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Nine Level Inverter with Boost Converter from Renewable Energy Source

Maruthu Pandiyan.R[*], Prabakaran. B[**], C. Vivekanandan[***]
Student, ME Power Electronics and Drives, Sri Shakthi Institute of Engineering and Tech, Coimbatore-62, India.
Assistant Professor-EEE, Sri Shakthi Institute Of Engineering and Technology Coimbatore-62, india
Professor-EEE, SNS college of Engineering Coimbatore

Abstract –
A new single phase nine level multilevel inverter is proposed. The input to the proposed nine level multilevel inverter is obtained from solar panel . The solar energy obtained from the solar panel is not constant and it varies with times. In order to maintain the constant voltage obtained from the solar panel the boost converter is used to maintain the constant output voltage using MPPT (Perturb and observe algorithm) algorithm. Then the buck boost converter output voltage is stored in the battery bank. Finally the battery energy is connected to the 9 level inverter circuits. The harmonics in the inverter is eliminated by using the fuzzy logic controller. The gate pulse for the multilevel inverter is given by the fuzzy logic controller which in turn reduces the harmonics in the inverter. Then the inverter output is connected to the grid are some application.
Keyword--- multilevel inverter, MPPT (Perturb and observe algorithm), fuzzy logic controller, Total Harmonic Distortion (THD).

I. INTRODUCTION

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. The definition of renewable energy includes any type of energy generated from natural resources that is infinite or constantly renewed. Examples of renewable energy include solar, wind, and hydro power. Renewable energy, due to its free availability and its clean and renewable character, ranks as the most promising renewable energy resources like Solar energy, Wind energy that could play a key role in solving the worldwide energy crisis. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of effective maintenance and pollution free. Solar electric energy demand has grown consistently by 20% to 25% per annum over the past 20 years, which is mainly due to its costs and prices. This decline has been driven by the following factors:
1)An increasing efficiency of solar cells,
2)Manufacturing technology improvements,
3)Economies of scale.

The focus of the Engineers is to make use of abundantly available PV energy and so to design and control an inverter suitable for photo voltaic applications. Power electronic circuits with pulse width modulation (PWM) are mostly used in energy conversion systems to achieve closed loop control. But even updated pulse width modulation (PWM) techniques; do not produce perfect waveforms, which strongly depend on the semiconductors switching frequency. Also, it is well known that distorted voltages and currents waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the load power but also the associated controller.

In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three level PWM Inverters. They offer improved output waveforms, smaller filter size and lower EMI, lower Total Harmonic Distortion (THD).
The three common topologies for multilevel inverters are as follows:

1) Diode clamped (neutral clamped),
2) Capacitor clamped (flying capacitors),
3) Cascaded H-bridge inverter.

The cascaded multilevel control method is very easy when compared to other multilevel inverter because it doesn't require any clamping diode and flying capacitor. The diode clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor) requiring only one dc source and the cascaded h-bridge inverter requiring separate dc sources. The latter characteristic, which is a drawback when a single dc source is available, becomes a very attractive feature in the case of PV systems, because solar cells can be assembled in a number of separate generators. In this way, they satisfy the requirements of the CHB-MLI, obtaining additional advantages such as a possible elimination of the dc/dc buck booster (needed in order to adapt voltage levels), a significant reduction of the power drops caused by sun darkening (usually, it influences only a fraction of the overall PV field), and therefore a potential increase of efficiency and reliability.

Performance of the multilevel inverter (such as THD) is mainly decided by the modulation strategies. For the cascaded multilevel inverter there are several well known pulse width modulation strategies such as space vector pwm, sinusoidal pwm, selective harmonics elimination and multicarrier pwm. Compared to the conventional method, the proposed method is subjected to a new modulation scheme adopting the sinusoidal pulse width modulation technique which reduces the total harmonic distortion.

II .OPERATING PRINCIPLE:

The proposed concept consists of the single phase PV cell are connected to a H-Bridge Multilevel Inverter using a boost converter. Maximum Power Point Tracking (MPPT) is implemented in solar array power system with direct control method. The Perturb and Observe algorithm is used to track the Maximum Power Point tracking, as it performs better control under rapidly changing atmospheric condition. Boost converter can step up the voltage without using a transformer. In multilevel inverter use of single dc sources with the 16 switches for conventional H bridge inverter to get required nine level output voltage and to reduce the harmonics. The main disadvantage of conventional H bridge inverter is input voltage is fixed to over this problem, in the proposed prototype boost converter is used to regulate and to obtain the desired input voltage and further the DC source is replaced by a renewable resource such as solar panels to get desired DC voltage to grid connected system. In this paper there will be inputs one is from PV array. 223V is taken from PV cell and PV array and then they are boosted to a voltage from 350V respectively by using boost converter. Finally a nine -level output is observed by giving the single supply voltages to the multilevel inverter.

