International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 9, September-2023, Impact Factor: 7.957

Multilevel inverter for solar pv cell application: A Review

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ABSTRACT

This paper presents modeling and simulation of a impartial Photo-Voltaic (PV) system with upgraded multilevel Inverter using MATLAB/SIMULINK. The filtration of lower order harmonics is a challenging issue. So as to reduce the harmonic contents the level of the output voltage is increased up to 25 levels by proper arrangement of multilevel inverter with reduced number of switchesThe model includes a 25 level inverter which claims that the total harmonic distortion (THD) reduced to approximately 3%. The proposed 25 level inverter uses only 12 numbers of switches which is very less than that of diode clamped, capacitor clamped and cascaded H-Bridge multilevel inverter (MLI). The comparative analysis of THD between the two system discussed in this paper says that the THD is increased by introducing the DC-DC converter which is approximately found to be 12% but it is less as compared to the other conventional multilevel inverters used for PV system . It also reduces the rating of the PV cell. The rating of the PV cell is higher in the system when the dc-dc converter is not included.

Keywords: multilevel inverter (MLI); PV system; maximum power point tracking; MPPT;Boost Converter; modified MLC converter; leakage current suppression; THD

INTRODUCTION

Global energy demands are increasing at a rapid rate. This has led to high consumption of fossil fuels with negative environmental consequences including global warming, acid rain and the depletion of the ozone layer. The diversification of energy resources is crucial in order to overcome the negative impacts of fossil fuel energy technologies that threaten the ecological stability of the earth. Furthermore, rising fuel prices and the growing scarcity of fossil fuel may have negative economic and political effects on many countries in the near future. The improvement of energy efficiency and the effective use of renewable energy sources are key to sustainable development.

A possible solution to this crisis lies in renewable energy systems. Various renewable energy technologies have been developed, which are reliable and cost competitive compared with conventional power generation. The cost of renewable energy is currently falling and further decreases are expected with the increase in demand and production [1].

Many countries have adopted new energy policies to encourage investment in alternative energy sources such as biomass, solar, wind, and mini-hydro power. Solar energy is one of the most significant sources of renewable energy and promises to grow its share in the near future. An international energy agency study, which examined world energy consumption, estimates that about 30 to 60 Terawatt of solar energy per year will be needed by 2050 [2]. One of the means of harvesting solar energy is photovoltaic cells. The problem with solar energy is that it is not available all the time and that the times when it is most available rarely coincide with the demand for energy. Moreover, photovoltaic plants sometimes experience cloud problems, which negatively affect the efficiency of the photovoltaic (PV) system by lowering its output power. It therefore seems appropriate to store the PV energy accumulated during high irradiance times not only to maintain power supply during low-irradiation times or cloudy periods, but also to provide a continuous electrical output. A battery is the common type of solar energy storage device used for this purpose.

Photovoltaic energy sources can be used as stand-alone systems and grid-connected systems and their applications include water pumping, battery charging, home power supplies, street lighting, refrigeration, swimming-pool heating systems, telecommunications, military space and satellite power systems, and hydrogen production and the layout is shown in figure 1. In the current study, PV system is used as stand-alone system[3].

Multilevel Inverters (MLIs)
These days, MLIs are being deployed in power systems because of their ability to meet the demand in power quality and power rating, as well as their reduced level of harmonic distortion and electromagnetic interference. There are several advantages of an MLI over the traditional two-level inverters where high switching frequency PWM is used [1,2]. MLIs are currently being considered as an industrial solution for high power quality and dynamic performance demanding systems, spanning through a power range of 1 to 30 MW [3]. Hence, MLIs are ideal for use in high voltage applications because they can generate low THD output voltage waveforms and can generate higher voltages with a limited device rating [4]. The sources of sustainable energy, such as PV cells, fuel cells, and wind can broadly interact with a multilevel converter system [5]. Mostly, the type of control algorithm utilized in the PWM of MLIs determine their operations, efficiency, power ratings, and application [6]. Several studies have proposed various MLI topologies over the last few decades [7–8]. The classification of the MLIs into two main groups based on the number of employed DC sources in their topology. Until now, the most commonly used topologies in the industries are the neutral point clamped (NPC) or diode clamped, the flying capacitor (FC), and the cascaded H-bridge (CHB) [9–11].

Multilevel Converters in PV Systems
The application of multilevel inverter (MLI) in PV systems to improve power quality and efficiency has received considerable interest recently. The selection of an appropriate converter for PV applications is one of the challenges since that has an impact on the behavior of the photovoltaic (PV) system. Therefore, many multilevel converters for the photovoltaic (PV) systems have been reported in the literature [12]. The study by [13] presented an MLC for PV systems with integrated ESS. The developed MLC can provide constant power irrespective of the weather conditions. The proposed MLC showed a smooth transition from the charging mode to the discharging mode. Hence, the cascaded H-bridge (CHB) converter can be used in grid interconnections owing to its modular attributes, high-quality output waveforms, and ability to connect to medium voltage grids. A CHB-MLC with DC-DC stage isolation has been presented by [14] for large-scale PV systems.

