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Studying the Impact of Solar PV integration in Medium Voltage Radial Distribution Network

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Abstract
Aggravating energy crises across the globe have motivated research efforts towards deployment of Renewable Energy Sources (RES) in modern distribution networks. RES solar Photovoltaics (PVs) are considered as vital candidates to meet the needs of future distribution mechanisms. In this paper, the impact of PV penetration on the voltage profile, power losses and load flow of medium voltage distribution network has been analyzed. Six scenarios with different levels of penetration and the placement of PV in the distribution network has been simulated on IEEE-33 bus medium voltage system as a microgrid using MATLAB/Simulink. The evaluated results are then discussed and compared with the existing literature and found in close agreement, hence validating our results.

Keywords: Renewable Energy Sources; Medium Voltage Network; PV penetration; Radial Distribution Networks; Microgrid.

1. INTRODUCTION

The energy demand is increasing rapidly all over the world due to modernization, electrification and growing population. It is estimated that the population will be almost double by the mid of this century [1]. [1]. In last few years environmentally irresponsible energy resources have been installed to overcome the energy demand, which leads to global warming [2], [3]. The increase in energy demand and global warming have forced the energy policy makers, engineers and researchers to think about clean, green and sustainable energy generation to overcome these issues [4], [5].

In the last few decades the RES installation in high, medium and low voltage distribution networks has been exponentially increased. In 2017 RES generation increased to 2,179 GW globally, which was 8.3 percent increase in global renewable energy generation [6], [7]. The percent share of each renewable energy source at the end of 2017 is shown in figure 1. Among all RES, PV is on the top with increase in the capacity of 94 GW (+32%) due to continuously decrease in its prices and increase in efficiency [6], [8]. The capacity growth of solar energy generation is shown in Figure 2.

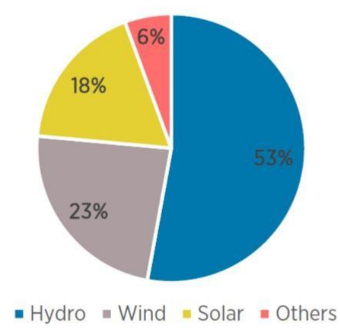

Fig.1. Renewable generation capacity by Energy source (source: International Renewable Energy Agency, March 2018).

With the increase in penetration level of PV in medium and low voltage distributed networks, it is necessary to study the impact of the distributed PV integration on the power system. Distributed PV generation have both positive and negative impact on the power system. These PV systems can provide assistance in minimizing power losses, enhancing voltage profiles, on-peak demand, minimizing system upgrades, efficiency and stability of the power system [9], [10]. On the other hand these distributed generation can increased the complexity of the system by introducing bi-directional power flow, and may cause fluctuations in the system voltages and power flow due to their variable and unpredictable nature [11]–[13].

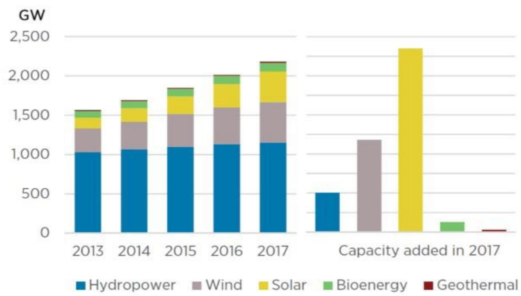

Fig.2. Capacity growth of RES (source: International Renewable Energy Agency, March 2018).

This paper emphasis the impact of distributed PV generation on the voltage profile, system losses and power flow of the medium voltage radial distribution network. The cost of power loss (CPL) is also calculated for each scenario and compared. The paper is organized as follow: System Modelling is presented in Section II. Different scenarios and simulation results are presented in Section III with detailed discussion. Finally, conclusion is deliberated in Section IV.

II. SYSTEM MODELLING

In this paper IEEE-33 bus medium voltage radial distribution system has been used, the operating voltages of the system is 12.66 kV with frequency of 60 Hz. The grid and distribution network are linked by 100 MVA transformer. PV generation farm of capacity 1 MW and 1.5 MW consisting of ten and fifteen PV panels respectively are integrated in the distribution network, each PV panel has capacity of 100 kW. The PV systems are integrated in the distribution network using central inverter and step up transformer. The complete system modeled in Matlab/Simulink is shown in figure 3.

