International Journal of Systems Signal Control and Engineering Application

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Effect of Wind Turbine Generators on a Radial Distribution System

Maheswari Muthusamy and Parvathy Ayalur Krishnamoorthy
School of Electrical Sciences, Hindustan University, Chennai, India

Key words: Distributed generation, doubly fed induction generator, squirrel cage induction generator, line loss reduction, voltage profile improvement, electrical transient analysis program

Corresponding Author:
Maheswari Muthusamy
School of Electrical Sciences, Hindustan University, Chennai, India

Page No: 35-40
Volume: 14, Issue 3, 2021
ISSN: 1997-5422
International Journal of Systems Signal Control and Engineering Application

Abstract: This manuscript analyzed a radial distribution system in which different wind turbine generators were integrated as Distributed Generation (DG) sources. A load-flow study was performed using IEEE 33-bus test system with three generation units. A comparative analysis was then conducted to investigate the enhancement of voltage at all buses and fall in line losses while integrating a Doubly Fed Induction Generator (DFIG) and Squirrel Cage Induction Generator (SCIG) into the radial distribution system. The test system was simulated using the ETAP software package. Simulation results showed a notably higher voltage at all buses and lower active and reactive power losses on integrating the variable speed wind generator than on integrating the fixed speed wind generator.

INTRODUCTION

Global warming concerns coupled with the depletion of fossil fuels and the increasing cost stimulates the increase in energy production from renewable energy sources. Recent developments in the electrical distribution system provide an opportunity for many technological innovations including the integration of distributed generators with the Power Grid. DG typically refers to low level electric power generation in the range of 1 kW to 50 MW at the point of consumption. If renewable energy sources are used as distributed generators, the generators may be called Embedded Renewable Generators (ERG). DG eliminates the cost, complexity, and inefficiencies associated with transmission and distribution. Because of the advancement in power electronics, wind energy in electrical power generation is on the rise when compared to other energy technologies worldwide. The Wind Turbine Generator Unit (WTGU) is the combined arrangement of a turbine and a generator unit. The wind turbine converts the kinetic energy into mechanical energy, then fed to generator through a gear, and generates electrical energy. The WTGUs are incorporated at the transmission level and also at distribution levels. With the penetration of WTGU into sources, the Characteristics of the distribution system such as the direction of power flow, voltage profile, line losses, power factor, and fault level[-5] have changed. Analytical methods were formulated to predict allowable penetration levels of DG resources[6]. The line loss reduction analysis with Distributed Generation was proposed by Chiradeja[7]. Appropriate load-flow techniques need to be followed to analyze the effect of WTGU on the Power Grid. Modeling and analysis of radial distribution network with basic backward and forward sweep method is depicted by Kersting[8]. Compensation based load flow algorithm is projected for weakly meshed transmission and distribution systems[9]. The present study explores the steady-state behaviour of fixed speed and variable speed wind turbines and their effect on the distribution system. In the proposed work, enhancement of voltage profile and fall in line loss with SCIG and DFIG as well as without DG were calculated.

Benefits of DG: Integrating DG in the distribution network has the following benefits. The major technical benefits are: enhancement of voltage profile, decrease in line loss, reduction of emissions of greenhouse gases, improvement in power quality, elimination of transmission and distribution congestion. The major economic benefits are: reduced capital cost due to small size of dg, reduced need for large infrastructure construction or upgrades enhanced productivity, reduced operating costs. Technical benefits broadly classified into the following two categories: improvement of certain attributes including voltage profile, power quality, and reliability. reduction of attributes including, line losses, congestion and emissions. To quantify the benefits such as enhancement of voltage profile and decrease in line loss, a factor can be derived for each of the attribute by computing the ratio of the measures of the attribute with and without DG[10].

Voltage profile enhancement factor: The fraction of the voltage profile of the load bus in the network with DG to the network without DG is defined as Voltage profile Enhancement Factor (VPEF):

$$\text{VPEF} = \frac{\text{VP}_{\text{W/DG}}}{\text{VP}_{\text{WO/DG}}} \quad (1)$$

Based on the definition, when VPEF<1, DG has no values, VPEF = 1, DG has no effect on the network voltage profile and VPEF>1, DG improves the voltage profile.

