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Performance Evaluation of Synchronous and Induction Machines Coupled with Distribution Network

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Abstract—With the rapid increase in energy demand all over the world and great advancements in technology, utilities are more interested in Distributed Generation (DG). Among different sources, synchronous and induction machines are widely used for DG applications. In this paper, a detailed performance evaluation is carried out for induction and synchronous machines in Distributed Generation mode. A typical radial distribution feeder is simulated in Electrical Transient Analyzer Program (ETAP) and the impacts of aforementioned sources are analyzed on DG. On the basis of comparison between sources, some basic technical factors such as voltage profile and electrical power losses are considered. It was found that the most desirable source depends on the characteristics of the distribution network, i.e. the core technical factors that might put constraints on the penetration level of DG.

Keywords— Distributed generation, Power losses reduction, Voltage profile improvement.

I. Introduction

The demand of electrical energy is satisfied via centralized power plants in majority of the countries. However, due to rapid increase in energy demand and environmental consciousness, interest in renewable energy based Distributed Generation DG has increased. Other important factors that results in the increasing interest of DGs are deregulation of market and advancements in the technologies [1]. In most of the DG installations today, either synchronous or induction machines are employed, which can be used in different types of power plants i.e. wind, thermal and hydro power plants [2]. Although, these sources are very clearly defined, but no clear consensus is provided for the best technology to be used under a specific technical perspective.

On the basis of the facts, it is very important to analyze the different impacts caused by these sources on the distribution network performance. In this research work, different results based on the DG interconnection scenarios and technical factors are presented. The main factors analyzed in this research work are voltage profile and electrical power losses. These results will be useful for utilities and design engineers to select the more feasible type of source considering the main characteristics of the distribution network.

This paper is organized in the following manner; Section II addresses network component models used in this research work. Section III discusses about the proposed system studies in detail. In Section IV, the impacts of these two different DG sources on the voltage profile is discussed briefly. Section V discusses the impacts of these DG units on power losses of the system. Sections VI finalize the main conclusion of this research work.

II. Network Component Models

All the major network components in this research work are represented by three phase models. In order to verify the impacts of these two different sources on voltage profile and power losses, the analysis are conducted by using a Newton-Raphson technique used in load flow algorithm. A typical radial 11KV feeder is selected which supplies power to five distribution points i.e. from bus 2 to 6. 3-phase 3-wire overhead cables are used to connect these distribution points which are selected as per load requirement. Actual data related to cables and electrical parameters is collected from the grid and implemented in software. This feeder powers seven distribution transformers (T1-T7) of 11/0.4KV ratings and loads on secondary are lumped.

A. Synchronous Generator

In most of the DG systems today, synchronous generators are employed that can be used in wind, hydro or thermal power plants for power generation. In most of the cases, a synchronous generator acts as constant active power when connected with the distribution networks, thus not effecting frequency. Due to this behavior, the mechanical power of the synchronous generator in this research work is kept constant, while other dynamics related to prime mover and regulator are neglected. Beside this, the excitation of the distributed synchronous generators can be controlled in two different modes. In voltage control mode, the voltage at the different terminals is kept constant while in power factor controlled case, it aims to keep power factor constant [3]. Independent power producers mostly uses power factor controlled mode to maximize the production of active power in the system. In this

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research work, synchronous generator adopting voltage control mode is installed to study its impacts on traditional radial distribution network.

B. Induction Generator

At present, most of the induction generators in operation mode are installed in wind power plants [4]. However, some of medium size hydro and thermal power plants have also used induction generators [5]. In order to get more generic results, the mechanical torque of induction generator is kept at constant by neglecting the regulator and prime mover dynamics. In all case studies simulated in this research work, the reactive power required for induction generator is absorbed from the system.

III. PROPOSED SYSTEM STUDIES

A. Description of the Test Feeder

Power flow analysis is required to carefully analyze the impacts of different DG sources on the performance parameters of the distribution network. A radial distribution feeder located at industrial area Peshawar, Pakistan is selected for this research due to high line losses and long power outage duration in the area. The test feeder is carefully designed on the basis of the actual data collected through field surveys and simulated in ETAP. Figure 1 shows the single line diagram of the test feeder while Table I shows the power injections from the grid and DG sources under different scenarios.