A. MODELLING OF SOLAR CELL

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modelled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell shown in the figure 1. Two diode models are also available but only single diode model is considered here.

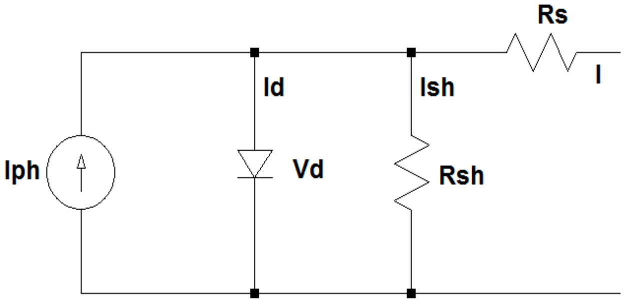

Fig.1 Circuit model of PV solar cell

The equation (2)that describe I-V characteristics of the solar cell based on simple equivalent circuit shown in Fig. 1, equations given below.

$$I_D = I_O\,[e^{\frac{q(V+IRs)}{KT}} - 1] \qquad (1)$$

$$I = I_L - I_O\,[e^{\frac{q(V+IRs)}{KT}} - 1] - \frac{V+IRs}{Rsh} \qquad (2)$$

Where:
I- is the cell current (A).
q-is the charge of electron = 1.6x10-19coulmbs
K -is the Boltzman constant (j/K).
T -is the cell temperature (K).
I_L- is the light generated current (A).
I_O- is the diode saturation current.
Rs ,Rsh-are cell series and shunt resistance (ohms).
V-is the cell output voltage (V)

B.PV Characteristics

Current Vs Voltage Characteristics: Equation (1) was used in computer simulation to obtain the output characteristics of a solar cell, as shown in the Fig.2

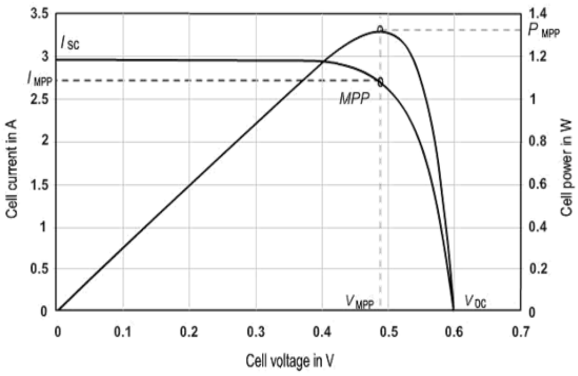

Fig.2 P-V,I-V curve of a solar cell

B.EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value shown in the fig 4. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated.

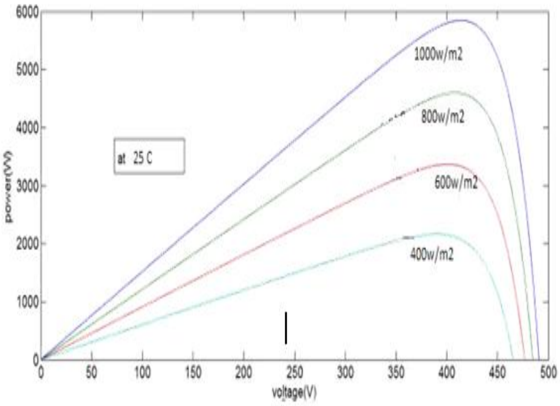

Fig.4 Variation of P-V curve with solar irradiation

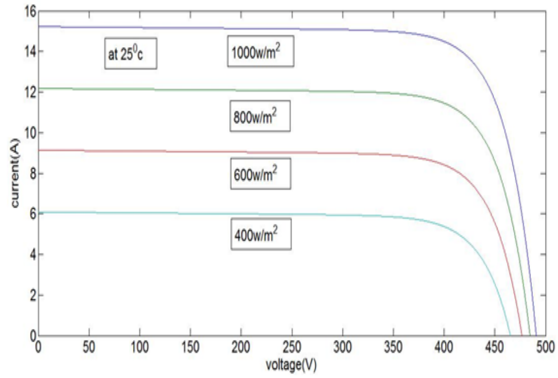

Fig.5 Variation of I-V curve with solar irradiation

C.EFFECT OF VARIATION OF TEMPERATURE

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value shown in the fig.6. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced.

