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Wind Integrated Time series load flow analysis for a Practical Distribution System

Análisis del flujo de carga de series de tiempo integrado para un sistema de distribución práctico en un modelo eólico

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ABSTRACT: Wind is a clean source of energy which is naturally available and has been replacing the harmful non-perennial conventional power plants such as Thermal, Hydro, Nuclear etc., The innovation in design has gradually reduced the cost to set up a wind power plant. This has increased the penetration of wind energy in the Distribution Network (DN). Being a seasonal power generation, wind energy integration in the distribution network has created many challenging issues like voltage stability, system reliability and power system network stability. Hence a thorough analysis of wind energy integration is needed to make the power system network more stable. This paper describes the dynamic behavior of the distribution system while integrating wind energy through time series analysis. The load flow is performed using Newton-Raphson method, with a variable load profile. Time series analysis is done which gives the performance characteristics of the system which is validated in a practical IEEE 123 test feeder.

RESUMEN: El viento es una fuente limpia de energía, que es naturalmente disponible y ha estado reemplazando las centrales de energía eléctrica convencionales no perennes tales como trmicas, hidroelectricas,nucleares etc., La innovación en el diseño ha reducido gradualmente el costo de instalar una planta de energía eólica, aumentando la penetración de este tipo de energía en la Red de Distribución (DN)de energía. Al ser una generación de energía estacional, la integración de la energía eólica en la red de distribución ha creado muchos desafíos como la estabilidad del voltaje, la confiabilidad del sistema y la estabilidad de la red del sistema eléctrico. Por lo tanto, un análisis exhaustivo de la integración de la energía eólica es necesario para hacer el sistema de energía más estable. Este artículo describe el comportamiento dinámico del sistema de distribución al tiempo que integra la energía eólica mediante análisis de series de tiempo. El flujo de carga se realiza utilizando el método de Newton-Raphson, con un perfil de carga variable. Se realiza un análisis de series temporales que da las características de rendimiento del sistema que se valida en un alimentador de prueba IEEE 123 práctico.

1. Introduction

Reduction of conventional energy sources and awareness of green energy to save the globe have resulted in utilization of Distributed Energy Resources (DER). Wind energy is one of the best alternatives, which is environment friendly, naturally available resource. The increased installation of wind power plants had highly contributed to meet the growing demand of electricity.

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The selection and classification of wind sites is the primary requirement for successful production of wind energy, as it totally depends on the wind velocity [1]. After the use of conventional induction generators, double output induction generators, were used to operate wind generators at various shaft speeds [2]. Load flow analysis was done to improve the PQ bus and for modelling the generator at steady state [3]. The penetration of wind energy reduces the line losses and with an effective reactive power control the voltage profile of the power system network was improved [4]. Optimal accommodation and smart operation of Renewable Energy Resources (RES) have minimized the energy losses in the power system network [5]. Wind power curtailment has been monitored and assesses the adequacy of

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availability of wind energy [6]. Furthermore, to increase the efficiency of the wind power generation and to use within three phase unbalanced load flow analysis, Doubly Fed Induction Generator (DFIG) and permanent magnet synchronous generators were introduced [7].To overcome the variability, in wind flow a flexible despatch margin was proposed. This flexible despatch margin provided flexibility in scheduling the hour-ahead energy market [8]. Furthermore, to produce constant power output while integrating the wind power plant, battery energy storage system was used as a hybrid which has considerably improved the power despatch capability of the system [9]. To have a frequency regulation in the power system network co-ordinated control of wind energy conversion system and battery energy storage system was introduced. This gave an active power control and frequency control for variable wind speed conditions [10]. To enhance active power control a distributive model predictive control using fast gradient method was proposed [11].

The Newton - Raphson method is one of the best conventional load flow solution method which uses the current injection at each node through rectangular co-ordinates. This method provides a faster power flow solution with less number of iterations [12]. Furthermore, to have comprehensive load flow analysis, a new NR method was proposed which has provided effective active and reactive power control [13]. Previous NR methods had many limitations and were not suitable for ill conditioned distributed system. Hence a new modified NR method was introduced which was a continuous version suitable for numerical integration techniques and solved load flow for ill conditioned system [14]. With the introduction of micro grid, the conventional NR load flow method was difficult for implementation in islanded micro grids. Hence a simple, efficient NR method was proposed to compute power flow for micro grids [15].

