Impact on Radial Distribution System by Integrating Wind Power with ZIP Load Considering Load Growth

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***Abstract*—Integration of wind based generation into the distribution system has significantly grown over few years. In this paper voltage sensitivity index (VSI) method has been taken for optimal placement of wind based distribution generation (DG) in radial distribution network. The main contribution of the paper is: (a) modeling of wind based generator (b) optimal placement of wind based DG using VSI method with constant load (c) optimal placement of wind based DG using VSI method with ZIP load, (d) optimal placement of wind based DG using VSI method in presence of Load Growth.Voltage profile, the real and reactive powers intake by the grid, real and reactive power losses are determined. The result show the importance of installation of wind based DG at the suitable location. The entire results are obtained on the IEEE 33-bus test system.**

Keywords*— Distributed generation; Voltage sensitivity index; ZIP load; Radial distribution system.

I. INTRODUCTION

In recent years due to rapid depletion of fossil fuel resources, renewable energy (RE) based DG were developing fast as they diminish power losses, power quality issues, carbon emission and also provide economical benefits. Many power companies are investing in renewable energy resources such as wind, photovoltaic cells, hydro-turbines with the distribution generation (DG), the main objective is to minimize total system power losses. Generating plant that serve a customer on-site or provide support to a distribution network is defined as Distributed generation (DG). Distributed generation (DG) can be used in isolated way or in integrated way. Wind turbine is the most promising DG technology among renewable energy sources. The integration of wind based DG offers the environmental and economical benefits and affects the system operating characteristics such as electric losses, voltage profile, stability and power system operation. Reduction in overall system losses and improve voltage profile of system is obtained by optimal placement of DGs in distributed system.

In literature, various methodologies have been developed for optimum location and size of DG. In Reference [1] optimal placement and size of DGs is determined by the PSO technique. Different types of DGs at different buses are considered for optimal power factor, real and reactive power by minimizing power distribution loss. PSO and analytical approach for optimal placement and size of DGs are proposed by author to minimize the power losses of system. For this, loads are sampled in small steps for each step optimal size and location of different DGs is obtained on IEEE-33 bus system in [2]. In Reference [3] dispatchable and non-dispatchable renewable DGs are considered for minimization of annual energy losses. For this aim, optimal size and power factor of DG is obtained by analytical approach then renewable DG are placed at optimal location for minimizing energy losses. In Reference [4] minimum power losses, reliability and voltage profile improvement are obtained by proper allocation of DGs in distribution system based on dynamic programming. Cost of DGs in radial distribution system is determined in [7] based on conventional, complex and triangular power limits. Optimal placement of DG in radial distribution system by analytical method to improve power losses are presented in [15]. In Reference [17] analytical method is proposed to determine the location, size and power factor of renewable DG to minimize energy losses.

In this paper, voltage sensitivity index method is proposed to find the optimal location of wind-based DG in Radial distribution (RD) system. Wind turbine is used as a DG and optimal size and location of DG source is calculated to reduce the system losses and to improve voltage profile. Load growth factor is also considered and the results are obtained on IEEE 33-bus. This paper sectioned into: 1.Modeling of wind based generator; 2. optimal placement of wind based DG using VSI method with constant load; 3.optimal placement of wind based DG using VSI method with ZIP load; 4.optimal placement of wind based DG using VSI method in presence of load growth.

II. PROPOSED METHODOLOGY AND MODELING OF SYSTEM

A. Modeling of Wind- based Generator

The wind power can be converted into electrical energy by wind turbine and the output power of wind turbine is given as

$$P_{out} = \frac{1}{2} C_p \rho A v^3 \tag{1}$$

Where C_p is the turbine power coefficient; A is area swept by rotor blades in m^2; ρ is air density and its value is 1.266 kg/m^2.

