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A Novel approach for Grid Connected PV System Based on MMC to Get Maximum Power under the Partial Shading Conditions

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Abstract

Photovoltaic energy generation is becoming an increasingly widespread meansof producing clean and renewable power. In PV systems, long strings of photovoltaic modules are found to be vulnerable to shading effects, causing significant reduction in the system power output. In the case of partial shading, the output power of the un shaded PV modules will be decreased by the influence of the shaded PV modules in one branch. In order to solve this problem, this paper proposes a novel topology for a PV power generation system by connecting aPV module to the capacitor in each sub module of a modular multilevel converter parallel. As partial shading occurs, the maximum power can be extracted by regulating the capacitor voltage to the maximum power point voltage. With this proposed topology, the maximum power tracking controller, the redundancy module controller, the voltage stability controller, and the grid-connected controller are studied. Simulation and experiment results show that comparing to the traditional topology; the proposed topology can greatly improve the output power of the PV system under the conditions of partial shading and features with low-voltage stress and high efficiency. Matlab/simulink simulations are presented in order to show the outstanding performance of the proposed design approach.

Key Words: MMC, Partial Shading Conditions, MaximumPower Point Voltage, Maximum Power Tracking Controller, Grid- Connected Controller.

Introduction

The increasing concern over environmental issues and the advantages that photovoltaic energy generation provides, if compared to other renewable energy sources, especially in terms of maintenance and reliability, attracted interest and remarkable investments in PV technology in the last decade. A PV field is comprised of a number of series connected strings that are arranged in parallel. Generally, cells in a PV field are assumed to be of the same type, or sometimes equal,but such a hypothesis is no longer valid when tolerances of manufacturing and aging-related parametric drift are accounted for. Moreover, due to possible different orientations of modules and to shadowing effects, the PV field very often works in mismatching conditions, and the possibility that some cells in a module or some modules in a string are potentially able to deliver strongly different currents is very high. To avoid one shadowed cell from narrowing the current path in a string, thus lowering the other ones in the series and reducing the overall power production of the whole string, bypass diodes are usually placed in anti parallel to small groups of series-connected cells. In case of mismatching, this arrangement helps to increase the power production of the PV field but makes its power versus voltage graph multimodal. The increasing concern over environmental issues and the advantages that photovoltaic energy generation provides, if compared to other renewable energy sources, especially in terms of maintenance and reliability, attracted interest and remarkable investments in PV technology in the last decade. A PV field is comprised of a number of series connected strings that are arranged in parallel. Generally, cells in a PV field are assumed to be of the same type, or sometimes equal, but such a hypothesis is no longer valid when tolerances of manufacturing and aging-related parametric drift are accounted for. Moreover, due to possible different orientations of modules and to shadowing effects, the PV field very often works in mismatching conditions, and the possibility that some cells in a module or some modules in a string are potentially able to deliver strongly different currents is very high. To avoid one shadowed cell from narrowing the current path in a string, thus lowering the other ones in the series and reducing the overall power production of thewhole string, bypass diodes are usually placed in anti parallel to small groups of series-connectedcells. In case of mismatching, this arrangement helps to increase the power production of the PV field but makes its power versus voltage graph multimodal.

Existing Method

In the PV modules are grouped by "binary" or "trinary," and then connected to the grid with H bridge converter. Although a higher voltage level could be obtained by this way, some switches have to suffer the high-voltage stress. To connect the PV array to the dc side of the MMC directly, and focuses on the design of the *LCL* output filter and to connect PV array to the dc sideof the MMC by a BOOST circuit. Both the methods improve the power quality under partial shading. In the PV modules are connected to the MMC cells through the dc/dc converters to obtain high efficiency and power quality, but the number of the dc/dc circuits is extremely huge. A novel topology for the PV system by connecting a PV module to the capacitor of each submodule (called PM in following) of MMC in parallel. As partial shading occurs, the maximum power could be extracted by regulating each capacitor voltage to the MPP voltage *V*MPP. The proposed topology could effectively improve the transmission voltage level by connecting the PM modules in series, which may help us to eliminate the step-up transformerand suits for the large PV plant. Because the PV modules are not connected in series directly, thepower losses of the unshaded PV modules in the series branch can be eliminated under partial shading conditions. This topology could also achieve the independent MPPT control of PV modules, and solve the multipeak optimization problem of MPPT under partial shading conditions which may occur in the series connection topology.

