization problem. Also, the number of variables varies with respect to the size of the system. The distribution system with 'n' switches will have 'n' variables. The demand for a radial operation also makes the mathematical model more difficult to represent efficiently and codification of a solution becomes difficult when metaheuristic techniques are employed. Even though reconfiguration strategy has above said limitations, it is a most widely recommended and most successful strategy with zero operating cost.

The feeder reconfiguration problem has been dealt in various papers. Civanlar et al.[1] conducted the early work on feeder reconfiguration for loss reduction. In [2], Baran et al. defined the problem of loss reduction and load balancing as an integer programming problem. Aoki et al. [3] developed a method for load transfer, in which the load indices were used for load balancing. In Shirmohammadi and Hong [4], the solution method starts with a meshed distribution system obtained by considering all switches closed. Then, the switches are opened successively to eliminate the loops. Developments in algorithm design techniques such as simulated annealing [5], heuristic fuzzy [6], Artificial Neural Network [7], population based evolutionary algorithms [8-9] provides much improvement in reconfiguration strategy. The plant growth simulation algorithm (PGSA) is employed to optimize the network configuration of the distribution system [10]. The PGSA provides a detailed description on switch state and decision variables, which greatly contracts the search space and hence reduces computation effort. In [11], harmony search algorithm has been proposed for reconfiguration.

As the nature of capacitor placement problem is complex combinatorial, different techniques have been followed by the authors in the past. The initial contribution was made by Schmill [12] using 2/3 rule for capacitor placement. Dynamic programming with assuming the capacitor sizes as discrete variables adapted by Duran [13]. The capacitor problem was viewed as a nonlinear problem by Grainger et al. [14], where variables were treated as continuous. The improvements in advanced optimization techniques such as genetic algorithm, micro genetic, particle swarm optimization, ant colony and differential evolution allowed the optimization procedures comparatively easier than the conventional procedures. Optimal capacitor placement was carried out through genetic algorithm by [15]. The number of locations was considered as the total variables for genetic algorithm. The microgenetic concepts involving enhanced genetic algorithm was proposed in [16]. The power flow constraints were handled through fuzzy logic concepts. Optimization procedure through particle swarm optimization principle was adapted in [17]. Optimization through plant growth simulation algorithm (PGSA) was first introduced for feeder reconfiguration in [12]. Later, the PGSA along with loss sensitivity factors was introduced [18] for optimal capacitor placement. Loss sensitivity factors were used to find the optimal location i.e weak buses which require capacitor. PGSA was incorporated in order to find out the optimal sizing of the capacitors.

The optimization procedure combining both capacitor placement and reconfiguration was recently introduced. In [19], the ant colony optimization algorithm was introduced for the optimization. The combined usage of deterministic approach and heuristic technique for network reconfiguration and optimal capacitor placement for power-loss reduction and voltage profile improvement in distribution networks [20]. The improved reconfiguration method along with GA used for simultaneous reconfiguration and capacitor placement for distribution network optimization in [21].

In this paper, Opposition based Differential Evolution [22] algorithm has been presented for simultaneous handling of reconfiguration and optimal capacitor placement. Further, heuristic fuzzy has been incorporated to look at constraints with objective. The effectiveness of the proposed approach is demonstrated by employing the feeder switching operation scheme to IEEE-33 bus.

II. Problem Formulation

The main objective of the optimal capacitor placement is to minimize the total annual cost of the system subject to the power flow constraints such as bus voltage ($|V_{min}| < |V_i| < |V_{max}|$), branch currents ($|I_{ji}| < |I_{max,j\epsilon nl}|$) and radiality constraints. The mathematical equation relevant to the objective function of the problem is defined as,

$$F = Minimize(C) \tag{1}$$

Where, the term 'C' represents the total cost of the distribution system, it includes the cost for energy loss and capacitor cost.

The problem carried out with following assumptions.

(i) Loads are static
(ii) Distribution system is perfectly balanced
(iii) Well reactive power compensated system
(iv) Operation and maintenance costs of the capacitors are negligible.