The proposed CHB converter offered quality currents with low distortion. Its modular design ensured that it could operate in high voltage conditions and could improve the power quality. The study by

[15] presented an improved CMLI with a reliable configuration for reduction of current leakages in transformer less PV systems; conduction and switching losses were also reduced, making high switching frequency operation possible.

The study by [16] presented a CHB converter for use in PV systems; the system utilized an H6-bridge power cell rather than the H-bridge type. The system significantly improved the current quality and output voltage in partial shading conditions compared to the CHB type; this improved the system efficiency and the energy injected into the grid. A modular MMC was used in grid-connected PV systems by [17]. The proposed system can perform in both active and reactive power conditions, and this extends the applicability of the PV systems. A hybrid modular MMC for grid-connected PV systems was presented by [18-19]; this system can be used in high power systems by simply increasing the number of submodules per phase.

Switch Mode Converters
Electronic switch-mode DC to DC converters are needed toreduce power losses as much as possible and to deliver and distribute power efficiently. They may be applicable to interface with the PV system in order to extract the maximum power from the PV modules and reduce the power losses that occur in direct coupled PV-load systems. They convert one DC voltage level to another, by temporarily storing the input energy and then providing the energy to the output at a different voltage. The storage may be in either magnetic field storage components like inductors or electric field storage components like capacitors. But the whole converter can be controlled through a controlled switch which operates in "ON" and "OFF" states [18]. As the switches are associated with some losses during operations in both states, one diode is placed in the switch-mode converter so as to reduce the switching losses.

The operation of the DC-DC converter consists of two different modes: Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). A switch is said to be operating in Continuous Conduction Mode, if the inductor current cannot reach zero in one switching cycle and in Discontinuous Conduction Mode, if the inductor current reaches zero before the end of one switching cycle and remains there for certain period of time. When the converter operates, the switch will be closed and open at constant frequency (f_s) for a certain period of time through a method called pulse width modulation (PWM), which control and regulate the output voltage [19]. This PWM control method employs the duty ratio (D) of the switch which is the ratio of on-time (t_{on}) to the total time duration of the switching period ($t_{on}+t_{off}$).

Maximum Power Point Tracking

The efficiency of solar cell is very low and in order to increase the efficiency, various methods are undertaken to match the source and load properly. One such method is maximum power point tracking (MPPT).This is a technique used to track the maximum possible power from a varying source. Due to non- linearity in the output waveforms of voltaic systems, it is difficult to power a certain load directly. There-fore a dc-dc converter is used in the load side whose input is fed from solar panel and the duty cycle is varied by using a MPPT algorithm [24]. Few of many algorithms are Perturb and Observe Method, Incremental conductance method, Estimated Perturb-Perturb method, Open circuit method,Short circuit method and Curve Fitting method. In the following sections, the most commonly used MPPT techniques (P and O method and EPP method) are described with the recently invented technique (Curve Fitting method)

Perturb And Observe Method

The P and O method gets its name from how it works. in this method, a slight perturbation is introduced which causes the power increase due to the perturbation is continued in that direction. After the peak power is reached, the power decreases at the next instant and hence state is reached, the algorithm oscillation around the peak point.

In order to keep the variation small, the perturbation size is kept very small [25].It is observe that there is some loss of power due to this perturbation and it fails to track the power due to this perturbation and it fails to track the power under varying atmospheric conditions. But still this algorithm is very popular and simple[26].

The operation of P and O MPPT consists in periodically perturbing the panel operating voltage incrementally, so that the power output can be observed and compared at consecutive perturbing cycles. If the power difference is positive, further perturbation is added to the operating voltage with same increment and again the output power is observed. This perturbing process is maintained until the power difference is negative. Thus, the direction of perturbation in operating voltage must be reversed. When the operating point is located on the left of MPP as shown in figure 4.1, PO method works by increasing the voltage, which results in an increase in the power output. When the operating point is on the right of the MPP, PO will work in the opposite direction by decreasing the voltage; this results in an increase in power output. Algorithm for PO MPPT is shown in figure 4.2 and Table 4.1 shows the summery of the PO MPPT.

Incremental Conductance Method

The Incremental Conductance (IC) method was proposed in order to overcome the drawbacks of the PO algorithm when subjected to fast changing environmental conditions. The incremental conductance (INC)method is based on the observation that the following equation hold for the MPP. The principle of this method is to judge whether the system work at MPP or work at left or the right. The MPP can be tracked by comparing the instantaneous conductance(I/V)to the incremental conductance(di/dv).Once the maximum power point(MPP)is reached, the pv array is maintained at the point unless a change in atmospheric conditions [27].

