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NOVEL THREE PHASE CASCADED MODULAR MULTILEVEL INVERTER FOR RENEWABLE ENERGY INTERFACING

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ABSTRACT

This proposed work focus on the three phase hybrid cascaded modular multilevel inverter topology which is derived from a modified H-bridge (MHB) module. This topology results in the reduction of number of power switches, losses, installation area, voltage stress and converter cost. For renewable energy environment such as Photovoltaic (PV) connected to the micro-grid system, it enables transformer less operation and enhances the power quality. The main advantages of this topology are; modular in construction, usage of less power electronic switches of the same voltage rating and with less number of gate drive circuit requirements. The H-bridge inverters are used to convert direct current (DC) into alternating current (AC) and it contains four MOSFET's. The MPPT converter stabilizes the DC voltage coming from the DC power source. To verify the applicability and performance of the proposed structure in PV renewable energy environment, simulation results are carried out by MATLAB/SIMULINK under both, steady state and dynamic conditions. Experimental results are presented to validate the simulation results.

Keywords – Hybrid Cascaded Modular Converter, H-Bridge, MPPT, Pulse Width Modulated (PWM) inverter.

I INTRODUCTION

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Clean development mechanism are being adopted by organizations all across the globe. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Overall, renewable energy are known to be much cleaner and produce energy without much harm to nature unlike other conventional systems. The results of a recent review of the literature concluded that as greenhouse gas (GHG) emitters begin to be held liable for damages resulting from GHG emissions resulting in climate change, a high value for liability mitigation would provide powerful incentives for deployment of renewable energy technologies. Considering the significance of the renewable energy sources for meeting the future demand and in order to successfully connect the sources to the micro grid, transformer less cascaded multilevel converter based topology is designed for this purpose [2].

II LITERATURE REVIEW

The conventional system which uses incremental conductance type MPPT algorithm and diode clamped inverter techniques holds many adverse effects in desired output [1]. The harmonic content and fast response is not up to the expected value. The proposed topology overcomes these problems of conventional systems. There are lots of MPPT techniques being used, but the most employed in the conventional scheme are incremental conductance method and hill climbing technique. The main problem associated with hill climbing technique is because of the trade-off between the stability of the system in constant radiation period and lack of fast response in rapidly changing radiation. The most used technique, (i.e) incremental conductance method (INC) holds some disadvantages even the MPPT speed and accuracy simultaneously effect a modified dynamic change in step size for INC hence the low cost implementation is possible but with of high complexity of the control system. This algorithm is more complex than P&O [3]. This increases computational time and slows down the sampling frequency of the array voltage and current. Also under low levels of insolation, the differentiation process becomes difficult and prone to measurement noise and results can be unsatisfactory. The step size may be increased to improve tracking speed, however accuracy is decreased. Likewise, reducing the step size improves the accuracy, but sacrifices the speed of convergence of the algorithm.

The constant voltage (CV) algorithm assumes that PV panel variations, such as temperature and irradiation are not significant, and the constant reference voltage is adequate to achieve performance close to the MPPT. For this reason, in practice, the CV algorithm may never exactly locate the MPPT. The proposed system implements P&O

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algorithm which holds many advantages over these conventional algorithms [8]. The speed of response is very high using this technique.

The conventional inverter techniques are mainly diode clamped and flying capacitor inverter. In a fundamental cycle, the conduction period of the inner devices is more than the outer devices. This causes unequal losses in devices in a leg, the fluctuation of the dc bus midpoint voltage, additional clamping diodes, complicated PWM switching pattern design. In diode clamping techniques the major negative aspects are, excessive clamping diodes are required when the number of levels is high. It is difficult to control the real power flow of the individual converter. The main draw backs are real power flow is difficult for a single inverter because the intermediate dc levels will tend to overcharge or discharge without precise monitoring and control. In Flying Capacitor, Multilevel Inverter Control is complicated to track the voltage levels of all the capacitors. Also, pre-charging of all the capacitors to the same voltage level and start up are complex [9].

Switching utilization and efficiency are poor for real power transmission [6]. The large numbers of capacitors are both more expensive and bulky than clamping diodes in multilevel diode clamped converters. Packaging is also more difficult in inverters with a large number of levels. These points clearly explain the disadvantages of Flying Capacitor Multilevel Inverter. The main drawback of this topology is complicated to track the voltage levels for all of the capacitors. Also the pre charging of all the capacitors to the same voltage level and start up are complex. The large numbers of capacitors are more expensive and bulky than clamping diodes in multilevel diode-clamped converters.