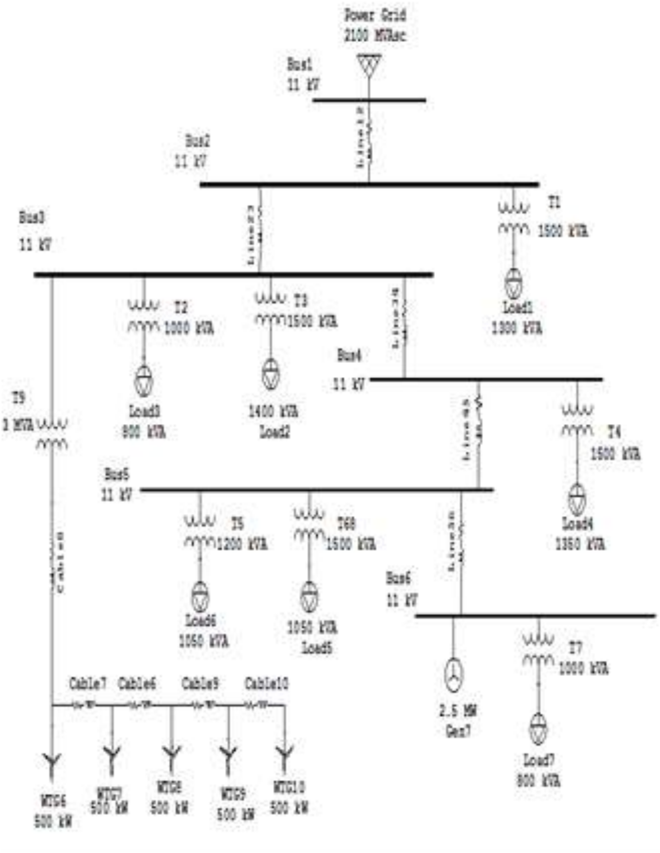

Figure 1: Single line diagram of the test feeder

TABLE I. CONTRIBUTION OF POWER FROM GRID AND TWO DG UNITS

Scenario	Active Power (KW)			Reactive Power (KVAR)		
	Grid	*DG1*	*DG2*	*Grid*	*DG1*	*DG2*
1	6294	0	0	4089	0	0
2a	3757	2500	0	2522	1600	0
2b	3781	2500	0	2579	1600	0
3a	4034	0	2500	6089	0	-1550
3b	4189	0	2500	6153	0	-1550
1	6294	0	0	4089	0	0

B. DG Interconnection Scenarios

In order to verify the effects of synchronous and induction machines on the performance parameters of the test circuit, the following study cases are performed considering two different DG units i.e. DG1 and DG2.

1. No DG unit will be connected and results of this case will be used as base.
2. A synchronous machine of 2.5MW capacity, will be connected in the following manner
   a. 2.5 MW DG unit coupled with bus 3.
   b. 2.5 MW DG unit coupled with bus 6.
3. In this case, five induction generators having capacity of 500KW each are coupled in the following manner
   a. 2.5 MW DG units connected at bus 3.
   b. 2.5 MW DG units connected at bus 6.

IV. IMPACTS OF DG ON VOLTAGE PROFILE

During system operation, load flow analysis is the basic tool to calculate voltages at different buses. Most of the electrical appliances designed by different manufacturers operate on rated voltages and frequency [6]. Depending upon those requirements, utilities must supply consumers with in that permissible range. The voltage drop is due to the flow of current in the components of the system having specific impedance which is directly proportional to the flow of current. With the interconnection of DG, current flow changes which in turn change the voltage at different buses. Table 2 shows the bus voltages for all the study cases. When no DG unit was connected in the first case, voltage drops increases gradually towards the final load point, because of the radial structure of the traditional distribution system as shown in figure 2. The effects of synchronous generator on the voltage profile of the different buses are shown in figure 3. While, figure 4 shows the impacts of induction generator on the voltage profile of the radial feeder. The source voltage in this circuit is kept constant at a rating of 11KV. With the interconnection of DG unit, voltage levels of the other five buses alter depending on the type, size and location of the DG unit. Power grid acts as an infinite bus supplied by132KV grid station. All the DG units interconnected to the system are synchronized having same terminal voltage at point of common coupling.

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TABLE II. BUS VOLTAGES UNDER DIFFERENT SCENARIOS

Bus	Bus Voltage (KV)				
	Scenario 1	*Scenario 2*		*Scenario 3*	
		a	*b*	*a*	*b*
1	11	11	11	11	11
2	10.82	10.892	10.891	10.864	10.859
3	10.67	10.814	10.812	10.759	10.75
4	10.49	10.633	10.763	10.578	10.663
5	10.367	10.509	10.771	10.454	10.635
6	10.333	10.475	10.869	10.42	10.7