The output power of wind turbine depends on wind speed at the site as well as the parameters of power performance curve. The output power during different states is calculated as in (2)

$$p_{out} = \mathrm{P}_r \begin{cases} 0, \nu \le \nu_i \\ \mathrm{P}_n(\nu), \nu_i < \nu < \nu_r \\ 1, \nu_r < \nu < \nu_0 \\ 0, \nu > \nu_0 \end{cases} \tag{2}$$

$$\mathrm{P}_n(\nu) = \frac{\nu - \nu_i}{\nu_r - \nu_i} \tag{3}$$

Where p_{out} is power output of wind turbine (KW or MW); ν_i is cut in speed; ν_r is the rated speed (m/s); ν_0 is cut out speed of wind turbine; P_r is rated power in MW and $\mathrm{P}_n(\nu)$ is the normalized power output in non-rated region. The values for wind parameters are given in Table I.

TABLE I. WIND TURBINE PARAMETERS

Wind Turbine Parameters			
Rated power (MW)	Cut-in speed (m/s)	Rated speed (m/s)	Cut-out speed (m/s)
2	3	11.5	20

(a) Weibull Modelling

Here, wind speed modeling is done by Weibull pdf [4]. The probability distribution function of Weibull distribution is given by (3)

$$f_v = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{\left(\frac{-v}{c}\right)^k} \quad 0 \le v \le \infty \tag{4}$$

Where, v is the wind speed (m/s); k is the shape index and c is scale index. In paper the value of k is 1.75 and c is 8.78.

$$k = \left(\frac{\sigma}{\nu_m}\right)^{-1.086} \tag{5}$$

Where $\mathrm{v_m}$ is mean wind speed in m/s and σ is standard deviation of wind speed.

$$c = \frac{\nu_m}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{6}$$

Also weibull probability distribution function is applied on the wind system to find the probability of wind speed occurrence for these 20000 samples are taken at random and are divided into six levels. The probability of occurrence of wind speed levels is given by

$$prob = \frac{NW}{TW} \tag{7}$$

Where, NW is number of wind samples and TW is total number of wind samples at a given level. Fig. 1 shows the pattern of wind velocity for six levels of wind speed and Table II shows the wind turbine output.

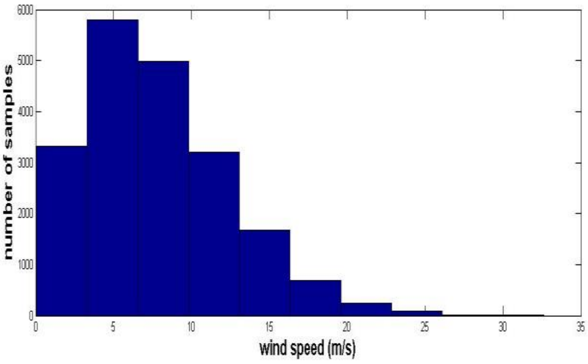

Fig. 1. Wind velocity pattern.

TABLE II. WIND TURBINE OUTPUT

Wind levels	***Speed range (m/s)***	***%age of turbine o/p power (%)***	***Probability of occurrence***	***Mean o/p power (MW)***	***Power o/p (MW)***
0	0-5	0	0.1416	0	0
1	5-8	12.0399	0.1683	0.2408	0.0405
2	8-10	40.5411	0.2636	0.8108	0.2137
3	10-12.5	77.8208	0.2250	1.5564	0.3502
4	12.5-20	100.000	0.1219	2.0000	0.2437
5	20-25	100.000	0.0654	2.0000	0.1307

B. Voltage Sensitivity Index [VSI] Method

This method is used to find optimal placement of wind-based DGs. Voltage sensitivity index is a numerical solution in which the operator knows how close the system is to collapse. This index is evaluated at all branches in radial distribution (RD) system by using (8)

$$VSI = \sqrt{\frac{\sum_{k=1}^{n}(1 - V_k)^2}{n}} \tag{8}$$

Where n is number of buses or nodes and k is set of nodes.

For stable operation of system the VSI should be less than unity. The bus with high sensitivity index is the most stable bus and selected for the placement of wind-based DG.