III PROPOSED DESIGN

The proposed topology overcomes the problems of conventional techniques [4]. The less complex and fast response MPPT algorithm (i.e.) P&O is been used in this topology and the latest inverter topology,

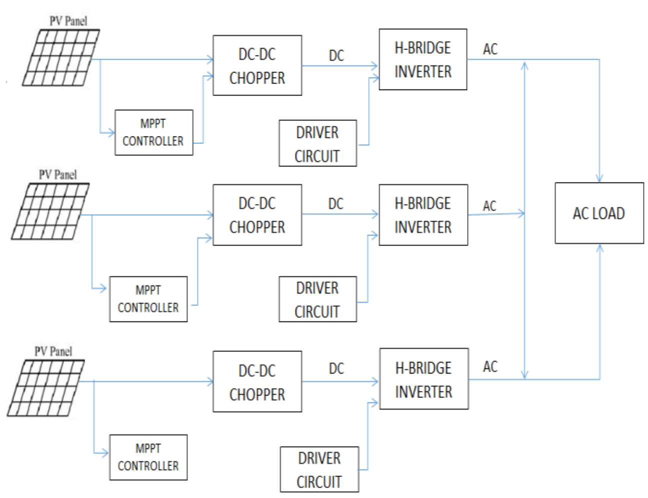

Figure 1 Block Diagram of the Proposed work

Cascaded H-bridge Multilevel Inverter has been implemented in this proposed topology which gives less harmonics content in output voltage and high stability and less complexity in structure.

A. Modified P&O MPPT Technique

The Modified P & O algorithm operates by increasing or decreasing the array terminal voltage, or current, at regular intervals and then comparing the PV output power with that of the previous sample point. The control system adjusts the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. At each perturbation point, the algorithm continues to operate in the same manner. The main advantage of this approach is the simplicity of the technique. Furthermore, previous knowledge of the PV panel characteristics is not required. Also, the perturbation step size must be sufficient so that the controller is not significantly affected by measurement noise, and generates a measurable change in the photovoltaic array output. The algorithm perturbs the maximum power point (MPP) of the PV panel by increasing or decreasing a control parameter by a small step size and measures the PV panel output power before and after the perturbation. If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction. The PV panel is not sufficient to provide the required output. A DC/DC converter is usually preferred to boost up the PV panel voltage to meet the requirement [5]. The output of DC/DC boost converter is dependent on the duty cycle (D), so MPPT is used to calculate the duty cycle to obtain the maximum output voltage. The modified MPPT

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P&O controlled boost converter is interleaved between proposed MLI module and each PV panel. Photovoltaic (PV) systems have a structure containing solar cells (SCs), connection, protection, and storage components and some additional elements depending on load characteristics. The most important element of these systems, the solar cells, also has distinctive features especially on the initial investment cost and the quality and quantity of other elements. Therefore, in the initial installation stage, it is very important to design for operating of SC under the best conditions and effectively. Switching power converters are used, that is called as maximum power point tracker (MPPT) for the solution of this problem. Under these conditions, the MPP of the PV array changes continuously; consequently the PV system's operation point must change to maximize the energy produced [8].

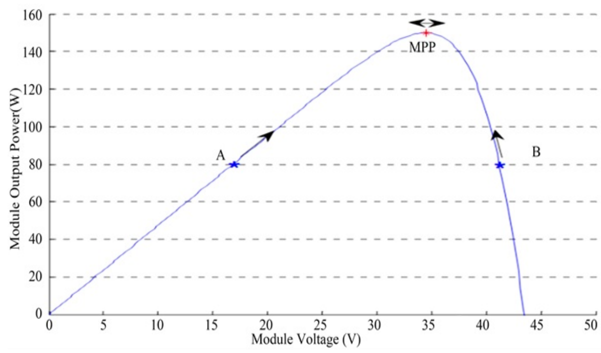

Figure 2 Solar panel characteristics showing MPP and operating points A and B

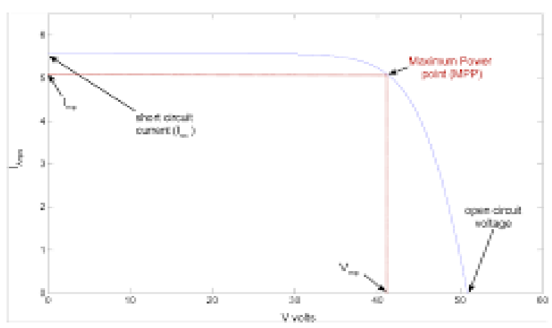

Figure 3 V-I characteristics of a typical PV panel with MPPT control

An MPPT technique is therefore used to maintain the PV array's operating point at its MPP. For this purpose, MPPT adjusts the output power of inverter or DC converter. If the PV output voltage is higher than MPP voltage, then transferred power to the load or network is increased, otherwise, it is decreased.

There are several MPPT method exists in order to maximizing the output power. Different MPPTs are suitable for various applications. Depending on the application, different aspects may be considered important when choosing the PV system. The P & O algorithm operated by the periodically perturbing (increasing or decreasing) the terminal voltage or current and then compare with the output power by the previous perturbation cycle. If the power increases then one continues increasing the voltage or current in the same direction. If power decreases then continue vary the voltage or current in the reverse direction. If the power drained from the array increases, the operating point varies towards the MPP which in turn suits therefore the working voltage in the similar direction. If the power drained from the PV array decreases, the operating point varies away from the MPPT, and thus the direction of the working voltage perturbation has to be overturned.

