Simulation and Comparison of MPPT in Centralized and Central-Distributed Photovoltaic Power Generation Systems: Postprint

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Abstract

Due to factors such as uneven terrain distribution and module aging and degradation, mismatch loss issues in photovoltaic modules are becoming increasingly prominent. For large-scale ground-mounted and mountainous power stations, the adoption of inverter multi-channel maximum power point tracking (MPPT) technology will inevitably become a trend to address such problems. This paper utilizes Simulink to conduct simulations of photovoltaic power generation systems, compares distributed-centralized and traditional centralized photovoltaic power generation systems, and verifies the superiority of distributed-centralized photovoltaic power generation systems in MPPT efficiency.

Full Text

Simulation and Comparison of MPPT for Centralized and Distributed Photovoltaic Power Generation Systems

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Abstract: Mismatch losses in PV modules have become increasingly prominent due to factors such as uneven terrain distribution and component aging degradation. For large-scale ground-mounted and mountain photovoltaic power stations, adopting multi-channel Maximum Power Point Tracking (MPPT) technology in inverters will become an inevitable trend. This paper utilizes Simulink to simulate photovoltaic power generation systems and compares distributed photovoltaic systems with traditional centralized systems, thereby verifying the superiority of distributed systems in MPPT efficiency.

Keywords: Distributed inverter, photovoltaic inverter, multi-channel MPPT, photovoltaic power generation system simulation

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1 Introduction

As fossil energy resources become increasingly depleted, developing renewable energy sources such as wind and photovoltaic power generation has become a global consensus. In 2017, global newly installed photovoltaic capacity reached 102 GW, representing a year-on-year increase of 33.7%. China alone installed 53 GW of photovoltaic capacity, exceeding half of the global total and becoming the world' s largest photovoltaic market. It is projected that China' s photovoltaic installed capacity will reach 55–60 GW in 2018, continuing to lead the world.

In recent years, due to smaller grid loads, long transmission lines, and slow growth in transmission capacity in northwestern China, the pace of local photovoltaic development has slowed considerably. Consequently, China' s photovoltaic power station construction has gradually shifted toward the southeast. The southeastern region features larger grid loads, making it easier to locally consume photovoltaic generation with less curtailment. Additionally, the higher population density and concentrated electricity load in these areas facilitate more convenient construction of photovoltaic transmission lines. However, limited land resources in the southeast create site selection challenges for photovoltaic power stations, resulting in most installations being built in hilly and mountainous terrain.

Currently, most large and medium-sized ground-mounted photovoltaic power stations adopt centralized inverter designs. This approach features relatively mature technology, high station reliability, and excellent cost-effectiveness. However, in hilly and mountainous power stations, non-uniform tilt angles and orientations of PV modules cause power mismatch between the inverter and the PV modules' Maximum Power Point Tracking (MPPT), leading to generation losses. To address these issues, distributed inverters transfer the MPPT function to DC combiner boxes, increasing the number of MPPT tracking channels and thereby resolving the mismatch problem between inverter power and PV module MPPT.

2.1 Centralized Inverter

Centralized photovoltaic power generation systems consist of PV modules, DC combiner boxes, DC distribution cabinets, grid-connected inverters, step-up transformers, cables, and the grid. Figure 1 [Figure 1: see original paper] illustrates the schematic diagram of a centralized photovoltaic power generation system. The DC combiner box primarily aggregates DC power from multiple PV module strings; the DC distribution cabinet further combines outputs from combiner boxes to feed the grid-connected inverter; and the photovoltaic grid-connected inverter converts DC power generated by PV modules into grid-compatible AC power for grid connection, while also performing the MPPT function for PV modules that affects power conversion efficiency.

In centralized generation systems, centralized inverters offer high integration, high power density, and low cost. With fewer inverters and components, they are easier to manage and provide high reliability. They also produce low harmonic content and DC components, ensuring high power quality, and feature complete active power regulation and low-voltage ride-through capabilities for excellent grid regulation performance. However, due to centralized inversion, the MPPT voltage range is narrow, preventing monitoring of individual module string operation and optimal performance of each string.

2.2 String Inverter

String photovoltaic systems meet distributed generation requirements and are suitable for rooftop, hilly, and other photovoltaic applications. Compared with centralized photovoltaic systems, string photovoltaic systems eliminate the need for DC combiner boxes and DC distribution cabinets but require AC combiner boxes, with PV module outputs directly connected to string inverter inputs. String inverters are lower-power inverters capable of monitoring each module string' s operation and tracking each string' s MPPT, thereby improving conversion efficiency. However, compared with centralized inverters, the increased number of inverters and components reduces reliability and raises costs.

