International Journal of Applied Science and Mathematics
Volume 3, Issue 2, ISSN (Online): 2394-2894

Optimal Placement and Integration of Wind Turbine Generators to the Grid

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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:

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

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:

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

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:

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

Where ΔP and ΔQ are called the mismatch equations:

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

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

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

International Journal of Applied Science and Mathematics
Volume 3, Issue 2, ISSN (Online): 2394-2894

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.

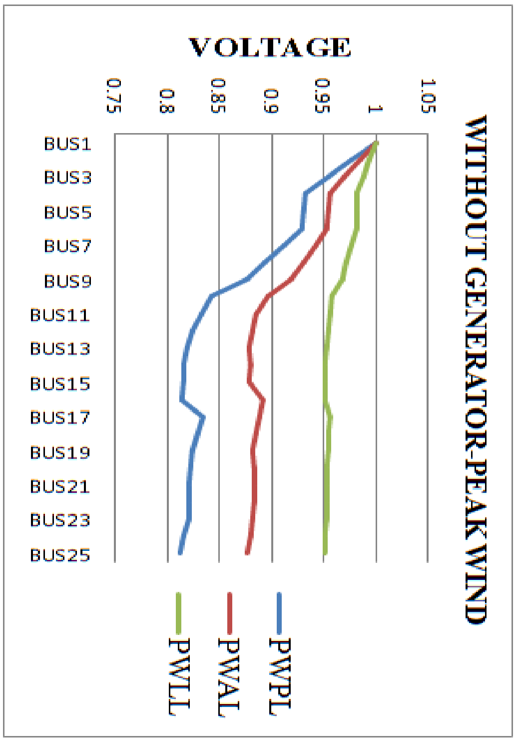

Fig. 1. Simulation Result

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 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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Dr.R.Muthukumar, completed B.E. in Electrical and Electronics Engineering in the year 2002, and completed M.E Power Systems Engineering in Government College of Technology, Coimbatore. He Received PhD from Anna University, Chennai in the year 2014, Tamilnadu. He is having 12 Years of Teaching Experience. He has published 4 Papers in National Conferences and twelve papers in International journals. He is Currently working as a Associate Professor in Shree Venkateshwara Hi-tech Engineering College, Gobi. He is a Life member of the Indian Society for Technical Education (ISTE). His research interest includes power system planning, voltage stability and application of evolutionary algorithms.

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