The impact of distributed photovoltaic on the distributed network

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Abstract. With the increasing of photovoltaic (PV) penetration in the distribution network recent year, the impact of PV is more and more obvious. This paper first study the mechanism of PV impact on distribution network through the equivalent circuit of grid-tied PV system. Then we establish a typical distributed network model which contain PV generator, the voltage profile is researched from the perspective of PV capacity, power factor, generator location and line parameter. In the end, we propose several ways to enhance the ability of absorbing more distributed PV from the perspective of reducing the effect of PV on the voltage at PCC (point of common coupling).

1. Introduction

With the continually consumption of fossil energy and increasingly focus on energy security and environmental issues, renewable and clean Energy has raised concern in electrical sector. For now, the research of PV is widely carried out in many countries, the impact of distributed PV generator on the distributed network is mainly generalized in the following two aspects. on one hand, distributed network become complex multi-terminal networks which is different from traditional radial networks, on the other hand, PV belongs to intermittent sources which have significant time-varying characteristics and is susceptible to weather. The varying of power flow will contribute to the change of the node voltage distribution, volatility and time-varying characteristics also cause the change of outputting power, both of them will contribute to limit exceeding in the worst-case scenarios.

The paper analyze the mechanism of the impact of PV generator on the distribution network, then establish a typical distribution network model to study the influence of PV in the perspective of voltage. Several factors such as capacity, power factor of PV, network parameters and the integrated way are discussed using the typical model. At the end, the paper put forward several measures to raise the capacity of distributed PV in the point of weakening impact of PV.

2. The mechanism of PV's impact on distribution network

Currently, the control method of most inverters is double-loop control, the outer loop is DC voltage or reactive power control, the inner loop is current decoupling control. The output current or voltage of the PV array is determined by the MPPT (Maximum Power Point Tracking) algorithm, there is a close correspondence between the calculated current and voltage, when the environment condition such as temperature and light changed, a new DC voltage reference signal calculated through MPPT compare with the actual value of DC voltage, the error import PI control link, getting the active current and reactive current reference signal of inner loop controller. The inner loop controller output active current i_d reactive current i_q, so DC voltage control virtually identical to the current control.

Analyzing the Equivalent Circuit presented in Fig.1, the node voltage at PCC after photovoltaic integrated to distributed network is determined by formula (1).

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$$\dot{U}_{pv} = \dot{E} - (R_m + jX_m)\dot{I}_{pv}$$
$$= \dot{E} - (R_m + jX_m)(I_p + jI_q) \quad (1)$$

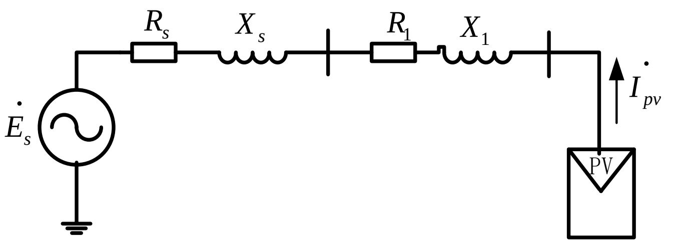

Fig.1: equivalent circuit

In the formula, R_s and X_s are equivalent resistance and reactance of the system respectively, $\dot{I}_{pv}$ is the current injected by PV generator, $\dot{U}_{pv}$ is the bus voltage connected with PV generator, $\dot{E}$ is equivalent voltage source of distributed system. $R_m = R_s + R_l$ is the total resistance of the system, $X_m = X_s + X_l$ is the total reactance of the system, I_p and I_q are active component and reactive component of the current injected by distributed PV generator respectively. Compared to the previous voltage PV generator access, the voltage variation at PCC can be calculated through formula (2).

$$\Delta U_{PCC} = (R_m + jX_m)\bullet(\Delta I_p + j\Delta I_q)$$
$$= |Z_m|\bullet|\Delta I|\bullet(\cos\varphi + j\sin\varphi)(\cos\theta + j\sin\theta) \quad (2)$$
$$\approx U\frac{\Delta S_{pv}}{S_K}(\cos\varphi\cos\theta - \sin\varphi\sin\theta)$$

U is the voltage magnitude at PCC, ΔS_{pv} is the injected power variation of PV generator, $S_K = U^2 / Z_m$ is the short-circuit capacity of the system at PCC, ΔI is current variation injected by PV generator, $\theta = \arctan(\Delta I_p / \Delta I_q)$ is the power factor angle of PV generator, φ is the short circuit impedance angle of power system.