C. ZIP Load Model

The load at each node is modeled as a combination of constant impedance (Z), current (I) and power (P). ZIP load is calculated by (9) and (10)

$$P_{di}(t) = \mathrm{P}_{di0}(t)\left[a(t)\left(\frac{\nu_i(t)}{\nu_0}\right)^{npr} + b(t)\left[\frac{\nu_i(t)}{\nu_0}\right]^{npc} + c(t)\left[\frac{\nu_i(t)}{\nu_0}\right]^{npi}\right] \tag{9}$$

$$Q_{di}(t) = Q_{di0}(t)\left[a(t)\overset{(6)}{\left[\frac{\nu_i(t)}{\nu_0}\right]^{nqr}} + b(t)\overset{(7)}{\left[\frac{\nu_i(t)}{\nu_0}\right]^{nqc}} + c(t)\left[\frac{\nu_i(t)}{\nu_0}\right]^{nqi}\right] \tag{10}$$

Where, a(t), b(t) and c(t) are fraction of constant impedance, current and power at time t are 0.2,0.2,0.6

respectively. The parameters npr, npc and npi are active power exponents 2, 1, 0 respectively to get ZIP load and reactive power exponents are same as active power exponents.

D. Load Growth factor

Increase in load demand increases the system power losses and voltage drop, so for efficient operation of distribution system the future expansion and planning of distribution system is desired to be estimated. Load Growth is given by

$$Load_i = Load \times (1+r)^m \qquad (11)$$

Where, r is annual load growth rate and m is period of load plan which is specified by the feeder. In this paper, 7.5 % load growth rate and 5 years for planning are taken for the study.

III. RESULTS AND DISCUSSION

In this paper, results are obtained for IEEE-33 bus Radial Distribution (RD) system with forward backward sweep load flow method. Voltage Sensitivity Index (VSI) method is used to find the optimal placement of wind-based DGs for voltage profile improvement and to reduce system losses. The base MVA and base KVAR for the test system are 100 MVA and 12.66 KVAR respectively.

The results are obtained by placing wind-based DG to obtain voltage profile, total power losses, each branch real and reactive power losses for constant load, ZIP load and Load Growth on IEEE-33 bus system.

A. Voltage Sensitivity index [VSI]

Voltage sensitivity index is a numerical solution in which the operator knows how close the system is to collapse. The bus having high sensitivity index is selected for the placement of DG. Fig. 2 shows the VSI plot for IEEE-33 bus system.

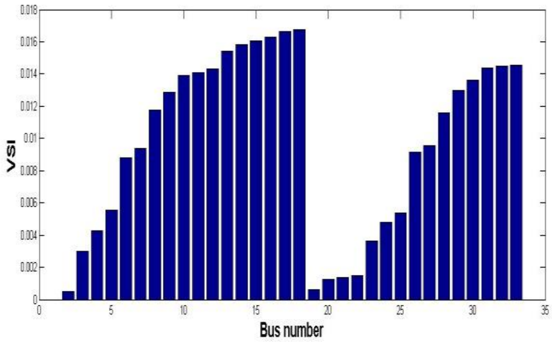

Fig. 2. VSI plot for IEEE-33 bus system.

Here VSI values are obtained for IEEE-33 bus and 18th bus is selected for the optimum placement of wind-based DG because it has high VSI as shown in Fig. 2.

B. Effect of Wind-based DG on Voltage Profile

The integration of wind-based DG increases the voltage profile of system. Voltage profile with wind-based DG and without DG for constant load, ZIP load and Load Growth are shown respectively in Figs. 3, 4, 5.