Curve Fitting Method

Curve fitting MPPT technique is a method to track the maximum power from the P-V curve of photovoltaic system. As stated earlier, PV power and voltage are rapidly varying with irradiance. So, a basic fitting technique is used to track the maximum power from the variation of irradiance [28].

It has a procedure to track the MPP:

Firstly, all the P-V curves are plotted for different irradiance. Basic fitting tool is applied to all the P-V curves and an analysis is done by deciding that which order curve is approximately fitted.

All the equations with their components are found out for each irradiance. Graphs are plotted between each nth order components verses irradiance. Again basic fitting tool is applied for all those above graphs and the corresponding equations are found out. Those equations are taken as the function of irradiance and from that equations, final power (P) equation can be found out which varies with PV voltage [29]. dP/dV is calculated.

RESULTS AND DISCUSSIONS

Effect of irradiance

photo current (I_{ph}) which depends upon two measure parameters, irradiance and temperature which affects the efficiency of the solar cell. When irradiance falls, the solar cell current decreases which results in decrease in the cell voltage. Figure 6.1 and 6.2 shows the I-V and P-V curve respectively for the variation in irradiance level. Here, the simulation is done for 1000 W/m^2, 800 W/m^2, 600 W/m^2, 400 W/m^2 and the cell temperature is kept constant at 25^{0}C.

Effect of Temperature

Generally the photo current is also a function of temperature and both are proportional to each other but energy production dropped off steadily, once the panel temperature reaches 45 degree Celsius. That means, if the temperature exceeds this permissible value, then the current value may increase but the voltage decreases. The effect of temperature on the PV power production varies depending on the solar panel units employed. Higher number of photovoltaic units are less negatively affected by high temperatures than the lower units.

Effect of Partial Shading

Nine PV modules are connected in series-parallel combination to create an array. Figure 6.5 and 6.6 shows the I-V and P-V curves for unshaded and partially shaded modules. Here the unshaded curves (marked as red) represents that irradiance is uniformly distributed on all modules. But the rest curves shows that the irradiance is different. Middle I-V and P-V curves (marked as blue) shows that the array is absorbing two different levels of irradiance. Therefore, the P-V curve is having two peaks where the higher one is known as global maximum point and the lower one is known as local maximum point. Similarly the lower curves (marked as brown) shows the results for three different levels of irradiance.

Challenges and Future Work Areas

Renewable energy systems have gained more application in the power grid due to the advancements in power electronics devices and related technologies. However, this has generated many concerns in terms of the power quality, protection, energy storage, the intermittent nature of the energy fed to the grid, and system reliability. Hence, several standards and codes have been developed for grid interfaced RESs to ensure the power quality at the grid is maintained . In view of the reviewed literature, there are areas in this regard that demand more studies; these are highlighted as follows:

1. The intermittent nature of the produced power by RESs remains one of the major issues in grid-connected RES. It is believed that the contribution of RESs to the global energy market will increase in the future; hence, this problem of power fluctuations in grid-connected RESs demands to be addressed.

2. Multilevel inverters (MLIs) have been widely used in both grid-connected and industrial applications over time owing to their numerous advantages. However, researchers have recently begun to introduce hybrid topologies which are developed from the classical topologies; these hybrid methods are developed to meet the high grid code standards and address the power quality problems in a cost-friendly mannerBeing that most of these new topologies have not been evaluated in the grid-connected RESs, there is a need to investigate their performance in grid integrated applications.

3. The MMC, a commonly used MC, remains the most suitable for large-scale RES application. MMC has become the basic building block for multi terminal direct current (MTDC) and DC grids due to its salient features, The MMCMTDC systems embedded into the present power system will significantly enhance system reliability and efficiency, support renewable energy integration, and improve the economy and flexibility of power transmission. However, there are still several technical challenges in the modeling, control, and protection of the MMC-MTDC.

4. More studies are needed on the performance analysis of the recent MLIs to efficiently address the issues encountered in the grid-connected RESs applications. Studies should also focus on the role of MLIs in smart grid technologies.

CONCLUSIONS

This paper has briefly outlined the aspects of multilevel inverters to highlight the need for further investigation. This paper has briefly outlined the aspects of multilevel inverters to highlight the need to produce new inverters or modified combinations of inverters for grid-connected and PV systems. MLIs have been elaborated in various aspects, such as classifications, advantages, disadvantages, and their abilities to enhance energy conversion in modern energy systems. Based on this review, a modified approach using MLIs for different levels should employ standard MLIs to reduce the switching count. Modified MLIs are promising solutions for PV and other renewable energy systems in terms of size, cost, less THD, and high efficiency energy conversion. Besides, the most recent MLIs grid-connected PV systems, and the minimizing current leakage suppression methods were highlighted in this work. Lastly, the challenges and practical recommendations for developing an efficient system were highlighted to motivate and guide society to focus on inventing an efficient and economic MLIs grid-connected system that combines most of the used and reported inverters' capabilities.

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