The fundamental mechanism of PV influencing distributed network is concluded as follows, the active and reactive current which PV generator injected into the grid lead to the change of power flow, thus the steady voltage of PCC varies. Besides, PV power is fluctuant with light and temperature, node voltage at PCC fluctuate with the operation conditions. Formula (2) imply that node voltage of PCC have a relationship with elements such as grid parameters, injected power and power factor.

3. Node voltage analysis of distributed network contain PV

For conventional radial distribution network, there is not any generator, the voltage gradually reduce along the direction of load flow in steady operation state. Distribution system became multi-power network from conventional network, the load flow may be reverse other than unidirectional from substation to each load, and more complex voltage situations will appear.

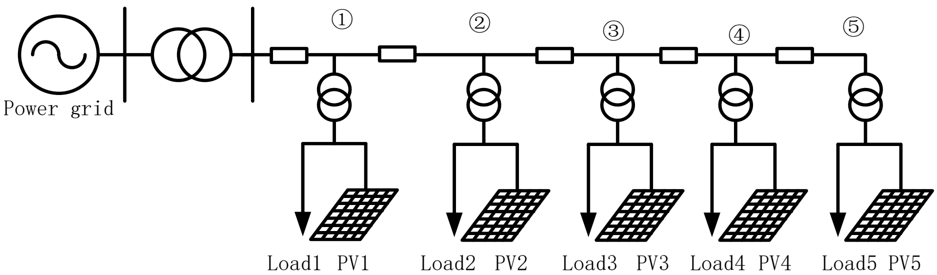

Fig.2: typical distributed network model

For now, distributed PV generally access in low-voltage network of which voltage level is 380V. Due to the complex structure of low-voltage grid, it is hard to analyze if we use the detailed model, so we build a simplified model which is equivalent to the low-voltage network under distribution transformer, the simplified model connect with utility grid by 10kV/380V transformer. The typical 10kV distribution network model established are depicted as Fig.2, the parameters of which are described as follows, line type is LGJ-150, load distributed evenly on the line and each load value is P+jQ=0.5MW+j0.1MVar.

3.1 Voltage analysis with different PV capacity and power factor

To research the impact of PV on the voltage with different capacity, four cases are developed. In each case, PV generator is connected with bus 4, the PV capacity is S1=1MW, S2=1.5MW, S3=2MW, S4=2.5MW respectively, the power factor of the PV is 1.0, the results of voltage distribution in each cases is depicted as Fig.3 (a).

Voltage profiles vary as the access capacity of PV generator, each node voltage increase with the capacity of PV increasing. In the first two cases which capacity is 1MW and 1.5MW, the voltage decreases along the line direction, the power PV supplied is provided for the load of line downstream; in the latter two cases, it is obvious that power of PV largely return to the grid, some of the node voltages even exceed substation voltage.

To study the impact of PV power factor on the node voltage, five cases are developed. In each case, PV capacity S=1MW, power factor is 0.8 inductive, 0.9 inductive, 1.0, 0.9 capacitive and 0.7 capacitive respectively, the calculated results of five cases are depicted as Fig.3 (b).

In the case of photovoltaic power absorbing reactive power, capacity is constant, the more active power of PV produce, the less reactive power absorb, and the larger node voltage is. In the case of PV power output reactive power, with the decrease of the power factor, voltage will drops if the active power reduced, but the voltage will increase if capacitive reactive power increase, these two factors work together. Every node voltage enlarge when power factor decrease from 1.0 to 0.9, node voltage besides bus 4 and bus 5 enlarge when power factor decrease from 0.9 to 0.7.

