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The Impact of Location and Size of the Wind Technology on Power Quality in a Distribution System with Different Loads

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Abstract ***The impact of wind technology on power quality for a distribution system is emphasized in this paper. The Power Quality of a Distribution system depends on voltage and Frequency quality. The pros of integrating the wind turbine to the system are loss reduction and voltage profile improvement but the cons of adding renewable energy to the distribution system are represented in this paper. such as voltage unbalance, flicker, power factor, and the impact of voltage and current harmonics are measured. The performed analysis results indicated the importance of the integration of DG based on Power quality Parameters.***

Key-terms ***Total Harmonic Distortion (THD), loss Minimization, Power quality and sizing , RMF- Rotating Magnetic field , Load flow analysis -LFA , DG-Distribution Generation***

I. INTRODUCTION

One of the most abundant sources of energy on earth is wind energy. The rapid growth of wind technology in recent years has developed wind energy as mainstream electricity supply technology. The global estimated wind resource potential is 53KTerawatt hours (TWh)3 . The global electricity demand by 2020 is expected to be 30kTerawatt (TWh)3. The total installed wind capacity in India as per march 2017 is 32GW power [1]. Additional support other than grid is required to balance the demand and the average load varies predictably on a daily and seasonally basis but there are unpredictable loads that vary randomly and cause unforeseen events to occur. Thus wind turbine generators influence the utility grid in the aspect of power quality measurement are voltage deviation, Real power, Reactive power, harmonics, Transients, and flicker are measured as per International and National Guidelines.The wind energy conversion system nature is oscillating and Electrical power from wind turbines affects the power quality of the grid [2]. The inability of a renewable energy source to produce energy continuously can be reduced by adding two or more renewable energy sources in combination i.e PV, Mini Hydro and wind, etc [3]. A control scheme is designed for a grid-connected wind energy system with a no linear load for power quality analysis.

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The proposed method reduced the THD values within limits [4]. A study indicates the impact of wind turbines in its proximity to faults or severe voltage events, and which influence on system stability near to the substation and It is seen that the swings in voltage and frequency improve significantly due to the wind penetration, regardless of the location [5]. The impact of Wind technology with utility is examined using IEC and IEEE standard and a possible solution to improve power quality at the point of common coupling is proposed and analysis which influences the possible fault in a distribution network are obtained [6]. The harmonics data are collected at the point of Common coupling (PCC) and the harmonics load flow analysis of wind turbine generators is performed in Matlab simulation for the 33KV Bus-bar system. The voltage and current harmonics from the wind turbine system are 5.96% and 2.625% which is less than 7% and 5% set by IEEE std-519[7]. In the wind power generation system because of power electronic controllers, the dynamic behavior of the power system parameters gets altered which might not be the same when hydraulic or steam turbines generator are used[8]. The harmonics are introduced due to nonlinear industrial loads and causes phase imbalance, resonance, high voltage or current variations in power system [9]. On the point of social and economic well being of people in rural areas. A qualitative method through survey sampling and non-directive interviews with the villager is carried out. From the survey and interview, the impact on the people in Tanjung Resang indicated long term wind energy can improve the quality of life for the people in this area [11].

II. MATHEMATICAL MODEL OF WIND GENERATION

2.1 Betz Limitation for extraction of wind power

The wind technology transforms wind power of air mass to mechanical power. In this paper, the horizontal axis turbine is used which is under the principle established by Betz. The blades are placed such that air force move through density () and Blade surface (S).

(1)

Where

= air density (kg/m3)

A=area swept by turbine blade(m)

V_W=wind speed(m/s)

$$m = \frac{\rho * S * (V_1 - V_2)}{2} \quad (2)$$

The mechanical Power Pm from a wind turbine is given by

$$P_m = \frac{(V_1^2 - V_2^2)}{2} \quad (3)$$

by substituting the equation of (2) in (3) we get

$$P_m = \frac{\rho * m * (V_1+V_2) * (V_1^2 - V_2^2)}{2} \quad (4)$$

The total wind power pass through the same area S with Undisturbed speed is given by

$$P_{m_t} = \frac{\rho * S * V_1^3}{2} \quad (5)$$

Only a fraction of kinetic energy can be extracted from wind turbine known as C_P Power Co-efficient of the wind turbine, is given by

