Analysis The Impact Of Photovoltaic System For Loss Minimization In Modern Power System

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Abstract: This paper proposes to analyze the influence of the installation of photovoltaic systems in the power system network. In conventional power system network contains a synchronous generator to generate real and reactive power and it is located far away from the load center due to availability of raw material and water etc. This long distance transmission of power leads to losses in the system and it can be reduced by placing the power generation system nearer to the load center. The development of renewable sources of energy like wind power generation system and photovoltaic power generation will play vital role in this direction of loss minimization of the power system network. In modern power system, the installation the renewable sources of energy are very much essential to avoid the contamination of environment and to meet the future increasing electrical power demand. Hence, it is important to analyze the benefits of photovoltaic systems for the minimization loss of power in the power system. Here, WSSC 9-bus system is considered to analyze the impact of the proposed scheme.

Keywords:photovoltaic system, loss minimization, reactive power, voltage profile, power flow

I. Introduction

The growth of electrical power demand is larger than the expansion within the electrical power generation cause a substantial amount of shortage of electricity. The Government of India has taken various initiatives for developing renewable sources of energy to satisfy the energy demand and improving rural electrification. The implementation of local renewable sources of energy system to fulfil the growing power demand to understand energy requirements.The utilities can enhance their power grid network capacity by implementing renewable sources of energy with suitable capacities. the facility generation from photovoltaic system is one among the hopeful source of renewable energy. Because it doesn't require any fuel, maintenance, and emission of harmful gases. Naturally India country have more solar power thanks to its geographic location. Our country has most days have sunshine, which is adequate meet the entire energy demand within the country. the traditional power grid was aimed to possess centralized power generation which is being provided to the consumers using the widespread transmission and distribution network. the right approaches for locating out the acceptable location of the photovoltaic system should be considered to understand the advantages of integration of photovoltaic sources. There are other several factors also to be considered for locating optimum location and capacity of photovoltaic systems.

An analysis of various parameters on the photovoltaic system with MATLAB interface is presented in [1]. A control system model is developed for attaining load demand of the solar power generation system to its highest possible value of power. The performances of the photovoltaic system are analyzed by considering varying, temperature, irradiance and shading. The maximum value of output power is achieved from the solar panel by using MPPT algorithm. In [2] discussed the influence of distributed generation with STATCOM in the multi-machine system to reduce the real power losses in the system for different load conditions. The Doubly Fed Induction Generator based wind turbine system is considered as a distributed generation system and the STATCOM device is installed to provide the necessary reactive power system. The analyzes was done with the help of PSAT with MATLAB Simulink environment. The additional requirement of real and reactive power for increase in load is supplied by the slack bus, it will increase transmission loss and also increase the burden to the slack bus. But, when installing STATCOM at the load bus will supply sufficient reactive power locally and improve the load bus voltage. When installing a DFIG wind system nearer to the load, it will supply required real power and reduce the slack bus burden, and reduces the total active power losses in the system.

The mathematical model of the optimal VAR source control in the power system and loss minimization is presented in [3]. The best possible value of control variables is determined by using revised linear programming technique. The objective function and constraints are linearized for applying linear programming optimization method. This method provides optimal VAR compensation so that voltage profile at all buses are improved and total real power losses in the system is reduced.The voltage stability constrained extreme loadability of the

Power system is studied in [4]. The authors have discussed the voltage stability of the Power system under maximum loading conditions. The acute loadability point is traced by the PV curve and by using the continuation power flow method. The development of the Loadability of the system with SVC and STATCOM is analyzed to retain the bus voltages within the satisfactory limit when the facility system network is subjected to the load changes. Transmission line loss minimization in the power system network using TCSC and UPFC is discussed in [5]. Here the installation of the FACTS devices under heavily stressed condition is considered. The best locations of FACTS devices and performance of the system at maximum loadability condition are clearly examined by conducting proper simulation. The weak bus in the system are identified by conducting power flow analysis under different loadability condition of the transmission line. The minimization of real power loss at maximum loadability conditions and maintaining the bus voltage within the safety level of the system is analyzed through the installation of UPFC and TCSC at optimum locations.