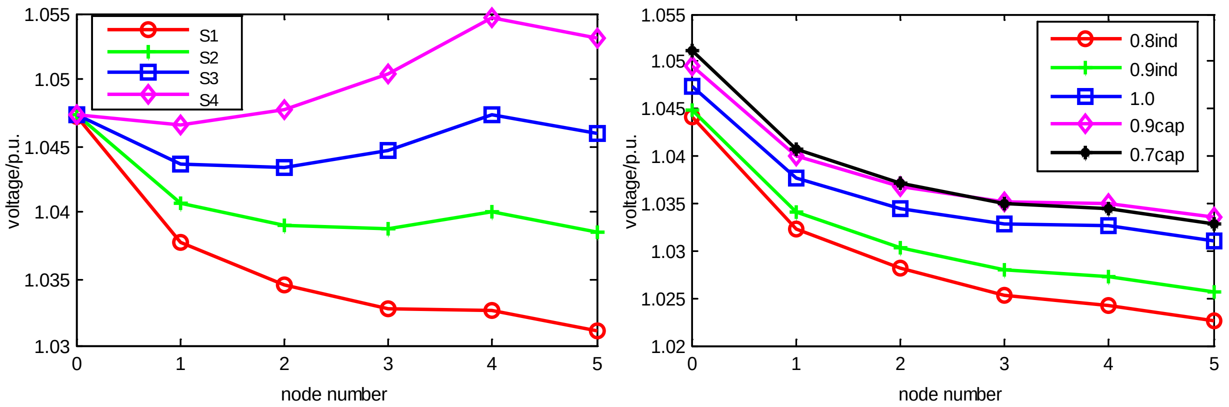

Fig.3: (a) node voltage with different PV capacity. (b) Node voltage with different power factor

3.2 Voltage analysis with different PV location

To study the impact of PV location on the node voltage, six cases are developed, no PV access in case0, PV connect with bus 1 in case 1 and bus 2 in case 2, the rest can be done in the same manner.

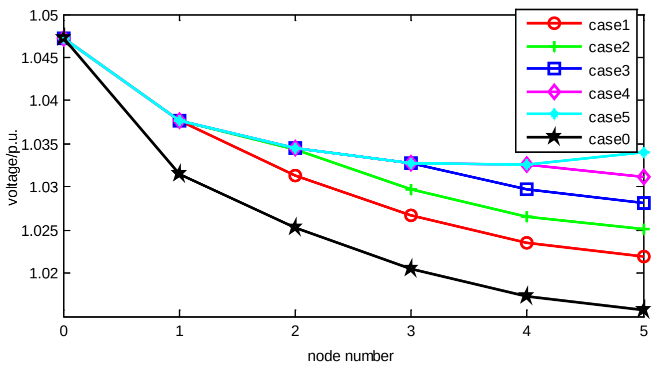

Fig.4: node voltage with different PV location

It can be seen from the Fig.4 that results vary widely when connected at different location, which is contributed by the changing of power flow. The larger equivalent impedance is, the more apparent the voltage-rise. In other words, the closer of PV to the end of the line, the more obvious voltage enhancement is.

3.3 Voltage analysis with different line parameters

In order to study the voltage profile with different line parameters, analyze the power flow in the grid with different typical feeders. Then calculate sensitivity of voltage amplitude to active power $\partial V/\partial P_{pv}$ and voltage amplitude to reactive power $\partial V/\partial Q_{pv}$, the results are listed in the table 1.

It can be concluded as follows from table 1, the greater line resistance is, the greater $\partial V/\partial P_{pv}$ is, the greater line reactance is, the greater $\partial V/\partial Q_{pv}$ is. For the common used low-voltage network, the ratio of X/R is quite small, so $\partial V/\partial P_{pv}$ is larger than $\partial V/\partial Q_{pv}$ at the point of coupling, the active power has a greater impact on the magnitude of the voltage.

Table 1: sensitivity results

Feeder style	$\partial V/\partial P_{pv}$	$\partial V/\partial Q_{pv}$
LGJ-70	0.0269	0.0058
LGJ-150	0.0126	0.0054
YJV-70	0.0163	0.0023
YJV-240	0.0045	0.0021

4. Summary

Voltage rises at load bus bars are a serious factor to limit the further access, absorptive capacity of PV in distributed network can be improved if we take a way to reduce the impact after PV integrated into distribution network. According to the analysis, we put forward several proposals to eliminate the impact of PV on the distributed network.

(1)Network upgrading, such as increasing conductor size, in this way, voltage rise can be ignored even the power PV output is great.

(2)Change network static set points, such as reduction of secondary LV transformer tap.

(3)By installing reactive power compensation to adjust the reactive power of network, or controlling the inverter of PV to adjust the outputting active and reactive power.

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