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Distribution System Power Loss Reduction through Distributed Generation

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Abstract: Pakistan power sector is facing energy crises mainly caused by generation demand gap. New power generation capacities are proposed to meet generation demand. Transmission and distribution network expansions are planned. Distributed Generation (DG) is small generation employing renewable energy resources and directly connected to distribution system. DGs are environmental friendly and offers advantages in terms of small construction time and eliminate need of complex transmission and distribution network between generation and utilization. DGs will also have impacts on voltage drop, stability and power losses of distribution system.

In this research work, one of 11kV radial distribution feeder is analyzed through simulation to observe impacts of different DG technologies in terms of power loss reduction. Wind generation using synchronous generator results in maximum power loss reduction due to their capabilities of injecting reactive power. Induction generator require reactive power from grid and therefore result in minimum power loss reduction. PV cells only produce active power and results in moderate reduction in power losses.

Keywords: Distributed Generation; Wind generation; Solar energy; Power losses; HESCO.

1. INTRODUCTION

Pakistan is facing a serious energy crisis, because of the rapid increase in demand, whereas power reserves increased negligible. Theft of electricity, increased transmission and distribution losses as a result of outdated infrastructure has worsened the situation. As a result, consumers face a prolonged load shedding (Siddique and Wazir, 2016).

In Pakistan, power is normally generated at 13.8 or 11kV. Conventionally, power is generated through large thermal and hydro plants located away from load centers. Generated power is supplied to load centers by transmission network using extra high voltages (EHV) of 500KV and 220KV to reduce power losses. Transmission systems supply power to the distribution system to supply consumer (Umer *et. al.* 2013).Thus power generated by the power plant reaches the end user through complex and large networks such as cables, transformers, overhead lines and other equipment. In fact, the energy generated by the power plant does not match the units consumed by the end-user because there is a percentage of loss in transmission and distribution networks. Hyderabad Electricity Supply Company (HESCO) is the power distribution utility having power losses in excess of 25% as compared toutilities in developed countries having 3% (Sahito *et al.* 2014).

Distributed Generation (DG) refers to electricity generation near the point of consumption (Uqaili, *et. al* .2015). It eliminates complex transmission network between generation and utilization. DGs normally use renewable energy resources for power generation and are considered as environmental friendly generation. Alteration of power system results in variations of voltage drops, stability, reliability and power losses (Kazemi and Sadeghi 2009).

Owing to increased penetration of DGs, it has become most researched area in power industry. Effects of DG units in terms of power system performance and then identifying techniques for maximum efficiency has become interest of researchers around the globe. Power loss reduction by solar photovoltaic (PV) integration as DG was observed by (Roediger, *et al.,* 2012) using MATLAB simulation with IEEE 13 bus unbalanced system. Similar results were observed for IEEE 34 bus test system by (Ravindran, *et al.,* 2013). (Sahito *et. al.* 2015) demonstrated DGs impacts on voltage profile improvement of radial distribution feeder in HESCO. Although benefits of DGs are explained by various researchers, but they all agree that impacts of DGs will vary with the size, type and location. Different types of DGs may have varying effects on single system. Similarly a single DG may show different impacts on different power system networks.

In this research work, impacts of solar (PV) cell, synchronous and induction generators for wind turbines are compared by selecting a radial distribution feeder of HESCO. Feeder network is simulated using Power System Simulation – Siemens Network Calculator (PSS SINCAL) assimulation platform. Network is modified

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with DGs integration at strategically selected locations. Simulation results are compared to observe impacts of different DG technologies on power losses of the selected feeder network.

Section 2 discusses different generation technologies used for DG units. Details of the selected distribution feeder and proposed DG units are given in section 3. Simulation results and discussions are given in section 4. Impacts of DG integration in terms of power sources and power losses are given in tabular form. Finally paper is concluded in section 5.

2. DISTRIBUTED GENERATION

DG is term applied to power generation facilities connected directly to distribution system (Uqaili *et. al.* 2015). It is also called as Embedded Generation as generation sources are located at different locations and then embedded in system network. Capacity of DG units vary according to system requirements and availability of site but it is smaller in size as compared to conventional generation sources. Most of the DG units use renewable energy sources and therefore are suitable to be installed near load centers. On the other hand conventional generation sources like thermal and nuclear have limitations of location based on water requirement, fuel transportation, carbon emission and human safety.

Wind and solar PV generation are most widely used DG technologies around the world. Light energy is directly converted into electrical energy using PV cell without using any rotational device. PV cell produces Direct Current (DC) power which may be used directly for DC appliances. Voltage regulation is provided using power electronic DC-DC converters. Conventionally Alternating current (AC) appliances are widely used in power system. Therefore Inverter circuits are required to convert DC produced by PV cell in AC. PV cells are grouped in PV panels and then arrays to increase power generation capacity of the PV system. PV generation only produces active power.

