Review Of An Inverter For Grid Connected Photovoltaic (PV) Generation System

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Abstract: The review of inverter is developed with focus on low cost, high reliability and mass-production for converting electrical energy from the pv module to the grid. Various inverter topologies are presented, compared, and evaluated against demands, lifetime, component ratings, and cost. Inverter based PV system to explain electrical performance subjected to different operating conditions. Multilevel inverter is one of the most recent and popular type of inverter founds its applications in the system based on renewable energy. This paper describes a new Single-phase Eleven level inverter topology for solar photovoltaic (PV) system using a carrier based PWM control scheme. This new topology has reduced number of switches for an increased number of levels when compared to conventional seven-level inverter. Here PWM switching scheme is used to control the switches in this multilevel inverter and this inverter is fed from a solar PV. By using this inverter topology, the harmonics is reduced and efficiency is enhanced significantly.

Index terms: Grid, Harmonic, Inverter topology, Multilevel inverter, PWM control scheme, PV modules, Renewable energy

1 INTRODUCTION

One type of renewable energy source is the photovoltaic (PV) cell, which converts sunlight to electrical current, without any form for mechanical or thermal interlink. PV cells are usually connected together to make PV modules, consisting of 72 PV cells, which generates a DC voltage between 23 Volt to 45 Volt and a typical maximum power of 160 Watt, depending on temperature and solar irradiation. The electrical infrastructure around the world is based on AC voltage, with a few exceptions, with a voltage of 120 Volt or 230 Volt in the distribution grid. PV modules can therefore not be connected directly to the grid, but must be connected through an inverter. The two main tasks for the inverter are to load the PV module optimal, in order to harvest the most energy, and to inject a sinusoidal current into the grid. One method, among many, to PV power more competitive is by developing inexpensive and reliable inverters.

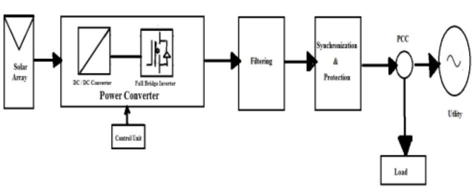

Fig 1. Grid Connected Solar PV System

The grid connected solar PV system is composed of solar PV array, boost converter, power inverter and utility grid as shown in Fig. 1. Solar PV array generates DC power at its maximum using boost converter with MPPT algorithm whereas power inverter converts this DC power to AC power and feeds to utility grid.

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1.1 Photovoltaic cell

A photovoltaic cell is the basic device that converts solar radiation into electricity which is made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load. A PV cell can either be circular or square in construction.

1.2 Photovoltaic module

Cells are arranged in a frame to form a module. The several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels. Each PV cell is rated for 0.5 –0.7 volt and a current of 30mA. Based on the manufacturing process they are classified as: Poly crystalline: efficiency of 12%. Amorphous: efficiency of 6-8% Life of crystalline cells is in the range of 25 years where as for amorphous cells it is in the range of 5years.

1.3 Photovoltaic array

The power that one module can produce is not sufficient to meet the requirements of home or business. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first connected in series to obtain the desired voltages, the individual modules are then connected in parallel to allow the system to produce more current.

1.4 Materials used in PV cell

The materials used in PV cells are as follows:

- Single-crystal silicon

- Polycrystalline silicon
- Gallium Arsenide (GaAs)
- Cadmium Telluride (CdTe)
- Copper Indium Diselenide (CuInSe2)

1.5 Efficiency of PV cell
The efficiency of a PV cell is defined as the ratio of peak power to input solar power. The efficiency will be maximum if we track the maximum power from the PV system at different environmental condition such as solar irradiance and temperature by using different methods for maximum power point tracking.

1.6 Series and parallel combination of cells

1.6.1 Cells in series
When two identical cells are connected in series, the short circuit current of the system would remain same but the open circuit voltage would be twice.

1.6.2 Cells in parallel
When two cells are connected in parallel. The open circuit voltage of the system would remain same as open circuit voltage of a single cell. But the short circuit current of the system would be twice as much as of a single cell.

1.7 PV array characteristic curves
The current to voltage characteristic of a solar array is Non-linear, which makes it difficult to determine the MPP the Fig 2 given below gives the V-I characteristic and P-V curve for fixed level of solar irradiation and temperature.

