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A control method of a Rooftop-PV system in distribution grids for voltage support during shading effects

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Abstract: *According to the Power Master Plan 8, Vietnam aims to have at least 50% of rooftops with solar systems in residential and offices by 2030. This target supports the energy transition plan of Vietnam towards a net-zero commitment before 2050. Due to its high dependence on the weather, the high penetration of rooftop solar power into the distribution grid will pose many operational challenges. One of the main issues is to ensure that the voltage is within the allowable limit under all operating conditions. This paper presents a control method applied for rooftop solar power systems in order to support voltage during shading duration. The effectiveness of the method is verified through simulations of typical scenarios.*

Keywords: *Reactive power control; rooftop PV; distribution network; voltage; shading effect.*

1. Introduction

The penetration of rooftop solar power into urban power grids is rapidly increasing in many countries. These solar power systems play a crucial role in supporting the grid by providing electricity to common urban loads, such as commercial centers and office buildings. However, integrating solar power into the grid also introduces several technical challenges that must be addressed to ensure both grid reliability and the efficient operation of solar systems. Research indicates that voltage profile variations and reverse power flow are the most significant power quality issues arising from PV system integration in distribution networks. These issues complicate voltage regulation and the operation of protection devices [1], [2].

Several control methods have been proposed to address these technical challenges. One approach is the coordination control of distributed energy storage systems (ESS) for voltage regulation in distribution networks, as demonstrated in [3], [4]. Simulation results show that this method successfully keeps network voltages within the required limits. Control algorithms for vehicle-to-grid (V2G) technology have been explored to regulate voltage and frequency in distributed networks, which integrate PV and electric vehicles [5]. Some studies suggest that power quality issues caused by PV systems can be mitigated using Flexible AC Transmission Systems (FACTS) devices, such as Static Var Compensators (SVC) and Distribution Static Compensators (DSTATCOM) [1], [6].

A review of the literature indicates that effective control of PV inverters can significantly address practical operational challenges. For instance, study [7] highlights that selecting an appropriate reactive power control method can provide essential ancillary services for supporting voltage regulation in urban grids. Smart inverter functions, like Volt-VAR control, can enhance the integration of PV systems into the grid, although they may sometimes reduce overall efficiency [8]. Coordinating smart inverters with advanced voltage control strategies in the distribution system is a promising solution. In case where the reactive power from battery inverters is insufficient, activating PV inverter response modes can help reduce active power curtailment and prevent inverter shutdowns [9]. A cooperative strategy for voltage regulation, which coordinates load tap changers and the reactive power of PV inverters, has also been proposed. This method leverages the fast-reacting nature of inverters and utilizes a multi-agent control architecture to minimize voltage violations [10].

The shading effect significantly impacts the performance of photovoltaic (PV) systems, being one of the primary factors leading to a reduction in voltage, current, and overall power output of solar panels [11]. A momentary shading of solar panels can cause high dynamics in the system stability [12]. To mitigate these detrimental effects on power system frequency, a control strategy has been proposed in [13]. In this approach, when one or more sections of the PV system experience shading, a central controller directs the unshaded sections to deploy their active power reserves, thereby smoothing the overall power output.

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Additionally, study [14] investigates the impact of various voltage converter configurations on shading and proposes optimal configurations to minimize the negative effects of shading on the PV system.

This paper proposes a reactive power control strategy for PV inverters aimed at providing enhanced voltage support at the point of common coupling (PCC) and improving voltage stability at load buses during shading events. The structure of the paper is as follows: Section 2 outlines the reactive power control method for the case study system; Section 3 presents the simulation results and discussion; and Section 4 provides the conclusion.

2. Representation of case-study system

Considering a power system shown in Figure 1 to explore the influence of shading on the voltage of the PCC point between a PV system and the distribution network. The PV system is connected to the PCC via two converters: a DC-DC converter with maximum power point control and an inverter with the dc voltage and reactive power control. The PCC is ending bus of a distribution line (L1) supplied from a feeder (main grid). The sending bus at the feeder is also connected to a load via a distribution line (L2). The voltage of this load will be observed to show the effect of shading phenomenon.