Proposed Topology

The proposed topology of the PV power generation system is shown in Fig. 1. Comparing to the traditional MMC circuit used in the PV system the proposed one removes the long string PV modules connected to the dc side of the MMC, and connects a PV module to the capacitor of each submodule of the MMC in parallel. Because no PV modules are connected in series, the bypass diodes are also removed. When there is partial shading, the maximum power can be extracted by regulating the capacitor voltage in each PM to VMPP. The voltage of the capacitor in the PM may fluctuate according to the irradiance. Although the voltage fluctuation is insignificant for a single module, it could not be neglected when a large number of PMs are connected in series. Therefore, a redundant module (RM) is designed to compensate the voltage loss.

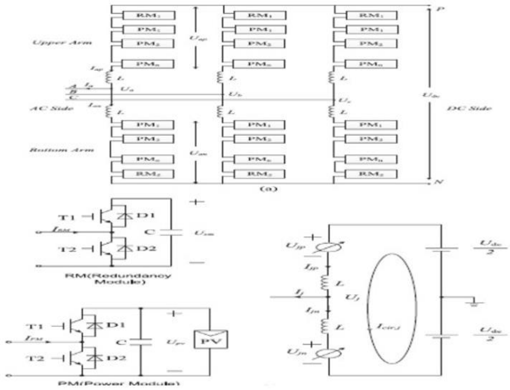


FIG-1 proposed topology of the PV power generation system.(a) Topology. (b) One-phase equivalent circuit

Taking phase A as an example, the block diagram of the control method is shown in Fig. 2, which is divided into four parts: I) the maximum power tracking controller, 2) the redundancy module controller, 3) the voltage stability controller, and 4) the grid-connected controller. The output of these controllers are Uref1 ,Uref2 ,Uref3 , and Uref4 , respectively. The grid-connectedcontroller gets the main modulation waveform Uref4 , and its purpose is to achieve the energy delivery from PV module to power grid. The voltage stability controller is used to balance the voltages between phases. The modulation waveform Uref3 generated by the voltage stability controller is superimposed on the main modulation waveform, which will change the output power of each phase. Through this adjustment, the voltage balance of phases can be realized. Theredundancy module controller is used to regulate the voltage of capacitor in RM. Its output modulation waveform ref2 is superimposed on the main modulation waveform too, which can change the charge and discharge time of the capacitor in RM. The maximum power tracking controller is used to obtain MPP voltage of the PV module. Its working principle is like that of redundancy module controller.

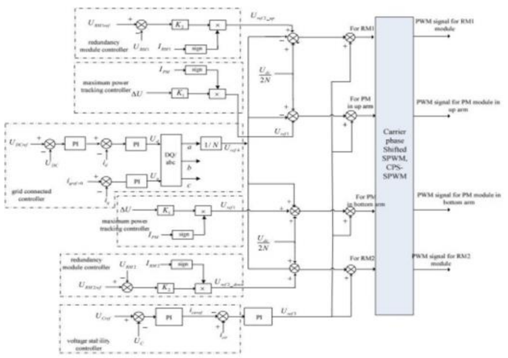


Fig-2 Block diagram

The maximum power tracking controller is used to obtain MPP voltage of the PV module. Its working principle is like that of redundancy module controller. When the PV modules work at the MPP, the voltages of capacitors in PMs may be unequal, but the difference is small, whichwill have a little influence on the THD of the output current of the topology.

Simulation Results

Case:1- Partial shading With the Proposed Topology and Control Method

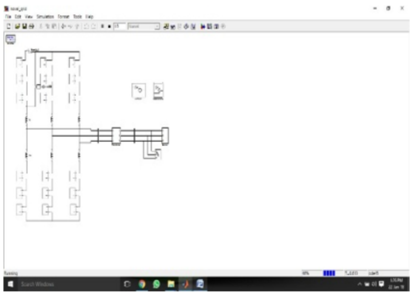


Fig:3.1 simulation diagram of Partial shading With the Proposed Topology and Control Method

