Maximum Power Point Tracking Based Multi-Level Inverter for Grid Connected PV Systems

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Abstract— This paper presents an investigation of cascaded H-Bridge MLI, their modulation and maximum power point tracking techniques for the grid connected PV systems. Nowadays, solar energy has become one of the most important renewable energy sources. It is preferred to use multilevel inverter (MLI) based PV power stations over a conventional Two-Level Inverter based system, especially for large-scale PV power stations. The MLI produces an output voltage of staircase with low harmonic. Also, MLI may inject a sinusoidal current with improved power factor. Thus, the MLI based grid-connected PV system can operate at the lower switching frequency with reduced filter requirements.

Index Terms— Grid connected PV systems, Cascaded H-Bridge MLI, MPPT

INTRODUCTION

The electricity production from renewable energy sources has been progressively increased supported by the increased demand of electric energy throughout the world. Their generation capacity is increased by 167 GW, or 8.3%, during 2017. Solar energy returned to the first place again, with a capacity increase of 94 GW (32%), followed by wind energy with an increase of 47 GW (10%) [1]. In addition to the decreasing prices of renewable energy sources such as photovoltaic (PV) panels [2], their use is also support by many advantages such as reducing carbon emission, renew and don't need expensive maintenance [3]. For these reasons, renewable energy utilization is highly motivated.

In the past few years, the power generation from solar energy sources has been steadily grown supported by the dramatically decrease of the price of PV systems over the past years. The integration of solar energy into power system also enables minimizing the environmental impact of conventional plants. This motivated many researchers to investigate solar energy integration issues [4, 5].

PV suffers from low efficiency in converting solar to electrical energy and, also, external climate conditions affect the output power of the PV module. Therefore, tracking solar radiation is an important issue to increase efficiency of PV. An MPPT method is used to extract the maximum power available from the PV module under any operating conditions. This can increase the PV efficiency. The most important and famous MPPT methods are discussed by many researchers. The perturbation and observation (P&O) or Hill Climbing [6, 7], the incremental conductance (IC) [8] and Fuzzy logic control [9]. In solar PV power stations, PV panels converts the solar energy to DC electrical power. This DC power is converted to the AC power through an inverter. Hence, the PV power become more effective and flexible, where it can be connected to the electrical grid and AC loads. The Cascaded H-Bridge based MLI is a very common topology for high power applications. Since independent DC sources are existed in PV systems, cascaded H-Bridge MLI based power conversion systems are preferable over other multilevel inverter topologies. Many researchers have investigated the topic of the MLI. In [10], various voltage source MLI types such as neutral point clamped inverter, flying capacitor type; cascaded H-Bridge multilevel inverters are investigated and compared.

In this paper, a performance analysis and comparison for cascaded H-Bridge MLI based grid connected PV system and central MPPT is considered. This paper is organized as the following sections, System description is presented in Section 2. The MPPT technique and the control approach of MLI are described in Section 3. Simulation results and discussion of system performance under different operation conditions is provided in Sections 4. Section 5 reports the conclusion.

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I. SYSTEM CONSTRUCTION

Typically, the structure of the cascaded H-Bridge MLI based grid connected PV system is shown in Fig. 1.The system is composite of PV modules, boost converter, cascaded H-Bridge MLI, filter and grid utility.

1. PV MODULE

The enormous availability of solar energy in Egypt increases the use of PV systems. Hence, the PV modules are extremely suitable dc source for the cascaded H-Bridge MLI units. The equivalent circuit model PV cell is shown in Fig. 2 and the basic equations that represent the PV model are well known as given in [11,12]. The PV modules which used to provide the inverter with dc power have the characteristics shown in Fig. 3. The model parameters that are used in this study are presented in Table I.