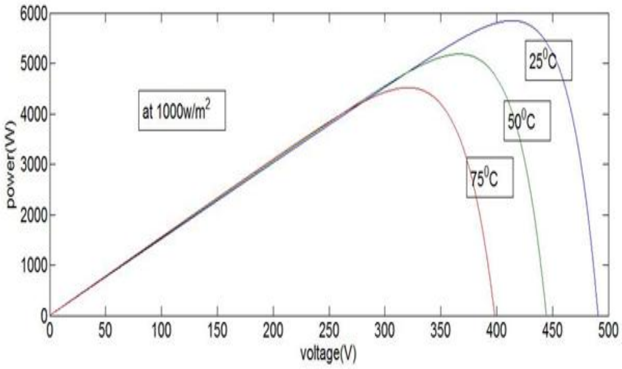

Fig.6 Variation of P-V curve with temperature

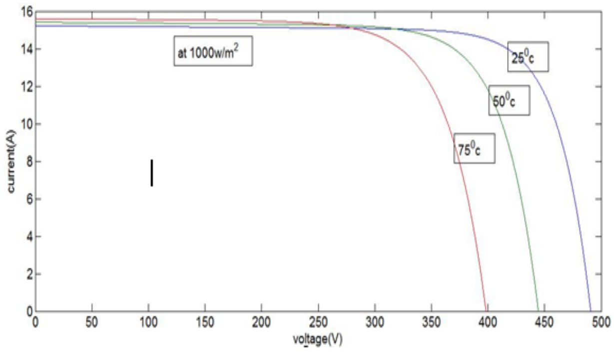

Fig.7 Variation of I-V with temperature

D.BOOST CONVERTER

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch the boost converter is shown in the fig 8. These in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

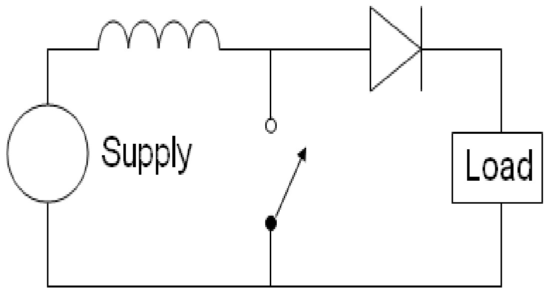

Fig.8 Boost converter

E. MPPT Algorithm Method:

Tracking the maximum power point of a photovoltaic array is usually an essential part of PV cell. As such many MPP tracking methods have been developed and implemented. The problem considered by MPPT techniques is to automatically find the maximum power output P_{Mpp} under a given temperature and irradiance

F. The MPPT methods are:
Perturb and Observe (P&O) method
This method is the most common. In this method very less number of sensors are utilized .The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples dP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until dP/dV is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP).

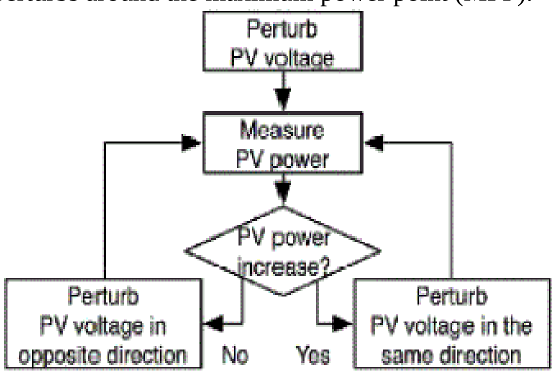

Fig.9 Flow chart of perturb & observe

III.MULTILEVEL INVERTER

The concept of multilevel converters has been introduced since 1975. The period multilevel originated with the three-level converter and subsequently, some multilevel converter topologies have been developed. The concept of a multilevel converter is to achieve higher power in which a series of power semiconductor switches with several lower voltage dc sources are arranged to perform the power conversion Capacitors, batteries and renewable energy sources can be used as the multiple DC voltage sources. A multilevel converter has several advantages over conventional two-level converter that uses high switching frequency Pulse Width Modulation (PWM)

The input source PV and wind generator is used to obtain maximum power point tracking from the solar panel and wind generator generate the maximum power give the charging battery fed at cascade multilevel inverter. The output voltage waveform of a multilevel inverter is composed of the number of levels typically obtained from eleven levels. As the number of levels reach infinity, the output Total Harmonic Distortion (THD) approaches zero. Three different major multilevel converter structures have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. The term multilevel converter is utilized to refer to a power electronic circuit that could operate in an inverter or rectifier mode. Multilevel converters not only can generate the output voltages with very low distortion, but also can decrease the dv/dt stresses.