In this the incremental change in power ΔP is measured. If the ΔP value is positive, the operating voltage is increased to get MPPT if the value of ΔP is negative, the direction of voltage adjustment is reversed and operating point in trying to make it is the closest to MPPT. The most effective method for extracting the solar energy at its maximum power point both positive and negative measurement is P&O algorithm.

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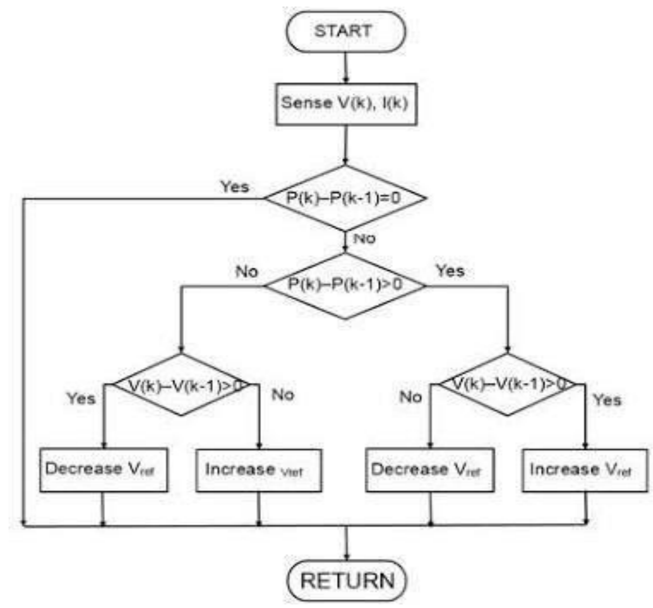

Figure 4 Modified P&O Flow Chart

The P&O algorithm continuously perturbs the operating point of the system causing the PV array terminal voltage to fluctuate around the MPP voltage even if the solar irradiance and the cell temperature are constants. Consequently, similar current and power fluctuations occur. These usually fluctuate between three levels provided that the perturbation frequency is low enough so that the system can reach a steady state before the next perturbation. The effectiveness of the modified P&O algorithm is reflected in the overall outcome.

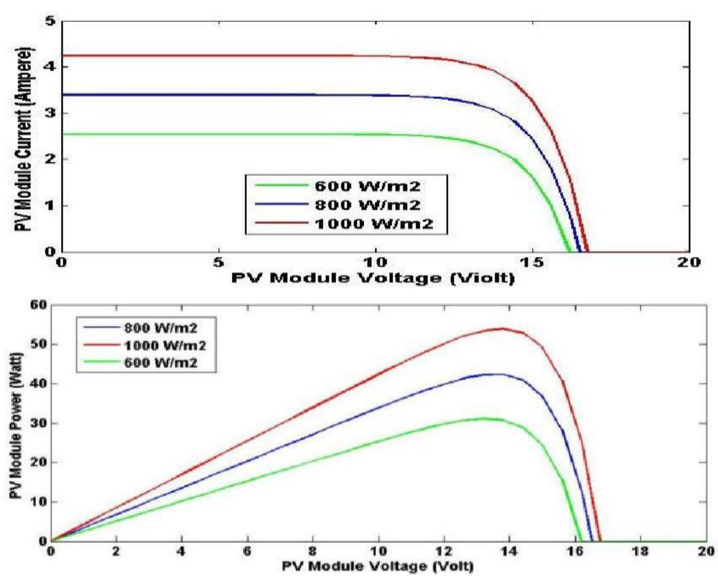

Figure 5 V-I Curve and P-V Curve for Different Solar Irradiance.

B. Proposed Cascaded Multilevel Inverter Topology

Multilevel inverter produces a desired AC voltage waveform from several levels of DC voltages. These DC voltages may be or may not be equal. AC voltage produced from these DC voltages is of stepped waveform. The power quality of the power system is affected by the harmonics generated on the AC side. Multilevel inverter widely replaces the conventional two level three phase Voltage Source Inverter (VSI) by its performance such as lower switching stress (dv/dt) and lower THD on output voltage. The multilevel inverters start from three levels. As the number of levels reach infinity, the output THD approaches zero.

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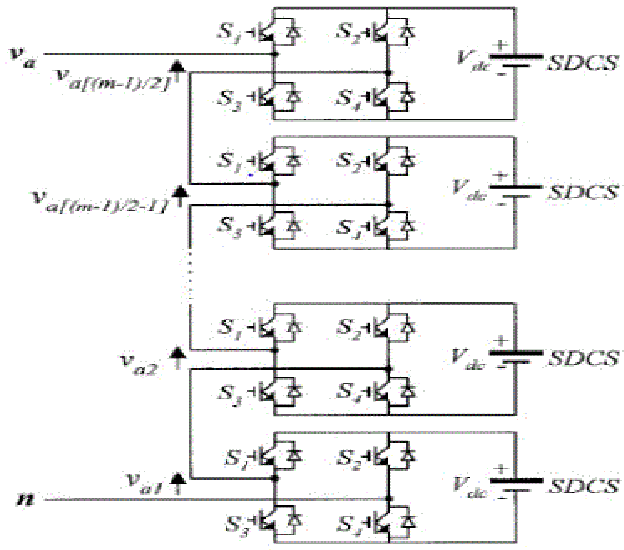