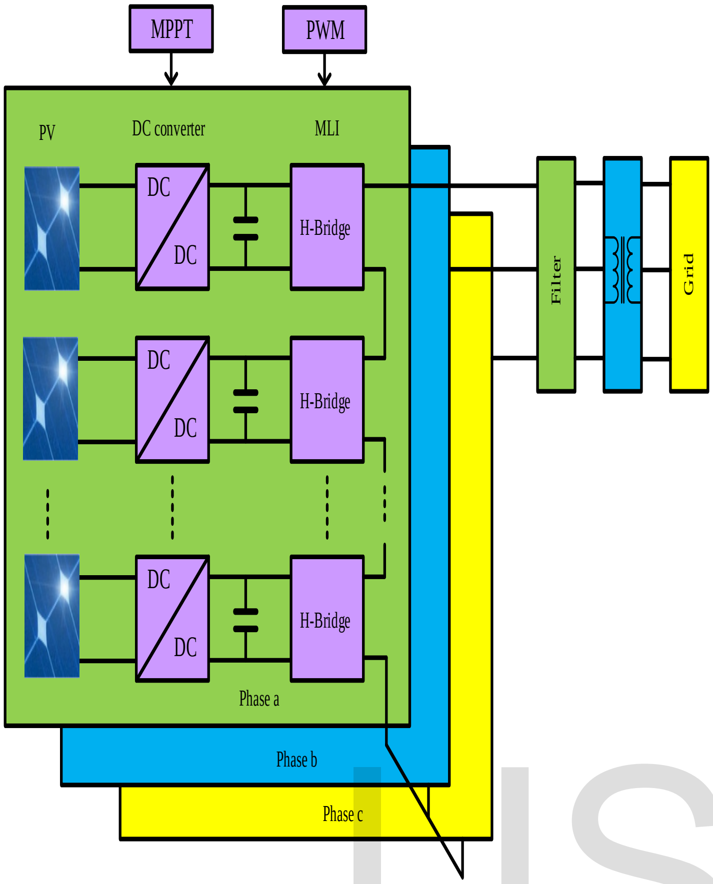

Fig. 1. Structure of the cascaded H-bridge MLI.

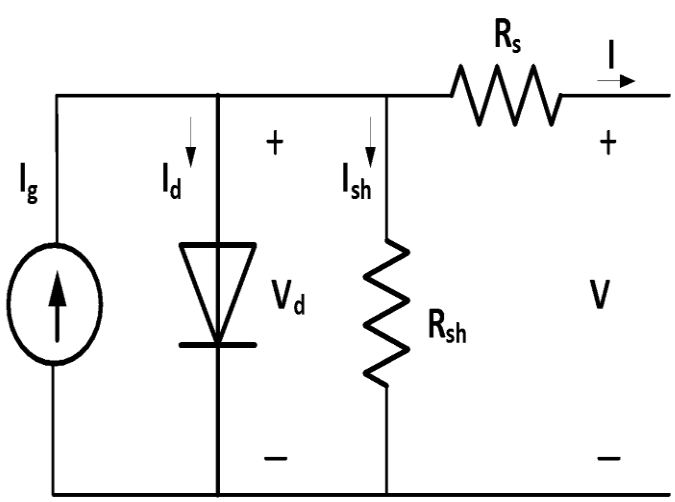

Fig. 2. PV equivalent circuit.

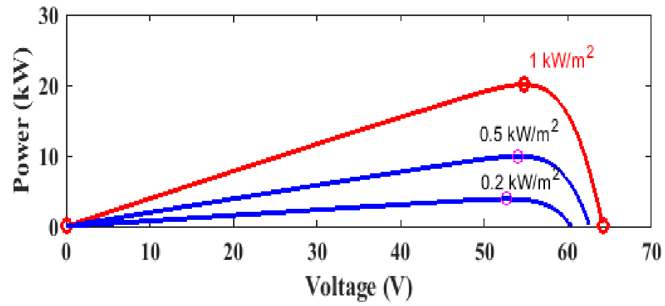

Fig. 3. PV characteristics.

Table 1. PV model parameter.