The optimum Placement of the distributed generator system in the distribution system for minimization of power loss by non-Linear programming and Power Loss Sensitivity technique is presented in [6]. The GAMS software is used to execute load flow solutions for both mesh and radial distribution networks. There are two scheme has been considered for distributed generator sharing in the distribution power system. In the first scheme, sensitive nominee nodes are nominated as optimum distributed generator locations by considering power loss sensitivity. In the second scheme, optimum distributed generator size is calculated with the help of CONOPT solver of GAMS. In [7] PV system design processes, tools, and uses are clearly mentioned. The Influence of Photovoltaic system on power system to reduce the losses in the system is addressed in [8]. The case study has taken to analysis of the power losses throughout the line with and without connecting the photovoltaic system in the line. The Neplan software is to carryout performance analyses of the system.

The effect of the PV system on power quality in electrical distribution networks is presented in [9]. The installation of renewable energy sources and their effects on power quality of distribution systems is considered for the case studies. The power electronics converters and nonlinear loads are considered as a harmonic source. The reduction of harmonics is achieved through single tuned passive filters. The simulation of distribution system with photovoltaic systems and influence of photovoltaic system to minimize the harmonics and their effect on the distribution system is done with help of ETAP software. In [10] discussed the transmission losses analyze in the desert area with large scale photovoltaic system of power generation. It is difficult to understand the transmission losses in a desert situation. The authors have described the transmission loss is high in strong irradiation area, and low in weak irradiation area.

The photovoltaic inverter based reactive power injection scheme on grid voltage regulation is discussed in [11]. The authors descried various reactive power schemes for voltage regulation of the system when applied to a multi bus grid feeder in the photovoltaic power generation system linked to each feeder of the bus. The considers the various system factors like dynamic transformer tap changing position, feeder impedance, various types of load and capacity of photovoltaic system installed. The reactive power control is achieved by optimum allocation of distributed generation for is presented in [12]. In this study, the optimum allocation of locations and sizes of the photovoltaic systems are discussed. A hybrid method is developed for optimum reactive power control in the distributed power generation system. The hybrid method optimally assigns the localities and the sizes of distributed generation systems with an objective function which minimizes voltage deviations initiated by the reactive power control of distributed power generation systems. The genetic algorithms optimization method is used to allocate the distributed power generation systems and maintain bus voltages of distribution system in the range of set value.

The modeling distributed generation based distribution feeder enhancement is discussed in [13]. The effect of distributed generation on the distribution network is examined, this study represents a distribution network enhancement by the photovoltaic system. The Digital Simulation and Electrical Network Calculation Program and the Open Distribution System Simulator are used for this study. This analyses initially inspects load models, voltage regulators, transformers existing in the system, then the photovoltaic system is added to the test feeder and observe its impact by examine the power flow results obtained. The selection of suitable FACTS devices for the Indian utility system to reduce the losses is discussed in [14]. The suitable locations of STACOM or TCSC in the test system are identified to improve the bus voltage magnitude and minimize real power losses are in the acceptable limits. The suitable location of these FACTS devices is identified based on the weak bus in the system.

The optimization solutions for grid adaptive energy conservation system is discussed in [15]. To extend system level efficiency, precise, energy and reduction of cost via innovative smart grid lineament and tools like Community Energy Storages (CES), Advanced Metering Infrastructure (AMI), Distributed Energy Resources (DER), Phasor measurement units (PMU). The authors reviewed the requirements of smart grid adaptive energy conservation and Volt-VAR optimization, in terms of communication, measurement, control and standards for grids. The stability analysis of the grid integrated of photovoltaic systems using partial power converters is discussed in [16]. The work represents a partial power DC-DC converter that will processes a part of the whole system power and therefore the remaining power is will be supplied to the output side. The phased locked loop is used for the grid frequency synchronization and an asynchronously rotating frame is considered for stability improvement. Voltage source inverter based grid connected photovoltaic system used depend on the voltage control loop responsible for the dc voltage regulation and internal current control fed with a generated current reference.