In this paper, the impact on integrating wind energy in a practical distribution system is developed using time series analysis. A practical test system with highly unbalanced load profile is taken and the power flow is run through NR method. The NR method used here is a modified version of the NR method using current injection method to compute the load flow analysis. Based on the inference, nodes are identified and wind generator is integrated along with continuously variable load profile. Time series analysis provides a better approach to study the dynamic behaviour of the power system network. The results are validated in an IEEE 123 test feeder and compared with and without integration of wind generator. The second section gives the modelling of wind generator and the third section gives the formulation of NR method. Fourth section explains the IEEE 123 test feeder description and fifth section gives the results and discussions over the implementation in the practical distribution system.

2. Wind generator Modeling

The wind generator is modeled as a PQ bus assuming the system real power and with the given power factor the reactive power consumed is calculated. Wind turbine can be operated either with fixed speed or variable speed. Fixed speed induction generator is directly connected to the grid, but the wind turbulence of the system will result in power variations and hence affects the power quality of the system. Hence for a variable speed wind generator, the generator is controlled through power electronic controller [16].

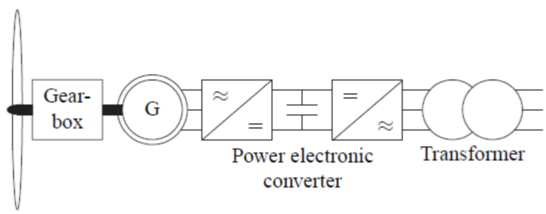

Figure 1 Wind generation model with induction generator

Fig. 1 shows the wind energy conversion system with induction generator. In this paper, when induction generator is used the wind turbine is connected through a gear box. The gear box is designed to produce maximum rotor speed of the generator. The stator of the generator is connected to a power electronic converter. When a synchronous generator is used as shown in Fig. 2 the generator is designed with multiple poles, hence gear box is not needed. The converter consists of an uncontrolled rectifier, a boost converter and a three phase pulse width modulated inverter [17].

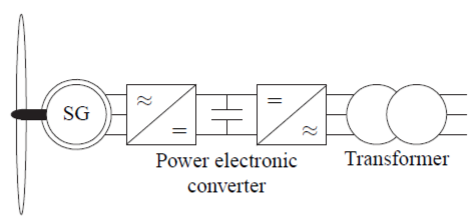

Figure 2 Wind generation model with synchronous generator

Aerodynamic modeling:
The mechanical input power P_m at the shaft is given in (1)

$$P_m = \frac{1}{2}\rho A (V_\omega)^3 C_p(\lambda) \quad (1)$$

where ρ = $1.25Kg/m^3$ is the air density.
$A = \pi r^2$ is the area of the rotor.
V_ω is the wind velocity.
$C_p(\lambda)$ is the aero dynamic power co-efficient.

For a three blade wind turbine the distance of each blade from the ground as a function of its angular position θ_i is given in (2)

$$h_i = H_{hub} + cRsin\theta_i \tag{2}$$

where $i = 1...3$

H_{hub} is the hub height. $C < 1$ which defines the distance of aerodynamic center of the blade from its root.

$$V_\omega(\theta, t) = V_{\omega(t)} \frac{H_{hub} + cRsin\theta}{H_{hub}} f(\theta). \tag{3}$$

The total input mechanical power on the shaft is given in (4)

$$P_m = \frac{1}{2}\rho A \sum i = 1^3 (V_\omega(\theta_i, t))^3 \frac{1}{3} C_p(\lambda_i) \tag{4}$$

where $i = 1...3$

3. Newton - Raphson Load Flow Analysis

Load flow analysis is carried out to determine the voltage and power flow of a practical distribution system. Many methods are available for performing load flow analysis. In this paper, Newton - Raphson method is used to run the power flow as it is suitable for mesh network. NR power flow modeling consists of two sets of equations. The first set of equations describes the current injection from the load into the system. They are split into real and imaginary parts as given in (5) and in (6).