Thus Electro Magnetic Compatibility (EMC) problems can be reduced. Multilevel inverters are synthesizing a large number of levels have lot of merits such as improved output waveform, a smaller filter size, lower Electro Magnetic Interference (EMI), and reduced harmonics. There are many control techniques to reduce harmonics in output voltage waveforms. Normally Pulse Width Modulation (PWM) is widely employed to control output of static power inverters. The reason for using PWM is that they provide voltage and/or current wave shaping customized to the specific needs of the application under consideration. In this work, maximum energy is obtained from the solar cell and wind generator which is then given to a multilevel inverter using PWM technique.

A .Cascade H-Bridge Multilevel Inverter:

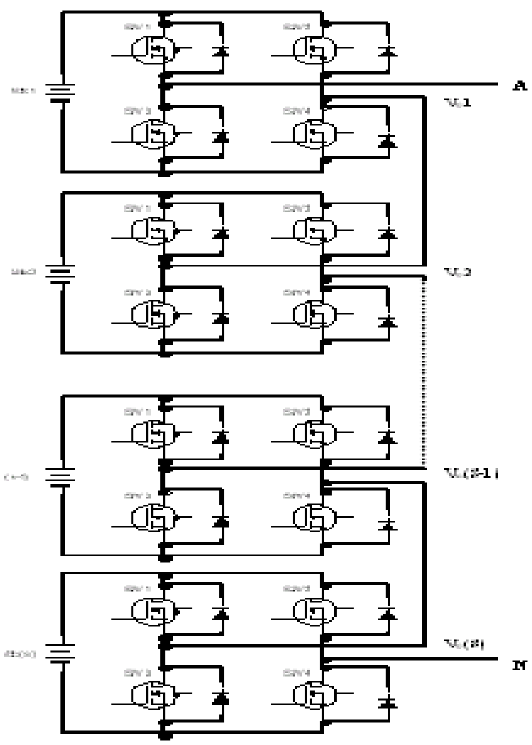

Fig.10 Nine Level cascaded multilevel inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig.10. 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, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the fours switchesS_1,S_2,S_3,andSsSS_4.

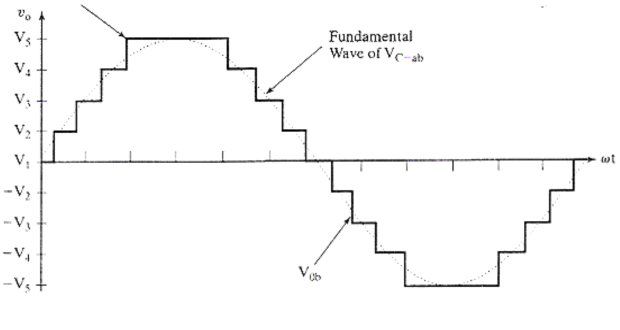

Fig.11 Nine Level cascaded multilevel inverter output voltage waveforms

To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_1. By turning on S_1, S_2, S_3, and S_4, 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 single dc sources .In the 9-level cascaded multilevel inverter with single DC sources are obtained. The DC sources feeding the multilevel inverter are considered to be varying in time.

IV. SIMULATION MODEL

A. Simulation Model of PV System:

The solar cell was modeled in the single diode format. This consists of a 0.1 ohm series resistance and an 8 ohm parallel resistance shown in the fig 12. This was modeled using the Sim Power System blocks in the MATLAB library. The Simulink model is as shown.

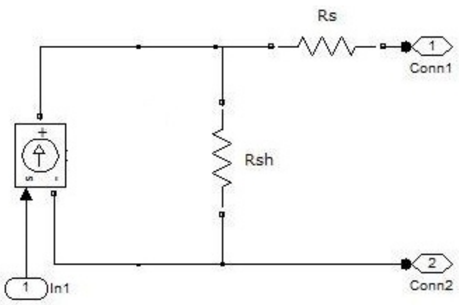

Fig.12 single Solar cell

The simplest model of a PV cell is shown in simulation model Fig.13 Below that consists of an ideal current source in parallel with an ideal diode. The current source represents the generated by photons, and its output is constant under constant temperature and constant incident radiation of light.