The effect of PV inverter system support on voltage profile improvement and power loss in medium voltage distribution systems is discussed in [17][19][20][21]. The impact of PV system on the voltage profile and power loss minimization in distribution systems is analyzed by considering inverters capacities, locations and different reactive power control strategies. The sensitivity matrix is used to analyze the impact on voltage stability when photovoltaic system connected at different locations. A detailed comparison of distributed photovoltaic and centralized photovoltaic installation is made. Here, the impact of photovoltaic system incorporation in the electric power system and the realization of real power loss reduction is analyzed.

2. Problem Formulation for the Selected System

The study has been performed on the WSCC 9-bus test system and shown in Figure 1. This system which consists of 9 buses in which one slack bus, two generator bus, three load bus, three two winding transformers, and six transmission lines. The base kV levels are 13.8 kV, 16.5 kV, 18 kV,230 kV, and base MVA is 100 MVA. The various case studies are conducted to analyze the impact of the photovoltaic system to reduce the real power loss in the power system network. It is assuming that the load is constant throughout the studies and only generation side analyses are made to find the best suitable location and photovoltaic penetration in the system. The analysis is made power system point of view and not from the power electronics equipment point of view. Also, assume that the photovoltaic system has sufficient capacity to supply the essential real power at the bus in which it is connected. Here, considered that 100 MW new photovoltaic system is installed at a suitable location by various case studies and observe the achievement of real power loss minimization.

The list of case studies is given below

Case 1: Base case power flow analysis with the existing conventional standard system.

Case 2: power flow analyzes with Photovoltaic system at bus-2 and replacing generator at bus-2

Case 3: power flow analyzes with Photovoltaic system at bus-3 and replacing generator at bus-3

Case 4: power flow analyzes with Photovoltaic system at bus-2 and bus-3 and replacing generator at bus-2 and bus-3

Case 5: power flow analyzes of case 4 with additional Photovoltaic system at bus-9

Case 6: power flow analyzes of case 4 with additional Photovoltaic system at bus-5

Case 7: power flow analyzes of case 4 with additional Photovoltaic system at bus-6

Case 8: power flow analyzes of case 4 with additional Photovoltaic system at bus-5 and bus-6