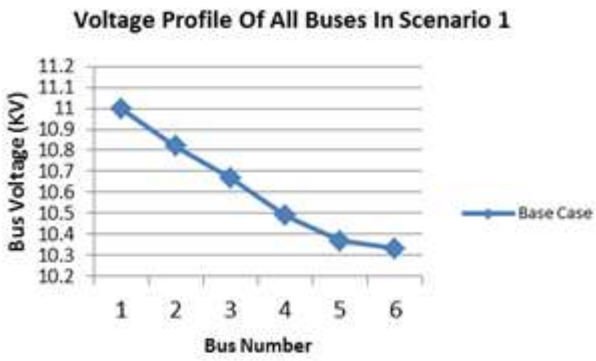

Figure 2: Voltage profile of all buses in Scenario 1

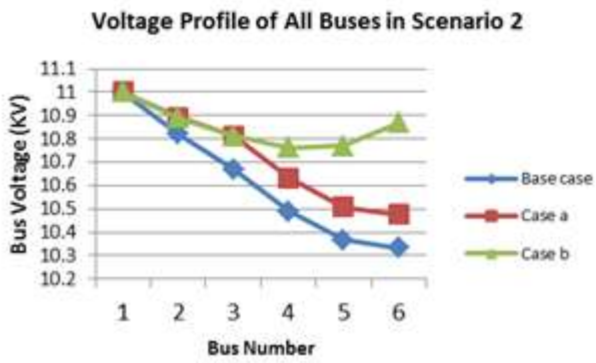

Figure 3**:** Voltage profile of all buses in Scenario 2

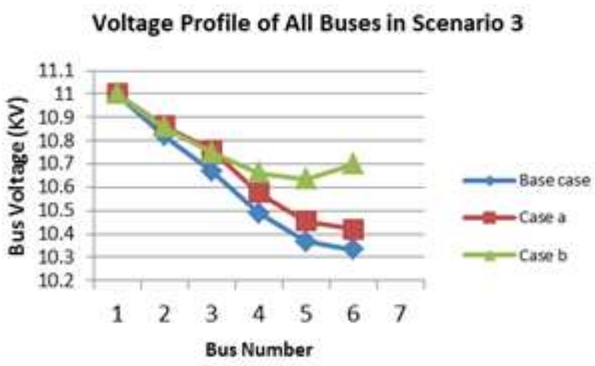

Figure 4**:** Voltage profile of all buses in Scenario 3

V. IMPACTS OF DG ON POWER LOSSES

Power losses are directly dependent on the flow of power which alters with integration of DG unit, causing the power flow from radial to bidirectional i.e. not only from grid to load [7-9]. Although, power loss is not only a major technical factor which gives an edge to the installation of DG units, but it also has a great importance from economic point of view [10]. Normally, with the integration of a DG unit, current flowing in the line decreases which in turn decreases overall losses of the system. However, this increase or decrease of losses is totally dependent on type, size and location of the DG unit [11]. The system losses are completely related to the voltage profile, not the power quality of the system [12]. Result of the simulations conducted in this research work shows the significant impact of DG units on the system active power losses. Branch-wise losses of all the lines in three different scenarios are given in Table III, which clearly shows the effects of coupling different types of DG units on the power losses of the system. Maximum power losses occur in Line12 during 1st scenario because maximum current flows through this line to fulfill load requirements. In first case of the 2nd scenario, when a synchronous generator of 2.5MW is connected at bus3, current flowing through Line12 decreases and thus causes significant reduction in the power losses of the overall system. However in second case, when the same DG unit was placed at bus 6, overall losses of the system significantly reduced as compared to the first case. In the 3rd scenario, when an induction generator of 2.5MW capacity is connected at bus 3, power losses increases as compared to synchronous generator case. It is because the induction generator draws MVAR from the system to inject MW in to the system thus causing increase in the flow of current in the lines. On the other hand, when the same induction generator was connected at the bus 6, it causes significant increase in the current flowing in the lines and thus increasing the overall losses of the system. Figure 5 shows the DG impact on reduction of power losses in Line12 in three different scenarios. Figure 6 shows the impact of the DG units installed in three different scenarios on the losses of the six different lines. On the other hand, figure 7 shows the impacts of the two different DG sources interconnected in three different scenarios on the overall losses of the distribution system.

TABLE III. BRANCH WISE POWER LOSSES

Line	Line Losses (KW)				
	Scenario 1	*Scenario 2*		*Scenario 3*	
		a	*b*	*a*	*b*
Line12	126.0	45.8	46.8	119.3	123.6
Line23	87.2	23.7	24.5	84.9	88.6
Line34	73.3	74.1	5.8	73.8	88.2
Line45	34.4	34.8	0.1	34.6	57.2
Line56	2.6	2.6	21.5	2.6	39.4
Total	**323.5**	**181**	**98.7**	**315.2**	**397.1**