Figure 6 Cascaded H-bridge inverter

The proposed system rules over the existing ones due to the following reasons, multilevel inverters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses. Therefore electromagnetic compatibility problems can be reduced. Multilevel inverters can operate at both fundamental switching frequency and high switching frequency PWM. Introducing multilevel inverters will decrease switching losses occurred in the power device. By comparing with two level inverters, smaller size filter is required for the elimination of harmonics. This reduces the inverter weight, dimension and cost. In H-bridge the number of possible output voltage levels is more than twice the number of DC sources (NL = 2s + 1).

The series of H-bridges makes for modularised layout and packaging. This will make the manufacturing process to be done more quick and cheap. The power quality of the power system is affected by the harmonics generated on the AC side. The power quality of the multilevel inverter is improved by performing the power conversion in small voltage steps. Multilevel inverter widely replaces the conventional two level three phase Voltage Source Inverter (VSI) by its performance such as lower switching stress (dv/dt) and lower THD on output voltage.

The multilevel inverters start from three levels. As the number of levels reach infinity, the output THD approaches zero. A multilevel inverter has several advantages over a conventional two level inverter that uses high switching frequency PWM.

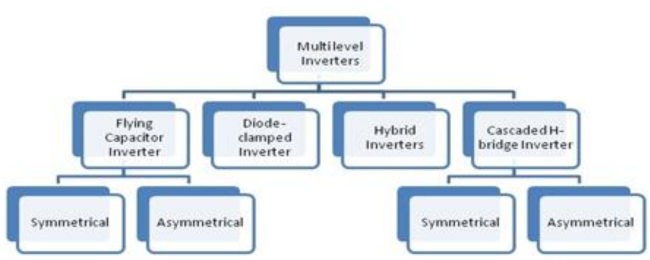

Figure 7 Multilevel Inverter Classification

Each Separate DC Source (SDCS) is connected to a single phase full bridge or H-bridge inverter. A single phase structure of l cascaded inverter is illustrated in Figure. 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. To obtain +Vdc, switches S1 and S4 are turned ON, whereas –Vdc can be obtained by turning ON switches S2 and S3. By turning ON S1 and S2 or S3 and S4, the output voltage of zero is obtained. The AC outputs of different full bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs.

Phase voltage waveform for cascaded H-bridge inverter is shown in Figure 6.5. The number of output phase voltage levels (NL) in a cascaded inverter is defined by

NL = 2s+1 -------------- (1)

Where,

s is the number of separate DC source.

Output phase voltage Van is given in Equation.

Van = Va1 + Va2 + Va3 + Va4 + Va ------------- (2)

By closing the appropriate switches, each H-bridge inverter can produce three different voltages: +Vdc, 0 and -Vdc.

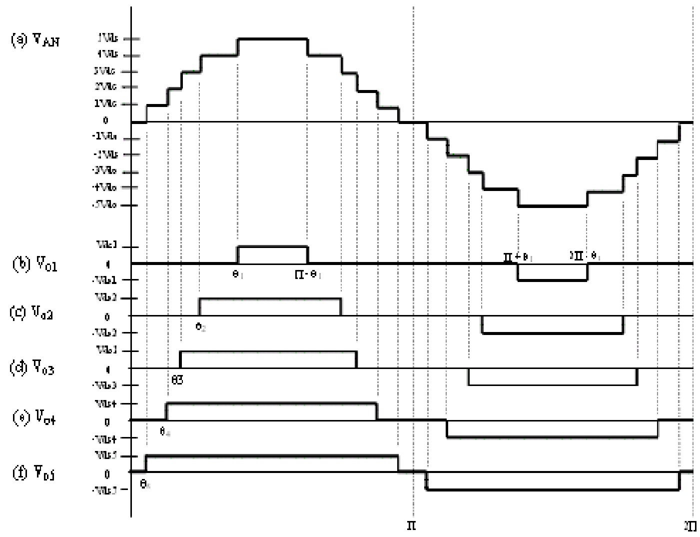

Figure 8 Output phase voltage waveform of cascaded inverter.

It is also possible to modularize circuit layout and packaging because each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitors. The number of switches is reduced using the new topology. A multilevel converter is the one which uses properly connected power semiconductor devices to several lower DC voltage sources to synthesize a near sinusoidal staircase voltage waveform. The small output voltage step results in high quality output voltage, reduction of voltage stresses on power switching devices, lower switching losses and higher efficiency. The adoption of MLIs results in reduction of cost and size of filtering requirements in transformer less PV system.

IV. MODULATION TECHNIQUES

Modulation is the process of switching the power electronic device in a power converter from one state to another. All modulations are aimed at generating a stepped waveform that best approximates an arbitrary reference signal with adjustable amplitude, frequency and phase fundamental component that is usually sinusoidal in steady state. Each topology has different switching configuration to achieve commanded output voltage. Modulation strategies are responsible for synthesizing reference control signals and for keeping all voltage sources balanced.