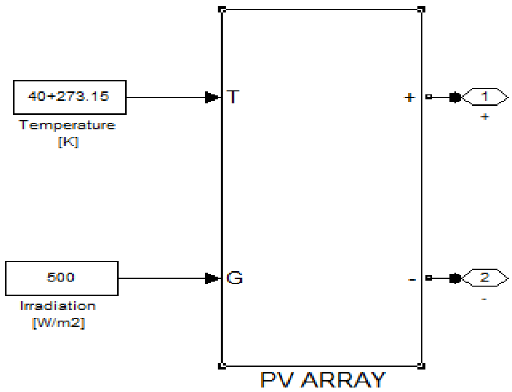

Fig.13 Simulation model of PV cell

B. Output Voltage of the PV cell

There are two key parameters frequently used to characterize a PV cell shorting together the terminals of the cell, the photon generated current will flow out of the cell as a short-circuit current(Isc) therefore, Iph=Isc). When around is no connection to the PV cell (open circuit) the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage(V) It is seen that the temperature changes affect mainly the PV output current .The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level. The output of the PV is shown in Fig.9. The PV output of 223V is obtained by adjusting the values of temperature. The amount of power produced by the PV system depend on the amount of PV radiation the power output can be optimized by choosing a correct system configuration corresponding to a given buck boost converter.

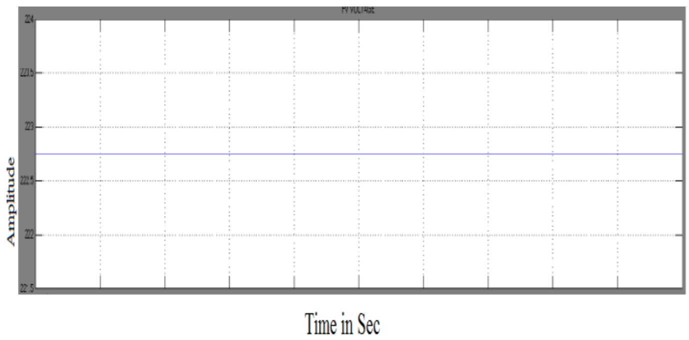

Fig.14 Output Voltage Waveform of a PV Panel

C .Simulation Model of MPPT DC/DC Converter:

The simulation diagram of the MPPT DC/DC converter is shown in the Fig.15. In case of MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, thus the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. The perturb and observe algorithm is used to track the MPPT, as it perform better control under rapidly changing atmospheric condition. So perturb and observe method is used in this proposed method.

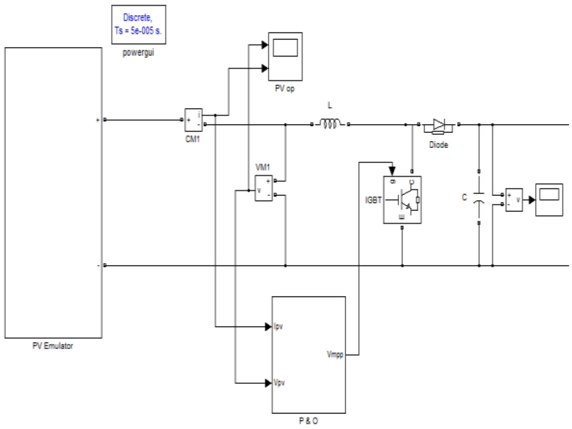

Fig.15 Simulation Model of MPPT DC/DC Converter

The output of the MPPT DC/DC converter is shown in Fig.16. MPPT is used for solar installation system. The output voltage varies with the input voltage. And this MPPT good output regulation. This MPPT is capable of improving the voltage level from 350 VDC to the required level.

