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Study on Load Model of PV Generation Planning

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Abstract

In distribution system planning with photovoltaic generations (PVGs), if load is not properly modeled in the simulation, the accuracy of results will be affected. A large number of studies show that load characteristics play a impotrant role in the system analysis. This paper presented the resultant load model, and on this basis, studied the impacts of the constant power load model and constant impedance load model on PV generation planning. Simulation results show that the selection of load models has an important impact on PV generation planning.

Keywords: PV generation; load model; distribution system voltage; planning

1. Introduction

Solar power is a kind of clean energy resource without the release of pollutants, waste, or destruction of atmospheric greenhouse gases, so it is a clean environmentally friendly renewable energy. But with the capacity and number of PVGs connected to distribution system increased, steady-state voltage distribution of the distribution system will be significantly influenced. Therefore, considering the impact of PVGs on the voltage of distribution system will have significance in the distribution system planning. The current literatures focus on the studies of the law of the impact of distributed generation (DG) on the voltage of distribution system , where the constant power load model is usually used[1-7]. Paper [8] compared the impacts of the different load models on the loss of distribution system with DGs, the results show that the selection of load models has an important influence on DG planning. In fact, for normally operating distribution system, if the amplitudes of bus voltages are within 5% of the rated bus voltage, they are considered as constants, then the load can be also handled as constant impedance load[9]. In this paper, The constant impedance load model and constant power load model are used to calculate the voltage of distribution system with PVGs, comparatively analyzing the impact of the two load models on the simulation results.

2. The traditional static load model of distribution system

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Static models represent the loads at any instant of time as function of voltage magnitude and frequency. In case of a small capacity DG connected to the network, the frequency with or without DG connection does not change much and is assumed constant[8,10], i.e., $f = f_N$. Then the expression is as follows.

$$\begin{cases} P_L = P_{LN}\left(\dfrac{U}{U_N}\right)^{\alpha_{pu}} \\ Q_L = Q_{LN}\left(\dfrac{U}{U_N}\right)^{\beta_{pu}} \end{cases} \tag{1}$$

Where

P_{LN}, Q_{LN} are the active and reactive power at rated voltage U_N ; U is operating voltage of the bus; α_{pu}, β_{pu} are Constants depending on the type of load, $\alpha_{pu} = \beta_{pu} = 0$ represents constant power load; $\alpha_{pu} = \beta_{pu} = 1$ represents constant current load; $\alpha_{pu} = \beta_{pu} = 2$ represents constant impedance load.

3. Load model of the distribution system with PVG

As can be seen from Fig. 1, the power flow flows from substation to users, or from sending-end to receiving-end before PVGs are connected to distribution system. After PVGs are connected to distribution system, seeing in Fig. 2. In this paper, PVGs are considered as "negative load" and the bus load are considered as " positive load". Thus, the sum of the two loads becomes a new load called “resultant load [11]”, seeing in Fig. 3.

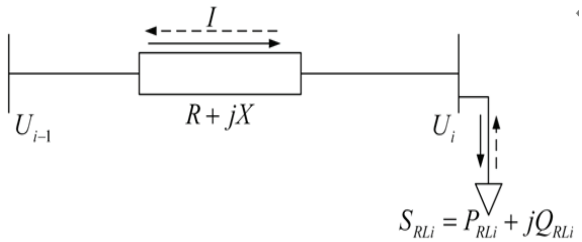

Figure 1. Distribution System with resultant load.

The power flow direction of from the bus to the load is assumed to be positive, the expression of the resultant load can be written as

$$S_{RLi} = S_{Li} - S_{PVi} = (P_{Li} - P_{PVi}) + j(Q_{Li} - Q_{PVi}) \tag{2}$$

well

$$P_{RLi} = P_{Li} - P_{PVi}$$

$$Q_{RLi} = Q_{Li} - Q_{PVi}$$

Where

P_{Li}, Q_{Li} are active power and reactive power at node i respectively; P_{PVi}, Q_{PVi} are the active power and reactive power of the PVG at node i respectively; P_{RLi}, Q_{RLi} are the active power and reactive power of the resultant load at node i respectively.