The single line diagram of the balanced distribution system shown in the Figure 1 used to describe the load flow calculations. In Figure 1, P_i and Q_i represents the real and reactive power flow between the sending and receiving end buses, P_{Li} and Q_{Li} denotes the real and reactive power loads. The line resistance and reactance are denoted as $R_{i,j}$ and $X_{i,j}$. $\frac{y_i}{2}$ is the total shunt admittance at bus i

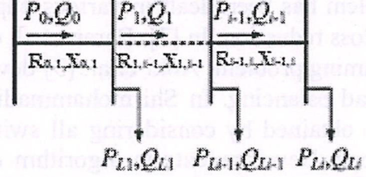

Figure 1 Single line diagram of a main feeder

The following set of equations are used to calculate the power flow,

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}\frac{P_i^2+Q_i^2}{V_i^2} \tag{2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}\frac{P_i^2+Q_i^2}{V_i^2} - V_i^2\frac{y_i}{2} \tag{3}$$

$$V_{i+1}^2 = V_i^2 - 2(R_{i,i+1}P_i + X_{i,i+1}Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2)\frac{P_i^2+Q_i^2}{V_i^2} \tag{4}$$

The power loss $P_{F,Loss}$ of the feeder is determined by summing the losses of all line sections of the feeder and it is given by,

$$P_{F,Loss} = \sum_{i=1}^{nl} R_{i,i+1} \frac{P_i^2+Q_i^2}{V_i^2} \tag{5}$$

The total energy loss cost (E_{cost}) has been calculated as,

$$E_{cost}=P_{T,loss} * K_p; \tag{6}$$

where K_p is the equivalent annual cost of power loss in \$/(kW-year)

In general, the cost per KVAR varies with respect to their size. The available capacitor sizes and their cost (K) were given in [19]. The total cost of the distribution system is given in equation (7).

$$C=E_{cost}+ C_{q,cost} \tag{7}$$

where,

$$C_{q,cost} = C_{q,fixed} + C_i^{annual} * Q_i$$

$C_{q,fixed}$ is the fixed cost for the capacitor placement \$/year

C_i^{annual} is the annual cost for the capacitor installation in \$/(KVAR-year) (i is the selected buses for capacitor installation)

Q_i is the reactive power in (KVAR)

III. Search Strategy For Capacitor Sizing Through Ode Algorithm

Opposition based differential algorithm is a recent evolutionary algorithm with enhanced features such as self acceleration, self migration and assured optimal search with least population size. The efficiency of the algorithm can be well proven by applying into complex and/or large problems. In this paper, the purpose of introduction of ODE is to find the optimal location for capacitor placement, optimal capacitor size and optimal configuration. The number of variables for ODE searching is the total of number of loops, number of locations and number of locations (for proper sizing). For instance, the system with 'x' loops and 'y' locations will require 'x+2y' ODE variables.

IV. Fuzzy Operations For Multi-Objective Capacitor Placement

In fuzzy domain, each objective is associated with a membership function. The membership function indicates the degree of satisfaction of the objective. In the crisp domain, either the objective is satisfied or it is violated, implying membership values of unity and zero, respectively. When there are multiple objectives to be satisfied simultaneously, a compromise has to be made to get the best solution. The four objectives such as power loss minimization, total cost minimization, bus voltage deviation minimization and branch current deviation minimization are fuzzified and dealt by integrating them into a min-max imperative of fuzzy satisfaction objective function.

In the proposed method for system optimization, the terms μ_{Fj}, μ_{Cj}, μ_{Vj} and μ_{Ij} indicate the membership function for power loss reduction, total cost reduction, bus voltage deviation and branch current deviation respectively of the j^{th} configuration. The higher membership value implies a greater satisfaction with the solution. The membership function consists of a lower and upper bound value together with a strictly monotonically decreasing and continuous function.