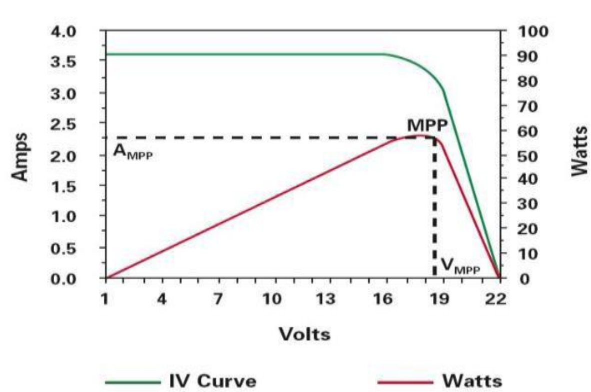

Fig 2. V-I and P-V characteristics curve of solar cell

2. DC-DC Boost Converter
A boost converter is a dc to dc voltage converter with an output dc voltage greater than input dc voltage. This is an SMPS containing at least two semiconductors switches, diode which act as freewheeling diode two ensure a path of the current during the off state of other switch and a transistor connecting in series of the source voltage). Filters made of capacitor and inductor is used to reduce the ripple in voltage and current respectively, is used at the output stage of the converter. The basic operating principle of the converter consists of the two distinct states. In on state, switch is closed, resulting in an increase in the inductor current. In off state, switch is open, resulting in decrease in the inductor current

2.1 Buck converter
This is a converter whose output voltage is smaller than the input voltage and output current is larger than the input current.

2.2 Boost converter
This is a converter whose output voltage is greater than the input voltage and output current is smaller than the input current.

2.3 Buck- boost converter
The buck–boost converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.

2.4 Cuck converter
The Cuck converter is a type of DC-DC converter where a negative polarity output may be desired with respect to the common terminals of the input voltage and the average output is either higher or lower than the dc input voltage.

3. Inverter
Photovoltaic generation system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW . Types of single-phase grid-connected inverters have been investigated. A device that converts dc power in to ac power at desired output voltage and frequency is called an inverter. Phase controlled converters when operated in the inverter mode, are called line-commutated inverters, but line-commutated inverters require at the output terminal an existing ac supply which is used for their commutation. This means that line commutated inverter cannot function as isolated ac voltage sources or as variable frequency generators with dc power at the input. Therefore voltage level, frequency and waveform on the ac side of line commutated inverters cannot be changed, on the other hands force commutated inverters provide an independent ac output voltage of adjustable voltage and adjustable frequency and have therefore much wider application. The inverters are categorized into four classifications: 1) the number of power processing stages in cascade; 2) the type of power de-coupling between the PV module(s) and the single-phase grid; 3) whether they utilizes a transformer (either line or high frequency) or not; and 4) the type of grid-connected power stage. Inverter can be broadly classified in to two types-voltage source inverter and current source inverter

3.1 Classification of inverters
1. Single phase voltage source inverters
   a. Single phase bridge inverters
   b. Steady state analysis of single phase inverters
   c. Modified McMurray half bridge inverters
   d. Modified McMurray full bridge inverters
   e. Modified McMurray Bedford half bridge inverters Modified McMurray-Bedford full bridge inverters

2. Three phase bridge inverters
   a. Three phase 180 degree mode VSI
   b. Three phase 120 degree mode VSI
3. Voltage control in single phase inverters
   a. External control of ac output voltage
   b. External control of dc output voltage
   c. Internal control of inverter
4. Pulse width modulated inverter
   a. Single pulse modulation
   b. Mmultiple pulse modulation
   c. Sinusoidal pulse modulation
   d. Realization of PWM in single phase bridge inverter
5. Reduction of Harmonics in the inverter output voltage
   a. Harmonic reduction by PWM
   b. Harmonic reduction by transformer connections
   c. Harmonic reduction by steppe wave inverters
6. Current Source Inverter
   a. Single phase CSI with ideal switch
   b. Single phase capacitor commutated CSI with R load
   c. Single phase auto sequential commutated inverter

3.2 Evolution of PV inverters

3.2.1 Centralized Inverters

The past technology was based on centralized inverters that interfaced a large number of PV modules to the grid. The PV modules were divided into series connections (called a string), each generating a sufficiently high voltage to avoid further amplification. These series connections were then connected in parallel, through string diodes, in order to reach high power levels. This centralized inverter includes some severe limitations, such as high-voltage dc cables between the PV modules and the inverter, power losses due to a centralized MPPT, mismatch losses between the PV modules, losses in the string diodes, and a nonflexible design where the benefits of mass production could not be reached. The grid connected stage was usually line commutated by means of thyristors, involving many current harmonics and poor power quality. The large amount of harmonics was the occasion of new inverter topologies and system layouts, in order to cope with the emerging standards which also covered power quality.