A. Sinusoidal Pulse Width Modulation

Sinusoidal PWM method is also known as the triangulation sub harmonic, sub oscillation method, Carrier Based Pulse Width Modulation (CB-PWM) is very popular in industrial applications.

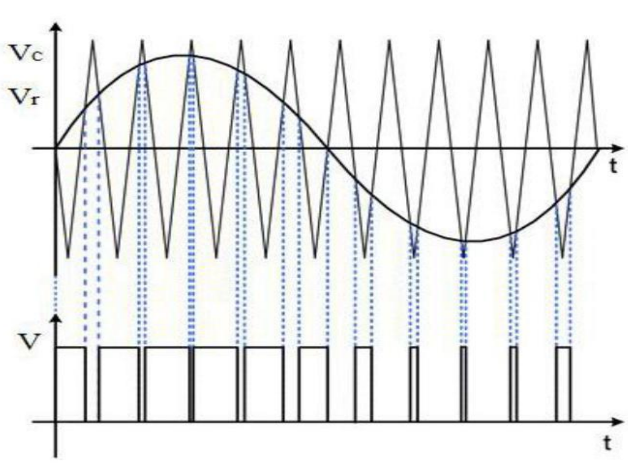

Figure 9 PWM wave output

For realizing SPW M, a high frequency triangular carrier wave is compared with a sinusoidal reference of the desired frequency. The intersection of sinusoidal reference and triangular waves determines the switching instants and commutation of the modulated pulse. Operating with constant frequency of carrier signal concentrates on voltage harmonics around switching frequency (which is of double the carrier frequency) and multiples of switching frequency.

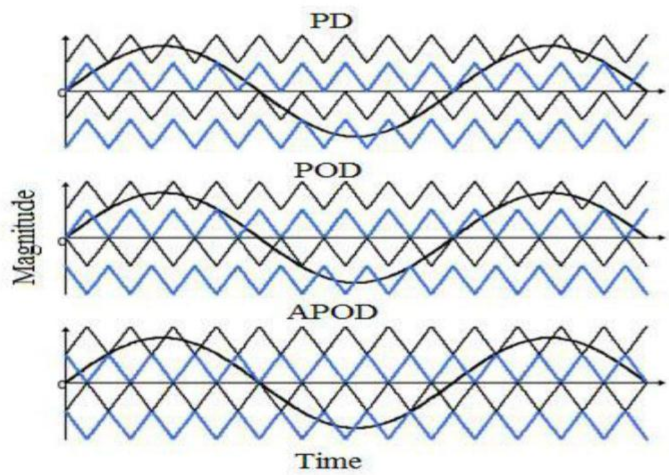

Figure 10 Level shifted PWM

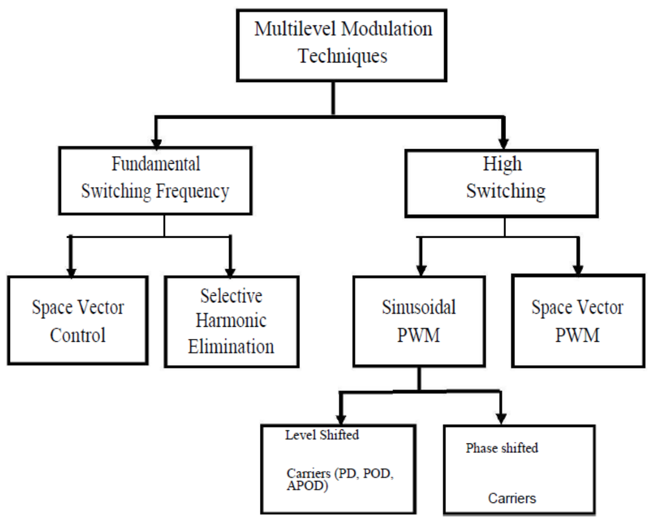

Figure 11 Classification of Modulation Techniques

B. Space Vector PWM

Each multilevel inverter has several switching states which generate different voltage vectors and can be used to modulate the reference. In SVM, the reference signal is generated from its closest signals. Some vectors have redundant switching states, meaning that they can be generated by more than one switching state. This feature is used to balance the capacitor voltages. A conceptually different control method for multilevel converters, based on the space-vector theory, has been introduced, which is called space vector control. The SVM technique can be easily extended to all multilevel inverters. Therefore it can be used for diode-clamped, capacitor-clamped or cascaded inverters. The SVM generate the output voltage as the weighted mean of the three vectors adjacent to the reference in the d-q plane.

The switches must be controlled so that at no time are both switches in the same leg turned on or else the DC supply would be shorted. This requirement may be met by the complementary operation of the switches within a leg. This leads to eight possible switching vectors for the inverter, V0 through V7 with six active switching vectors and two zero vectors. To implement space vector modulation, a reference signal Vref is sampled with a frequency fs (Ts = 1/fs). The reference signal may be generated from three separate phase references using the αβγ transform. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses. Compared to SPWM the Total harmonic distortion (THD) and lower order harmonics (LOH) contents are decreased in SVPWM. Reference voltage is sampled at regular interval T. Within sampling period, vref is synthesized using adjacent vectors and zero vectors. Zero voltage is applied for the rest of the sampling period.