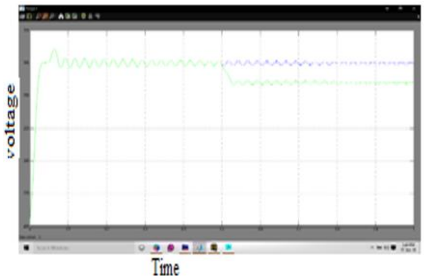


Fig:3.2(a) Capacitor voltages of PM1 and PM2

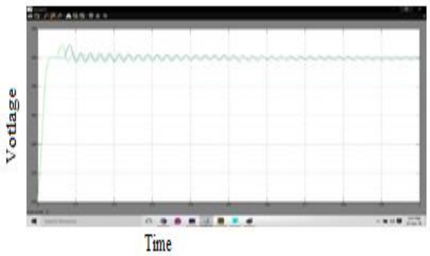


Fig:3.2(b) Capacitor voltages of PM3 and PM4

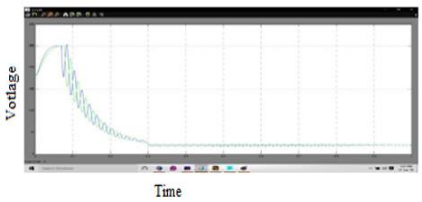


Fig:3.2(c) Capacitor voltages of RM1 and RM2

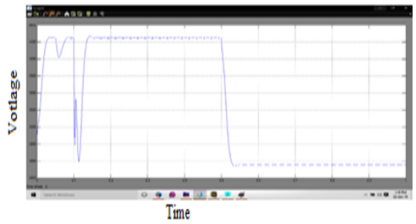
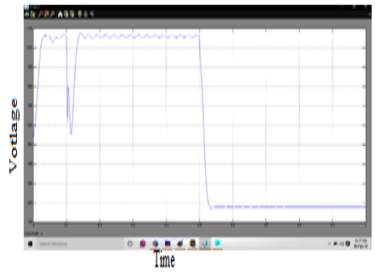
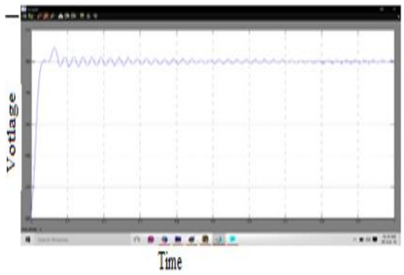


Fig:3.2(d) Output power waveform.





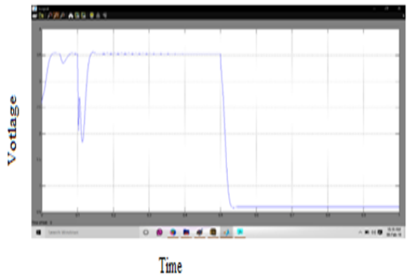


Fig:3.2 (e) Output waveforms of PV1 module in PM.

In this case, the irradiance of all PMs is set to 1000 W/m2 initially. After 0.5 s, the irradiance is changed to 200, 800, 400, and 1000 W/m2, respectively. The simulation results are shown in Fig.5.2. Fig. 5.2(a) shows the capacitor voltages of two PMs in upper arm of phase A. Both of the voltages are about 300 V initially, and then change to 278 and 300 V with a ripple of about 6 V, respectively. Because the output power of the PV module is closely related to its output voltage, the ripple of capacitor voltage of PM will decrease the output power of PV module. The capacitance value of PM needs to be increased to reduce this voltage ripple. According to the *P– U* characteristics of the PV module, it is known that within a short range near the MPP, the change of output voltage has a little effect on the output power of the PV module. Therefore, thispaper selects the capacitance to be

