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Active and Reactive Power Control in a Photovoltaic integrated Power System

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Abstract. Nowadays the application of photovoltaic source in power system is in great demand. Therefore, power system is required to maintain the reactive power control with the integration of photovoltaic system. Further the transfer energy to the distribution system is a usual case. This main objective is to present a new design for the transfer of photovoltaic source to the utility system. The system is based on a push-pull converter attached to a three-phase DC/AC inverter. In particular, a great interest is focused on the steady operating conditions of energy transfer. For computing the dynamic regime the photovoltaic source is integrated into the grid with maximum active power and zero reactive power. To validate the system require simulations are carried out which ensures the performance of the system.

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1. Introduction

At present, the large-scale application of distributed photovoltaic (DPV) is one of the major strategic measures to alleviate environmental pollution and cope with the energy crisis, and is also an inevitable choice for the development of active distribution networks and smart grids. With an increasing penetration of DPV in distribution networks, the overvoltages caused by PV reverse currents and the stability of grid voltages are becoming more and more serious [1-4].

In order to alleviate the voltage control problem, the current research mainly studies from three aspects: active power curtailment (APC), reactive power control (RPC) and active and reactive power coordination control (A/RC) [5-7]. In terms of APC strategy, overvoltage control is mainly realized by active power curtailment; in terms of RPC strategy, the local voltage control is realized by PV inverter's reactive power adjustment; for A/RC strategy, reasonable PV active curtail and reactive power support is coordinated to improve the performance of PV integration and further increase PV hosting capacity of the distribution networks.

This paper studies the related research and mainstream methods of DPV voltage control by combing the existing research [7-11] at home and abroad. It can be explained from three aspects, namely 1) PV system local voltage control strategy, 2) coordination voltage control strategy between the PV system and distribution network, and 3) other key measures for voltage control such as battery energy storage system. The described voltage control strategies and methods reviewed in this paper can provide a theoretical basis and practical reference for the development of high-density DPV in China.

2. Photovoltaic system local voltage control strategy

Active power curtailment method

Active power curtailment mainly achieves overvoltage control by means of curtailing excess active power. [12-13] studied two active power droop control strategies of grid-connected PV inverters in low-voltage distribution systems. The first control strategy makes all PV inverters use the same droop coefficient. The second control strategy allows each inverter to adopt different droop control coefficients to achieve the average distributed curtailment power of each inverter. An artificial neural network (ANN) is modeled in [14] to predict the PV output, and then the inverter can determine the active power should be curtailed. And through the historical data training of the ANN prediction module, the optimal curtailed power of the inverter under different PV grid-connected point voltage conditions can be obtained.

Although the APC method can effectively suppress the overvoltage phenomenon, it does not fully utilize the PV power generation capacity installed in the distribution network. Restricting PV output will lead to the occurrence of energy abandonment, and considering reactive power control (RPC) at this time is another effective choice.

Reactive power control method

In terms of reactive power control, the authors in [15-16] improved the standard Q(V) control to location-adaptive Q(V) control. This control strategy takes the inverters different Q(V) control curves according to the PV system's location. The Q(V) control parameters of each inverter are no longer set to be the same. The closer to the transformer, the Q(V) control curve is shifted to the left so that the inverter energy coefficient close to the transformer is further reduced, and the voltage is increased. Fig. 1 is a schematic diagram showing changes in the control characteristics of each inverter as a function of its installation position.