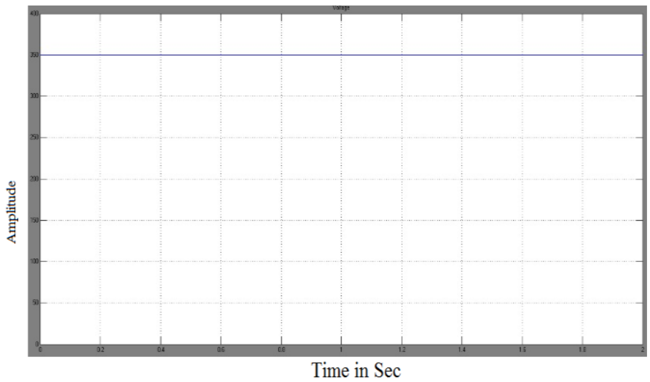

Fig.16 Output Voltage Waveform of MPPT DC/DC Converter

D. Simulation Model of 9-Level Cascaded H-Bridge Multilevel Inverter:

The nine - level multilevel inverter has been developed by using MAT LAB is shown in Fig.17 To operate cascaded multilevel inverter using a solar source. Considering a cascaded multilevel inverter with four H-bridges and the nine level stepped output voltage is obtained. Simulation model of nine level cascade multilevel inverter modulation scheme are pulse width modulation technique is obtained. It consists of fuzzy logic used to determine the shape of the output are obtained.

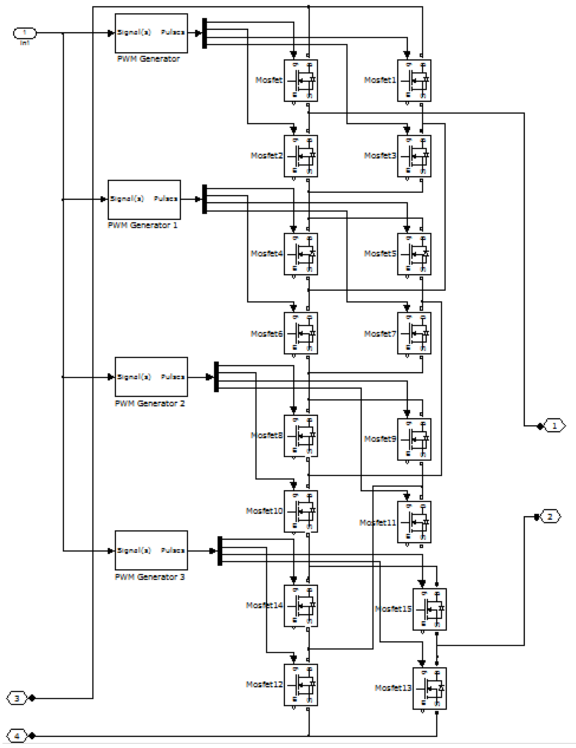

Fig..17 Simulation Model of 9-Level Cascaded H-Bridge Multilevel Inverter

The Single Phase n -Cascaded H-Bridge Inverter for PV applications, *k* dc generators and *k* cascaded H-bridges arranged in a single phase multilevel inverter topology. Each dc generator consists of PV cell arrays connected in series and in parallel, thus obtaining the desired output voltage and current. H bridges basically consist of four metal oxide semiconductor field effect transistors embedding an anti parallel diode and a driver circuit. The number *k* of H-bridges depends on the number n = 2*k*+1 of desired levels, which has to be chosen by taking into account both the available PV fields and design considerations. Higher the number of levels the better the sinusoidal output waveforms. However, the number of level increases the complexity and the cost of the system while reducing its switching frequency in comparison with two level converters.

Since low voltage transistors (typically MOSFETs) present significantly higher switching frequency than high power transistors (typically IGBT), MLIs can operate at significantly higher switching frequencies than two level converters. This allows the use of smaller low pass filters. Each H-bridge can be driven by a square waveform with a suitable duty cycle or a PWM pattern, thus resulting in a staircase without or with PWM. In the considered single phase 230V system, the cells are arranged into five distinct arrays, thus resulting in an eleven level inverter, which can be considered a reasonable trade-off among complexity, performance, and cost.

V.CASCADED H-BRIDGE MULTILEVEL CONTROLLER

This paper shows the potential of a Single Phase Cascaded H-bridge nine level inverter governed by the fuzzy logic controller using photovoltaic power source.