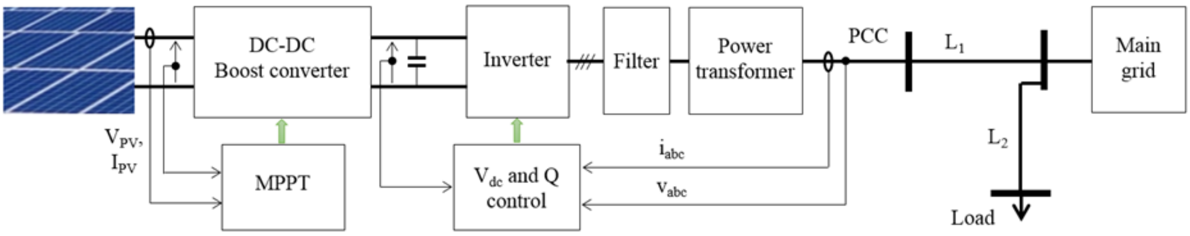

Fig. 1: Diagram of distribution network integrated with PV system

It is common that the inverter can be controlled to provide more services to the main grid, including power, voltage and frequency control. In this study, the reactive power control is carried out to provide more support to voltage at the PCC. Consequently, the voltage level of load buses can be improved during the shading duration.

To control the reactive power, a regulator is added, shown in Figure 2. The regulator outputs the reference of q-axis component, which is used for current regulator. In this scheme, the AC output currents, AC output voltages and the DC voltage are measured. The reactive power (Q) is computed from the AC voltages and currents while the reference of reactive power is calculated according to the selected method for controlling. The analysis and comparison among various techniques for reactive power control can be referred to the literature, for instance see [7]. Therefore, the controller is designed with inner loops for the currents and outer loops for the DC voltage and reactive power. The reactive power regulator typed proportional-integral (PI) is responsible for keeping the reactive power in accordance with demanded value computed using equation (1).

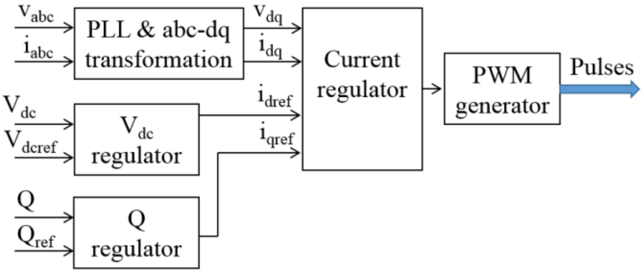

Fig. 2: Diagram of inverter controller

It was recommended that the reactive power should be controlled according to the following relation with the voltage [7], [15]:

$$Q(t)=\begin{cases} Q_{max}(t) & ; \quad V(t)\le V_2 \\ \dfrac{V_3-V(t)}{V_3-V_2}Q_{max}(t) & ; \quad V_2<V(t)\le V_3 \\ 0 & ; \quad V_3<V(t)\le V_4 \\ -\dfrac{V_4-V(t)}{V_4-V_5}Q_{max}(t) & ; \quad V_4<V(t)\le V_5 \\ -Q_{max}(t) & ; \quad V_5<V(t) \end{cases} \qquad (1)$$

where V(t) is the terminal voltage of the inverter; Q(t) is the reactive power that is demanded to supply the PCC point.

3. Simulation results and discussion

This section presents the simulation of the system of Figure 1 in order to illustrate the shading effect on the voltage of the distribution network. The distribution network includes following components:

- PV system with the power of 100 kWp; parameters are given in Table 1 in the appendix; The data of radiation is adopted from [16];
- Distribution lines: L_1, L_2 (5 km), 24 kV;
- The main grid: short-circuit power of 4 MVA;
- Load: 150 kW, 75 kVAr in (8-17) h, 90 kW, 45 kVAr in the remaining period of the day;
- The shading occurs in (10-11) h which is considered as the period with the morning peak load of the day [16].