3.2.2 String Inverters

This technology increases the overall efficiency compared to the centralized inverter, and reduces the price, due to mass production.

3.2.3 Multi-String Inverters, AC Modules, and AC Cells

The multi-string inverter is the further development of the string inverter, where several strings are interfaced with their own dc–dc converter to a common dc–ac inverter. This is beneficial, compared with the centralized system, since every string can be controlled individually. Thus, the operator may start his/her own PV power plant with a few modules. Further enlargements are easily achieved since a new string with dc–dc converter can be plugged into the existing platform. A flexible design with high efficiency is hereby achieved. Finally, the ac cell inverter system is the case where one large PV cell is connected to a dc–ac inverter. The main challenge for the designers is to develop an inverter that can amplify the very low voltage, 0.5 1.0 V and 100Wper square meter, up to an appropriate level for the grid, and at the same time reach a high efficiency.

5. Review of PV Based Single – Phase Modified H – Bridge Multi – Level Inverter

A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three-level pulse width-modulated (PWM) inverters. They offer improved output waveforms, smaller filter size, and lower EMI, lower total harmonic distortion (THD). In a single-phase five-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel pulse width-modulated (PWM) control scheme. Two reference signals identical to each other with an offset equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. A digital proportional–integral current control algorithm is implemented to keep the current injected into the grid sinusoidal and to have high dynamic performance with rapidly changing atmospheric conditions. The inverter offers much less total harmonic distortion and can operate at near-unity power factor. The proposed system is verified through simulation and the results are compared with the conventional single-phase three-level grid-connected PWM inverter. The three common topologies for multilevel inverters are as follows: (1) diode clamped (neutral clamped) (2) capacitor clamped (flying capacitors) and (3) cascaded H-bridge inverter . In addition, several modulation and control strategies have been developed or adopted for multilevel inverters, including the following: multilevel sinusoidal (PWM), multilevel selective harmonic elimination, and space vector modulation. To overcome this limitation, this paper presents a five-level PWM inverter whose output voltage can be represented in the following five levels: zero, +1/2Vdc, Vdc, −1/2Vdc and −Vdc. As the number of output levels increases, the harmonic content can be reduced. This inverter topology uses two reference signals, instead of one reference signal, to generate PWM signals for the switches. Both the reference signals *V*ref1 and *V*ref2 are identical to each other, except for an offset value equivalent to the amplitude of the carrier signal *V* carrier because the inverter is used in a PV system, A proportional– integral (PI) current control scheme is employed to keep the output current sinusoidal and to have high dynamic performance under rapidly changing atmospheric conditions and to maintain the power factor at near unity. Simulation and experimental results are presented to validate the proposed inverter configuration. The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated .In this topology the number of phase voltage levels at the converter terminals is 2N+1, where N is the number of cells or dc link voltages. In this topology, each cell is separate by individual dc link capacitor and the cells across the capacitor might have different voltage drops. Therefore it requires one dc voltage source for each power circuit. The number of dc link capacitors is proportional to the number of phase voltage levels. Each H-bridge cell might have positive, negative or zero voltage. Final output voltage is the sum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd. Cascaded H-bridge multilevel inverters typically use IGBT switches. These switches have low block voltage and high switching frequency. Consider the seven-level inverter. It requires 12 IGBT switches and three dc sources. The cascaded H-bridges multilevel inverter is simply a series connection of multiple H-bridge inverters. Every H-bridge inverter has the same configuration as a typical single-phase full-bridge inverter. The new topology has reduced number of switches for an increased number of levels when compared to conventional seven-level multilevel inverter. Here PWM switching scheme is used to control the switches in this multilevel inverter and this inverter is fed from a solar PV. In this proposed topology, six power electronic switches are used for a seven-level inverter. By using this topology, the harmonics is reduced and efficiency is enhanced significantly.