4.1 Fuzzy-set Model for Power Loss Minimization

The deviation of power loss of the new configuration (P_{nloss}) to the previous configuration loss (P_{oloss}) is to be identified with the objective of minimizing the system power loss. The power loss of the system has been obtained from radial load flow for each new configuration. Moreover, the amount of the P_{nloss} resulting from capacitor inclusion can be estimated as 'very close, 'close' or 'not close' to the P_{oloss}. Therefore, the linguistic terms can be formulated as a membership function by the fuzzy notation. The membership function μ_{Fj} has been depicted using Equation (8). A small difference between P_{nloss} and P_{oloss} possesses a larger membership value. The membership function at j^{th} configuration can be expressed as follows,

$$\mu_{Fj} = \begin{cases} \dfrac{X_{max} - X_j}{X_{max} - X_{min}} & \text{for } X_{min} < X_j < X_{max} \\ 1.0 & \text{for } X_j \le X_{max} \\ 0.0 & \text{for } X_j \ge X_{max} \end{cases} \qquad (8)$$

where, $X_j = P_{nloss}/P_{tloss}$

V. Simulation Results

The effectiveness of the algorithm has been validated through IEEE 33-bus test distribution system [19]. The system has 5 normally opened switches, 32 normally closed switches with 33 buses and it is assumed as balanced three-phase with 12.66kV. The corresponding power loss is 202.7kW. It has been carried out by considering the system working under normal conditions, i.e., all the branches are being loaded without violating its limits, voltage at the buses is within limit and the phases are balanced.

The optimization process starts with identifying the total variables, such as number of locations for capacitor placement and loops present in the distribution system. For the test system, it has been considered as 5 loops and 3 locations for the capacitor placement based on experience and earlier studies. Therefore, total number of variables required for ODE searching is 11(ie. 5 for loops, 3 for locations and 3 for sizing).

5.1 Variable Size

For the 5 loops, as per the PGSA [10], decision variables are designed for the system, which is shown in Fig. 2.

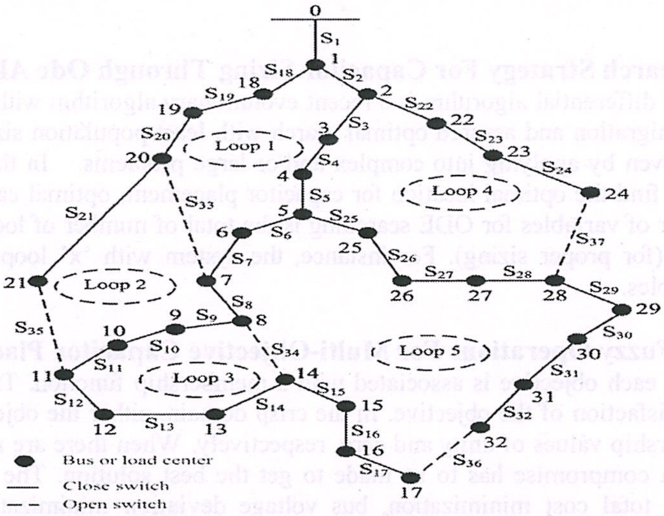

Figure 2 IEEE 33-bus RDS with state variable sketch

The description of the switch states is identified as,

i. the open switches are S_{33}, S_{34}, S_{35}, S_{36}, and S_{37};
ii. the closed switches are S_1 to S_{32};
iii. the permanently closed switches are S_1, S_2, S_3, S_{18} and S_{22} (since these switches are near to the feeder);
iv. the temporary closed state switches are S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{25}, S_{26}, S_{27}, and S_{28} (since these switches are common to more than one loop;

As a result, the solution sets are re-defined as,

$$\left.\begin{aligned} L_1 &= \{S_4, S_5, S_6, S_7, S_{20}, S_{19}, S_{33}\} \\ L_2 &= \{S_8, S_9, S_{10}, S_{11}, S_{21}, S_{35}\} \\ L_3 &= \{S_{12}, S_{13}, S_{14}, S_{34}\} \\ L_4 &= \{S_{25}, S_{26}, S_{27}, S_{28}, S_{23}, S_{24}, S_{37}\} \\ L_5 &= \{S_{15}, S_{16}, S_{17}, S_{32}, S_{31}, S_{30}, S_{29}, S_{36}\} \end{aligned}\right\} \qquad (9)$$

The equation (9) reveals that the system has five loops with set of switches. The searching for the best set of open switches from each loop has been carried out with ODE. The number of switches present in each loop such as 7,6,4,7 and 8 defines the range for the variables. Therefore, the range for the searching process is selected as (1-7), (1-6), (1-4), (1-7) and (1-8) for the variables L_1, L_2, L_3, L_4 and L_5 respectively.