2000 μF, and with this capacitance value, the voltage ripple is reduced to be less than 3%, the power loss is less than 1%. Fig. 5.2(b) shows the capacitor voltages of two PMs in the bottom arm. The voltages change from 300 to 292 V and 302 V, respectively, which is caused by the MPPT controller. It is known that all PV modules still operate at their MPP even under partial shading. Fig. 5.2(c) shows the capacitor voltages of two RMs. The value is near 0 V initially, and that means the redundancy modules do not work under non shading conditions. After 0.5 s, the capacitor voltages of RM1 and RM2 increase to 14, 5 V, respectively. It means that the redundancy module can compensate the voltage loss which is caused by partial shading. Fig. 5.2(d) shows the output power waveform of phase A. Its value is about 4400W before 0.5 s and 2585Wafter 0.5 s. This value is very close to the theoretical value,2602 W, which can be calculated. Fig. 5.2(e) shows the output waveforms of the PV module in PM1. The output current is 3.65 A initially, and then drops to 0.56 A immediately at 0.5 s for the irradiance changing to 200 W/m2. With the adjustment of MPPT controller, the current come back to 0.65Aat 0.52 s. The output power is dropped from 1106 to 170Wat 0.5 s and come back to 192Wat 0.52 s. These results are very close to the theoretical value which justifies the effectiveness of the MPPT controller. Note that the voltage reference of RMs is 0 V before 0.5 s, but the capacitor voltages of RMs cannot be a negative value. Hence, during the discharge process, the capacitor voltages of the RMs could only be reduced to 0 V, and during the charging process, the capacitor voltages start to rise. In view of the overall process, the average value of the capacitor voltage has an offset from zero. The offset is not big, and its influence can be ignored. Furthermore, when the RMs need to contribute a big voltage compensation, the offset will disappear automatically.

Case:2- Some PM is Burnt Out Suddenly

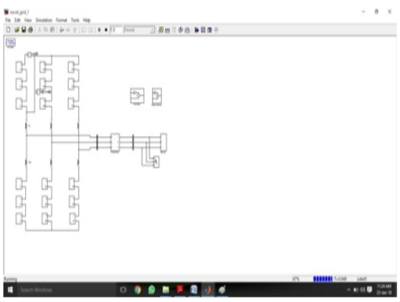


Fig:4.1 simulation diagram of Some PM is Burnt Out Suddenly

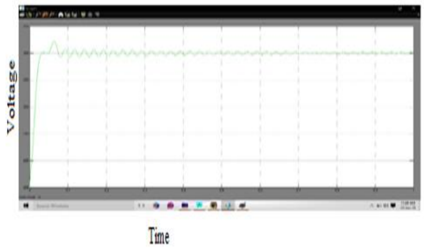


Fig:4.2(a) Capacitor voltages ofPM1and PM2

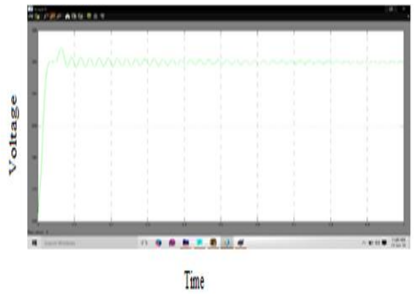


Fig-4.2(b) Capacitor voltages of PM3 and PM4

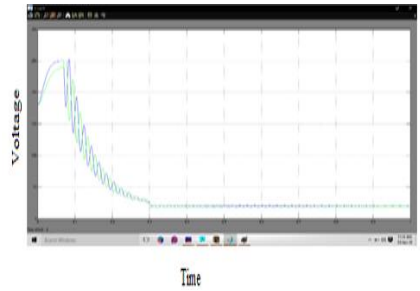


Fig:4.2(c) Capacitor voltages of RM1 and RM2.

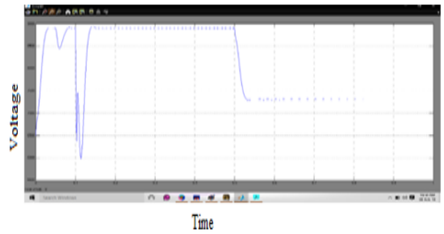
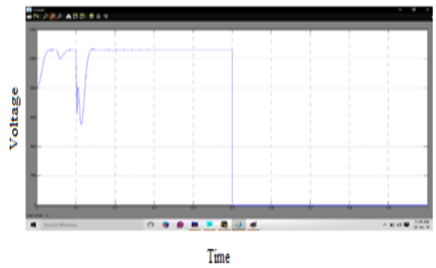
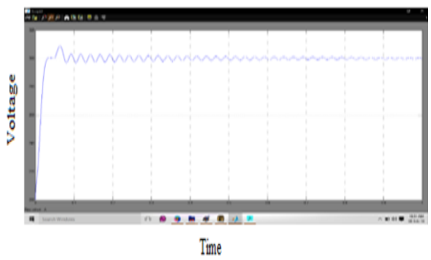


Fig:4.2 (d) Output power waveform





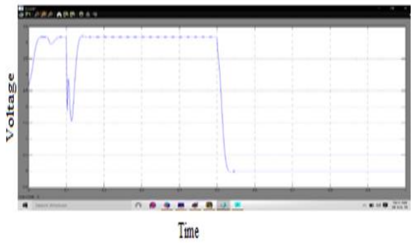


Fig:4.2. Voltage and power waveforms when PM1 is burnt out. (e) Output waveforms of PV module in PM1.