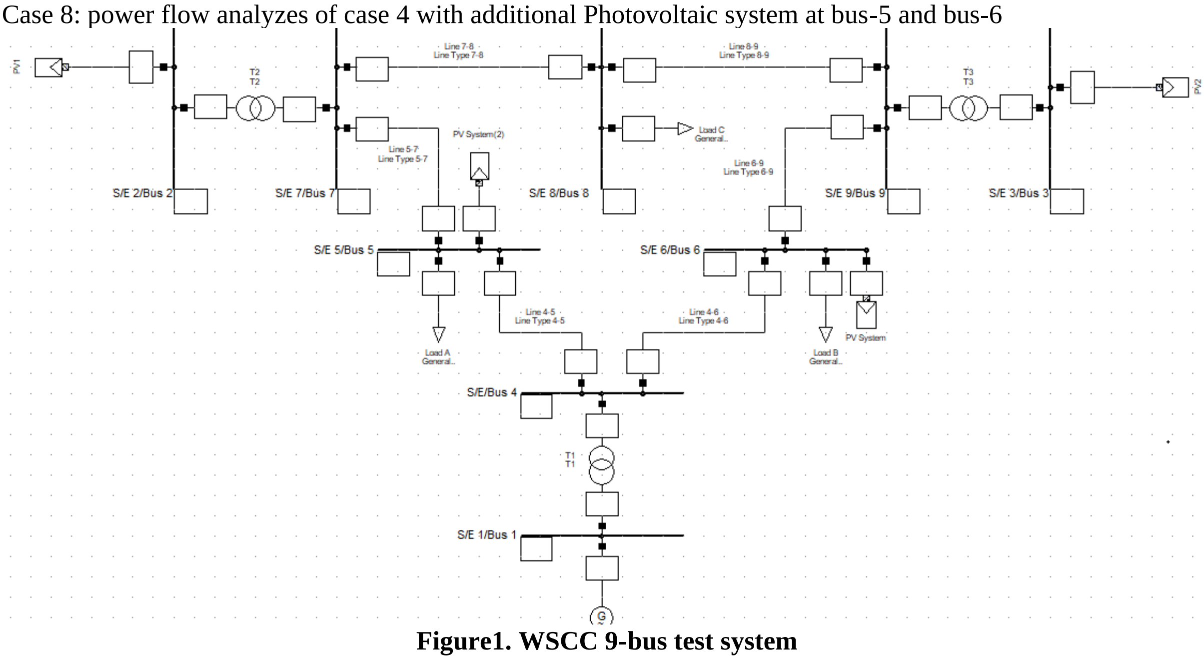

Figure1. WSCC 9-bus test system

3. Photovoltaic System

The arrangement of the photovoltaic module and other components to generate the electric power is shown in Figure 2. The outline of solar photovoltaic systems incorporation into electricity grids is discussed in [18]. The solar thermal systems use thermal energy received from the sun to generate thermal energy and it is converted into electrical power with help of a synchronous generator. But, in photovoltaic power generation Photovoltaic solar panels generate DC electric power with the help of sunlight through the Photovoltaic effect. The direct current electrical power is converted into alternating current electrical power by using inverters. Inverters are needed to supply constant value of voltage and frequency irrespective of varying load conditions. The inverter output is connected to the low voltage side of the bus bar and the power grid is connected to a high voltage side of the bus bar. A Step-up transformer is essential to step up the inverter output voltage to match the grid bus bar voltage level. With help of photovoltaic power generation, it is possible to make bi-directional power flow. However, conventional electric transmission and distribution systems are not having any bi-directional power flow. Any installation of photovoltaic generation must be closely matched to the load. When photovoltaic system power generation more than the local energy demand, then more power flow in the distribution feeder system and local substation will leads to distress the stability of the utility grid. Hence it is important to make the simulation study on the integration of photovoltaic power penetration in the conventional power system network before going to install in the actual practice.

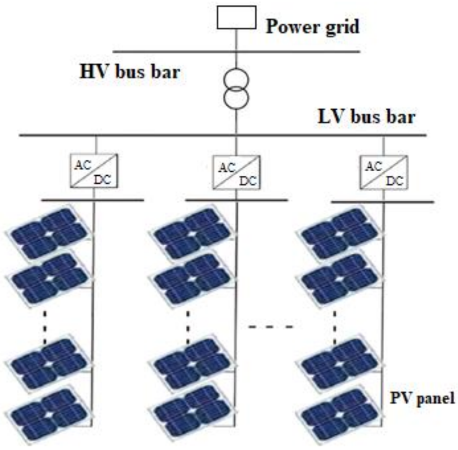

Figure 2. photovoltaic module arrangement

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4. Results and Discussion

The Figure. 1 shows the WSSC 9-bus test system considered for the analyze of the proposed work. In this system the slack bus is connected to the bus-1, synchronous generators are connected to the bus-2 & bus-3 and loads are connected to the bus-5, bus-6, bus-8. The total load in the system is 315 MW and total reactive power load is 115 MVAR. In this analyze the total demand in the system is assumed to be constant. The initial base case power flow analyses are carried out to determine the generated power of synchronous generator at bus-1 and bus-2 and slack bus power generation at bus-1 to meet the total load on the system. The base case power flow results obtained are presented in the Table.1. From the Table.1, it is observed that the all the bus voltage magnitudes are nearer to the unity and there are no bus voltage violations. The total real power losses in the system are 4.64 MW. In further studies, the conventional synchronous generators are replaced by photovoltaic system and observe the possibilities to minimize the real power losses in the system.