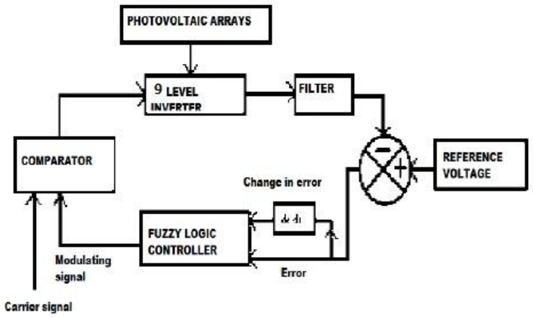

Fig.18 Block diagram of fuzzy logic controller

Fig.18 shows the block diagram of fuzzy logic controller consists of one PV array, filter and the load. This function is substituted by a reference voltage generator imposing amplitude, frequency and phase, thus implementing a *PV* control strategy. Feedback signals are included in the FLC, whose outputs applied to the MLI "Driver" block which consists of a conditional statement functions producing the discrete signals for gating the inverter MOSFETs. The input variables to the FLC are as follows:

1) *Vn* , i.e., the inverter output voltage measured after a low-pass filter

2) The difference between the actual and reference signals is *AVdiff* = Vout –Vref

Inverter output voltage measured after the load terminals. This choice improves the quality of the control without introducing delays. Filter bandwidth is chosen around 1kHz with resistive load. The output of the controller is applied to the inverter gate drivers. The FLC output may assume nine different states .The First step during the FLC design was the creation of a knowledge base, i.e., fuzzy rules, expressed in terms of statements, conditions, and actions. Starting from the condition "TRUE" (i.e., the situation is verified), a set of rules was defined for the error conditions were defined accordingly, obtaining variable reactions. The number and type of membership functions (MFs) represent a key point for the controller. Their shape depends on the input data distribution and can influence both the tracking accuracy and the execution time.

Figs. 19 and 20 show the membership functions chosen for the two input parameters. The labels "NB," "NS," "ZE," "PS," and "PB" used for AV diff stand as follows:

"NB"=negative−big,"NS"=negative−small, "ZE" = zero, and so forth. The fuzzy sets for both the input and output variables were nine, as the number of levels ,ZE,I+,II+,III+,IV+,V+. A Mamdani-based system architecture was realized; Max − Min, composition technique, and the centre-of-gravity method were used in the inference engine and in the defuzzification process, respectively. In this paper, the number and type of the control rules were decided according to a sensitivity analysis made by varying the number and type of rules.

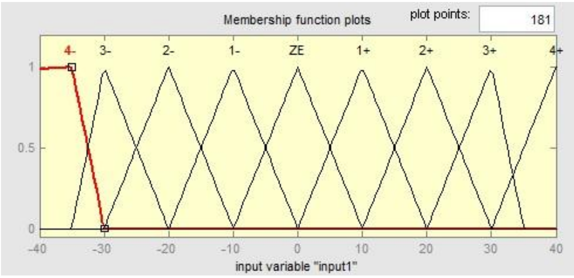

Fig.19 Membership functions of parameter *AV*diff

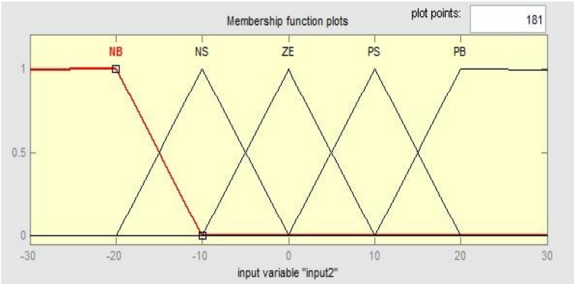

Fig.20 Membership functions of parameter *Vn*.

INFERENCE RULES

V_n	AV_{diff}				
	NB	NS	ZE	PS	PB
IV^+	IV^+	IV^+	IV^+	III^+	III^+
III^+	IV^+	IV^+	III^+	II^+	II^+
II^+	III^+	III^+	II^+	I^+	I^+
I^+	II^+	II^+	I^+	ZE	ZE
ZE	I^+	I^+	ZE	I^-	I^-
I^-	ZE	ZE	I^-	II^-	II^-
II^-	I^-	I^-	II^-	III^-	III^-
III^-	II^-	II^-	III^-	IV^-	IV^-
IV^-	III^-	III^-	IV^-	IV^-	IV^-

TABLE: 1

The following logic was adopted for designing the inference rules:

1) If AVdiff is equal to ZE, the current state is correct, and the inverter conserves its current state.

2) Consider a generic state ,if AV diff is positive Vout > Vref, then the inverter state should be reduced; if AVdiff is negative Vout < Vref, the inverter state should be increased.