6 Critical Review of PV Based Single Phase Modified H – Bridge Eleven – Level Inverter

The harmonic minimization of 11-level cascaded H-multilevel inverter using PV systems with a Pulse Width Modulation (PWM) control scheme. The photo-voltaic arrays are connected to eleven level multilevel inverter through DC-DC boost converter. By implementing maximum power point tracking (P&O) algorithm are producing power from PV array. The DC power from the PV array is boosted by using the DC-DC boost converter. Which is controlled by PI controller. This methodology of simulation has been carried out and verified through the MAT LAB/SIMULINK to achieve a mitigated Total Harmonic Distortion (THD). The simulation analysis of a PV based single-phase modified H-bridge Eleven-level inverter. Multilevel inverters offer high power capability, associated with lower output harmonics and lower turn-off losses. This study informs a PV based multilevel inverter using a H-bridge output stage with four bidirectional auxiliary switches. The inverter is capable of producing Eleven levels of output-voltage levels ($+V_{dc}/5$, $+2V_{dc}/5$, $+3V_{dc}/5$, $+4V_{dc}/5$, $+V_{dc}$, '0' level, $-V_{dc}/5$, $-2V_{dc}/5$, $-3V_{dc}/5$, $-4V_{dc}/5$ and $-V_{dc}$) from the DC supply. Theoretical predictions of the proposed PV based single-phase modified H-bridge eleven-level inverter with MPPT are validated using simulation in The modeling of PV based single-phase MHBELI was done and simulated using MATLAB SIMULINK. The development of simulation model has been successfully simulated and the results of PV characteristics, Incremental conductance MPPT, switching sequence for single-phase MHBELI and output voltage waveform were obtained. The concurrence between the theoretical forecasts and simulated results show clearly that the developed simulation model works as expected PV based single-phase MHBELI and provides a broad approach on solar energy based multilevel inverters. The proposed model has obvious advantage of using single phase supply and it can be implemented using an embedded system. This approach can be used for grid connected photovoltaic MATLAB SIMULINK energy applications single phase photo voltaic powered eleven level cascaded H-Bridge multilevel inverter has been proposed. The paper has presented a PWM switching scheme for the proposed multilevel inverter it utilize reference signals and a triangular carrier signal to generate PWM switching signals Multilevel inverter is one of the most recent and popular type of inverter founds its system based on renewable energy. The Single-phase eleven level inverter topology for solar photovoltaic (PV) system using a carrier based PWM control scheme. This new topology has reduced number of switches for an increased number of levels when compared to conventional seven-level multilevel inverter. Photovoltaic (PV) arrays were attached to the inverter via a dc-dc boost converter. The power generated by the inverter is to be delivered to the power set -up, so the utility grid, rather than a load, was used. The dc-dc boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the load. The inverter used in the power stage offers a significant enhancement in terms of lower component count and condensed design complexity when compared with the other existing seven-level converters. In the control circuit, the ATMEL AT89S52 microcontroller can provide all essential switching pulses for power switches, results another significant drop in cost and circuit complexity.

6.1 Advantages

A single-phase simplified multilevel inverter has the following merits over other existing multilevel inverter topologies.

1) It consists of single-phase conventional H-bridge inverter, bi directional auxiliary switches (number varies depending upon level) and a capacitor voltage divider formed by capacitors.
2) Improved output waveforms.
3) Smaller filter size.
4) Lower electromagnetic interference (EMI) and total harmonic distortion (THD).
5) Reduced number of switches employed.
6) Less complexity of the circuit as the levels increase.
7) Attains minimum 40% drop in the number of main power switches required.

Moreover, since the capacitors are connected in parallel with the main dc power supply, no significant capacitor voltage swing is produced during normal operation, avoiding a problem that can limit operating range in some other multilevel configurations.

6.2 Cascade H-Bridge Multilevel Inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig.3 Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter Each inverter level can generate three different voltage outputs, +Vdc , 0, and –Vdc by connecting the dc source to the ac output by different combinations of the four switches, S1 , S2 , S3 , and S4.

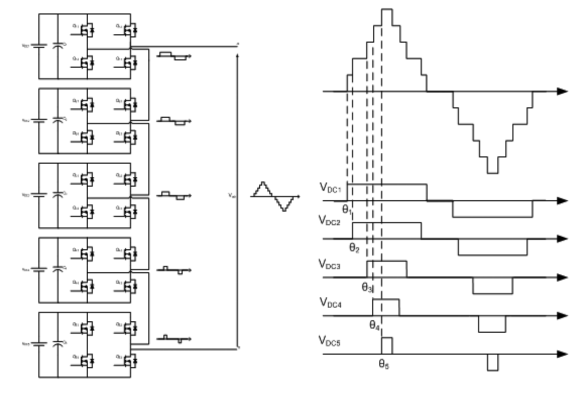

Fig 3. Eleven Level cascaded multilevel inverter and output voltage waveforms.