Line loss decreasing factor: The fraction of total line loss in the network with DG to the network without DG is defined as Line Loss Decreasing Factor (LLDF). It is expressed as:

$$\text{LLDF} = \frac{\text{LL}_{\text{W/DG}}}{\text{LL}_{\text{WO/DG}}} \quad (2)$$

Based on the definition when LLDF<1, DG decreases electrical line losses, LLDF = 1, DG has no effect and LLDF>1, DG generates more line losses.

MATERIALS AND METHODS

The IEEE 33-bus distribution network depicted in Fig. 1 was considered for the simulation study. The network consisted of 33 buses with a voltage of 11 kV.

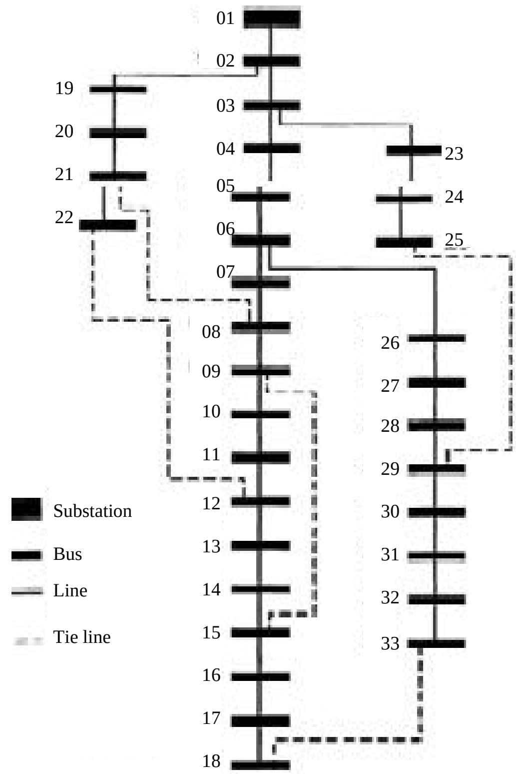

Fig. 1: IEEE 33-bus radial distribution network

WTGUs of 600 kW capacities were connected at the nodes with a voltage of 690 V. In Case A, all the WTGUs of the SCIG type with an operating power factor of 0.9 lag to 0.9 lead were used. In Case B, all WTGUs of the DFGI type were used. The loads were modelled as constant power loads with the voltage of 11 kV. In this study, the IEEE 33-bus radial distribution network was considered for analysis. The network had 32 sectionalizing branches, a voltage of 11 kV and a total system real power load of 3.62 mW and reactive power load 1.8 MVAR.

The following assumptions are made for the analysis: three-phase radial distribution networks are balanced and represented by their one line diagrams. At the distribution levels, charging capacitances are neglected. All the loads are constant power loads. Copper losses of the distribution transformers are neglected. In general, constant power models can be represented as:

$$P = P_0(V/V_0)^n \quad (3)$$

$$Q = Q_0(V/V_0)^n \quad (4)$$

where P_0, Q_0 and V_0 are per-unit real power, reactive power and per-unit voltages, respectively[11]