Parameter	Value
Number of Series Cells	96 cells
Open Circuit Voltage	Voc = 64.2 V
Short Circuit Current	Isc = 5.96 A
Voltage at Maximum Power	Vmp = 54.7 V
Current at Maximum Power	Imp = 5.58 A
Maximum Power	Pmax = 305.2 W

2. Cascaded H-Bridge MLI

The cascaded MLI contains n number of series connected H-bridge modules. Each H-bridge module is connected to PV panel through the boost converter and dc link.
Fig. 4 shows the structure of the one H-bridge. The H-bridge is composed of four IGBT-diode switches S11, S12, S13, S14 connected in H form.
Each H-bridge inverter can produce three different output voltages -Vdc, 0, and +Vdc by connecting the DC source to the AC output through different combinations of the four switches, S11, S12, S13, S14.

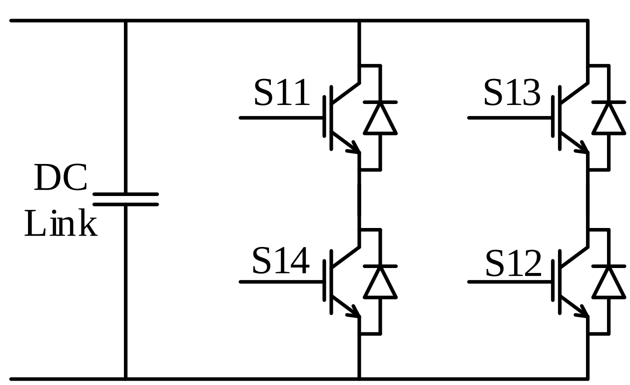

Fig. 4. H-bridge construction.

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II. CONTROL TECHNIQUES

The control strategy, for the system under study, is consists of two stages: the MPPT stage and the modulation stage. The MPPT technique is performed in the first stage, which provide voltage reference of each PV panel, based on IC algorithm. The second stage performs the modulation technique, which provide the driving signals for the inverter cells by means of a PWM technique. The description of the two stages are described in the following subsections.

1. MPPT CONTROL METHOD

The MPPT technique is implemented via a DC-DC converter that raise the input voltage level of the inverter or DC-link capacitor to the voltage value at which maximum power is obtained.
Many techniques were developed to determine the MPP. They differ in their aspects such as: the required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking and hardware needed for the implementation or popularity [13].
In this study, the incremental conductance (IC) method is used. The IC method is based on the fact that the power slope of the PV is null at MPP (dP/dV = 0), positive in the left and negative in the right, as shown in Fig. 3Due to this condition, the MPP can be found in terms of the increment in the array conductance.
This method searches the MPP in the same way as Perturbation and observation method, and also features a modified version, but it is not necessary to calculate the PV output power and presents very good transient performances when subjected to rapidly changes in atmospheric conditions. The flowchart of the IC algorithm is presented in Fig. 5.

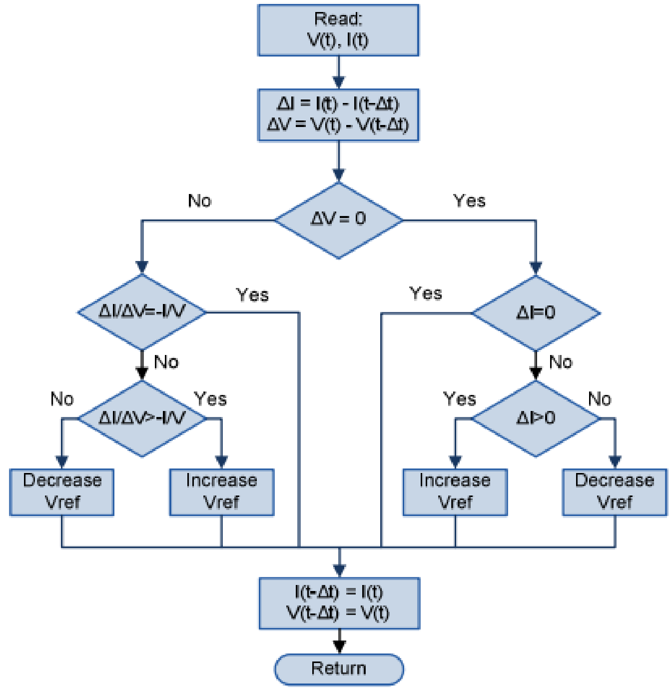

Fig. 5. The flowchart of the IC method.