Wind generation is most widely used DG technology around the world. Kinetic energy of wind is converted in electrical energy using wind turbine. Generators are coupled with wind turbines to produce electrical power. Number of wind turbines are connected together and termed as wind farm. Electricity generation from wind turbine mainly depends upon the velocity of wind at generation site. Wind turbines and generators are selected according to system requirements (Kazemi and Sadeghi 2009).

Both synchronous and induction generators are used in wind power generation. Synchronous generator produce active as well as reactive power. Active power is controlled through rotation of wind turbine and reactive power through DC excitation provided to windings placed on rotor. **(Fig. 1)** shows a typical arrangement of direct driven synchronous generator and its interconnection to utility grid. Speed of synchronous generator is not controlled through gear box arrangement. Hence variable frequency AC power is generated. Generated power is rectified to DC for excitation of the generator. DC link is used to control output voltage and frequency for interconnection to utility grid.

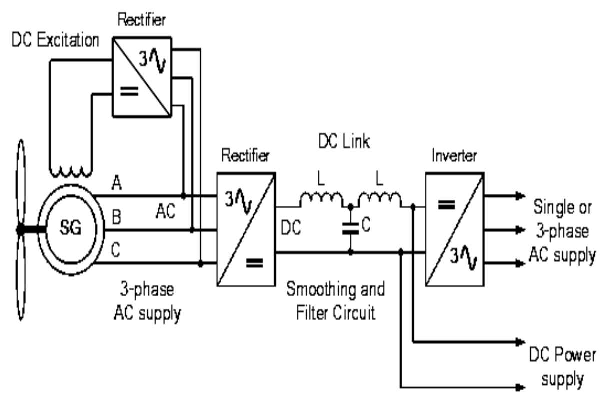

Fig. 1. Direct driven synchronous generator

When Induction motor is made to run above synchronous speed, it is termed as induction generator. Induction generators may be directly connected to utility distribution network whereas synchronous machines need to be synchronized with utility network. Mechanical gear box is used with induction generators to maximize its efficiency and reliability. An induction generator requires reactive power for its operation. Hence utility network must be capable of providing additional reactive power or shunt capacitors are installed with induction generators.

Doubly fed induction generator (DFIG) is similar like induction generatorbut with greater control over generator output parameters. DFIGuses additional windings on rotor making it possible to provide better control in terms of frequency and terminal voltage. Power electronic circuits are used with DFIG to make them it operative on different reactive power factors.

Pakistan is blessed with huge generation possibilities from solar and wind. Coastal areas of Sindh and Baluchistan have wind speeds sufficient for power generation throughout the year. Around 90,000 MW of power production potential through wind is estimated in areas of Sindh only (Shami, *et al,* 2016).Average monthly solar radiation intensity remains 137 to 288 W/m^2 in the country(Adnan *et al.,* 2012). Almost 90% of Pakistan has sun light for whole year making solar PV generation as one of the best choice. Number of consumers are using independent solar generation for their needs. Rural areas are specially benefited using PV panels and DC load appliances.

3. SYSTEM DESCRIPTION

In this research work, 11kV Anwer Villaz feeder is selected to observe impacts of DG on power losses. **(Fig. 2)** shows node diagram for H.T network of selected feeder. Around 3000 residential and commercial consumers are supplied through 58 Pole Mounted Transformers (PMT) having total capacity of 7600 kVA. Dog and Rabbit conductors are used for high tension (H.T) network of 7.42 km.

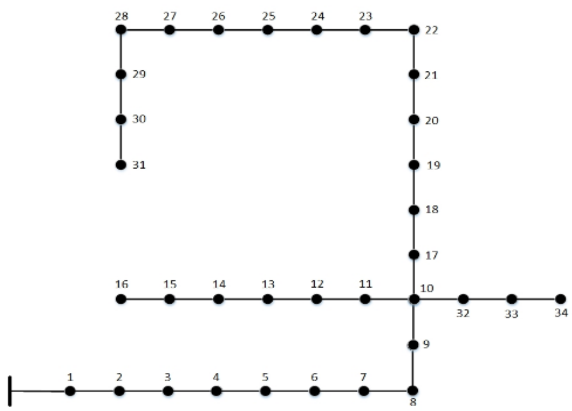

Fig.2. Node diagram of 11kV Anwar Villaz feeder

Four DG units are proposed at nodes 6, 10, 18 and 28 respectively. Three different cases for DG types are used. All DG units are selected to have similar active power capacity of 1 MW. PV cell only produces active power and therefore its reactive power generation is 0. Each Synchronous generator injects reactive power of 500kVAR whereas each induction generator absorbs reactive power of 500 kVAR.

Collected data is used to model and simulate existing network of selected feeder using PSS-SINCAL as simulation platform. DGs are integrated using network additions at prescribed nodes. Simulations are performed in four cases to analyze impacts DGs on power losses of the selected feeder. Four cases for analysis are listed in **(Table 1)**.