$$C_P = \frac{P_m}{P_{m_t}} \quad (6)$$

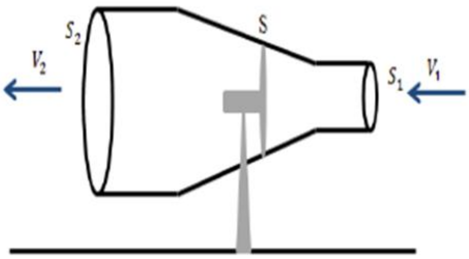

Figure 1: Horizontal axis turbine

$$C_P = \frac{(1+\frac{V_1}{V_2})((1-\frac{V_1}{V_2})^2)}{2} \quad (7)$$

The above equation indicates that Cp has a maximum value of 0.59 as seen from figure (2) shows the theoretical limit for a particular given speed called a Betz limit

$$P_a = S * \rho * V_w^2$$

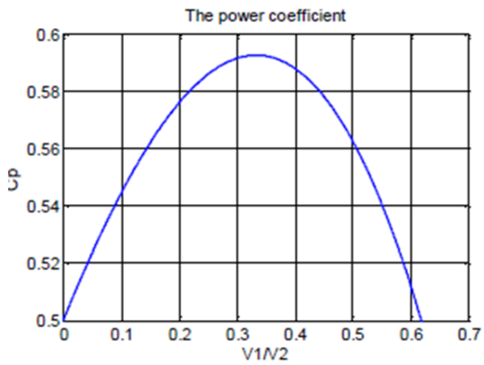

Figure 2: Co-efficient of Power

2.2 Modeling of wind Turbine

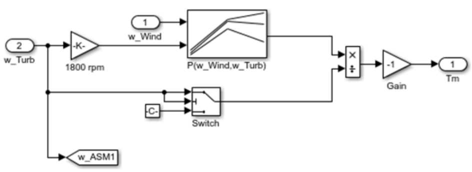

Figure 3: Wind Turbine

The wind turbine mechanical output is

$$P_m(t) = \frac{1}{2} * \rho * C_P * \lambda * \beta * V_2^3(t) \quad (8)$$

Where C_P Performance Co-efficient of turbine,

A_b- Area of cross section to wind turbine Ab (m2).

V_w^3 -The output power varies at cubic value .

The speed ratio λ is given by

$$\lambda = \frac{W_r * R}{V_W} \quad (9)$$

V_W - linear wind speed of blade in m/sec, W_R is the mechanical angular velocity(rad/s), The rotational speed n (r/min) and angular speed $[\omega_R]$ are given as

$$\omega = \frac{2*\pi*n}{60} \quad (10)$$

The variable wind speed turbine (VWST) is modeled and the C_P is as shown in (11)

$$C_P = 0.729[\frac{151}{\Lambda_i} - 0.59\beta - 0.002\beta^2.14 - 13.12] * e^{\frac{-18.6}{\lambda_i}} \quad (11)$$

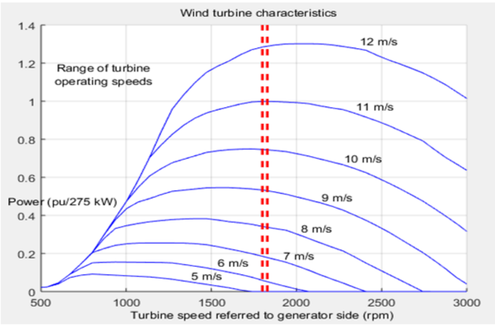

Figure 4: Wind Turbine characteristics

2.3 Modeling for Asynchronous generator

The AC generator normally used for a wind turbine is Induction Machine or Asynchronous machine and the Synchronous machine can also be used.The three-phase stator armature winding (AS, BS, CS) and a three-phase rotor winding (AR, BR, CR) as shown in Fig. 5. when a RMF (Rotating magnetic field) is produced. The ωs angular speed of RMF is known as synchronous speed, ωs. For the machine to work as a generator the external wind toque or mechanical torque to the rotor drive is applied to rotate the machine above ωs, later the power is pumped to the Network.

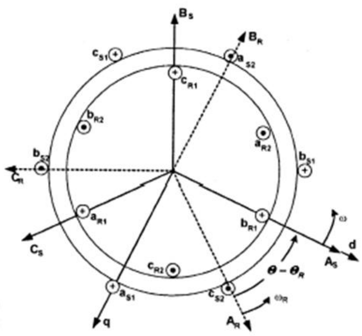

Figure 5: Asynchronous winding diagram

2.3.1 Stator transients modeling

For the simulation of Asynchronous Generator and wind technology,the following parameters are needed.