Table.1: Base case WSSC 9 bus system (case 1) – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.040	0.000	71.64	27.05	0	0
Bus 2	1.025	9.280	163.00	6.65	0	0
Bus 3	1.025	4.660	85.00	-10.86	0	0
Bus 4	1.026	-2.220	0	0	0	0
Bus 5	0.996	-3.990	0	0	125	50
Bus 6	1.013	-3.690	0	0	90	30
Bus 7	1.026	3.720	0	0	0	0
Bus 8	1.016	0.730	0	0	100	35
Bus 9	1.032	1.970	0	0	0	0

In case-2 studies, the conventional synchronous generator at bus-2 is replaced with photovoltaic system capacity of 163 MW and all other components are kept same. The power flow results for the case-2 system is shown in the Table.2. From the Table.2 it is observed that the all the bus voltage magnitude is within the allowable limits and total real power losses in the system is 4.74 MW.

Table.2: case 2 Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	71.74	31.41	0	0
Bus 2	1.0100	9.5800	163.00	0	0	0
Bus 3	1.0250	4.7200	85.00	-5.93	0	0
Bus 4	1.0230	-2.2300	0	0	0	0
Bus 5	0.9900	-4.0000	0	0	125	50
Bus 6	1.0100	-3.6900	0	0	90	30
Bus 7	1.0150	3.8800	0	0	0	0
Bus 8	1.0080	0.8000	0	0	100	35
Bus 9	1.0300	2.0100	0	0	0	0

In case-3 studies, the conventional synchronous generator at bus-3 is replaced with photovoltaic system capacity of 85 MW and all other components are kept same. The power flow results for the case-3 system is shown in the Table.3. From the Table.3 it is observed that the all the bus voltage magnitude is within the permitted limits and total real power losses in the system is 4.59 MW.

Table.3: case 3 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	71.59	20.65	0	0
Bus 2	1.0250	9.1500	163.00	-0.75	0	0
Bus 3	1.0480	4.3600	85.00	0	0	0
Bus 4	1.0290	-2.2100	0	0	0	0
Bus 5	1.0000	-3.9900	0	0	125	50
Bus 6	1.0210	-3.6900	0	0	90	30
Bus 7	1.0300	3.6200	0	0	0	0
Bus 8	1.0260	0.6200	0	0	100	35
Bus 9	1.0490	1.7600	0	0	0	0

In case-4 studies, the conventional synchronous generator at bus-2 and bus-3 are replaced with photovoltaic system capacity of 163 MW and & 85 MW respectively and all other components are kept same. The power flow results for the case-4 system is shown in the Table.4. From the Table.4 it is noted that the all the bus voltage magnitude is within the acceptable limits and total real power losses in the system is 4.56 MW.

Table.4: case 4 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	71.56	19.03	0	0

Bus 2	1.0280	9.0800	163	0	0	0
Bus 3	1.0500	4.3200	85	0	0	0
Bus 4	1.0300	-2.2000	0	0	0	0
Bus 5	1.0010	-3.9800	0	0	125	50
Bus 6	1.0230	-3.6900	0	0	90	30
Bus 7	1.0330	3.5700	0	0	0	0
Bus 8	1.0280	0.5900	0	0	100	35
Bus 9	1.0510	1.7300	0	0	0	0

In case-5 studies, the additional 100 MW capacity of photovoltaic system is installed at bus-9 along with case-4 system arrangement. The power flow results for the case-5 system is shown in the Table.5. From the Table.5 it is observed that the all the bus voltage magnitude is within the acceptable limits and total real power losses in the system is reduced to 3.99 MW. It is also observed that the need of power generation at the slack bus generator is reduced from 71.64 MW to 70.99 MW, at bus-2 real power generation requirement reduced from 163 MW to 113 MW and bus-3 the real power generation requirement is reduced from 85 MW to 35 MW. The real power generating burden on bus-2 and bus-3 are reduced, because of installation of additional 100 MW photovoltaic system at bus-9.