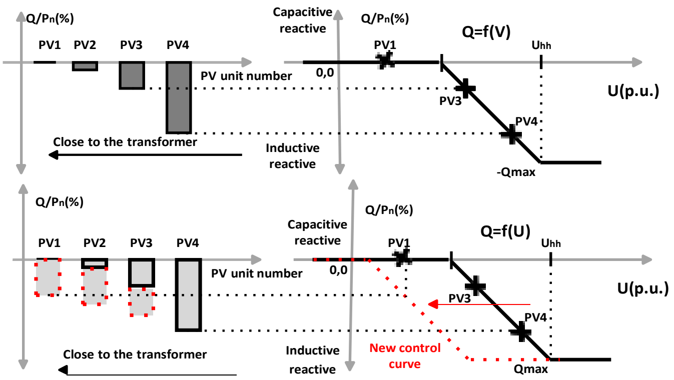


Figure 1. Location-adaptive Q(V) control curves for PV inverters

Reference [17] proposed a novel cos$\varphi(P,U)$ control method that combines the advantages of cos$\varphi(P)$ and Q(V). Compared with Q(V) control, although it slightly increases the reactive power demand and reactive power loss of the whole network, it can greatly increase the PV hosting capacity of the distribution network under the condition of allowing the transformer to have a certain overload capacity. The multi-agent system (MAS) on the basis of Control Network Protocol (CNP) is proposed to control the reactive voltage of the PV system at the feeder level [18]. A decentralized interactive control function of the MAS system is utilized to realize the mutual coordination communication of each inverter in the feeder and the effect of bidding to achieve stable voltage.

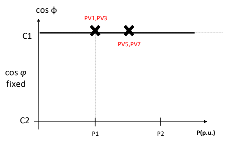
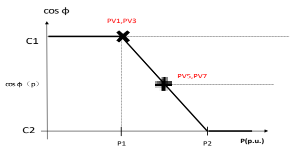
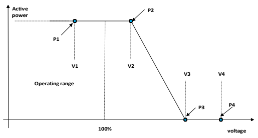
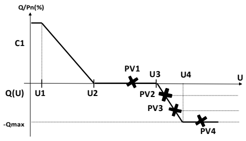
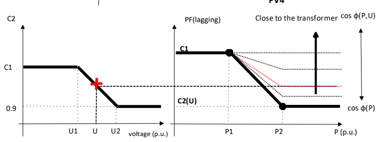
Active and reactive power coordination control method

Although the two kinds of APC and RPC voltage control methods described above can effectively prevent the voltage from exceeding the limit, the APC method does not guarantee the fairness of each PV system; the RPC method requires additional inverter capacity to ensure adequate reactive power regulation. Therefore, an active and reactive voltage coordination control has become the focus of research on voltage control [19]. An optimal inverter dispatch (OID) framework is proposed in [20]. The optimal power flow determines the active and reactive set points of each inverter and is more flexible than the RPC and APC strategies. The overall idea of [21] is the same as [20], but the paper extends the OID framework to the distributed DIOD framework. The problem of inverter parameter setting based on optimal power flow calculation can be decomposed into two small problems of PV system owners for the power grid and resident users, and the problem can be solved by limited information interaction.

Comparative analysis of various control methods

The advantages and disadvantages of the various voltage control methods described above are comprehensively compared and listed below.

Table 1. Comparison of advantages and disadvantages of each voltage control method.

Control methods	Control characteristic curve	Advantage	Disadvantage
Constant reactive power control	Q=*const*	Simple control, no need for mutual communication between inverters.	As long as there is active output, it will absorb reactive power, increase reactive power loss and transformer load.
Constant power factor control	PF=1.0，PF=0.98 	Compared with Q=const control, it has adaptive reactive power adjustment capability. The greater the active output, the more reactive power is absorbed, and the stronger the voltage regulation capability.	The total reactive power demand of the whole network increases and the rated power of the inverter needs to increase.
$\cos\varphi\,(P)$		It ensures that the PV emit more active power at low penetration, and no reactive voltage regulation is performed.	Causes active loss, is not easy to maximize PV output, and the corresponding reactive power loss will increase when PV output is large.
P(U)		Active power curtailment is more effective for voltage regulation.	Causes active loss and is not easy to maximize PV output.
Q(V)		Each inverter can determine how much absorption is reactive according to the voltage of the respective photovoltaic grid point.	Need to optimize the inverter droop control parameters.
$\cos\varphi\,(P,U)$		Combining the advantages of cosφ(P) and Q(V), and without communication, it can greatly improve the PV capacity of the distribution network, and the PV inverters of the whole network can participate in the reactive voltage regulation.	Reactive power demand is larger than Q(V) control.

3. Coordination voltage control strategy between the PV system and distribution network

When the distributed PV penetration reaches a certain level, and the adjustment capability of the inverter is difficult to meet the voltage regulation, it is necessary to combine the regulation measures (OLTC, VR, SC, etc.) of the original distribution network of the upper layer for coordinated control.