The power flow directions of the resultant load are relevant to the power output level of PVG and load level as well as their operation modes. Thus, according to the power flow directions and their operation modes, the characteristics of resultant load can be summarized as follows.

- If P_{RLi} and Q_{RLi} have the same sign, the resultant load has lagging power factor, namely, $P_{RLi} > 0$, it absorbs active power and reactive power from grid; $P_{RLi} < 0$, it supplys active power and reactive power for grid.
- If P_{RLi} and Q_{RLi} have the opposite sign, the resultant load has lagging power factor, namely, $P_{RLi} > 0$, it absorbs active power from grid and supplys reactive power for grid; $P_{RLi} < 0$, it supplys active power for grid and absorbs reactive power from grid.
- If $P_{RLi} = 0$ and $Q_{RLi} < 0$, the resultant load being equivalent reactive power source supplys reactive power for grid; if $P_{RLi} = 0$ 且 $Q_{RLi} > 0$, the resultant load being equivalent to pure inductive load absorbs reactive power from grid.
- If $Q_{RLi} = 0$ and $P_{RLi} < 0$, the resultant load being equivalent the active power source with unit power factor supplys active power for grid; if $Q_{RLi} = 0$ and $P_{RLi} > 0$, the resultant load being equivalent to pure resistance load absorbs active power from grid.
- If $P_{RLi} = 0$ and $Q_{RLi} = 0$, no power flow is on the line.

4. The power flow algorithm of distribution system with PVG considering the load characteristics

In the traditional power flow calculation, constant power load model is used mostly, and the detailed characteristics of the load are ignored, such as voltage-dependent or frequency-dependent characteristics. In fact, for normally operating distribution system, the bus voltage can be considered to be constant as long as the voltage fluctuation is within 5% of rated voltage, and then constant power model can be also handled as a constant impedance load[9], then the following expression can be obtained through (1),

$$S_L = P_{LN}\left(\frac{U}{U_N}\right)^2 + jQ_{LN}\left(\frac{U}{U_N}\right)^2. \tag{3}$$

Again, $P_{LN}/U_N^2 = G_{LN}$, $Q_{LN}/U_N^2 = B_{LN}$, then the expression of constant impedance load can be written as

$$S_L = G_{LN}U^2 + jB_{LN}U^2. \tag{4}$$

Where

G_N, B_N are the conductance and susceptance of constant impedance load at rated voltage respectively; U_N is rated voltage of the bus; U is operating voltage of the bus.

For the common $N-$bus radial distribution system, it is assumed that the current column vector is $\dot{I}_{RL}$, then

$$I_{RLi} = \left(\frac{S_{RLi}}{U_i}\right)^* \tag{5}$$

The branch current vector I_L is

$$I_{RL} = AI_L \tag{6}$$

Let $A_0 = A + V$, then

$$I_L = A_0 I_L - I_{RL} \tag{7}$$

Then the bus voltage equation is

$$(U_1, 0, \cdots, 0 \cdots)^T + A^T U = Z_L I_L \tag{8}$$

Then

$$U = (U_1, 0, \cdots, 0 \cdots)^T + A^T U - Z_L I_L \tag{9}$$

When considering static voltage characteristics of load, i.e., using constant impedance load, the current column vector I_{RL} is

$$I_{RLi} = \frac{(G_{LN} U_i^2 - P_{pv}) - j(B_{LN} U_i^2 - Q_{pv})}{U_i^*} \tag{10}$$

Where

A is Branch Incidence Matrix; V is Unit Matrix whose order is equal to A ; U is column vector of bus voltage; U_1 is system bus voltage; U_i is the i th bus voltage; Z_L is branch impedance.