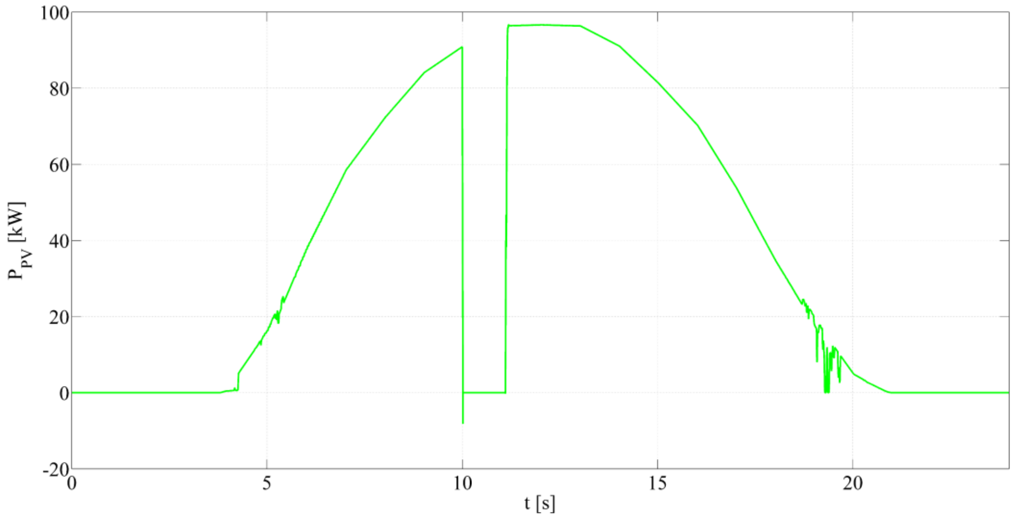

Fig. 3: Output power of PV system with the shading in (10-11) h.

Fig. *3* shows the output of the PV system in a day, in which a period of shading occurs in (10-11) h. It is seen that the output power decreases to the most unexpected level that is approximate 0. Since this duration is the morning peak load, the lack of power leads to more power demand from the feeder. Consequently, the voltage drop on the line D1 increases that causes the voltage to drop under the lower limit of 0.95 p.u according to Vietnamese grid codes [17], as shown in blue curve in Fig. *4* (upper). When the reactive power control is applied, the voltage is improved to be closer to the nominal value (1.0 p.u), especially during the shading period, as viewed in green curve in Fig. *4* (upper). It is due to the fact that the inverter is controlled to supply more reactive power to the PCC in order to improve the voltage level. It can be seen in Fig. *4* (lower) that the current grows up corresponding to the increase of the reactive power compared with the mode without reactive power control.

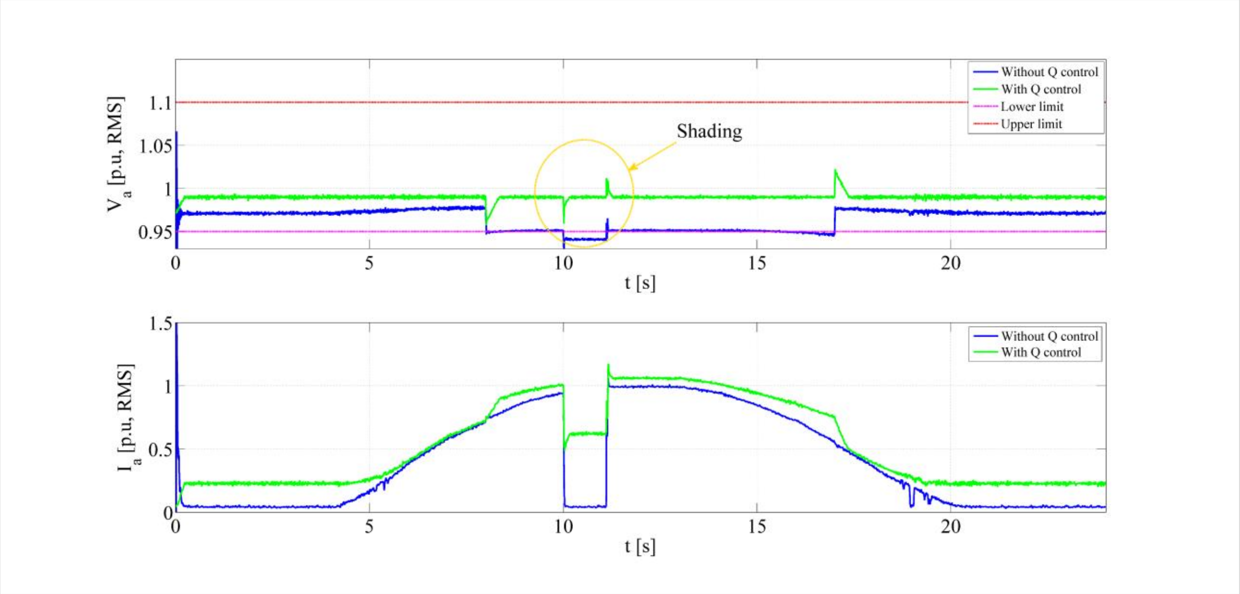

Fig. 4: The RMS values of voltage (upper) and current (lower) at PCC: a comparison between modes with and without reactive power control