In case-6 studies, the additional 100 MW capacity of photovoltaic system is installed at bus-5 along with case-4 system arrangement. The power flow results for the case-6 system is shown in the Table.6. From the Table.6 it is observed that the all the bus voltage magnitude is within the acceptable limits and total real power losses in the system is reduced to 1.84 MW. It is also observed that the need of power generation at the slack bus generator is reduced from 71.64 MW to 68.84 MW, at bus-2 real power generation requirement reduced from 163 MW to 113 MW and bus-3 the real power generation requirement is reduced from 85 MW to 35 MW. The real power generating burden on bus-2 and bus-3 are reduced, because of installation of additional 100 MW photovoltaic system at bus-5.

Table.5: case 5 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	70.99	-7.44	0	0
Bus 2	1.0760	6.6700	113	0	0	0
Bus 3	1.0900	1.9900	35	0	0	0
Bus 4	1.0450	-2.1600	0	0	0	0
Bus 5	1.0280	-3.8400	0	0	125	50
Bus 6	1.0470	-3.7700	0	0	90	30
Bus 7	1.0780	3.1800	0	0	0	0
Bus 8	1.0780	2.3000	0	0	100	35
Bus 9	1.0900	1.0000	100	0	0	0

Table.6: case 6 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	68.84	-15.62	0	0
Bus 2	1.0700	2.9400	113	0.0	0	0
Bus 3	1.0810	-2.4600	35	0.0	0	0
Bus 4	1.0490	-2.0800	0	0	0	0
Bus 5	1.0420	-2.1700	100	0	125	50
Bus 6	1.0480	-5.3200	0	0	90	30
Bus 7	1.0720	-0.5900	0	0	0	0
Bus 8	1.0640	-3.8600	0	0	100	35
Bus 9	1.0810	-3.4700	0	0	0	0

In case-7 studies, the additional 100 MW capacity of photovoltaic system is installed at bus-6 along with case-4 system arrangement. The power flow results for the case-7 system is shown in the Table.7. From the Table.7 it is observed that the all the bus voltage magnitude is within the acceptable limits and total real power losses in the system is reduced to 1.91 MW. It is also observed that the need of power generation at the slack bus generator is reduced from 71.64 MW to 68.91 MW, at bus-2 real power generation requirement reduced from 163 MW to 113 MW and bus-3 the real power generation requirement is reduced from 85 MW to 35 MW. The real power generating burden on bus-2 and bus-3 are reduced, because of installation of additional 100 MW photovoltaic system at bus-6.

In case-8 studies, the additional 50 MW capacity of photovoltaic system at bus-5 and 50 MW capacity of photovoltaic system at bus-6 is installed along with case-4 system arrangement. The power flow results for the case-8 system is shown in the Table.8. From the Table.8 it is observed that the all the bus voltage magnitude is within the acceptable limits and total real power losses in the system is reduced to 1.39 MW. It is also observed that the need of power generation at the slack bus generator is reduced from 71.64 MW to 68.39 MW, at bus-2 real power generation requirement reduced from 163 MW to 113 MW and bus-3 the real power generation requirement is reduced from 85 MW to 35 MW. The real power generating burden on bus-2 and bus-3 are reduced, because of installation of additional 50 MW photovoltaic system at bus-5 and bus-6.