In this case, the irradiance of all PMs of phase A is set to 1000 W/m2 initially. After 0.5 s, the PV module in PM1 is burnt out, and the output current of this PV module drops to zero immediately. The simulation results are shown in Fig. 5.4. Fig. 5.4(a) and (b) are the capacitor voltages of PMs in upper arm and bottom arm, respectively. The voltage of capacitor in each PM is about 300 V before 0.5 s, which means that all PV modules work at their MPP. After 0.5 s, the capacitor voltage of PM1 is slightly decreased to 294 V, and then goes back up to300 V at 0.6 s. However, the other PMs still work at their MPP, keeping the capacitor voltages at 300 V. Fig. 5.4(c) shows the capacitor voltages of RM modules. The capacitor voltages of RM1 and RM2 are near 0 V all the time. It is because that when any PV module is burnt out, the corresponding PM works as a RM. So theoretically speaking, the voltage loss can be compensated no matter how many PMs are burnt out. Fig. 5.4(d) shows the output power. The value is about 4400W before 0.5 s and 3300 W after 0.5 s. Fig. 5.4(e) shows the output waveforms of the PV module in PM1. The current is 3.6A before 0.5 s, and then drops to zero immediately for the reason that the PV module is burnt out, and the output power is dropped from 1106 W to 0 immediately too. These simulation results consist with the theoretical analysis well.

Case:3 Reconfigure Structure Under Partial Shading

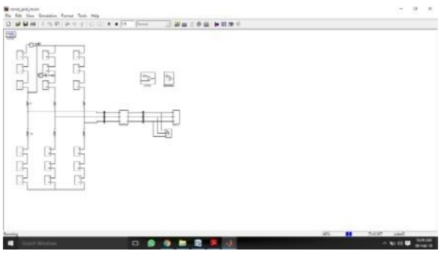


Fig:5.1. Simulation diagram of Reconfigure Structure Under Partial Shading

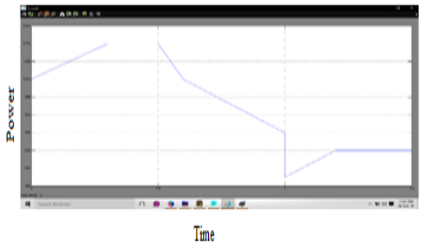


Fig:5.2 Power and voltage waveforms with reconfigure structure under partial shading. (a) Output power

Fig:5.2 Power and voltage waveforms with reconfigure structure under partial shading.(b) Output voltage of PV array.

So, the global MPPT will be easier to realize. The output power is about 4400 W initially, and suddenly drops to 0 W, which is because that the structure of PV array is reconfigured, and the terminal voltage of PV array exceeds its open-circuit voltage, as shown in Fig. 5.10(a) clearly. The terminal voltage of PV array is 1195 V before 0.5 s and then decreases to 610 V gradually. That means the MPPT method converges to point B, and the output power of PV array reaches to 2323W, which is more than that of traditional topology, but still less than that of the proposed topology.

Conclusion

A novel topology for the PV array is proposed, where a PV module is connected to the capacitor of each sub module of MMC in parallel. It aims to improve the output power under partial shading by regulating the voltage of capacitor in each PM to the MPP voltage of PV module. A RM is designed and connected to each bridge arm of the MMC to compensate the voltage loss caused by the irradiance variation. The proposed PV topology has lower voltage stress on switching device and higher efficiency. The control strategy has four parts: 1) the maximum power tracking controller, 2) the redundancy module controller, 3) the voltage stability controller, and 4) the grid-connected controller. Experimental verifications were performed by building a 3-kW PV system experimental platform. Simulation results show that the proposed topology has the same efficiency as that of the traditional topology under non shading, but achieves higher efficiency under partial shading, and compared with the reconfiguration structure, the proposed topology not only eliminates the complexity of the reconfiguration structure, but also achieves the ability of higher output power under partial shading.

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