$$\triangle I_{rn} = \frac{(P_n)(V_{rn}) + (Q_n)(V_{in})}{(V_{rn})^2 + (V_{in})} - \sum_{k=1}^{m} \sum_{t} (G_{nk}V_r - B_{nk}V_{ir}) \tag{5}$$

$$\triangle I_{in} = \frac{(P_n)(V_{in}) + (Q_n)(V_{rn})}{(V_{rn})^2 + (V_{in})} - \sum_{k=1}^{m} \sum_{t} (G_{rk}V_in - B_{rk}V_r) \tag{6}$$

where
$\triangle I$ is the current injection in the bus
n is the bus number.
t represents all phases connected to the bus.
P is the real power of the load.
Q is the reactive power of the load.

If E_n represents voltage of the bus such that
V_{rn} is the real portion of the voltage
V_{in} is the imaginary portion of the voltage

$$E_n = V_{rn} + jV_{in} \tag{7}$$

With the current injections calculated the voltage updates are calculated through:

$$\begin{bmatrix} \triangle I_{rn} \\ \triangle I_{in} \end{bmatrix} = -J^-1 \begin{bmatrix} \triangle V_{in} \\ \triangle V_{rn} \end{bmatrix}$$

where J^-1 is the inverse Jacobian.

$$J = \begin{bmatrix} \frac{\delta \triangle I_{in}}{\delta V_{rn}} & \frac{\delta \triangle I_{in}}{\delta V_{in}} \\ \frac{\delta \triangle I_{rn}}{\delta V_{rn}} & \frac{\delta \triangle I_{rn}}{\delta V_{in}} \end{bmatrix} \tag{8}$$

For any bus k the real and reactive power of the network is given in (9) and (10)

$$P_k = V_k \sum_{n=1}^{N} Y_{kn} V_n cos(\delta_k - \delta_n - \theta_{kn}) \tag{9}$$

$$Q_k = V_k \sum_{n=1}^{N} Y_{kn} V_n sin(\delta_k - \delta_n - \theta_{kn}) \tag{10}$$

Equations 5, 6, 7 and 8 are frequently used to calculate the nodal voltages, using current injections into the system through NR method. Equations 9 and 10 are used to compute the real and reactive power flow in the line.

4. System Description

The IEEE 123 Node test feeder is taken for demonstrating the power flow and realizing the impact of wind energy integration. Fig. 3 shows the line diagram of the IEEE 123 test feeder [18].

The IEEE 123 test feeder is a practical test system with a source voltage of 115 KV and a nominal voltage of 4.16 KV. This feeder is taken for time series analysis as this feeder is a lengthy feeder and has voltage drop problems. This voltage drop problems are solved by adding four step type regulators at necessary locations. It