2. PHASE SHIFT PWM CONTROL METHOD

Multilevel inverters can be controlled using different modulation techniques. These techniques can be divided according to the switching of frequency as follows [14]:
Fundamental switching frequency modulation (FSFM)
High switching frequency modulation (HSFM)
For both cases, a stepped output waveform is obtained, but when using the high switching frequency methods, steppes are modulated with some sort of PWM.

Phase shift PWM technique which is considered as one of the high switching frequency modulation, is used in this paper.
In general, a multilevel inverter with m-levels requires (m-1) triangular carriers. In this kind of modulation, all carriers (the triangular) have the same frequency and the same amplitude, but there is a phase shift between any two adjacent carrier waves, given by the following equation:

$$\emptyset c = \frac{360}{m-1}$$

The gate signals are generated by comparing the modulating wave with the carrier waves.
The gate signals are generated by comparing the modulating wave with the triangular waves. This means that, for the fifteen levels inverter, fourteen triangular carrier waves are needed with a (25.714°) phase shift between any two adjacent carriers as shown in Fig. 6.

III. SIMULATION RESULTS AND DISCUSSION

PV panels are used to supply the grid and are connected through a boost converter and 15 level cascaded H-bridge MLI. The used PV panels have 20.1kW for each panel as maximum power at standard conditions. The partial or complete shading on PV array causes reduction in output power and also results non-linearity in output I-V characteristics with multiple local maxima on P-V curve. This phenomenon makes the system susceptible to many times of transients. Also, surrounding temperature affects the generated power from PV panels.

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Thus, the PV panels are subjected to changes in solar radiation and temperature. Two cases are considered in this study.
1. Case A: change in climate conditions without MPPT.
2. Case B: change in climate conditions with MPPT.

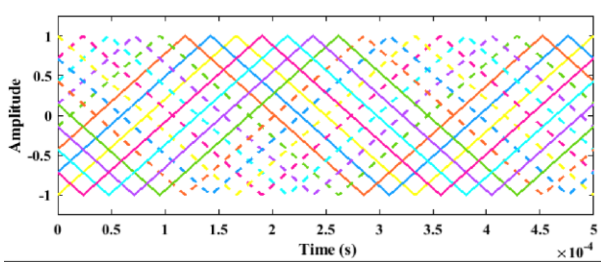

Fig. 6. Triangular carriers based on phase shifted modulation.

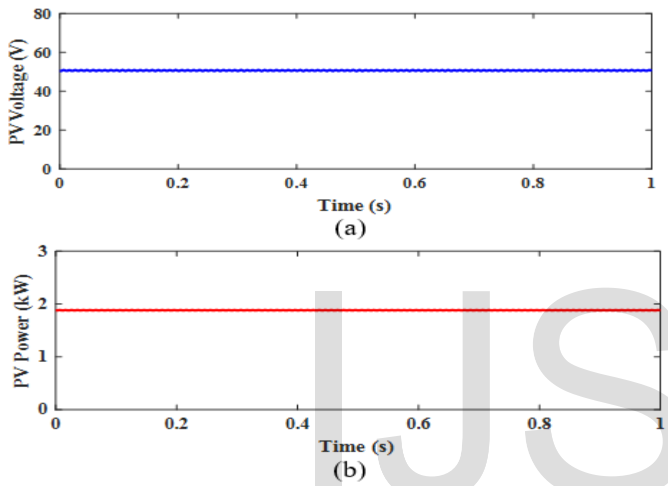

Fig. 7. (a) The voltage of each PV panel (a), (b) The output power of each PV panel.