Six different scenarios are made by placing PV at different buses in IEEE-33 bus network shown in figure 4. Each scenario is represented by the circle with different number in it. In Fig 4. the orange

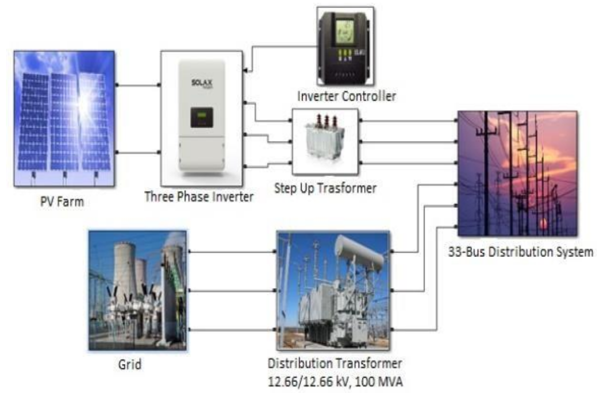

Fig.3. Complete model in Matlab/Simulink.

circle with number “1” inside it represent the first scenario when PV is integrated at bus 18. Similarly, the green circle with number “2” inside it represents the second scenario when PV is integrated at bus 33 and so on. The two circles with the same number and color represent a scenario when two PV systems are integrated at two different buses. Like the two red circles with number “6” inside it represents a scenario where one PV system is integrated at bus 18 and the second PV system is integrated at bus 8.

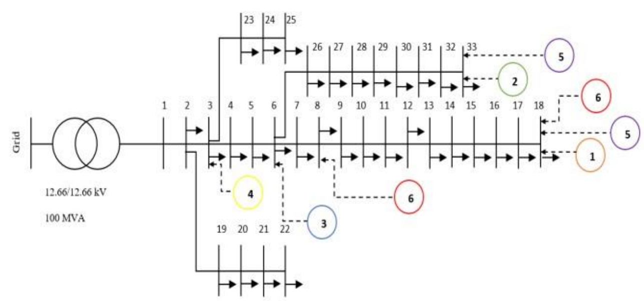

Fig.4. IEEE-33 Bus System with six different scenarios indicated.

A. Mathematical Equations

The equation for total real power loss (TPL) is given as follow:

$$P_{loss} = \sum I_{ij}^2 R_{ij} \tag{1}$$

Where

I_{ij} represents the current from bus i to bus j. And R_{ij} is the resistance between bus i and bus j.

The equation for CPL is given below:

$$CPL[million\ USD] = [TPL] \times [E_c \times T_y] \qquad (2)$$

Where

E_c is the cost of power in cent/kW.

T_y is the time in year.

Equation (1) and (2) are used to calculate the TPL and CPL.

III. SIMULATIONS AND RESULTS

Simulation results are anticipated below including the results of six different scenarios mentioned before. The voltage profile of the network when no PV integration is shown in figure 5. The TPL and CPL for the six different scenarios has been calculated and displayed in table 1 and will be discussed later with respect to each scenario. As can be seen from table 1, the active power from grid is 3.52 MW, in which 106.65 kW are line losses when no PV integration and the CPL is too high.

Table 1. TPL, CPL and Active power from grid for different placement and penetration of PV.

Distributed Generation	Active power from grid (MW)	TPL (kW)	CPL (USD)	Cost Saved per year (USD)
No PV integrated	3.523	106.65	32250.7	0
1500 kW PV at bus 18	2.2	86.5	26157.6	6093.1
1500 kW PV at bus 33	2.17	76.7	23194.1	9054.56
1500 kW PV at bus 6	2.13	68.244	20636.9	11613.7
1500 kW PV at bus 3	2.175	90.413	27449.4	4801.27
1000 kW PV at bus 18 and bus 33	1.725	72.833	22024.7	10225.7
1000 kW PV at bus 18 and bus 8	0.91	76.403	23104.3	9146.4