Convergence criterion used in power flow calculation is that the maximum value of the differences of all bus voltages after two iterations is less than a given value, i.e., $\max\left\{ U_i^{k+1} - U_i^k \mid \right\} < \varepsilon, i \in N$, ε is iterative precision, and per unit is used when calculating.

The specific steps of the power flow iterative algorithm are as follows.

- Set initial value of each bus voltage $U^{(0)}$, where system bus voltage is a given value U_1^s ;
- The current injecting into each bus is calculated through the voltage of each bus. if the load model is constant power model, (5) is used; if the load model is constant impedance model, (10) is used;
- The branch current is calculated through (7);
- The given system bus voltage U_1^s and (9) are used to calculate the voltage of each bus.
- The convergence condition is checked. If satisfied, the power flow calculation is over, or go ahead by returning the second step.

5. Steady-state voltage distribution

In actual operation of distribution system, even if there are several distributed generations (DG) in distribution system, the total capacity of the load is still greater than that of DGs, which is to ensure that the entire distribution line is strictly by the end of the absorption-type network[2], the same is true for Photovoltaic Generation (PVG). Thus, the case of a DG connected to distribution system is firstly considered. the voltage loss of each bus will have some changes, but also the load will also change, going back and forward to see from the position with PVG. For the point with DG, the bus voltage increases. It is found out that the location and capacity of DGs have a great impact on the distribution of line voltage[2,12]. In this paper, to quantify the changes caused by PVG, variation rate index of voltage is employed as follows[2]

$$\varepsilon = \frac{U_i^{'} - U_i}{U_i} \tag{11}$$

ε indicates that the greater it is, the greater the impact of PVG on distribution system is.

6. A numerical example

In this paper, PVGs are concentratedly connected to the end of a 10kV traditional radial distribution system[2], seeing in Figure 2, where the system base power, base voltage, system bus voltage are 10MVA, 10kV, 1.05p.u. respectively.

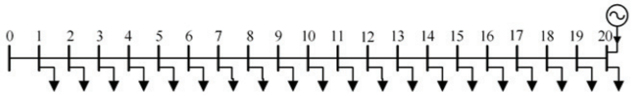

Figure 2. A 10kV traditional radial distribution system with PVG.

PV power output level is defined as the ratio of PV active power output to total active power existing in the distribution system. Simulation results are as follows.

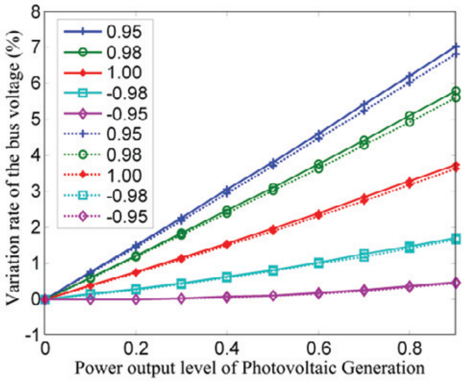

Figure 3. Impact of PVG with different power factors and power output levels on the bus voltage with PVG.

As can be seen from the Fig. 4, the solid line marked represents the simulation results under constant power load model and the dotted line marked represents the simulation results under constant impedance load model. The following simulation figures are the same representation. the simulation results of using constant power load model are greater than that of using constant impedance load model. In case of PV power output level is high, the lower lagging power factor is, the more obvious the difference between two load models used is. The difference is very small for the PVGs with leading power factor. Obviously, the results using constant power load model will lead to larger calculation results of the bus voltage with PVGs, where the impacts of PVGs with lagging power factor on the bus voltage of distribution system are somewhat pessimistic; the impacts of PVGs with leading power factor on the bus voltage of distribution system are also somewhat pessimistic, but the difference is very small, and can be negligible.