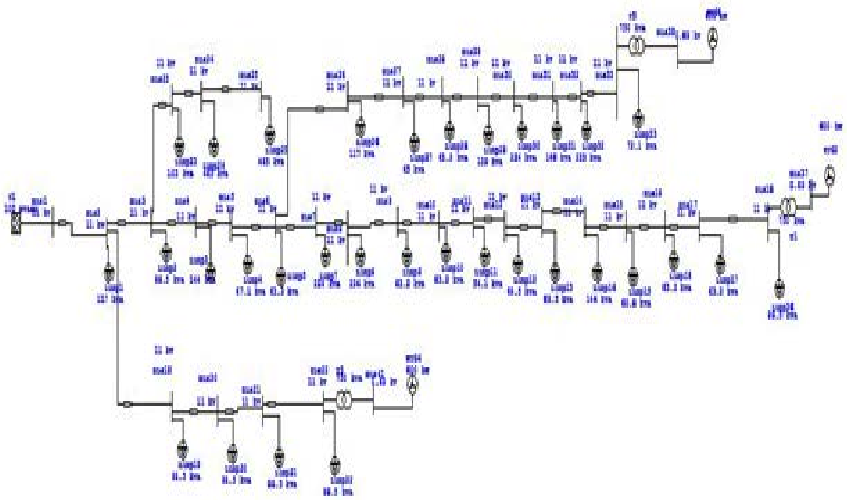

Fig. 2: Simulation circuit with DG integration

Table 1: Transformer data

Primary voltage (kV)	Secondary voltage (V)	Rating (kVA)	Z (%)	X/R ratio
11	690	750	5	4
11	690	750	5	4
11	690	750	5	4

Transmission lines are modelled as Nominal Pi Model. The transmission line resistance and reactance and Load data are extracted from IEEE 33 bus radial distribution system[12] and the transformer data are given in Table 1.

Effect of dg on the distribution network

Grid case scenarios: The simulation was performed using a 11 kV radial distribution network with 33 buses. The simulation circuit with DG integration is depicted in Fig. 2. To assess the effect of fixed speed wind turbine generators (i.e., SCIG) and variable speed wind turbine generator (i.e., DFIG) on the voltage profile and system losses, three different cases were simulated:

- Case A: Simulation with SCIG (fixed speed) in buses 18, 22, and 33
- Case B: Simulation with DFIG (variable speed) in buses18, 22 and 33
- Case C: Simulation without distributed generators

Nine scenarios were created on the basis of wind-power generation and loading pattern .Scenarios are presented in Table 2. In each case, enhancement of voltage profile and decrease in line loss were compared and confirmed for SCIG, DFIG and without DG. The simulation circuit, IEEE 33 bus radial distribution system with DG Integration is depicted in Fig. 2.

Load flow analysis was performed for each case and the minimum voltage in the network was noted. For Case A-C, the active power losses, reactive power losses and voltage at the wind turbine connected buses is presented in Table 3.

Table 2: Grid case scenarios

Load pattern	Wind power generation	Scenario
Low load	Low Generation	LLLG
Low Load	Medium generation	LLMG
Low load	Peak Generation	LLPG
Medium load	Low Generation	MLLG
Medium load	Medium Generation	MLMG
Medium load	Peak Generation	MLPG
Peak load	Low Generation	PLLG
Peak load	Medium Generation	PLMG
Peak load	Peak Generation	PLPG

Table 3: Load flow results at wind turbine integrated buses for different loading conditions and wind patterns

Case	Scenario	Voltage at wind turbine unit bus (%) 18	22	33	Real power loss (kW)	Reactive power loss (kVAR)
ASCIG	LLLG	95.8	99.3	96.25	85	95
	LLMG	97.8	99.7	97.52	100	127
	LLPG	99.6	100	98.71	133	181
	MLLG	90.9	98.8	91.64	208	176
	MLMG	93	99.3	93.02	199	193
	MLPG	94.9	99.7	94.3	211	236
	PLLG	86.8	98.5	87.87	378	287
	PLMG	89.1	98.9	89.36	345	289
	PLPG	91.2	99.3	90.73	337	321
B DFIG	LLLG	99.4	100	98.63	15	20
	LLMG	101	100	99.87	30	50
	LLPG	103	101	101.1	61	101
	MLLG	94.8	99.8	94.26	90	67
	MLMG	96.8	100	95.6	82	83
	MLPG	98.7	100	96.85	93	123
	PLLG	91	99.5	90.72	213	144
	PLMG	93.2	99.9	92.15	184	148
	PLPG	95.2	100	93.48	176	177
C	LL	96.6	99.7	96.84	23	14
W/O	ML	91.8	99.2	92.31	134	84
DG	PL	87.8	98.9	88.62	291	184