For location variables, total number of buses except feeder bus has been considered as the maximum range for the variables. For 'n' bus system, the maximum value of the variable has to be 'n-1'.

For capacitor sizing variables, the range for the variables and corresponding cost has been shown in Table 1 [18].

Table 1 Capacitor sizes and cost

Sl. No.	Q in kVAR	Capacitor cost in $/kVAR	Sl. No.	Q in kVAR	Capacitor cost in $/kVAR
1	150	0.500	15	2250	0.197
2	300	0.350	16	2400	0.170
3	450	0.253	17	2550	0.189
4	600	0.220	18	2700	0.187
5	750	0.276	19	2850	0.183
6	900	0.183	20	3000	0.180
7	1050	0.228	21	3150	0.195
8	1200	0.170	22	3300	0.174
9	1350	0.207	23	3450	0.188
10	1500	0.201	24	3600	0.170
11	1650	0.193	25	3750	0.183
12	1800	0.187	26	3900	0.182
13	1950	0.211	27	4050	0.179
14	2100	0.176			

5.2 Implementation

For instance for variable L_1, by the control strategy "DE/current-to-rand/1" the value generated is 3 then S_6 is the switch assumed as opened in the loop 1 and the same process is continued for the rest of the variables. The initial population and their respective losses were calculated and stored. With the initial values of F=0.8 and CR=0.6 searching was done for the fixed number of iterations. The proposed method reduces the power loss from 202.67 kW to 101.42 kW, and maintains the bus voltages well above minimum value. The kVAR at the buses 27, 28 and 29 are 149, 727 and 149 respectively. With the effective influence of capacitors at the optimal locations the total operating cost of the system has been reduced from 34,049.75 $/Year to 18,198.96 $/Year. Thus the proposed algorithm has achieved 46.55 % of cost saving with the combined reconfiguration-optimal capacitor placement case. Furthermore, the bus voltages are maintained within the limit. The results of the three cases are compared in Table 2 along with the results of the previous published work [20]. From the Table, it is understood that the annual operating cost and power loss has been greatly reduced with the combined reconfiguration and capacitor placement approach.

Table 2 Summary of results for 33-bus RDS

Parameters	Initial Configuration	Reconfiguration Only [10]	Capacitor Placement Only [18]	Reconfiguration and Capacitor Placement [20]	Proposed Reconfiguration and Capacitor Placement
Loss (kW)	202.67	139.54	159.89	101.49	101.42
Min. bus Voltage (pu)	0.913	0.9378	0.933	0.957	0.959
Total Capacitor size (kVAR)	-	-	2940	1685	1027
Power Loss Cost ($/(KW-yr))	-	23444.62	26861.59	17038.56	17039.03
Capacitor Cost ($/yr)	-	-	1529.87	722.84	159.94
Total Annual Cost ($/yr)	34049.75	23444.62	28,391.46	18761.4	18198.96
% saving	-	31.14	16.61	44.9	46.55

VI. Conclusion

An efficient approach that combines the reconfiguration and optimal capacitor placement for power loss reduction and bus voltage improvement has been proposed in this paper. ODE has taken care of reconfiguration, optimal capacitor location and capacitor sizing. With the effective inclusion of heuristic fuzzy, the power flow constraints were considered along with loss reduction. The proper use of ODE improves the efficiency in terms of reduced number of load flow executions, reduced computational executions and removal of unfeasible solutions in the search space. The results obtained with the present approach, when compared with the previous methods proposed by the authors shows that the introduction of the algorithm with hybrid FODE has contributed to reduce the number of power flows and has incorporated the network constraints. Hence with the effective introduction of the proposed algorithm, loss reduction was done subjected under constraints such as bus voltage limit and branch current limit and can be applied to any large real radial distribution system supplied from both single and multi feeders.