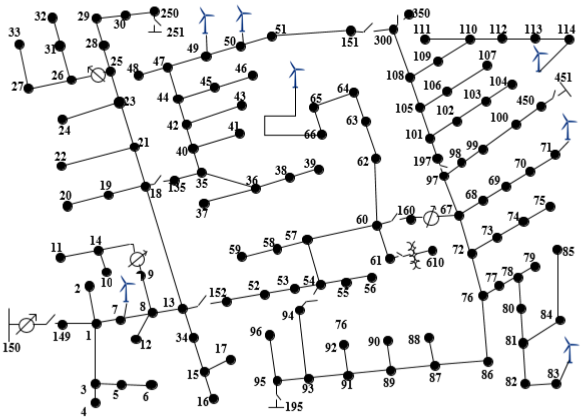

Figure 3 IEEE 123 Test Feeder

consists of a mesh network with enough inter connectivity switches, which can be optimized as per the requirement. The feeder consists of overhead and underground lines with various phasing. It has a combination of all loads such PQ, constant current and constant impedance loads and is unbalanced.It is a highly unbalanced system with three phase and single phase laterals with all the loads being spot loads. The system has an inline distribution transformer with a nominal voltage of 4.16 KV for a small span of the network. It has 85 spot loads, out of which 15 loads are constant impedance loads, 13 loads are constant current loads and 57 loads are PQ loads. The total real power at phase A is 1420kW and in phase B it is 915kW and in phase C it is 1155kW. The network has two regulators with 24 three phase laterals and 10 single phase laterals. It has four inline shunt capacitors to maintain the voltage profile. The feeder is well behaved and does not have a convergence problem. The power flow is carried out using Newton - Raphson load flow analysis. For running the power flow the line to neutral voltage is considered. At the substation the line to neutral voltage is 66.397 KV and the voltage at the distribution transformer end is 2401.847 V.

Table 1 Load Voltage before integration of wind generator

Load nodes	Voltage_A (V)	Voltage_B (V)	Voltage_C (V)
load_1	2495.83	2505.42	2503.46
load_7	2486.81	2504.38	2502.22
load_28	2447.36	2499.76	2494.43
load_29	2446.40	2500.31	2494.34
load_30	2446.40	2500.31	2494.34
load_35	2453.16	2491.70	2493.97
load_42	2448.57	2487.70	2491.52
load_47	2445.06	2485.34	2488.65
load_48	2444.35	2484.76	2488.01
load_49	2445.06	2485.34	2488.65
load_50	2445.06	2485.34	2488.65
load_51	2445.06	2485.34	2488.65
load_52	2471.68	2501.86	2501.64
load_53	2470.90	2501.86	2502.32
load_55	2469.96	2502.11	2502.71
load_56	2469.96	2502.11	2502.71
load_60	2471.16	2498.89	2505.90
load_62	2469.97	2496.20	2504.38
load_63	2469.14	2494.32	2503.32
load_64	2467.48	2490.58	2501.19
load_65	2465.40	2489.03	2498.66
load_66	2465.40	2489.03	2498.66
load_76	2600.27	2519.11	2587.22
load_77	2603.67	2523.97	2590.41
load_79	2603.74	2525.55	2591.30
load_80	2610.06	2529.58	2596.06
load_82	2618.71	2537.31	2602.25
load_83	2621.70	2539.97	2604.39
load_86	2603.04	2518.42	2588.19
load_87	2604.88	2518.10	2588.69
load_95	2605.00	2517.56	2589.81
load_98	2596.15	2517.28	2582.44
load_99	2597.05	2516.97	2580.59
load_100	2597.54	2516.86	2579.58

5. Results and Discussions

The load flow analysis is carried out in the IEEE 123 test feeder and the output is analysed using time-series simulation and the impact of wind energy integration is analysed by taking time step values of power and voltage during the month of July, when the wind source is maximum. The wind data for the complete year have been taken and integrated in the program. Wind energy is totally depending upon the wind speed in that particular location. To illustrate this, time series simulation was carried out for one day in a time step of one hour resolution. In Fig. 4 we have compared the feeder power and the wind speed, it is observed that when the wind speed increases the feeder power reduces and vice versa.

Wind generator is proposed to integrate in the IEEE 123 test feeder and analysis was done with and without integrating wind energy and time series simulation was done for the month of July through NR method. Fig. 5 gives the wind diffuse for the month of July. It is observed that the average wind speed ranges between 10 to 15 m/sec which is quiet sufficient for wind power generation. Table 1 gives the load voltages in all the three phases before integrating wind generator. It is observed that the voltage level in phase A is less when compared with other phases. The voltage mismatch in nodes 7, 28, 29, 48, 49, 50 and 51 are more. To improve the voltage profile PQ nodes are identified at remote locations and wind generators are integrated in these nodes. The identified nodes are 7, 49, 50, 66, 71, 83 and 114.