To obtain +Vdc, switches S1 and S4 are turned on, whereas Vdc can be obtained by turning on switches S2 and S1. By turning on S1, S2, S3, and S4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the MLI outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources. In the 11-level cascaded multilevel inverter with separate DC sources are obtained. The DC sources feeding the multilevel inverter are considered to be varying in time.

7. PLANNING OF RESEARCH

In this study an attempt will be made in the following phases.

1. Careful study the available literature and procedure for design of an inverter for PV system.
2. Select and develop the suitable inverter topologies.
3. Design and develop the photovoltaic inverter.
4. Design and develop the controller in photovoltaic inverter.
5. Testing the PV module interface, inverter, and Grid interface.
6. Optimize the inverter in respect to the microcontroller, the switch mode power supply, oscillator, power analyses, measuring- and protection circuits.
7. Find out the losses of Resistive element, MOSFET and diode.
8. Cost Estimation of various components, and design of magnetic, capacitor, MOSFET, and diode.
9. The inverter should be tested for immunity to abnormal grid operation and analyze the grid performance (power quality).
10. Using MATLAB, simulink technique for the study, simulation, and data analysis of complete PV system.
11. Result of the work will be analyzed and discussed.
12. Conclusion will be drawn from results analysis and discussion.

8. RESEARCH METHODOLOGY

The work may be stated briefly as following.

1. Select the inverter topologies.
   A. The main specifications are: PV module voltage is the range from 23 V to 50 V. Maximum PV power is equal to 160 W. The RMS value of the grid voltage is 253 V, and the power factor shall be 0.95. For selection the inverter topologies depends on electrical specification such as cable, electrolytic capacitor, silicon device, and magnetic.
   B. The inverter situated inside the residence, and the PV module is located on the roof.
   C. Topologies with HF link.
   D. Topologies with DC link.
2. Design of the photovoltaic inverter-
   A. PV connected DC-DC converter- The inverter is made up input capacitor, four MOSFETS with freewheeling diode, high frequency transformer, four diode in a full wave rectifier, DC link inductance and Electrolytic capacitance.
   B. Grid connected DC-AC inverter-The inverter is made up a dc link capacitor, four MOSFETS with freewheeling diode, and LCL filter(the stability of the system is evaluated with filter)
3. Design of controller in photovoltaic inverter-
   A. For Control of PV current a MPPT (maximum power point tracker) algorithms (i.e., optimizing of the captured energy from the PV module) is used.
   B. Other type of algorithms also exits e.g. fuzzy logic, neural network, etc.
   C. Phase locked loop (PLL) to synchronized the inverter with the grid.
   D. Control of dc link voltage.
4. Testing of PV module interface, Testing the inverter, and Testing of Grid interface.
   A. DC-DC Converter connected to the PV module.
   B. Microcontroller connected to the host PC.
   C. DC-AC inverter connected to the grid.
   D. Internal switch mode power supply (with battery backup).
5. Current mode controller (integrated circuit - IC) is used to control the DC-DC converter, where the reference is the current drawn from the PV module. It becomes in this way possible to regulate the operating point of the PV module.
6. Performance and Testing of system in simulated conditions.
7. Testing of the newly developed system and comparison with the previously existing system.
8. We use the PV array which is available in MATLAB library (ECEN2060) 6 are connected in series. More members of panels can be connected to get higher voltage. Mainly we are using DC-DC boost converter because the controller design in AC is most complicated by DC. Inverter is mainly used for DC to AC and as per inverter gate triggering the grid voltage will be varied. Set DC to AC Iref to balance the power .That is to keep VDC constant. The boost converter has advantages like reduce hardware and good output voltage regulation. Thus the boost converter is capable of improving the voltage level from 15V to require level. Fuzzy logic controller and more new controllers can be used to improve efficiency

9. Conclusion

As per the design of the proposed 11-level multilevel inverter, the total harmonics distortion is dramatically reduced to 2.62%. This will be implemented controls to maintain the magnitude and fundamental voltage and PI technique controller in this proposed model the THD can still be minimized. Multilevel inverters offer high power capability, associated with lower output harmonics and lower turn-off losses. The focusing on the harmonic minimization of 11-level cascaded H-multilevel inverter using PV systems with a Pulse Width Modulation (PWM) control scheme. The photo-voltaic arrays are connected to eleven level multilevel inverter through DC-DC boost converter. By implementing maximum power point tracking (P&O) algorithm are producing power from PV array. The DC power from the PV array is boosted by using the DC-DC boost converter.

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