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Optimal Placement and Integration of Wind Turbine Generators to the Grid

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Ms. Sunitha P

***Abstract* – Wind energy conservation systems exhibits variability in their output power as a result of change in their prime movers (wind speed).This introduces a new factor of uncertainty on the grid and posses a lot of challenges to the power system planner and the utility operators in terms of power system grid integrity (i.e.) power system stability, power system security and power quality. This paper discusses the various challenges (poor voltage profile, over loading of components, increase in loss, increased short circuit rating, harmonics, maloperation of relays etc...) of wind power when integrated into the grid and identifies different mitigating strategies for its smooth integration. This paper therefore enables the specifications for mitigation or integration technologies to be appreciated and quantified. The main objective of this paper is to reduce the losses and loading, increasing the voltage profile by adding wind turbine generator to Tamil Nadu grid in appropriate location. The entire Tamil Nadu grid of 33 KV transmission line is to be modeled using the ETAP software (Electrical Transient Analysis and Programme).**

Smart grid aims at 20% renewable energy integration to the grid by 2020. Tamilnadu has already integrated more than 40% of wind into the grid. Since private entities are encouraged to setup wind on their own for the past two decades and nobody is to regulate the interconnection, which leads to unplanned growth which causes high losses, poor voltage profile, high equipment loading etc. This also reduces plant load factor of wind farms drastically due to unavailability of grid.

Paper aims at increasing plant load factor by means of strengthening network for existing wind forms and necessitates proper guidelines for upcoming wind farms. Paper also dealt with modeling of WTGs to study the impact in macro level.

***Keywords* – Wind Integration, TNEB 400kV Network, Etap-12.6, Impact of Wind.**

I. Introduction

The conventional energy sources are limited and lead to environmental pollutions. Efforts are geared towards grid integration of renewable energy sources into a grid as a result of environmental concerns and the quest for energy security. Wind energy is the fastest growing and most promising renewable energy sources among them because it is abundant, cheap, inexhaustible, widely distributed, clean and climate benign.

The major challenge associated with the wind power generation is due to the intermittent nature of the wind. Challenges using wind energy includes that wind cannot be stored and all the energy in the wind cannot be completely harnessed during the time of light demand.

As dated on March 3rd 2013 installed capacity of wind energy is 7010MW. Tamilnadu has dispatched history of more than 3500 MW which shows the wind potential utilization and future expansions. Tamilnadu has large wind potential in Palladam and Pollachi region also in the aralvaimozhi and kayathar is the major potential of wind energy available in the southern region of Tamilnadu.

The major impact of wind turbine generators while integration are voltage profile, transmission line losses and equipment loading level. In 1991 Tamilnadu has very less capacity of wind energy and it was the beginning stage of wind plants in Tamilnadu. In 1996, wind contribution has improved to a much extend because of private entities. This scenario continued till 2006 and the power from wind was increased drastically. This period was generally called it as "booming period".

Addition of wind starts saturated from the year of 2007. In 2012 only 30 MW is added which is nearly 0.05% of total installed capacity. It shows the clear indication that growth of wind mill will be questionable if adequate steps are not taken to improve the transmission network strength. Total installed capacity in Tamilnadu so far is 26,032 MW. For an optimal integration the voltage profile should be good, transmission line losses and equipment loading must be as low as possible. PLF could be improved if the transmission bottlenecks and connectivity issues are taken care. Etap-12.6 software is used to simulate the grid model with wind farms. Newton Rapshon method is used to solve the load flow analysis considering the convergence of such large system without compromising accuracy.

II. System Modeling

Tamilnadu 33 kV transmission network with various type of Wind Turbine Generators are considered Simulation. Various scenarios are included such as Peak Wind Peak Load, Peak Wind Average Load, Peak Wind Low Load, Average Wind Peak Load, Average Wind Average Load, Average Wind Low Load, Low Wind Peak Load, Low Wind Average Load, Low Wind Low Load.

An AC power-flow model is a model used in electrical engineering to analyze power grids. It provides a nonlinear system which describes the energy flow through each transmission line. The problem is non-linear because the power flow into load impedances is a function of the square of the applied voltages. Due to nonlinearity, in many cases the analysis of large network via AC power-flow model is not feasible, and a linear (but less accurate) DC power-flow model is used instead.

Usually analysis of a three-phase system is simplified by assuming balanced loading of all three phases. Steady-state operation is assumed, with no transient changes in power flow or voltage due to load or generation changes. The system frequency is also assumed to be constant. A further simplification is to use the per-unit system to represent all voltages, power flows, and impedances,

scaling the actual target system values to some convenient base. A system one-line diagram is the basis to build a mathematical model of the generators, loads, buses, and transmission lines of the system, and their electrical impedances and ratings.