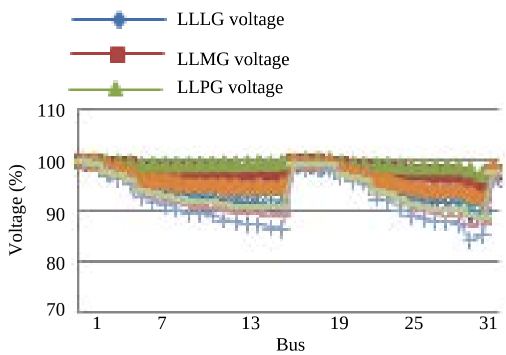

Fig. 3: Voltage profile with SCIG (Case A)

RESULTS AND DISCUSSION

Voltage summary analysis: From Table 3, for a specified load profile, a boost in active power generation from zero to near the nominal value was found to cause a voltage increase in all buses. Sometimes, voltage on the network bus was higher than the slack bus voltage because the total generation was higher than the system load. Due to raise in power injected by the wind turbine generator unit, system voltage magnitude increases. In comparison with DFIG, SCIG always consumed reactive power. The amount of power consumed depended on the active power supplied and voltage on the bus. The connection of SCIG to the distribution network resulted in a decrease in voltage on the bus in which they were connected. This lead to a decrease in voltage profile of the system.

Loss analysis: It is thus possible to conclude that there was maximal power from DG as a function of the total demand, which minimized the losses of the network. Compared with SCIG, DFIG generated maximal power and, thereby reduced the losses of the system.

Simulation results: Figure 3-5 depict the voltage profiles at all buses for all scenarios of the three cases. The peak generation conditions with varying load patterns were considered for further analysis. The results for Low Load Peak Generation (LLPG), Medium Load Peak Generation (MLPG) and Peak Load Peak Generation (PLPG) criteria are shown in Fig. 6-8. In all the results, it was proved that the voltage profile improved in the "with SCIG integration" condition when compared with those in the "without distributed generator" condition. But voltage profile is further improved in the "with DFIG condition" when compared with that in the "with SCIG condition."

Figure 9 and 10 gives comparison for real and reactive power loss with SCIG, DFIG and without distributed generation. It can be inferred that real and

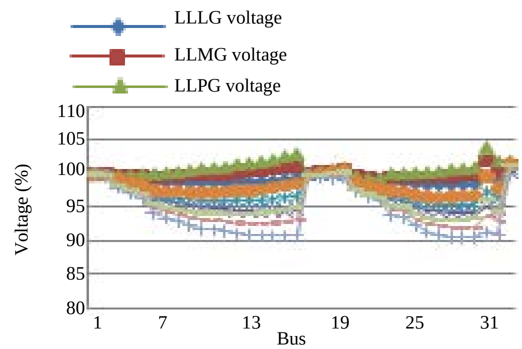

Fig. 4: Voltage profile with DFIG (Case B)

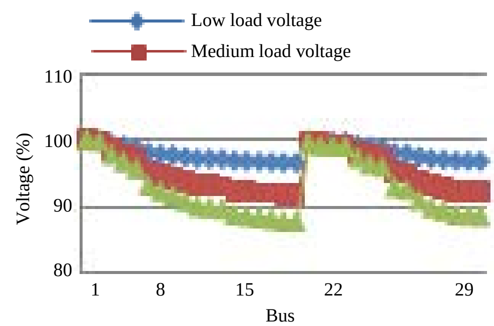

Fig. 5: Voltage profile without DG (Case C)

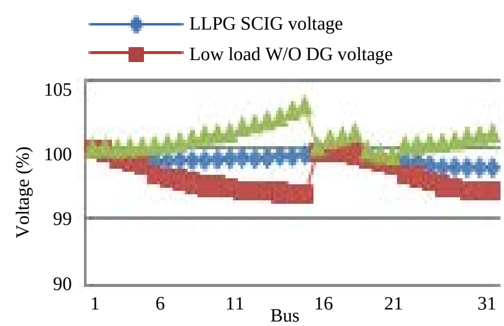

Fig. 6: Voltage profile comparison (Low load peak generation)