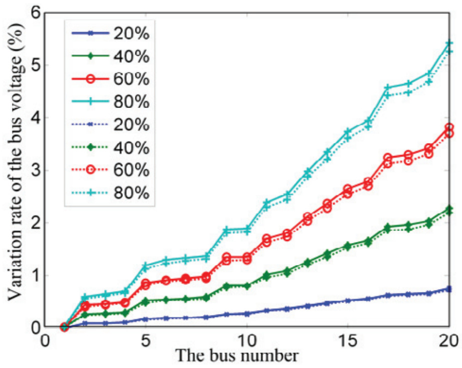

Figure 4. Impact of PVG with lagging power factors 0.95 and power output levels on the each bus voltage of distribution system.

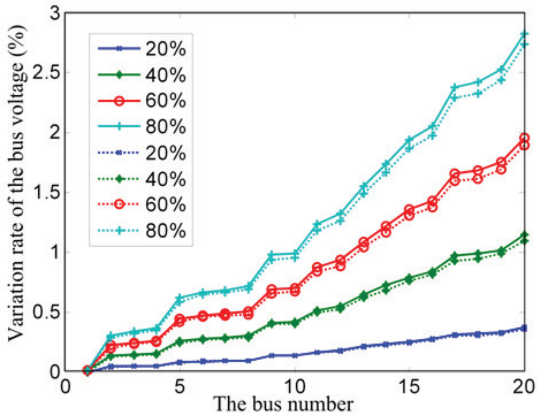

Figure 5. Impact of PVG with unit power factors and power output levels on the each bus voltage of distribution system.

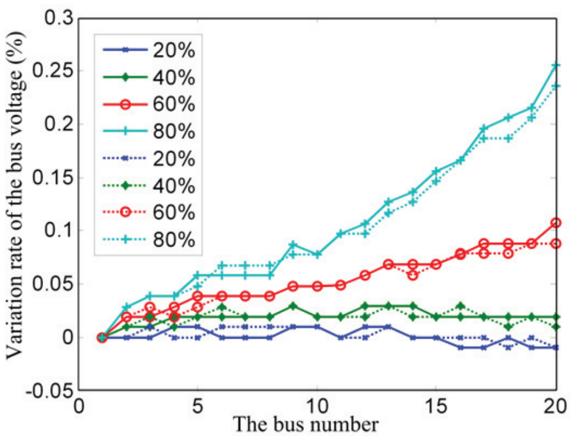

Figure 6. Impact of PVG with leading power factor 0.95 and power output levels on the each bus voltage of distribution system.

The impacts of PVGs with different power factors and power outputs on all bus voltages of distribution system from Fig. 5 to Fig.7. The variations are basically same in Fig. 5 and Fig. 6, i.e., for each bus voltage of distribution system, the differences between the simulation results using constant power load model and the simulation results using constant impedance load model become more obvious when the PVG output level is high. The closer PVGs are away from system bus side, the smaller the differences are. when PVG output level is low, the differences between results using the two load models are very small, even negligible. The impacts of PVGs with different power outputs on all bus voltages of distribution system become more complex in Fig. 7, where the solid line of the simulation results using constant power load model and the dotted line of the simulation results using constant impedance load model sometimes overlap, sometimes alternate each other. To sum up, when the impacts of PVGs on the voltage of distribution system are analyzed, results will be different due to using different load models, and the difference between them will be great under some power output and power factor of PVG.

7. Conclusion

Power flow calculation of distribution system with PVGs is different from traditional power flow calculation of distribution system, so the power flow calculation method being suit for the characteristics of distribution system is needed. This paper presents resultant load model, and on this basis, power flow calculation method of distribution system with PVGs is given, where constant power load model and constant impedance load model are employed. The method is simple and practical.

By comparing the simulation results, it can be concluded that the research results of the impact of PVGs on distribution network voltage will be different Whether to consider load characteristic. Further simulation showed that with the length of distribution lines and the growth of load level, the differences will become larger. And network loss is also the same. With the improvement of the accuracy requirements of modern power system analysis, distribution system planning with PVGs needs detailed load model to provide more accurate reference informations. In addition, traditional power flow calculation using constant power load model is not fully consistent with engineering practice. whether to use a more detailed load model needs to be determined to research the impact of PVG on distribution network according to actual situation.

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