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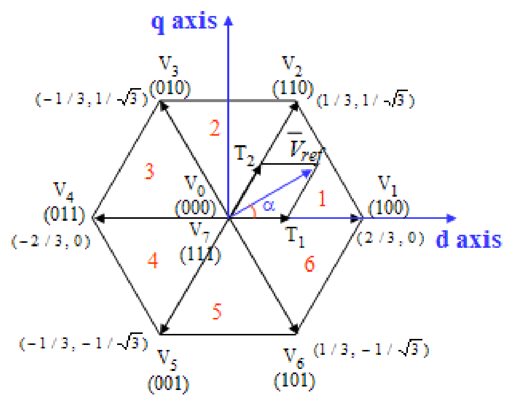

Figure 12 Basic switching vectors and sectors.

V. SIMULATION RESULTS

A. PV Module

The PV panel input being set as a ramp signal, two series PV panel being added up using a summer block and the voltage and current value is been measured and the input value has been converted as it's a numerical value in to an electrical quantity. This measured voltage and current value is then send to the MPPT block where the voltage and current is checked and the required orientation is been carried out in accordance with that. The output from the solar panel is of 24 volts and a short circuit current of 3.3 amps. The current and voltage at Pmax are 3amps and 24 volts respectively. The voltage and current output from the solar array is been sent to the MPPT block for comparing it with the preset. According to the perturbation the change in duty cycle of the DC chopper is triggered. The algorithm implemented here is perturb and observation as it is less complex and have high speed of response.

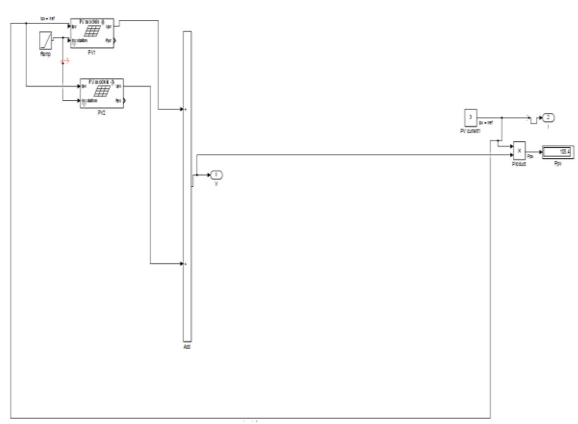

Figure 13 PV Block Simulation Model

B. MPPT Module

The output voltage and current of pv panel is been made as the input to the MPPT block, the algorithm used here is of perturb and observation method. Here the pre input voltage and current is required to P&O operation. So a delay is been used to perform this operation. The algorithm compares the preset power and the input power which been obtained from the PV block output. The preset power is been checked and the comparison checks for the need of incremental and decremental of the power and in accordance with that value the chopper being triggered, the gate circuit functions in accordance with this value. The output from the block been input to the next block that's the chopper block.

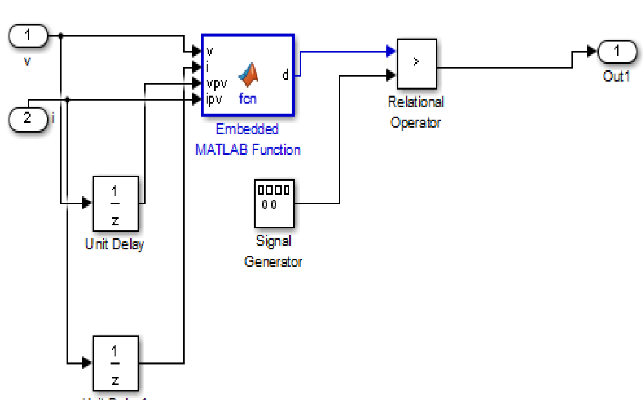

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Figure 5.2.1 P&O Based MPPT

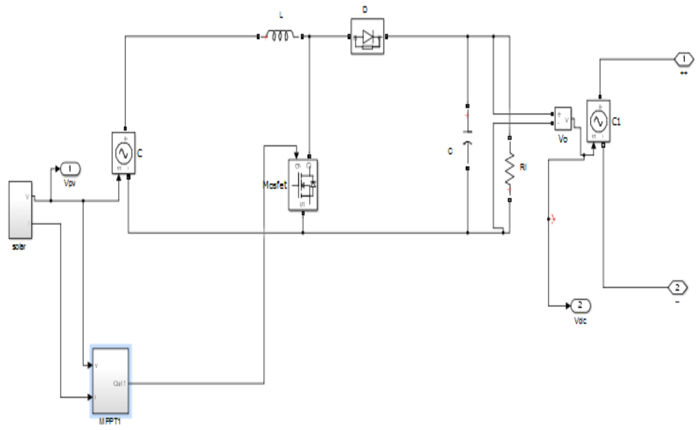

Figure 14 PV Module Design

So Solar block consists of PV module and MPPT block, the output from the solar block is the reference pulse for triggering the DC chopper circuit. The subsystem PV output is connected to the input of MPPT algorithm where the voltage and current is been obtained as input. The preset power value is been compared with the observed and the necessary triggering pulse is been generated according to the comparison value.