V_{ds} -Stator direct axis voltage

V_{qs} -Stator

Quadrature axis voltage
I_{ds} -Stator direct axis current
I_{qs} -Stator Quadrature axis current

The $0dq$ reference rotating frame at ω_s is vital ,by considering positive currents from the machine we get Magnetic flux

$$\phi_{ds} = X_s * I_{ds} + X_m * I_{dr}$$
$$\phi_{qs} = X_s * I_{qs} + X_m * I_{qr}$$
$$\phi_{dr} = X_s * I_{dr} + X_m * I_{ds} \qquad (12)$$
$$\phi_{qr} = X_s * I_{qr} + X_m * I_{qs}$$

Voltage

$$V_{ds} = -R_s * I_{ds} + \omega * s\phi_{qs} - \frac{d\phi_{ds}}{dt}$$
$$V_{qs} = -R_s * I_{qs} - \omega * s\phi_{ds} - \frac{d\phi_{qs}}{dt}$$
$$0 = -R_r * I_{dr} + s * \omega * s\phi_{ds} - \frac{d\phi_{qr}}{dt} \quad (13)$$
$$0 = -R_r * I_{qr} - s * \omega * s\phi_{dr} - \frac{d\phi_{qr}}{dt}$$

The successive equations for the asynchronous generator model are expressed in the 0dq rotating reference frame at ω_s and it consists of successive equations of magnetic flux and voltage. The d and q-axis co-ordinate are represented for stator and rotor quantities with sub-index (s,r) in a rotating synchronous frame of reference. The V_{qr} and V_{dr} are rotor voltage which is equivalent to zero. If (ωs) synchronous speed and (ωg) generator rotor speed then rotor slip S is

$$\omega_s = \frac{(\omega_s - \omega_g)}{\omega_s} \qquad (14)$$

For motoring mode the slip is positive and for generating mode it is negative. The variables Rs, Xs, Xm, Rr and Xr are resistance and Reactance of stator.
The eq(15) represents electrical torque:

$$T_e = \phi_{qr} * I_d r - \phi dr * I_{qr} \qquad (15)$$

If the torque developed is positive indicates motoring action and if negative then it is generating action. Hence the eq(16) represents output of active (KW), Reactive(Kvar) and apparent power(KVA) .

$$P_{active} = V_{ds} * I_{ds} + V_{qs} * I_{qs}$$
$$Q_{reactive} = V_{qs} * I_{ds} - V_{ds} * I_{qs}$$
$$P = V_{ds} * I_{ds} + V_{qs} * I_{qs} + V_{qs} * I_{ds} - V_{ds} * I_{qs} \quad (16)$$

2.4 Constant Power Wind Modeling

A constant mechanical input is considered for the simple presentation of the wind turbines. The mechanical torque or mechanical power is calculated below

$$T_{Mechanical} = \frac{P_{mechanical}}{\omega_{turbine}} \qquad (17)$$

In this paper constant -power is considered since the constant torque model is proportional to rotational speed, Under certain cases output leads to unstable conditions. In comparison, the constant-power of the torque is an inverse function of the rotational speed and introduces a stabilizing Condition into the mechanical system. Crucial, a constant-power model will in most cases reflect the physical behavior of the wind turbine more accurately than a constant-torque model.

2.5 Emphasis on power quality

2.5.1 Voltage sags

occur due to sudden increase in loads such as Faults in the network or short circuit, electric heaters turning on or motor starting, or an unforeseen event results in an increase in source impedance.

2.5.2 Voltage swells

are caused by an abrupt reduction in load on a network with a poor or damaged voltage regulator and mostly caused by a damaged or loose connection during this period the sudden rise in r.m.s line-voltage from 110 to 180 percent of the nominal line-voltage for duration of 0.5 cycles to 1 minute.

2.5.3 Harmonic Distortion (V,I)

Harmonics Distortion is used to determine the service quality of distribution system network and its effective value can be applied to both Current and voltage. As per IEEE-519 standards the total voltage and current harmonics should be less than 5% and 8% , respectively. The mathematical equation is given by

$$THD_V = \frac{\sqrt{\sum_{k=2}^{\infty} V_k^2}}{V_1} \qquad (18)$$

$$THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \qquad (19)$$

where V_1 and I_1 are RMS value of the fundamental and V_K and I_K value of K order harmonics component and To improve the efficiency of wind turbine, power electronics converters are added but this power electronics device produces non sinusoidal wave forms.