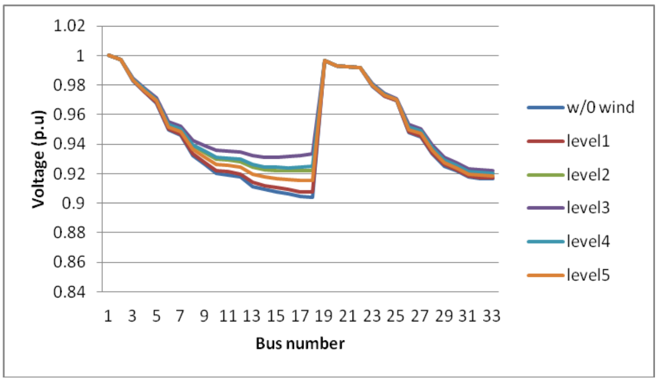

Fig. 3. Voltage profile for constant load

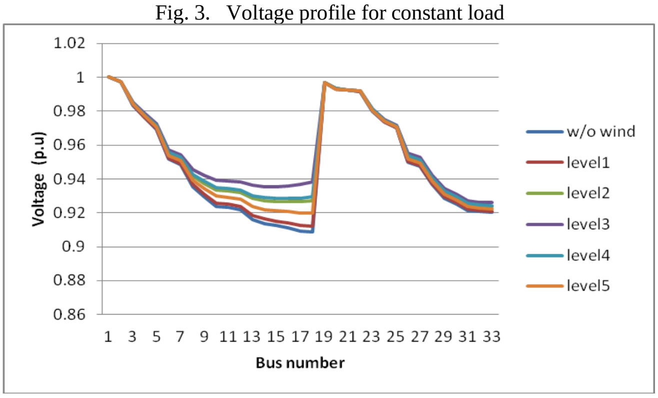

Fig. 4. Voltage profile for ZIP load

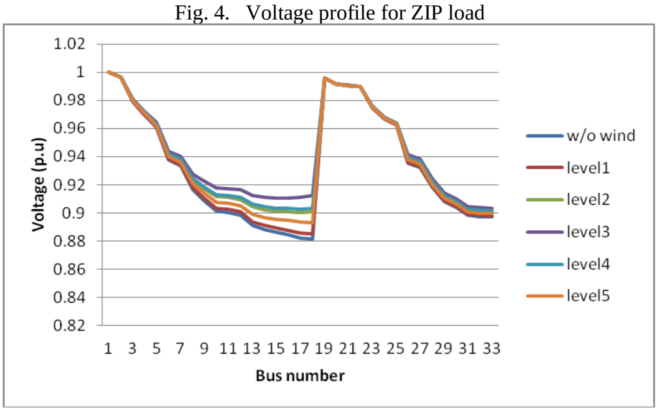

Fig. 5. Voltage profile for Load Growth

The Voltage profile obtained for constant load, ZIP load and Load Growth for Wind-based DG2 is shown in Fig. 6.

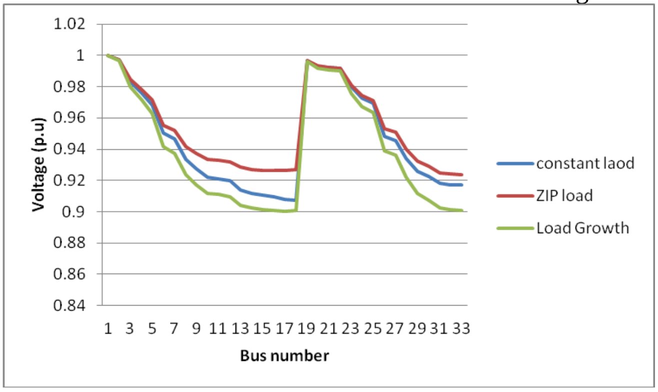

Fig. 6. Voltage profile for constant load, ZIP load and Load Growth for wind-based DG2

From the figures 3,4,5and 6, it is observed that voltage profile is improved with placement of wind-based DG and voltage values are reduced considering Load Growth due to its increased load demand.

C. Effect of Wind-based DG on Total Power Losses

The optimum allocation of wind-based DG by VSI is at 18th bus by placing DG at 18th bus and varying the levels of wind-based DG power stepwise, the variation of total power losses is obtained. Table III, IV shows real and reactive power losses for different loads without wind or with wind speed levels respectively.