Inverter Triggering Circuit

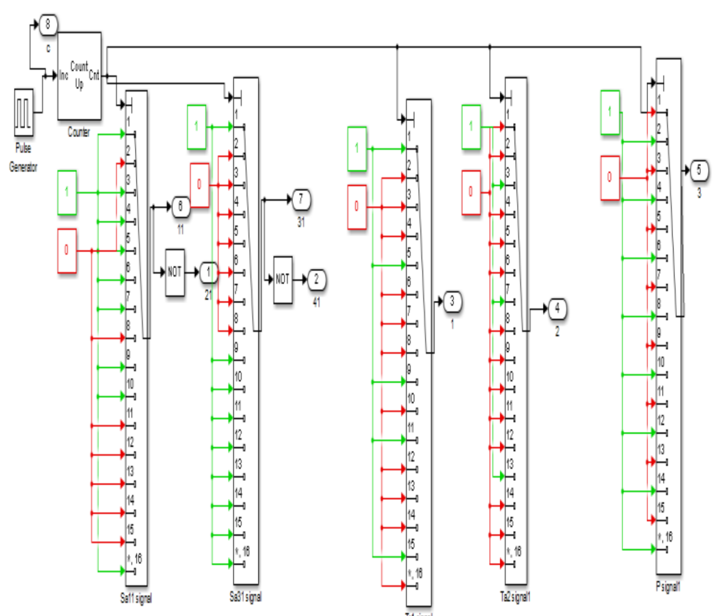

Figure 15 Inverter triggering block (SVM)

The logic operation of switching is carried out using space vector theory and in accordance with the switching table available the triggering block is been made.

C. Overall Simulation Model

The input source is solar which collected using PV arrangement was given to the MPPT block. Where the voltage and current is been measured and necessary switching is produced for DC chopper. The output voltage is been measured using a sensing element and is fed to the switching sequence arrangement where SVM technique is been followed.

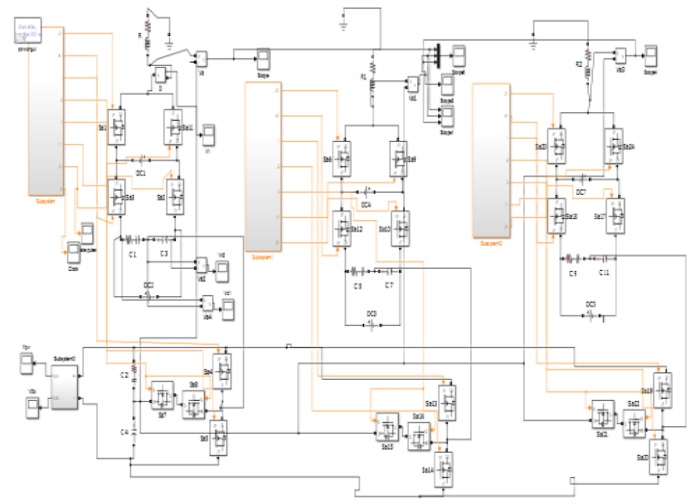

Figure 16 Overall simulation block

D. Simulation Results

The PV input is of 12V DC, where it's voltage and current sent to the MPPT block. The simulation output is observed as given in figure.

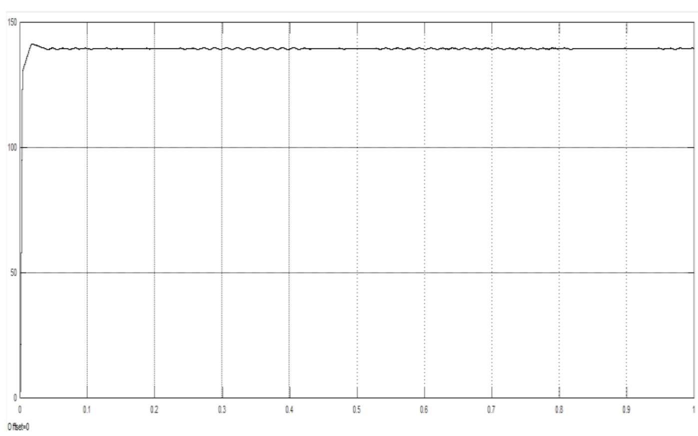

Figure 17 PV dc voltage output

The inverter output voltage is observed of peak value 210volts AC. The output waveform is of nine level as the number of levels increases the THD value get reduced. Thus the system will be less prone to harmonics.