2.5.4 flicker

The flicker is the human Perception on rapid change in fluctuating loads which result in visual sensation as induced by a light stimulus which is spectral or luminance. Here are two concepts of flicker the first one is the short term flicker for 10 minutes (P_{st}) and the second long term flicker (P_{lt}) and its acceptable limit are 3% and 1%

2.5.5 Crest Factor

it is defined as the ratio of instantaneous peak value to Root Mean Square (R.M.S) value of voltage or current waveform

$$Crestfactor = \frac{Peak_{value}}{r.m.s_{value}} \qquad (20)$$

2.5.6 Voltage Unbalance

It is defined as the ratio of -ve or zero sequence component to +sequence component

$$voltageUnbalance = \frac{max(\Delta V_{avg})}{V_{avg}} \qquad (21)$$

III. PROBLEM FORMULATION

3.1 Objective

The impact of wind generation on power quality parameters. In the previous paragraph points out the type of power disturbance encounter and limitation as per IEEE standards followed for integration of wind turbine. The total (KW) real power loss is :

$$P_{loss} = \sum_{i=1}^{n} P_{loss_i} \tag{22}$$

3.1.1 Inequality constraits

The bus voltage magnitude at any instance should be within a reasonable limit. Vmin ≤ Vin ≤ Vmax

3.1.2 Power factor

Since Asynchronous machine is used and its power factor is less compare to other machine. There for it's very important to consider power factor in the system.

3.1.3 Importance of Integration of wind turbine

If we integrate wind energy sources in large number .The effect of penetration of Renewable energy sources on system performance based on power quality need to analyze in order to develop suitable controllers to mitigate the performance issues where ever it is required.

3.2 Methodology

3.2.1 location of DG

The location of the DG is placed from tail end of the given IEEE 5 bus test system and moved towards reference bus.

3.2.2 Sizing of DG

The two different size rating of wind turbine is considered for the IEEE 5 bus test system I,e 500KW and 1MW machine

3.2.3 Distribution system LFA

Matlab Simulation approach is considered for the load flow analysis of Test system

3.3 Procedure carried out

The Simulation procedure of the work done is as follows:

1. Modeling of considered test system is done in matlab simulation.
   (a) Test system is modeled
   (b) Residential load considered
   (c) Wind turbine and Asynchronous generator is connected
2. Run the simulation and note down all the data such as Voltage, active power, reactive power, Phase angle and total loss at all buses for base case.
3. Connect the wind turbine to the n bus and run the simulation.
4. Note down power quality parameters such as Frequency ,Power factor and harmonics of THDv and THDi.
5. Calculate the power quality indices, such as flicker, Voltage deviation, frequency deviation, Total harmonic distortion of voltage and current, power factor , Crest factor, Unbalanced voltage and Total loss.
6. Repeat the step 3 with (n-i) by increment i =1,2,3….n
7. Plot the following when wind turbine connected from bus 5 to bus 2.

a) Frequency at all bus
b) Voltage profile at all buses
c) Power factor of wind turbine
d) THDi and THv
e) Real power (Pb) and(Qb) Reactive power flow
f) Real power(Ploss) and Reactive power losses(Qloss)
g) Unbalanced voltage

8. Repeat the step from 2 to 8 by using Industrial load
9. Update the rating of wind Generation to 1 MW and repeat the steps from 2 to 9.

IV. RESULTS AND DISCUSSION

4.1 Residential load

This planned work is done for IEEE-5bus Radial Distribution system as shown in the table below:

Sl No:	Parameters	Data
1	P_{base}	100MVA
2	V_{base}	11KV
3	Total Real load connected (KW)	1.322 KW
4	Total reactive load connected (KVar)	0.430 KVar
5	Total real power loss(KW)	26.86 KW
6	Total Reactive power loss(Kvar)	11.2345 KVar