Table.1.Cases for system simulation

Case #	Description
I	Existing Network without any DG
II	Four PV cell based DGs connected
III	Four synchronous generator based wind farm DGs
IV	Four induction generator based wind farm DGs

4. RESULTSAND DISCUSSIONS

Simulation results for four cases given in **(Table. 1)** are analyzed to observe impacts of different DG technologies on power losses on radial distribution feeder. **(Table. 2)** gives current flows in different branches of H.T network for four cases. **(Table 3)** compares active and reactive powers supplied by grid for four cases under discussion. DGs are assumed to provide constant power. It is clear that with introduction of DGs, power supplied by grid is decreased and load demand is met by nearby DG unit. Reactive power supplied by grid without any DG is 3832 kVAR, which reduces to 3410 kVAR with PV based DGs integrated to network. Although PV generation does not contribute to reactive power but it reduces current flows through lines and therefore reactive power lost in H.T lines is reduced resulting in reduced reactive power drawn from grid. In case of synchronous generator maximum reduction in reactive power is observed as reactive power demand is also met locally by DGs. In case IV of the induction generator based DGs, reactive power has increased to meet demands of induction generators. Thus reactive power losses will also increase.

Table. 2. Current flow comparison in H.T branches

Branch	Current (A)			
	Case I	Case II	Case III	Case IV
1-2	330	179	67	301
2-3	315	174	60	296
3-4	311	172	58	292
4-5	30	167	54	287
5-6	295	163	51	284
6-7	293	168	86	261
7-8	278	156	74	250
8-9	270.54	150.75	66.71	243.73
9-10	256.49	141.46	56.46	234.41
10-11	62.39	56.74	54.81	59.08
11-12	55.21	50.18	48.47	52.27
12-13	46.66	42.40	40.95	44.17
13-14	31.47	28.60	27.62	29.79
14-15	16.71	15.18	14.67	15.81
15-16	6.44	5.85	5.64	6.093
10-17	152.19	83.16	26.44	145.01
17-18	138.38	76.58	23.34	137.5
18-19	122.19	73.10	46.70	104.24
19-20	103.84	58.84	31.49	90.21
20-21	100.04	56.08	28.45	87.5
21-22	95.93	53.17	25.23	84.63
22-23	76.22	41.04	12.65	72.19
23-24	68.88	37.65	11.38	68.25
24-25	66.44	36.71	11.71	67.05
25-26	63.86	35.88	12.46	65.89
26-27	44.95	33.95	24.17	59.44
27-28	32.25	37.28	34.01	58.04
28-29	29.01	25.10	23.97	26.53
29-30	22.40	19.21	18.32	20.37
30-31	11.99	10.06	9.54	10.75
10-32	41.92	37.71	36.32	39.43
32-33	24.91	22.37	21.54	23.41
33-34	6.48	5.84	5.63	6.11

Table. 3. Grid power for four cases under discussion

Case	Active Power (kW)	Reactive Power (kVAR)
I	4867	3832
II	385	3410
III	209	1256
IV	742	5717

Comparison of power losses for four cases is given in **(Table.4)**. It is clear that DGs using synchronous generator based wind generation result in maximum power loss reduction due to their capability of supplying reactive power. Induction generators have minimum power loss reduction as their required reactive power is also supplied by grid. Maximum power loss reduction is observed for H.T network. Although DG integration does not change L.T network or transformer, but small power loss reduction is also observed for these networks. This small reduction is caused by improved terminal voltage of the transformers. Thus current flowing through transformer and L.T networks are reduced resulting in reduced power losses.

Table. 4. Power loss comparison

Branch	Power Loses (kW)			
	Case I	Case II	Case III	Case IV
H.T	600	186	29	517
Transformer	101	88	84	93
L.T	224	176	160	185
Service Line	36	30	24	31
Total	961	480	297	826

5. CONCLUSIONS

In this research work, impacts of different DG technologies on power losses of distribution feeder are analyzed through network simulation. PSS SINCAL is used as simulation tool for power flow studies on the selected feeder. Analysis of existing system network is compared with those modified by integrating four DGs of equal capacity at four distinct locations. PV cell and synchronous and induction generator based wind generations are used as DGs.

Simulation analysis shows that all three types of DGs results in reduction of distribution feeder losses. Wind farms using synchronous generators results in maximum reduction of (961-480=481) kW. This maximum reduction is due to generator's abilityto produce reactive power and thus current flows through lines are reduced significantly. Induction generator based DGs result in small reduction in power losses because their reactive power demand is supplied by grid. Induction generator need shunt capacitors to be connected in parallel to meet reactive power demands locally. PV cells only produce active power and therefore power losses reduction is in between those for synchronous and induction based wind generation.

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