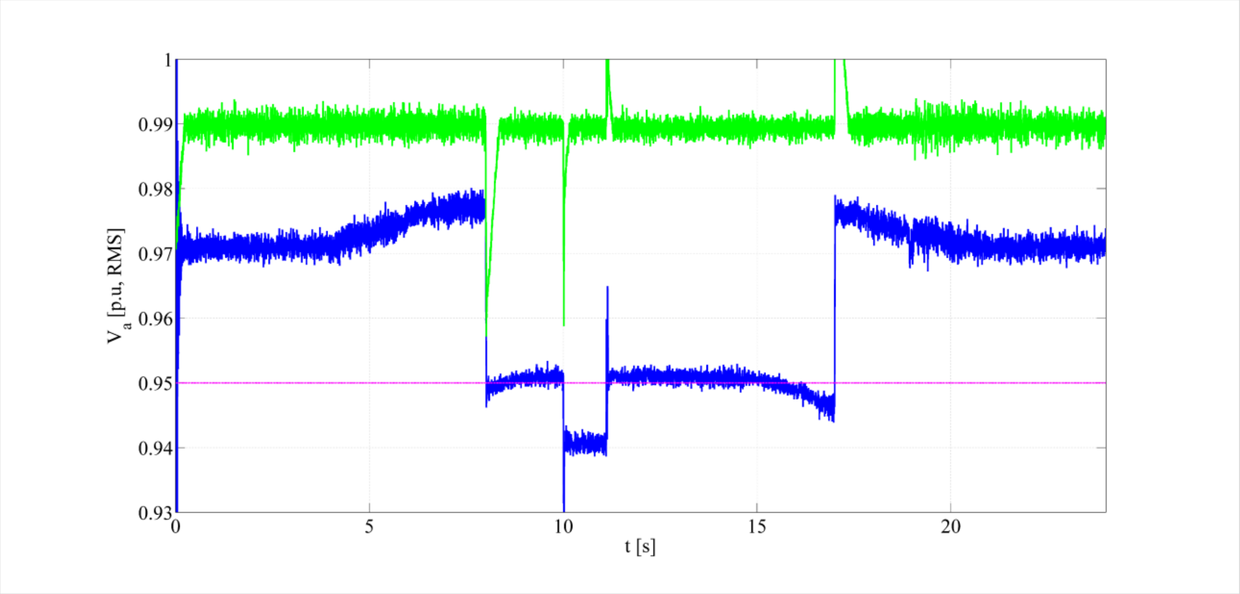

Fig. 5: Load RMS voltage: a comparison between modes with and without reactive power control

Fig. *5* illustrates the effect of shading on other node voltage in the distribution system. It is also noted that the voltage profile of the load is enhanced and remained in the permitted range, even in the condition of lacking PV power due to the shading effect.

4. Conclusion

The shading phenomenon is random and occurs frequently, it causes negative effects on voltage quality in the distribution grid. The proportion of rooftop solar power sources connected to the Vietnamese distribution grid is increasing, many grids have a solar power penetration rate of over 50%. Therefore, a solution to control solar power sources participating in ensuring voltage quality in shading situations is essential. This paper has built and proposed a rooftop solar power control system to improve voltage quality in shading conditions. The verification results of the Vietnamese grid based on Matlab simulation software have shown the effectiveness of the proposed solution. The next research directions of the authors are the coordination between rooftop solar power control solutions and transformers in normal and abnormal conditions. These proposals help Vietnam increase the penetration rate of rooftop solar power sources, thereby moving towards the government's commitment to net zero emissions before 2050.

Appendix

Tab. 1. Parameters of the main components in the distribution network [7].

	Value	Unit
PV system		
Maximum power, Pmp	305.2	W
Maximum power voltage, Vmp	54.70	V
Maximum power current, Imp	5.58	A
Open circuit voltage	64.20	V
Short circuit current, Isc	5.96	A
Series resistance of PV model, Rs	0.038	Ω
Parallel resistance of PV model, Rp	993.5	Ω
Number of parallel strings	66	-
Number of series panels in a string	5	-
Filter resistance	0.2	mΩ
Filter inductance	250	µH
Parameters of reactive power controller		
K_{pQ}	0.03	-
K_{iQ}	1	-
Power transformer		
Nominal power	100	kVA
Resistance of the primary, secondary windings	0.001	pu
Leakage inductance of the primary, secondary windings	0.03	pu
Magnetization resistance	500	pu
Magnetization inductance	500	pu
Power lines		
Unit resistance	0.115	Ω/km
Unit inductance	1.05	mH/km
Length	5	km

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