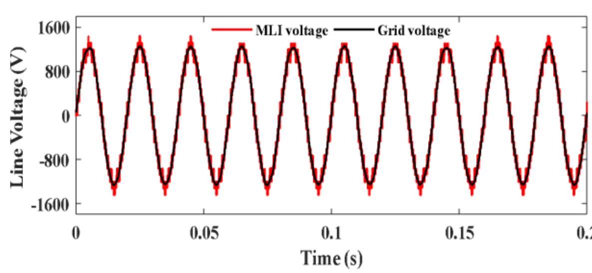

Fig. 8. Voltage at MLI terminal.

The selected case study is simulated firstly under normal operating conditions where a steady climate conditions is considered (radiation of 100W/m^2, temperature of 25 ˚C), and the PV operates at maximum power point.

The simulation results of the system at normal operating conditions is shown in Fig. 7 and, Fig. 10. It can be seen that the voltage at maximum power point is 50.54 V while the maximum power extracted from each PV panel 1.88 kW. The voltage and power of each PV panel. On the other hand, the voltage at MLI output terminals which is shown in Fig. 9 is zoomed to show 10 period of the full operating period in order to clear the inverter performance.

Case A:

The PV modules that used to supply the system is subjected to change in solar radiation and temperature. Two climate disturbances as shown in Fig. 9 are simulated at 0.1 s and 0.5 s, while the MPPT control was turned off. At 0.2 s, the radiation is increased by20% of its nominal value and, then, at 0.5 s, the temperature is increased by 40 % of its nominal value. When the radiation and temperature become stable at their new values, the MPPT control is turned on to extract the maximum power at 0.7 s as shown in Fig. 10.

In Fig. 11 (a) the voltage of each PV panel is shown where the voltage exhibits almost no changes during either radiation change or temperature change. On the other hand, the voltage of PV panel decreased approximately from 51V to 49 V when the MPPT control is turned on at time 0.7 s. the output power of the PV panel shows a significant change during the period of increasing the radiation. At 0.7 s, an increase of the power by approximately 1% of its value before the MPPT control is turned on is observed as shown in Fig. 11 (b).

Fig. 14 shows the voltage at MLI terminals which is approximately kept constant with small ripples, whereas the PV voltage that decreased during the period of enabling the MPPT control. This clear that the control of the MPPT and MLI are capable of extracting the maximum power and control the voltage even if a change in the PV voltage is existing.

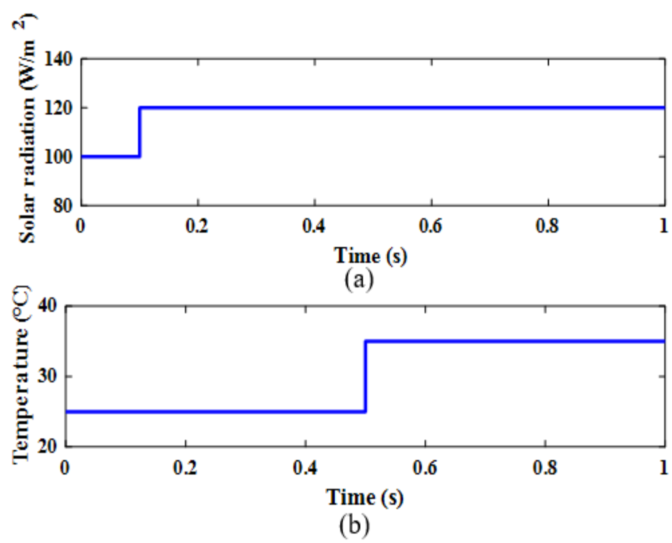

Fig. 9. (a) Solar radiation, (b) Surrounding temperature.

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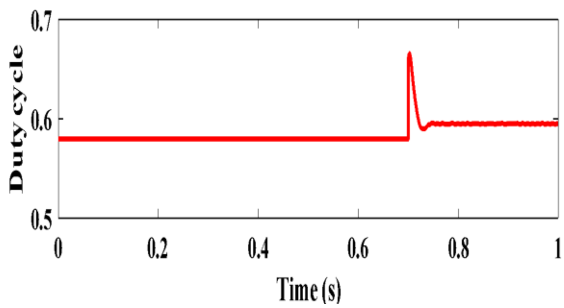

Fig. 10. Duty cycle.