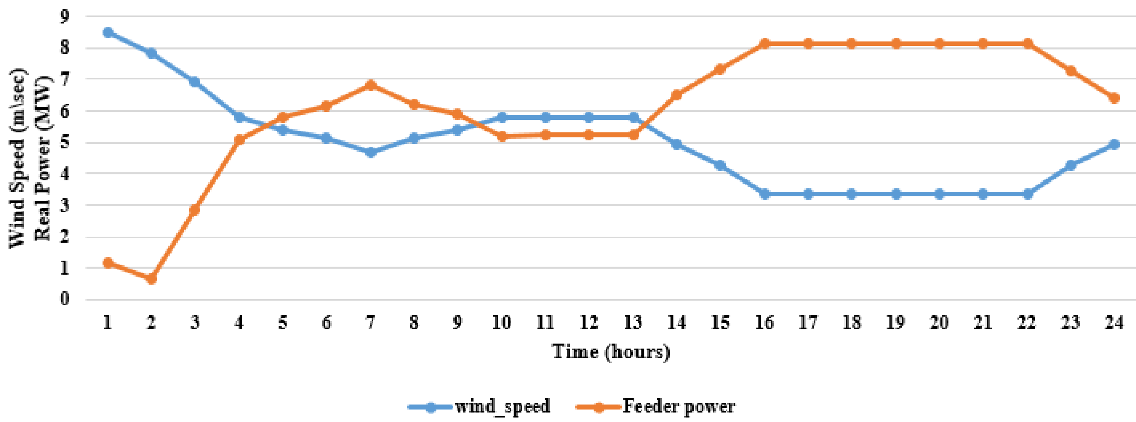

Figure 4 Comparison of wind speed and feeder power

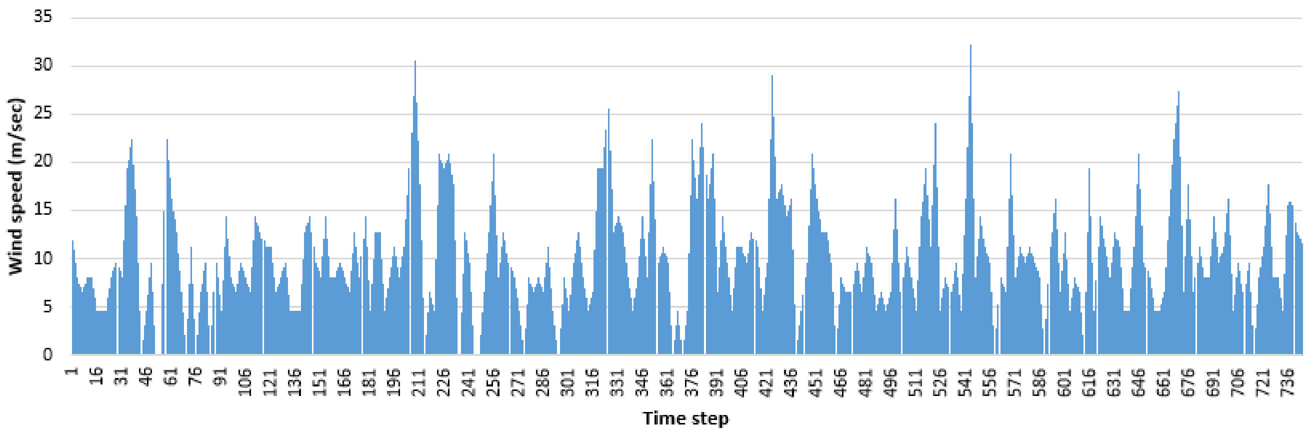

Figure 5 Wind diffuse

The time series analysis is carried out in the IEEE 123 test feeder with and without integrating wind energy. Seven 25 MW wind generators were integrated at the identified load nodes, which need voltage profile improvement. The simulation is carried out with an one-hour time step over a one month period. The analysis is carried out using Newton Raphson method. Fig 6 illustrates the real and reactive power flow in the substation.

The impact of the voltage profile was studied after the integration of wind generators. Fig. 7 gives the comparison of load voltages in phase A before and after integration of wind generator in the IEEE 123 test feeder. It is observed that there is a better improvement in the voltage profile after integrating wind energy in the distribution system. Here phase 'A' voltage profile alone is compared, as only is phase 'A' the voltage profile was observed to be less than the nominal voltage.