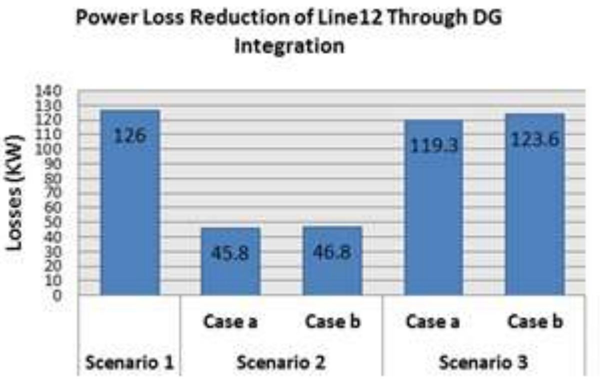

Figure 5: Power losses of line12 with DG unit

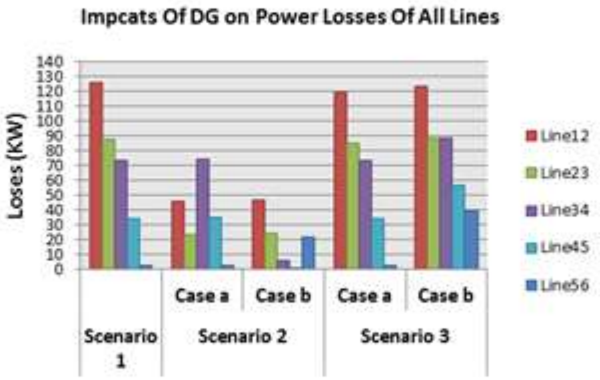

Figure 6: Power losses of all lines with different DG units

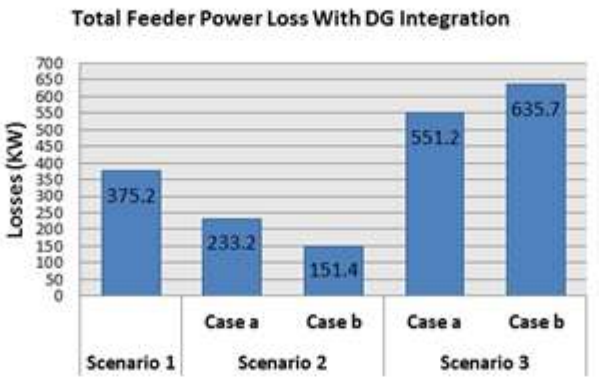

Figure 7: Total feeder power losses with different DG units

In the first case of the scenario 2, when DG1 is connected to bus 3 which is supplying power to the loads connected at bus 2 and 3. In this case, the flow of current in Line12 and Line23 from the power grid decreased significantly which in turn decreases power losses in the respective lines. However, the flow of current towards the remaining buses 4, 5 and 6 remains constant, thus keeping the power losses unchanged in Line34, Line45 and Line56. In second case of the scenario 2, when DG1 is connected at bus 6 supplying power to the loads connected at bus 4, 5 and 6. In this case, huge reduction in power losses is witnessed in Line34 and Line45 as shown in Figure 6. Therefore, major decrease in the power losses of the overall system can be seen in the 2nd scenario as compared to 1st scenario as shown in figure 7. In first case of the 3rd scenario, when induction generator of 2.5MW capacity was placed at bus 3, same current flows in all the lines as that of the 1st scenario thus keeping the losses of all the lines constant. However, when the induction generator was placed ta bus 6, current flowing in the lines increased thus increasing the overall losses of the lines as shown in figure 6 and 7. This increase in losses is due to the absorption of MVAR for induction generator from the system to deliver MW in to the system. Also, some losses occurs in the in the distribution transformers and cables which supplies power to 11kV loads directly. But these losses mostly remain constant for all the three scenarios because the current flows through them are only due to their respective loads.

It is clearly shown in results that the integration of DG units can have significant effects on the power losses in the radial distribution system which purely depends on the size, type and location of the DG unit. Figure 7 shows the overall maximum power losses in the test feeder under three different scenarios of DG interconnection. In the1st scenario where no DG is connected, power losses were 375.2KW. In the 2nd scenario, when a synchronous machine of 2.5MW was connected at bus 3 and 6, power losses reduced to 233.3KW and 151.4KW respectively. Whereas in the 3rd scenario, when induction machine of 2.5 MW capacity was placed at bus 3 and 6 each, power losses increases to 551.2KW and 635.2 KW respectively.

VI. Conclusion

It is observed from the above three DG interconnection scenarios that some important factors such as size, location and type of DG unit have great impacts on the behavior of the distribution networks. From the detail analysis of DG impacts on the voltage profile and power losses, it is observed that a synchronous machine provides better improvement in voltage profile and power loss reduction when operated at a lagging power factor. Induction machine also improves voltage profile of the buses but increases the power losses in the network. Thus it is found from the different case studies that the synchronous machine is much more economical in DG mode than Induction generator. The synchronous generator supplies both active and reactive power in to the system which results in high reduction in power losses and improves the voltage profile.

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