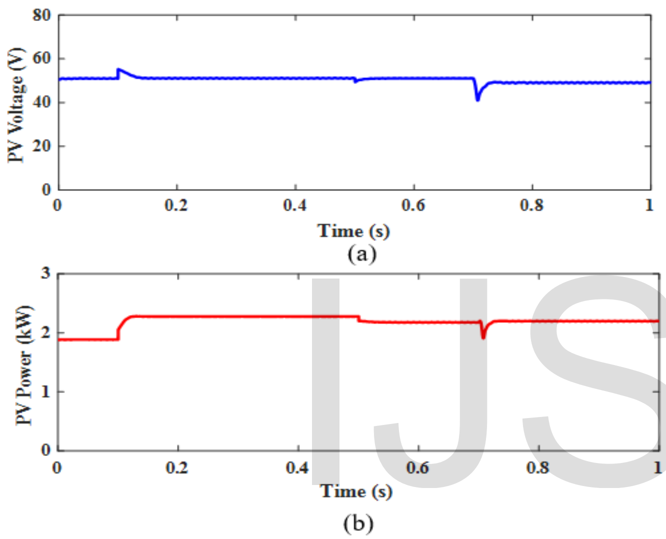

Fig. 11. (a) The voltage of each PV panel: case A, (b) The output power of each PV panel: case A.

CASE B:

Another case study with another operating condition is presented. Fig. 13 shows the change in climate conditions applied on the PV panels. The simulation starts with turning the MPPT control on and it turned off at 0.8 s. MPPT controller changes the value of duty cycle to achieve maximum power point, while the duty cycle has a set before value during period of turning off the controller as shown in Fig. 14.
It is clear from Fig. 15that the used controller is capable of extracting the maximum power of each PV panel even if a changes in climate conditions are existing.
Comparing Fig. 11 and Fig. 15, it is worth noting that the perturbation time has been increased because of the MPPT controller. Moreover, due to the modulation index control, the sudden change in the input voltage move the operating point bit far from the MPP. Thus, the MPPT technique, based on IC method, is affected by a degradation of performance at the rising/falling irradiation edges.
In Fig. 16, the behavior of the MLI terminal voltage are shown compared to the respective reference grid voltages. It is inferred that at the time of turning off MPPT control, the inverter does not control anymore the voltage of the MLI.
The total output power from the inverter is shown in Fig. 17. The behavior of MLI output power is approximately similar to the PV output power, but the value is different. Also, small fluctuation is existed in the MLI power.

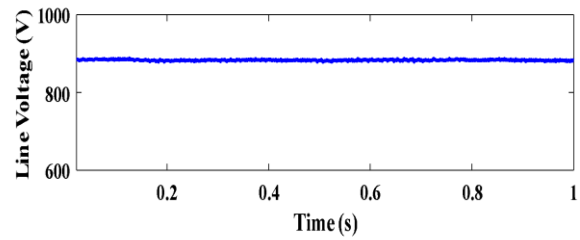

Fig. 12. RMS line voltage at MLI terminal.

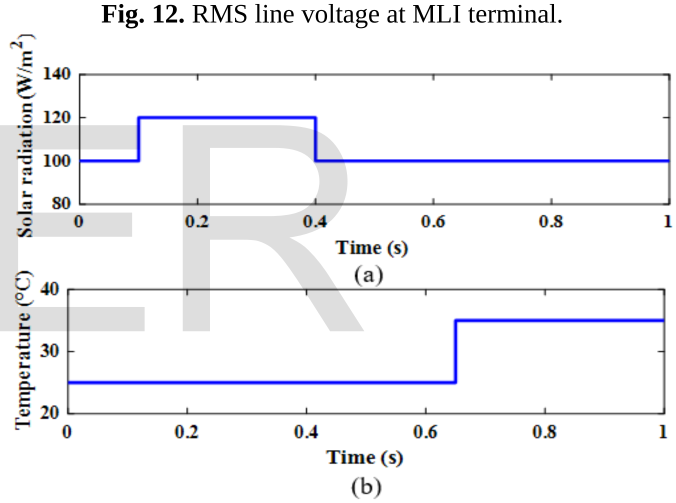

Fig. 13. (a) Solar radiation: case B, (b) Surrounding temperature: case B.