TABLE III. TOTAL REAL POWER LOSSES

Wind DG	**Total Real Power Losses (KW)**		
	Constant load	***ZIP load***	***Load Growth***
w/o wind	210.9824	192.7107	319.1046
Level1	204.4866	186.6089	310.6467
Level2	180.9839	164.6837	279.2783
Level3	167.0252	151.8585	259.7145
Level4	177.5843	161.5409	274.6075
Level5	191.4042	174.3687	293.3395

TABLE IV. TOTAL REACTIVE POWER LOSSES

Wind DG	**Total Reactive Power Losses (KVAR)**		
	Constant load	***ZIP load***	***Load Growth***
w/o wind	143.0219	130.411	216.4626
Level1	138.2395	125.9236	210.2367
Level2	121.2822	110.1444	187.5125
Level3	111.6499	101.3537	173.7864
Level4	718.8936	107.9472	184.1944
Level5	128.7198	117.0336	197.6167

The real and reactive power losses for the IEEE-33 bus are 210.9824 KW and 143.0219 KVAR respectively without installation of DG and 204.4866 KW and 138.2395 KVAR with wind-based DG1 respectively. From this it is observed that losses are reduced with DG and for each level it varies according to the wind power output.

D. Effect of Wind-based DG on Real and Reactive Power loss in each branch

The integration of DG sources at the various location of distribution system lead changes in the characteristics of the system network with more variable real and reactive power flow. The results are obtained for constant load, ZIP load and Load growth for IEEE-33 bus system.

(a) Real and Reactive power loss with constant load

Fig. 7 and Fig. 8 shows Real and Reactive power loss with constant load, which show maximum power loss without installation of wind-based DG and minimum loss with wind-based DG. Wind-based DG which has the maximum power output i.e. level3 gives less real and reactive power loss.

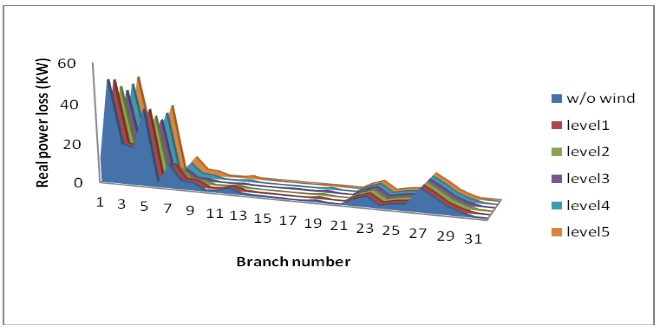

Fig. 7. Real power loss for IEEE-33 bus with constant load

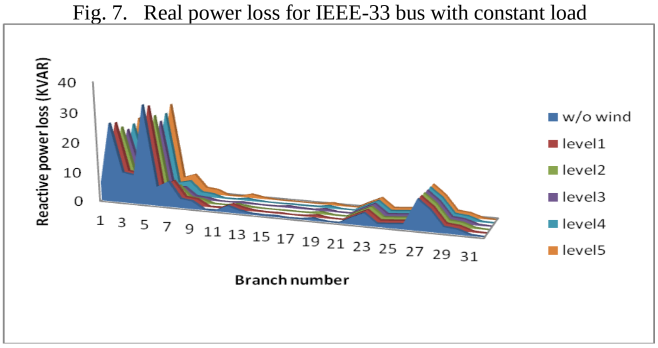

Fig. 8. Reactive power loss for IEEE-33 bus with constant load

(b)Real and Reactive power loss with ZIP load

Fig. 9, 10 shows Real and Reactive power loss for DG with wind power and without wind. Here without wind DG, system gives maximum losses and minimum losses are obtained for level3 which is having maximum power considering ZIP load.