2.3 Distributed Inverter

Distributed inverters combine the advantages of centralized and string inverters, featuring distributed tracking with centralized grid-connected inversion. The schematic diagram of this photovoltaic generation system is shown in Figure 2 [Figure 2: see original paper]. Distributed inverters add DC/DC conversion functionality to centralized combiner boxes, enabling multi-channel MPPT capability. Additionally, the step-up module in DC combiner boxes increases DC transmission line voltage, reducing losses in DC transmission cables and inverter self-heating losses.

3.1 PV Module Characteristic Curves

The simulation technical parameters of the selected PV module (SunPower SPR-315E-WHT-D) are: open-circuit voltage $V_{oc} = 64.6\,\mathrm{V}$; short-circuit current $I_{sc} = 6.14\,\mathrm{A}$; maximum power point voltage $V_{mp} = 54.7\,\mathrm{V}$; maximum power point current $I_{mp} = 5.76\,\mathrm{A}$; maximum power $P_{mp} = 315.072\,\mathrm{W}$; open-circuit voltage temperature coefficient $a = -0.0027269/°C$; and short-circuit current temperature coefficient $b = 0.00061694/°C$. The simulated characteristic curves of this PV module are shown in Figures 3 [Figure 3: see original paper] and 4 [Figure 4: see original paper].

Analysis of these characteristic curves reveals that PV module output characteristics are affected by irradiance and temperature. Temperature variations exhibit a negative correlation with output characteristics: higher temperatures result in lower output current and power. Irradiance variations show a positive correlation: stronger irradiance yields greater output current and power. Observation of the module output characteristic curves indicates that irradiance affects PV module output more significantly than temperature. Therefore, in practical applications, increasing irradiance is commonly employed to enhance PV module output power.

3.2 Photovoltaic Power Generation System Modeling and Simulation

Two photovoltaic power generation system models were established: a centralized system and a distributed system (see Figures 1 and 2). Both models employ the PV modules described above, with each string comprising 5 modules, 64 strings forming a 100 kW PV array, and 4 such arrays totaling 400 kW. The MPPT performance of the two systems was compared by varying the irradiance and temperature of the PV arrays.

3.2.1 Impact of Irradiance on MPPT in Both Systems

In one PV array of both systems, the irradiance was set to vary dynamically as shown in Figure 5 [Figure 5: see original paper], with temperature held constant at 25°C. The voltage and current inputs to the inverters for both systems were obtained, as shown in Figures 6 [Figure 6: see original paper] and 7 [Figure 7: see original paper], and the inverter input power was calculated.

Analysis of Figures 6 and 7 indicates that the centralized photovoltaic system does not perform voltage step-up before the centralized inverter, resulting in lower voltage and higher current compared with the distributed system, which leads to greater losses in DC transmission cables. As shown in Figure 8 [Figure 8: see original paper], the distributed photovoltaic system achieves higher output power than the centralized system and responds more quickly during model startup and irradiance changes, demonstrating superior MPPT performance.

3.2.2 Impact of Temperature on MPPT in Both Systems

In one PV array of both systems, the temperature was set to 45°C with irradiance held constant at 1000 W/m². The voltage and current inputs to the inverters were obtained, as shown in Figures 9 [Figure 9: see original paper] and

10 [Figure 10: see original paper], and the inverter input power was calculated, as shown in Figure 11 [Figure 11: see original paper].

Figures 9 through 11 demonstrate that the distributed photovoltaic system achieves higher output power than the centralized system and responds more quickly during model startup, confirming its better MPPT performance.

4 Conclusion

This paper first analyzed existing problems in current mountain and large-scale ground-mounted photovoltaic power stations, then introduced centralized, string, and distributed inverters with comparative analysis of their advantages and disadvantages. Finally, Simulink was used to model and simulate two photovoltaic power generation systems. By separately varying irradiance and PV module temperature, the inverter input power was compared, revealing that distributed inverters achieve higher input power and better MPPT tracking performance. Consequently, distributed inverters improve MPPT tracking effectiveness by transferring the inverter MPPT function to DC combiner boxes, increasing the number of MPPT tracking channels, and resolving the mismatch between inverter power and PV module MPPT. Simultaneously, the step-up module in DC combiner boxes increases DC transmission voltage, reducing DC transmission line losses and inverter self-heating losses, thereby providing practical engineering guidance.

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Note: Figure translations are in progress. See original paper for figures.