6. Conclusion

In this paper, the impact of the wind generator when integrated with a practical distribution system is presented. The time series analysis carried out provides the dynamic behaviour of the system. The load flow is run through Newton Raphson method and the results have been validated in a practical distribution system. Based on the voltage solutions, nodes were identified and wind generators were integrated suitably. The load flow was performed and the results were compared. It is found that there is a greater impact while integrating the wind generator. The time series analysis was done which gave the dynamic behaviour of the system. This paper describes the impact of wind generator integration in the time domain for the distribution system with penetration at suitable locations and change in load demand.

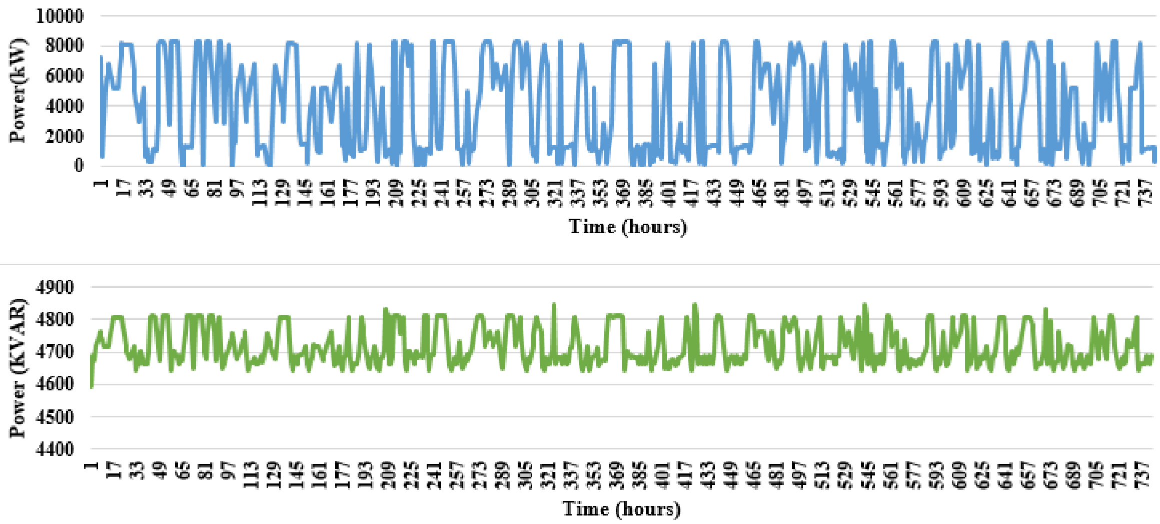

Figure 6 IEEE 123 Feeder Real and Reactive Power Output

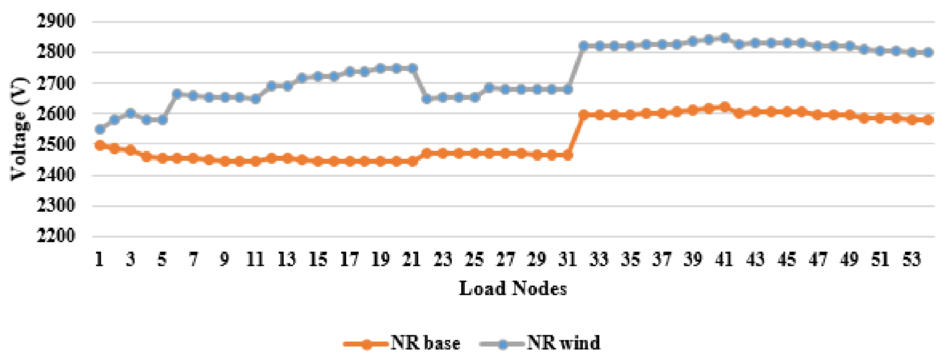

Figure 7 Comparison of load voltages in phase A

7. References

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