The goal of a power-flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. Due to the nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance.

The solution to the power-flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus. A bus without any generators connected to it is called a Load Bus. With one exception, a bus with at least one generator connected to it is called a Generator Bus. The exception is one arbitrarily-selected bus that has a generator. This bus is referred to as the slack bus.

In the power-flow problem, it is assumed that the real power PD and reactive power QD at each Load Bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real power generated PG and the voltage magnitude |V| is known. For the Slack Bus, it is assumed that the voltage magnitude |V| and voltage phase angle are known. Therefore, for each Load Bus, the voltage magnitude and angle are unknown and must be solved for; for each Generator Bus, the voltage angle must be solved for; there are no variables that must be solved for the Slack Bus. In a system with N buses and R generators, there are then 2(N-1)-(R-1) unknowns.

In order to solve for the 2(N-1)-(R-1) unknowns, there must be 2(N-1)-(R-1) equations that do not introduce any new unknown variables. The possible equations to use are power balance equations, which can be written for real and reactive power for each bus. The real power balance equation is:

$$0 = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \tag{2.1}$$

where P_i is the net power injected at bus i, G_{ik} is the real part of the element in the bus admittance matrix YBUS corresponding to the ith row and kth column, G_{ik} is the imaginary part of the element in the YBUS corresponding to the ith row and kth column and θ_{ik} is the difference in voltage angle between the ith and kth ($\theta_{ik} = \delta_i - \delta_k$). The reactive power balance equation is:

$$0 = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \tag{2.2}$$

Where Q_i the net reactive power is injected at bus i. Equations included are the real and reactive power balance equations for each Load Bus and the real power balance equation for each Generator Bus. Only the real power balance equation is written for a Generator Bus because the net reactive power injected is not assumed to be known and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the Slack Bus.

In many transmission systems, the voltage angles θ_{ik} are usually relatively small. There is thus a strong coupling between real power and voltage angle, and between reactive power and voltage magnitude, while the coupling between real power and voltage magnitude, as well as reactive power and voltage angle, is weak. As a result, real power is usually transmitted from the bus with higher voltage angle to the bus with lower voltage angle, and reactive power is usually transmitted from the bus with higher voltage magnitude to the bus with lower voltage magnitude. However, this approximation does not hold when the voltage angle is very large.

There are several different methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton–Raphson method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1}\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{2.3}$$

Where ΔP and ΔQ are called the mismatch equations:

$$\Delta P_i = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \tag{2.4}$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \tag{2.5}$$

III. System Network

Tamilnadu is one of the state which is located in southern corner of India and is surrounded by Andhra pradhesh, Kerala, Karnataka and Pondicherry.

Tamilnadu has installed capacity of thermal power of 4420 MW, hydro power of 2240 MW, Other Gas/Naptha/Diesel power of 2732 MW, other power plants of 806 MW and wind power of 7040 MW. Central government sector contribution to Tamilnadu is 8810 MW. Total installed capacity of power is 26,032 MW. Tamilnadu has peak demand of 12,933 MW. Also TN has off-peak demand of 12,658 MW. Average demand of TN is 13,366MW. Southern regional grid maintains the system frequency of 50 Hz with tolerance of + or – 0.5 Hz after implementation of Availability Based Tariff.

Table I Generator data

Generator Name	Scheduled Power MW	Voltage kV	Qmin MVAR	Qmax` MVAR
Neyveli	210	11	0	130.03
Neyveli-Ext	250	11	0	295
Kudamkulam	1000	21	0	484.32
Tuticorin-ST4	500	21	0	242.71

Tuticorin	500	21	0	242.71
Ind-Bharath	600	21	0	290.60
Coastal Ene	600	21	0	290.60
Mettur	500	21	0	242.17
Chennai	660	21	0	319.64
North Chennai	600	21	0	290.60
North ChennaiABAN	600	21	0	290.60

All the generators are not allowed to operate reactive power consumption mode because of stability issues which will be dealt in separate paper.