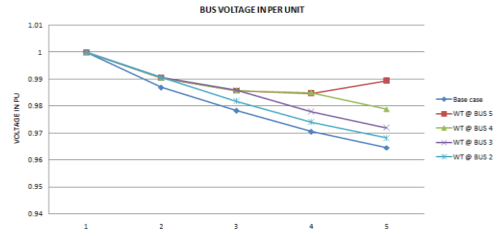

Figure 6: Voltage at all buses with integration of wind turbine

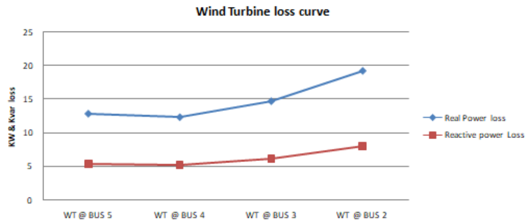

Figure 7: Real and Reactive power loss in KW and KVar

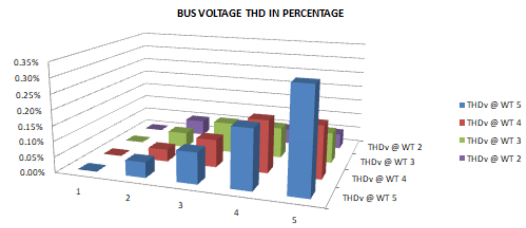

Figure 8: Total Harmonic Distortion in Voltage

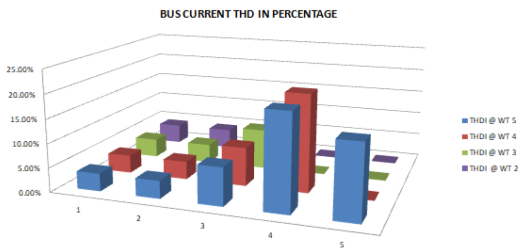

Figure 9: Total Harmonic Distortion in Current

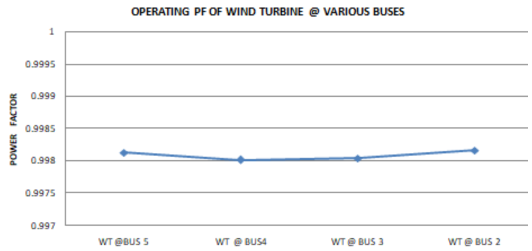

Figure 10: Power factor when DG's connected at buses

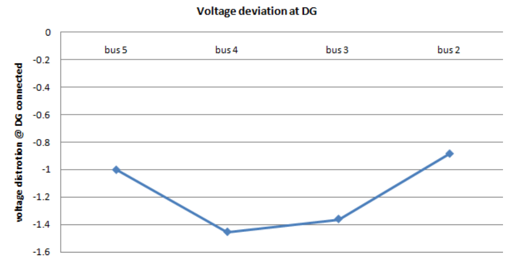

Figure 11: Voltage Deviation when DG's connected at Buses

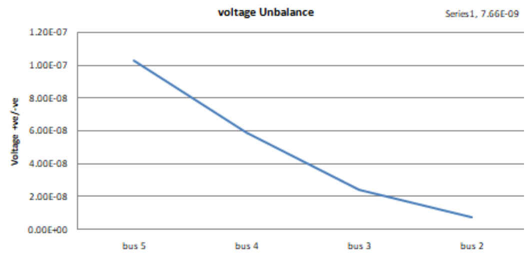

Figure 12: Voltage imbalance in percentage

From fig 6 the voltage at all buses is plotted when the wind turbine is connected to bus 5, The voltage profile improves and a Negative impact of voltage profile occurs when DG connected to other Buses.

From fig 7 the Real and reactive power losses are noted which implies that when DG is connected at the tail end of the test system losses observed are minimal when compared to DG connected near the reference bus.

From fig 8 the Total harmonics distortion of voltage is compiled for the DG's connected from bus 5 to bus 1. The THDv, when connected at bus 5, is more compared when the DG connected at other buses and as per IEEE standards, the Integration of wind turbines in a Residential load is within the limit of 5%.

From fig 9 the Total harmonics distortion of Current is plotted for the DG's connected from bus 5 to bus 1. The impact of current harmonics is more compared to voltage harmonics in the test system. The total harmonic effect is reduced when DG is connected near the reference Bus.

From fig 10 the power Factor improves as wind turbine connected at the tail end is moved towards the Reference bus

From fig 11 it's important to note the voltage deviation at bus 2 is less compare to bus 5.

from fig 11 the voltage imbalance percentage is less on bus 2 compare to bus 5.