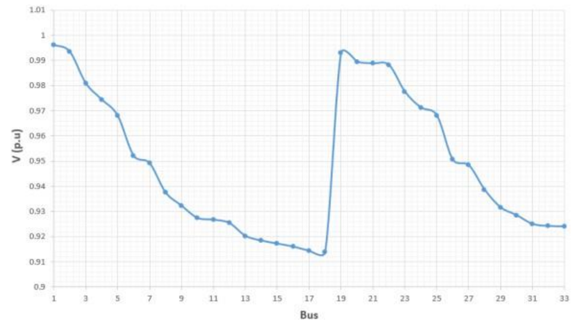

Fig.5. Bus voltages when no PV is integrated.

A. *Case 1: When 1500 kW PV is integrated at bus 18*

When the PV is connected to bus 18, i.e. at the end of line away from the grid, the effect on voltage profile is most significant as shown in figure 6. When PV or any distributed generation (DG) is connected to the end bus, it can easily cause the voltage over-limit, as the voltage of bus 17 and 18 is above 1 p.u. But from table 1, it can be seen that TPL and CPL are significantly decreased, which shows that when DG is placed near the load end, the losses can be minimized to high extent.

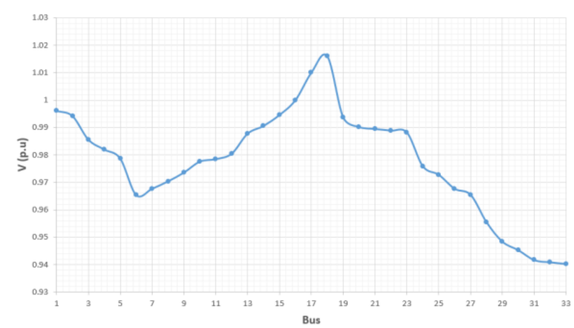

Fig.6. Bus voltages when PV is integrated at bus 18.

B. *Case 2: When 1500 kW PV is integrated at bus 33*

In this case the PV is integrated to bus 33 which again is the end bus of the line. But in this case the voltages are in allowable limit shown in figure 7. The effect of PV on the voltage is significant as compared to the bus voltages of the same line when there was no PV. From table 1 we can predict that there is significant decrease in TPL and CPL, which means the transmission losses has been minimized to high extent.

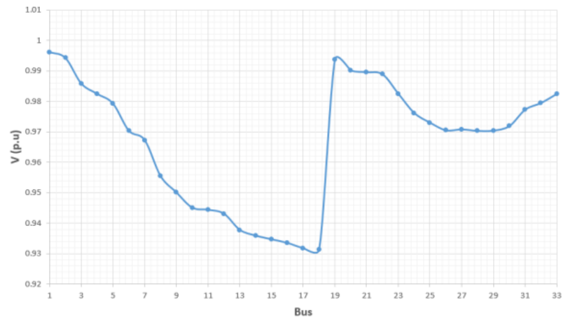

Fig.7. Bus voltages when PV is integrated at bus 33.

C. Case 3: When 1500 kW PV is integrated at bus 6.

In this case the PV is connected to the middle of the feeder i.e. bus 6, the effect on the voltage profile is not much significant as shown in figure 8. But the losses are minimized significantly and the reduction in the TPL and CPL values can be clearly seen from table 1, as well as the cost saved per year by minimizing losses is noteworthy.

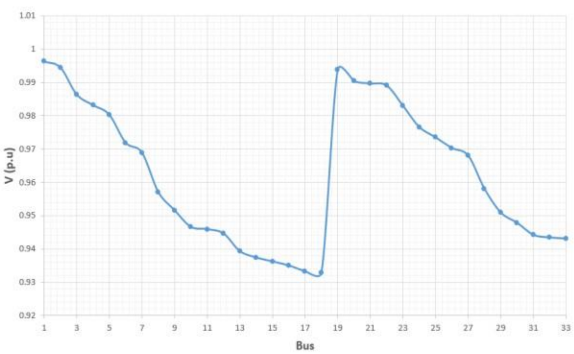

Fig.8. Bus voltages when PV is integrated at bus 6.