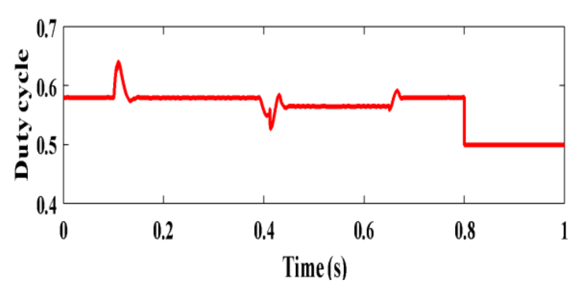

Fig. 14. Duty cycle: case B.

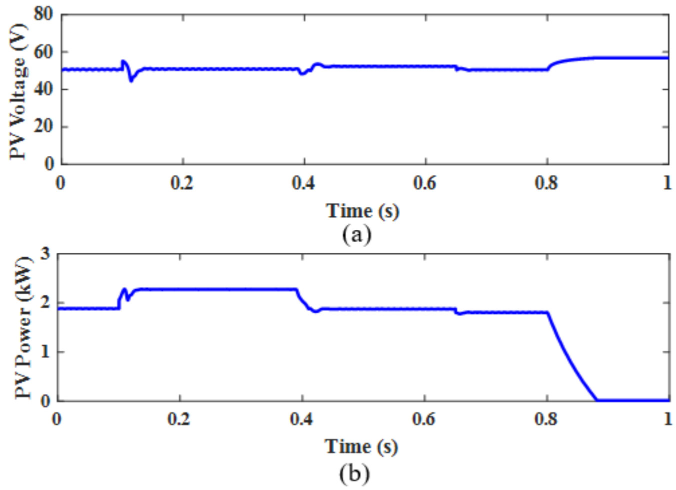

Fig. 15. (a) The voltage of each PV panel: case B, (b) The output power of each PV panel: case B.

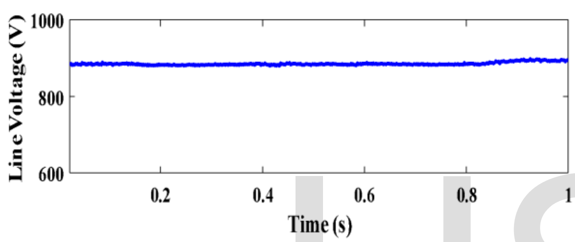

Fig. 16. RMS line voltage at MLI terminal: case B.

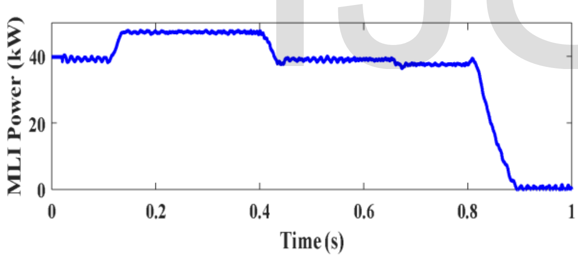

Fig. 17. Total output power of MLI: case B

Conclusion

This paper introduced an extensive study for the MPPT of PV system based on a CHB inverter. Controls at different stages are explained. The simulation results of the proposed system under normal condition is presented. In addition, the results of two case considering different climate conditions and operation of MPPT are presented. The results show that the MPPT technique, based on IC method, is affected by a degradation of performance at the rising/falling irradiation edges because of the modulation index control. Also, the design must consider the variation range of PV power and voltage as the MLI cannot be able to control all the voltage ranges.

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