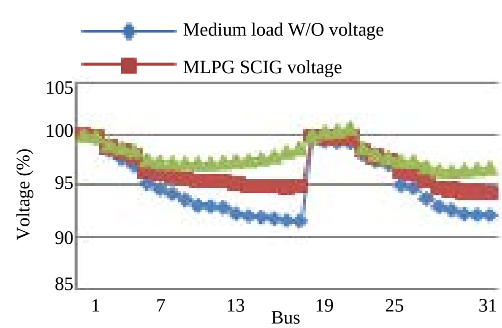

Fig. 7: Voltage profile comparison (Medium Load Peak Generation)

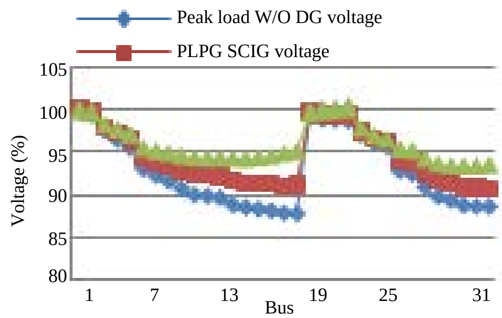

Fig. 8: Voltage profile comparison (Peak load peak generation)

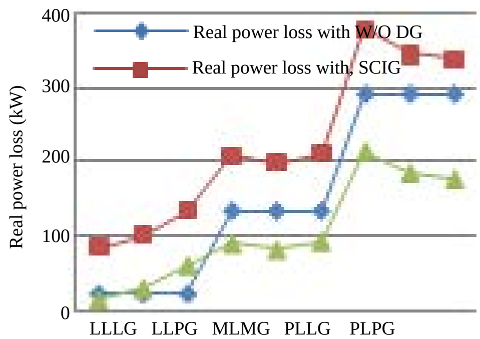

Fig. 9: Real power loss comparison at all scenarios

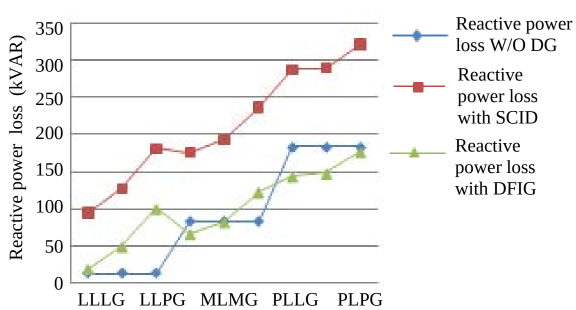

Fig. 10: Reactive power loss comparison at all scenarios

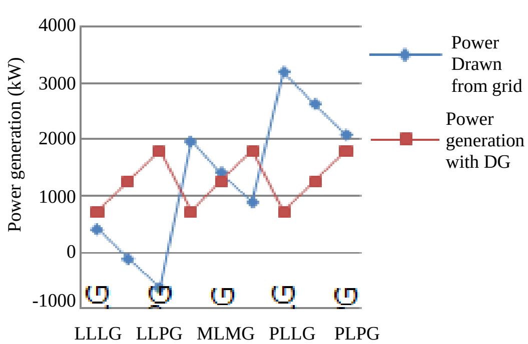

Fig. 11: Power generation from DG Vs power drawn from the power

reactive power loss is reduced while integrating DFIG as distributed generator in radial distribution network. Figure 11, depicts that if power generation using DG increases, power drawn from Power Grid decreases. Power generation is maximal during peak wind condition.

CONCLUSION

In this study, a simulation study was performed on a radial distribution system with WTGU operating as DG sources. Load-flow analysis was performed to assess the steady-state behaviour of the various WTGU types, such as SCIG and DFIG, under different load patterns and wind conditions. From the study, the insertion of DG in the network was found to result in voltage increase in all buses. This voltage can be higher than the slack bus voltage when generation is greater than the demand. With the integration of DG in the network, there is a decrease in losses. Compared to SCIG, DFIG injects more power in to the network; thus it minimizes losses. In summary, the integration of DFIG into the network is beneficial to the overall functioning of the system. The system can be further investigated for obtaining a more optimized location of DG.

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