D. Case 4: When 1500 kW PV is integrated at bus 3

In this case the PV is integrated to the head terminal bus of the line i.e. bus 3 which is too close to the grid. So the effect on the voltage profile of all buses of the network is almost negligible as shown in figure 9. Also from table 1, we can observe that there is trivial decrease in TPL and CPL. Thus it is observed that when DG is integrated to the generation end it has trivial effect on the voltage profile of the network and transmission losses.

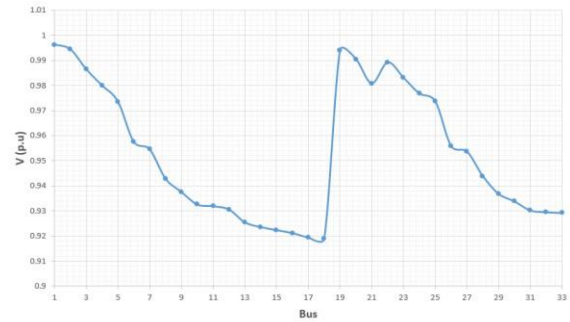

Fig.9. Bus voltages when PV is integrated at bus 3.

E. Case 5: When 1000 kW PV is integrated at bus 18 and bus 33.

Two PV farms each having capacity of 1000 kW are integrated in the system in this case, one at bus 18 and the other at bus 33. The voltage profile of the end line buses is significantly improved as shown in figure 10. This shows that it is more favorable to integrate PV with low power rating at multiple buses to increase the system reliability and maintain the end line buses voltages in allowable limits. It also has a significant effect on CPL and TPL.

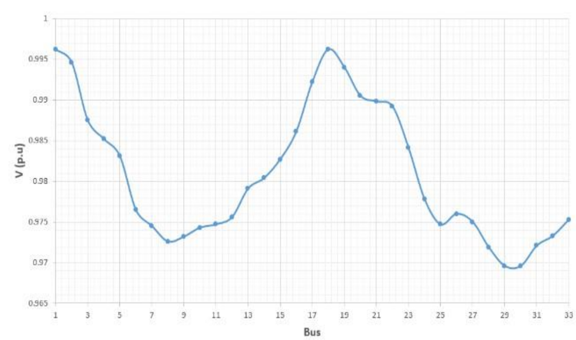

Fig.10. Bus voltages when PV is integrated at bus 33 and bus 18.

F. Case 6: When 1000 kW PV is integrated at bus 18 and bus 8.

This case is same as previous but different placement of PV. One PV system is connected to bus 18 and other is at bus 8 each having capacity of 1 MW. The voltage profile has significantly improved as shown in figure 11. There is significant decrease in CPL and TPL as shown in table1. As previously explained that when multiple DGs with small capacity are integrated at multiple buses can improve system bus voltages and decrease system losses.

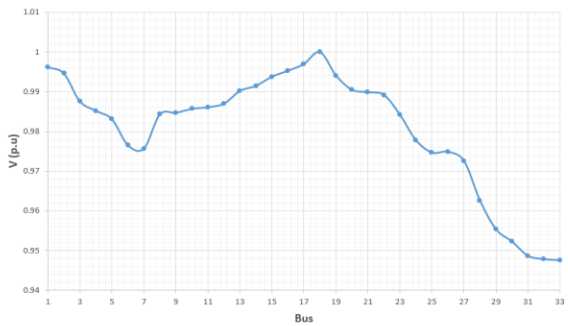

Fig.10. Bus voltages when PV is integrated at bus 18 and bus 8.

IV. CONCLUSIONS

With the increasing penetration level of DGs in distribution network especially the renewable energy sources, it is important to integrate these DGs in systematized way to enhance the system performance. From above case study it is concluded that when the PV is integrated to the head terminal bus, the effect on the voltage profile and system losses is negligible. When PV is integrated to middle of the feeder the effect on the voltage profile and system losses are noteworthy. And when the PV is integrated to the end line bus, it has significant effect on the voltage profile but may cause voltage over limit. To ensure that the voltages of all buses are in allowable limits, it is important to integrate multiple PV/DGs units at different buses. In this way the voltage profile as well as the losses of the distribution network can be improved.

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