4.2

Sl No:	Parameters	Data
1	P_{base}	100MVA
2	V_{base}	11KV
3	Total Real load connected (KW)	1.322 KW
4	Total reactive load connected (KVar)	0.430 KVar
5	Total real power loss(KW)	53.0936 KW
6	Total Reactive power loss(Kvar)	22.1986 KVar

Industrial load

When the wind turbine generator is connected to a industrial load, The characteristics of voltage profile, power factor , real and reactive power losses are same as residential load. The THD_i and THD_V is high compare to residential load and to limit the THD_i as per IEEE standards is necessary.when the Capacity of the DG is increased to 1MW and there is a maximum real and reactive power loss reduction in the system. The power factor at buses improves and voltage profile at all bus are near to 1p.u. Since a large integration of DG occurs at bus Frequency deviation, Voltage Deviation , Voltage unbalance and Total Harmonics of current and voltage are heavily distorted. The Basic data of 5 bus IEEE Test System connected to Grid with industrial load is shown in the table below:

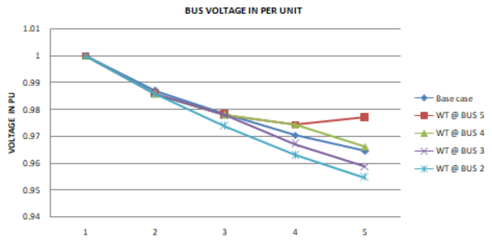

Figure 13: Voltage at all buses with integration of wind turbine

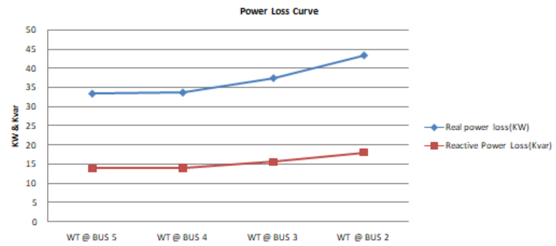

Figure 14: Real and Reactive power loss in KW and KVar

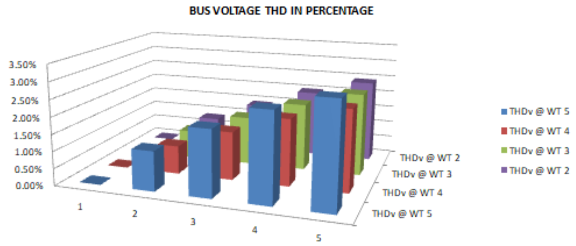

Figure 15: Total Harmonic Distortion in Voltage

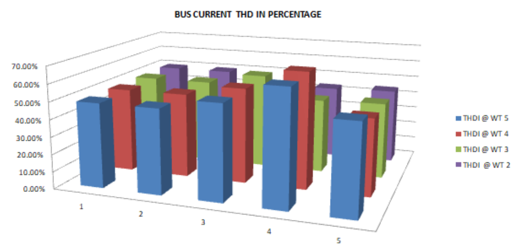

Figure 16: Total Harmonic Distortion in Current

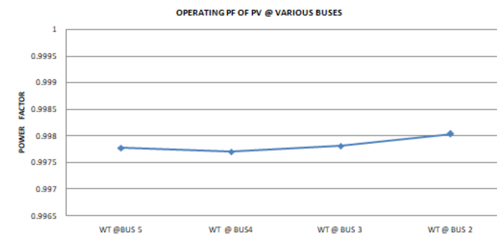

Figure 17: Power factor when DG's connected at buses

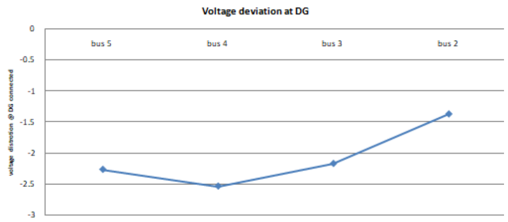

Figure 18: Voltage Deviation when DG's connected at Buses

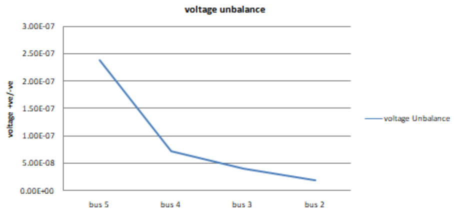

Figure 19: Voltage imbalance in percentage

CONCLUSION

It is observed that the location and size of wind turbine generation have major impacts on power quality parameters. when wind turbine generators are placed at tail end node losses can be minimized and voltage steady state at all buses are enhanced effectively compared to the placement of wind turbine generation near reference bus but harmonics, voltage unbalance, voltage flicker, frequency variation are more when wing turbine generator placed at a tail-end node compared to the placement of Wind turbine generator at reference bus. Hence in this work, it can be concluded for effective and optimal placement and sizing of wind turbine generators on distribution system power quality parameters are to be considered as a constraint.

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