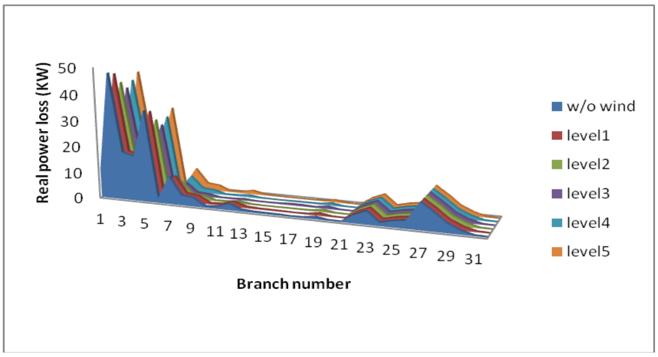

Fig. 9. Real power loss for IEEE-33 bus with ZIP load

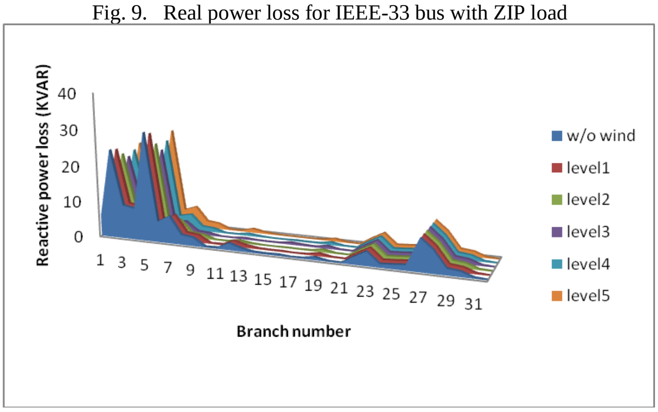

Fig. 10. Reactive power loss for IEEE-33 bus with ZIP load

(c) Real and Reactive power loss with Load growth

Radial distribution system when integrated with wind-based DG considering load growth give maximum real and reactive losses. Fig. 11, 12 shows Real and Reactive power loss for Load Growth considering constant load.

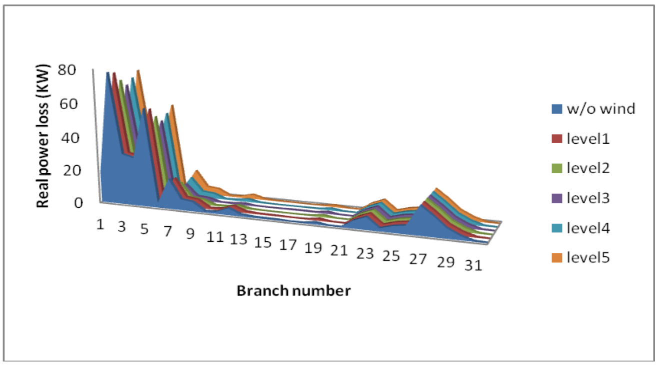

Fig. 11. Real power loss for IEEE-33 bus with Load Growth

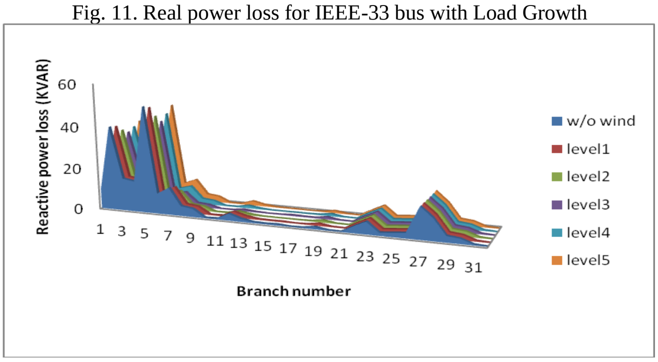

Fig. 12. Reactive power loss for IEEE-33 bus with Load Growth

The real and reactive power losses for constant load, ZIP load and Load Growth for wind-based DG1 are shown in Fig. 13 and 14.