In [2], it focuses on three types of methods for active distribution network voltage control, namely, distributed voltage control, centralized voltage control, and coordinated voltage control. A multi-level voltage control framework for active distribution networks is constructed in [7], which is based on MV/HV cooperative control and MV/LV two-way control. In [22], the sub-regional cooperative control principle of the LV system and MV system is proposed considering the disadvantages of non-global optimization brought by local voltage regulation of inverter. In [23-24], the optimal control of transformer multi-taps on the feeder is carried out. The coordinated control of on-load tap changer

(OLTC) achieves the maximization effect of PV consumption while ensuring the minimum number of tapping actions.

4. Other key measures for voltage control

Adopting the "distributed PV+energy storage" mode has become a key measure for the integration of intermittent distributed renewable energy power generation. The introduction of energy storage can better solve the voltage management problem [26]. Reference [27] controls the energy storage devices in a low-voltage distribution network to achieve voltage control by adopting a “receding horizon” method. The proposed method is characterized by the ability to predict future possible voltage problems based on very small amounts of information. As shown in the figure below [28], after the introduction of energy storage, the excess output will be stored in the energy storage unit at the peak of the PV output at noon, and the power will be used for the load during the night period, effectively avoiding the overvoltage caused by the excessive PV output.

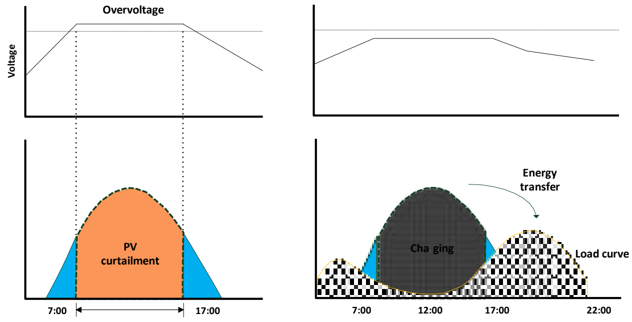


Figure 2. Overvoltage prevention effect using energy storage for load-shift

Three charge and discharge modes of energy storage were compared. 1) Voltage control mode, 2) Minimizing reverse power flow mode, and 3) Scheduling mode, as shown in Figure 5. In the voltage control mode, as long as the voltage exceeds the limit, the battery is charged. The minimum reverse power flow mode is charged until the battery state of charge (SOC) is lower than the upper limit until the battery is full. The scheduling mode is to charge at a certain time every day regardless of the voltage. The results of the example show that the voltage control mode is better than the other two modes.

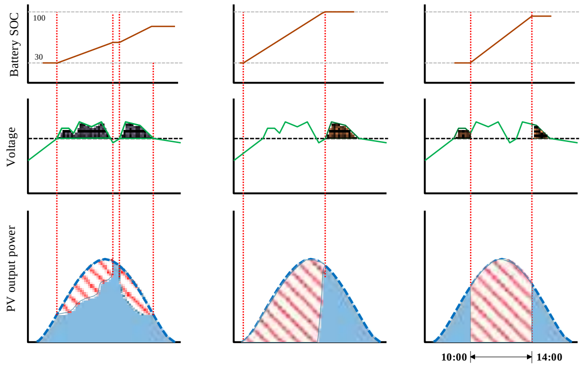


Figure 3. The effect of three charge and discharge modes of energy storage on overvoltage control

5. Conclusions

With large-scale distributed PV system integrated into the medium and low voltage distribution network, it will completely change the unidirectional power flow characteristics of the traditional distribution network. In the increasingly complex operating environment of power distribution systems, it is necessary to rely on efficient and practical new operation control technology, thereby actively supporting the safe operation of the distribution network. The implementation of voltage flexible control methods will provide important theoretical and methodological support for the development of active distribution networks and smart grids. The above PV active and reactive power control methods all consider the technical aspects of improving the local PV consumption capacity and ensuring the safe and stable operation of the power distribution system. In the future, we should focus on the economics of different voltage control technologies, and explain the principle of optimal active and reactive power control of PVs from the perspective of economic efficiency, aiming at achieving the technical and economic balance of voltage control in distribution systems. At the same time, the influence of power distribution system flexibility, availability of renewable energy, installation capacity and other parameters on voltage optimization control should be further analyzed.

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