Table.7: case 7 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	68.91	-14.49	0	0
Bus 2	1.0680	1.8700	113	0	0	0
Bus 3	1.0850	-1.2500	35	0	0	0
Bus 4	1.0490	-2.0900	0	0	0	0
Bus 5	1.0310	-5.4800	0	0	125	50
Bus 6	1.0620	-1.8200	100	0	90	30
Bus	1.0700	-1.6700	0	0	0	0

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Bus 8	1.0660	-3.9800	0	0	100	35
Bus 9	1.0850	-2.2500	0	0	0	0

Table.8: case 8 – Power flow results

Bus	V	phase	P gen	Q gen	P load	Q load
	p.u.	deg.	MW	MVAR	MW	MVAR
Bus 1	1.0400	0	68.39	-19.27	0	0
Bus 2	1.0740	2.3700	113.00	0	0	0
Bus 3	1.0880	-1.8500	35.00	0	0	0
Bus 4	1.0510	-2.0600	0	0	0	0
Bus 5	1.0400	-3.7900	50	0	125	50
Bus 6	1.0590	-3.5300	50	0	90	30
Bus 7	1.0760	-1.1300	0	0	0	0
Bus 8	1.0700	-3.9000	0	0	100	35
Bus 9	1.0880	-2.8400	0	0	0	0

The various case studies are carried out in different combination of additional installation of 100 MW photovoltaic system at various buses with the existing WSSC 9-bus system. The power flow results, bus voltages, real power loss and reactive power losses are tabulated. When installation of additional 50 MW capacity of photovoltaic system at bus-5 and 50 MW capacity of photovoltaic system at bus-6 the total real power losses in the system is very much reduced. The base case system the total real power loss is 4.64 and case-8 system the total real power loss is 1.39 MW. Hence, for the same WSSC 9-bus system the real power loss is reduced from 4.64 MW to 1.39 MW. The reduction of total real power losses in the system will be 70.04%. The total burden on the slack bus is reduced from 71.64 MW to 68.39 MW.

Table 9. Comparison of real power loss for different case studies

	Total Generation		Total Load		Total Loss
Case studies	Real Power (MW)	Reactive Power (Mvar)	Real Power (MW)	Reactive Power (Mvar)	Real Power loss (MW)
case1	319.64	22.84	315	115	4.64
case2	319.74	25	315	115	4.74
case3	319.59	19.9	315	115	4.59
case4	319.56	19.03	315	115	4.56
case5	319	-7.44	315	115	3.99
case6	316.84	-15.62	315	115	1.84
case7	316.91	-14.49	315	115	1.91
case8	316.39	-19.27	315	115	1.39

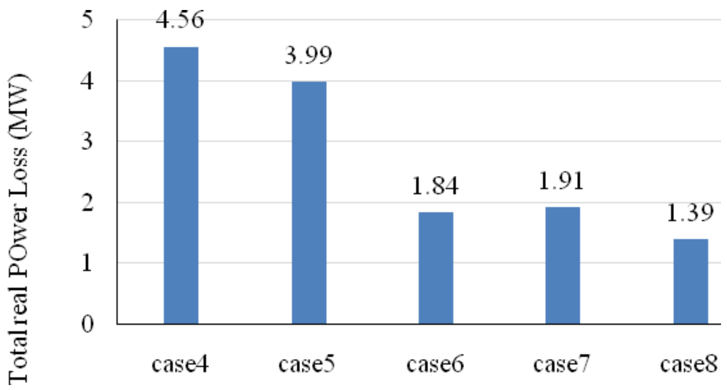

Figure 3. Comparison of real power loss of different case studies

The Table.9 indicates the comparison of real power losses for different case studies and Figure.3 demonstrate the real power loss variation for the various case studies is considered. From the Table.9 and Figure.3, it is understood that the case-8 system arrangement will give the minimum real power losses.

5. Conclusion

In this paper, the impact of the installation of a photovoltaic system in the power system network is analyzed. The test system considered here is assumed to have a constant load. The various case studies are carried out in the test system by installing of Photovoltaic system in different buses. In each case study, total real power losses in the system are observed. When the installation of a photovoltaic system nearer to the load center and a suitable amount of real power support to the corresponding bus leads to a reduction in the total system real power loss so that cost of the energy generation will also be reduced. The simulation study will encourage the electric utility to install more renewable sources in the conventional power system network to meet the increasing demand for electrical power and reduce environmental pollution.

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