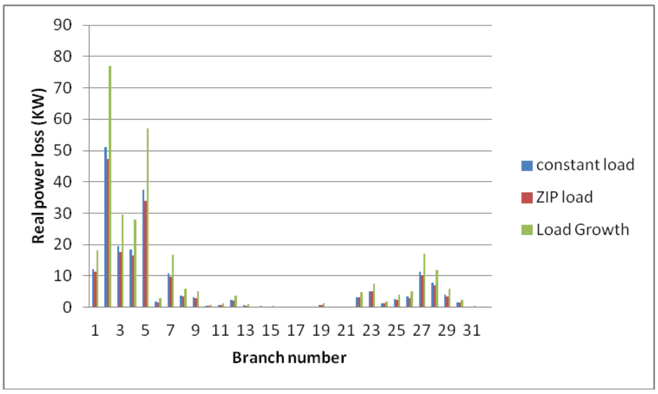

Fig. 13. Real power loss with constant load, ZIP load and Load Growth for wind DG1

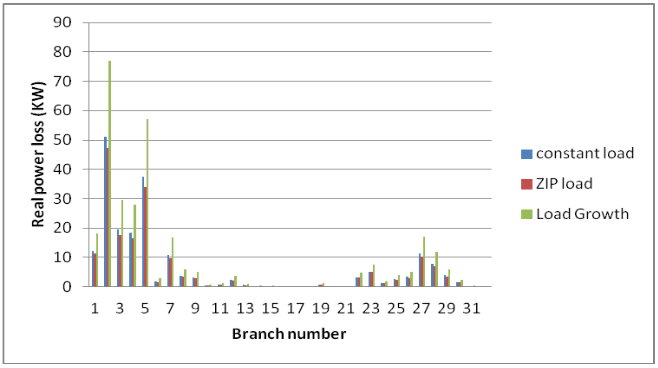

Fig. 14. Reactive power flow with constant load, ZIP load and Load Growth for wind DG1

From above Fig. 13 and 14 it is observed that level1 wind-based DG with ZIP load gives minimum real and reactive power losses and maximum losses are obtained for considering Load Growth. Here ZIP load is voltage dependent load, based on the bus voltages load at each bus is varied according to that losses in each branch varies.

E. Effect of Wind-based DG on Cost of Energy Losses

Annual cost of energy loss is calculated by total real power losses and energy rate. Cost of energy loss is calculated by (12)

$$\text{Cost}_{EL} = (\text{Total Active Power Loss}) \times (Ec \times t) \qquad (12)$$

Where Ec is energy rate ($/KWh) and t is time duration (h), the value of Ec and t taken for study are 0.06 $/KWh and 8760 h respectively.

Total real power losses are reduced with installation of wind-based DG due to this there is a significant decrease in cost of energy losses. Here, the cost of energy losses without wind-based DG is 110.8923 $ and 107.4782 $ with installation of wind-based DG1 respectively. Table V shows the cost of energy losses without DG and with DG considering constant load, ZIP load and Load Growth.

TABLE V. COST OF ENERGY LOSSES

Wind DG	**Cost of Energy Losses ($)**		
	Constant load	***ZIP load***	***Load Growth***
w/o wind	110892.3	101288.7	167721.4
Level1	107478.2	98081.6	163275.9
Level2	95125.1	86557.8	146788.7
Level3	87788.4	79816.8	136505.9
Level4	93338.3	84905.9	144337.0
Level5	100602.0	91648.2	154179.2

IV. CONCLUSION

Here in this paper results are obtained on IEEE-33 bus Radial Distribution (RD) system. Optimal placement of wind-based DG is obtained by Voltage Sensitivity Index (VSI) method and wind generator is modeled by using weibull probability distribution function. Load Growth is considered for IEEE-33 bus standard system for future planning. This integration of wind-based DG in the system is done to improve the voltage profile and to reduce power losses with constant load and ZIP load and also considering load Growth. The real and reactive power losses for IEEE-33 bus are 210.9824 KW and 143.0219 KVAR respectively, without installation of DG and 204.4866 KW and 138.2395 KVAR with wind-based DG1 respectively. From this it is concluded that losses are reduced and voltage profile is improved with wind-based DG comparing to without wind DG. With ZIP load minimum power losses are obtained and maximum losses are obtained for considering Load Growth for both the cases with and without wind-based DG. In the Future the same analysis can be done on mesh distribution system by integrating both wind and solar-based DG's.

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