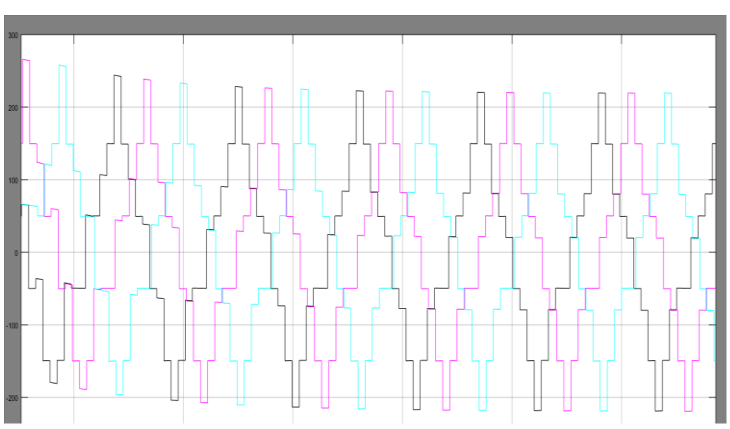

Figure 18 Vabc voltage of three phases

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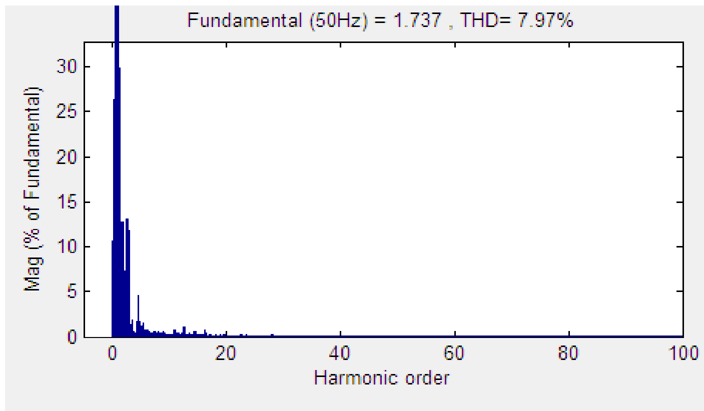

Figure 19 THD measurement

E. Experimental Setup

The Complete hardware setup is performed in the laboratory premises and the output was recorded.

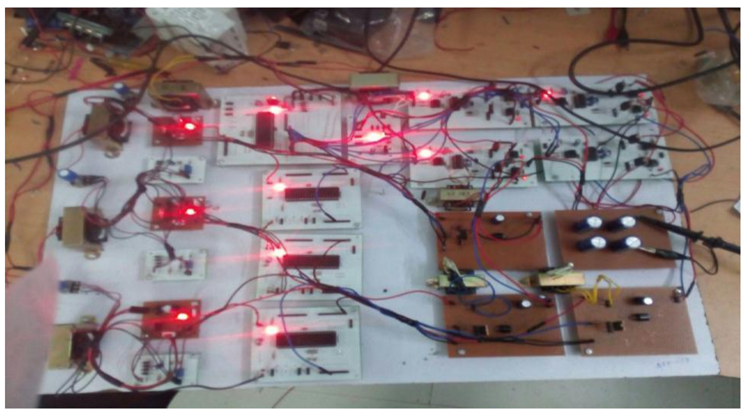

Figure 20 Hardware Setup

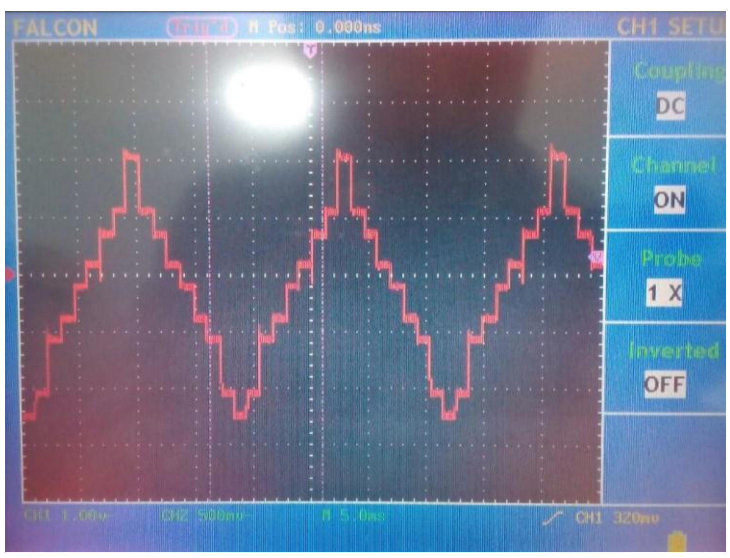

Figure 21 Observed Output (CRO)

VI. CONCLUSION

The proposed topology is suitable for micro grid connection. The comparative study of PWM and SVPWM is carried out for the cascaded multilevel converter topology. Output waveforms are compared and the simulation results shows the THD value of proposed system is 7.42%, which is very low. It's clear from that the proposed system has very low harmonic content. The increased number of level suppresses the harmonics. The comparison of other MPPT techniques with P&O is done and the advantages of P&O over other is observed. The validation is observed from the simulation results. The symmetrical and asymmetrical operation are checked and the performance of the multilevel inverter is observed during steady state and dynamic conditions.

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