Table II Transformer Data

Transformer	Rating MVA	HV Voltage kV	LV Voltage kV	Impedance in pu
Neyveli	250	400	11	0.14
Neyveli-Ext	300	400	11	0.14
Kudamkulam	1200	400	21	0.14
Tuticorin-ST4	560	400	21	0.14
Tuticorin	560	400	21	0.14
Ind-Bharath	670	400	21	0.14
Coastal Ene	670	400	21	0.14
Mettur	560	400	21	0.14
Chennai JV	740	400	21	0.14
North Chennai	670	400	21	0.14
North Chennai ABAN	670	400	21	0.14

Table III Conductor Data

Type	R()	X	Y
Twin Moose (+Ve Seq)	0.1	0.4	0.00001
Twin Moose (-Ve Seq)	0.1	0.4	0.00001
Twin Moose (Zero Seq)	0.1	0.4	0.00001

Load data is considered based on the daily report of Tamilnadu from SRLDC website. Power factor is also considered based on the operating condition.

IV. Simulation Results

Load flow analysis for the Tamilnadu grid without addition of wind farms provides result of very good voltage profile, less equipment loading and 1.3% of transmission line losses {i.e Wind generators are considered as out of service}.

Load flow result for Tamilnadu grid with addition of wind farms {50% of installed capacity is considered} provides poor voltage profile, high equipment loading & line losses {1.8%}.

Load flow result for Tamilnadu grid with our proposal for transmission network with 50% of wind installed capacity is studies. Result shows good voltage profile, less equipment loading and less line losses {1.4%}. It also shows very high availability of transmission network during peak windy seasons.

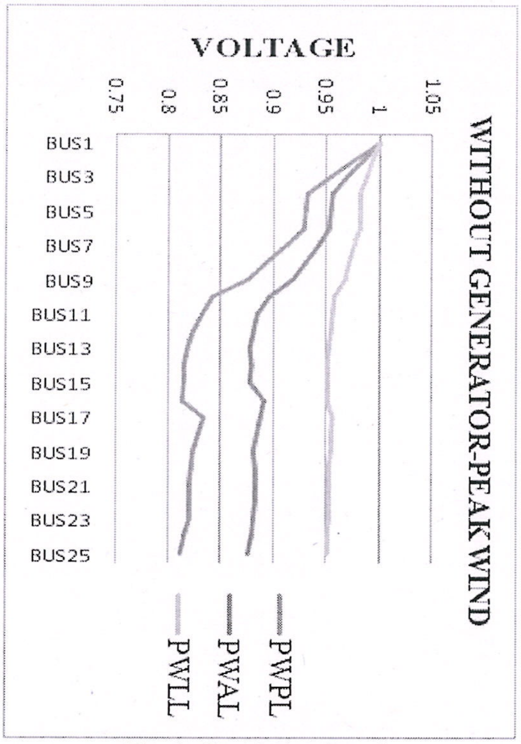

Fig. 1. Simulation Result

This results in increasing the Plant Load Factor which falls down due to unavailable transmission network. The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. ETAP allows you to select from several different methods in order to achieve the best calculation efficiency. Fig 1 shows the voltage profile at various loading and wind conditions. Table provided in the annexure 1 provides the voltage profile at various buses and loading. The study is repeated with many configuration and contingencies to identify the optimal configuration for connecting the Wind Turbine Generators. Result shows that optimal configuration reduce the losses to the extent of 18% in peak load conditions and about 11% during peak load with average wind conditions. Results have severe impact on the financial viability of the project since these values directly have an impact on deciding power evacuation scheme of existing and proposed generators.

V. Conclusion

A detailed analysis on the impacts of integrating the wind turbine generators with the Tamilnadu grid has been presented in this project. A 33 kV transmission system has been taken as an example for the analysis. The system has been modeled with ETAP (Electrical Transient Analysis and Programme) software. The voltage level at each bus and the losses that occurred in the transmission lines has been simulated and tabulated. The impacts of integrating the wind turbine generators along with the specified grid

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has been analyzed by choosing different scenarios such as low wind, average wind and peak wind. The outcome of the scenarios has been represented in the graphical representation. Paper increased the plant load factor by means of strengthening network for existing wind forms and necessitates proper guidelines for upcoming wind farms. Paper also dealt with modeling of WTGs to study the impact in macro level.

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