A.SINUSIODAL PULSE WIDTH MODULATION TECHNIQUE:

PWM technique is extensively used for eliminating harmful low-order harmonics in inverters. In PWM control, the inverter switches are turned ON and OFF several times during a half cycle and output voltage is controlled by varying the pulse width. SPWM techniques are characterized by constant amplitude pulses with different duty cycle for each period. The width of this pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. Sinusoidal pulse width modulation is the most commonly used method in motor control and inverter application .In order to verify the ability of the proposed multilevel inverter topology to synthesize an output voltage with a desired amplitude and better harmonic spectrum, SPWM technique is applied to determine the required switching angles. It has been proved that in order to control the fundamental output voltage and eliminate „n" harmonics, „n+1" equations are needed. Ideally, for a given fundamental voltage V1, it is required to determine the switching angles so that output voltage Vo(wt)=V1sin(wt) and a specific higher harmonics of Vn(nwt) are equal to zero. According to the three phase theory in balanced three phase system third order harmonic is cancelled. One approach to solve the set of nonlinear transcendental equations is to use an iterative method such as the Newton-Raphson method .In contrast to iterative methods, the approach here is based on solving polynomial equations using the theory of resultants which produces all possible solutions. The transcendental equations characterizing the harmonic content can be converted into polynomial equations. Then the resultant method is employed to find the solutions when they exist. These sets of solutions have to be examined for its corresponding total harmonic distortion (THD) in order to select the set which generate the lowest harmonic distortion.

VI.SIMULATION RESULTS:

In this paper, the simulation model is developed in MATLAB/Simulink. Figs. 22 & 23 show the closed loop configuration of nine -level inverter. Filtered output voltage obtained from the eleven-level inverter through RC low pass filter. Output voltage feedback is given to the summer to compare the output voltage with reference voltage and the error voltage level obtained from the output of the summer for further operation. There are two inputs to the fuzzy logic controller one is error and derivative of the error , derivative of the error obtained from the previous sample value of the error voltage signal. The role of fuzzy logic controller is to convert the given crisp inputs to fuzzy sets using fuzzification, and then process the fuzzy sets as per the fuzzy rules and evaluation mechanism using fuzzy inference system. Output of the inference system is fuzzy sets, which is again converted to crisp output through defuzzification process. This modulator output compared with triangular wave to produce pulses to the switches of nine-level inverter.

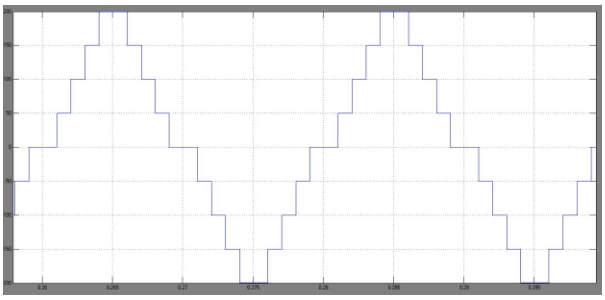

Fig.21 Output waveform of Nine Level Inverter without filter

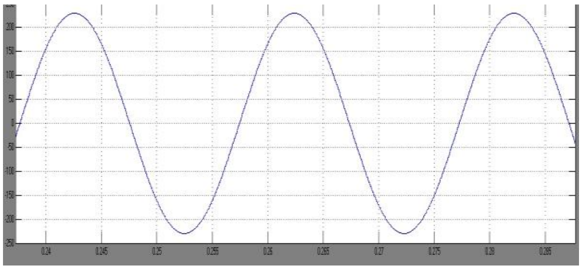

Fig.22 Output waveform of Nine Level Inverter with filter

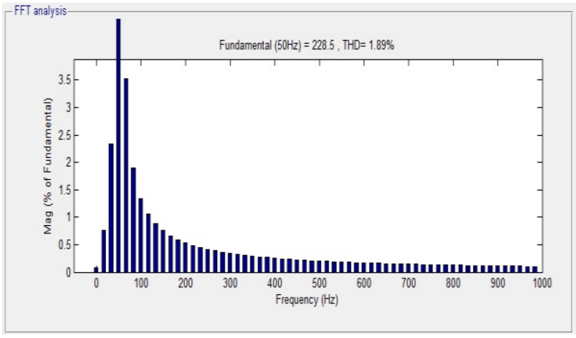

Fig.23 FFT analysis for nine level inverter

The nine–level output voltage of the inverter before filter and after the RC low pass filter.

Based on the harmonic analysis, total harmonic distortion is less in the filtered output of the nine level inverter. The FFT analysis shown fig 19 ,it is observed that the total harmonic distortion is 1.89%

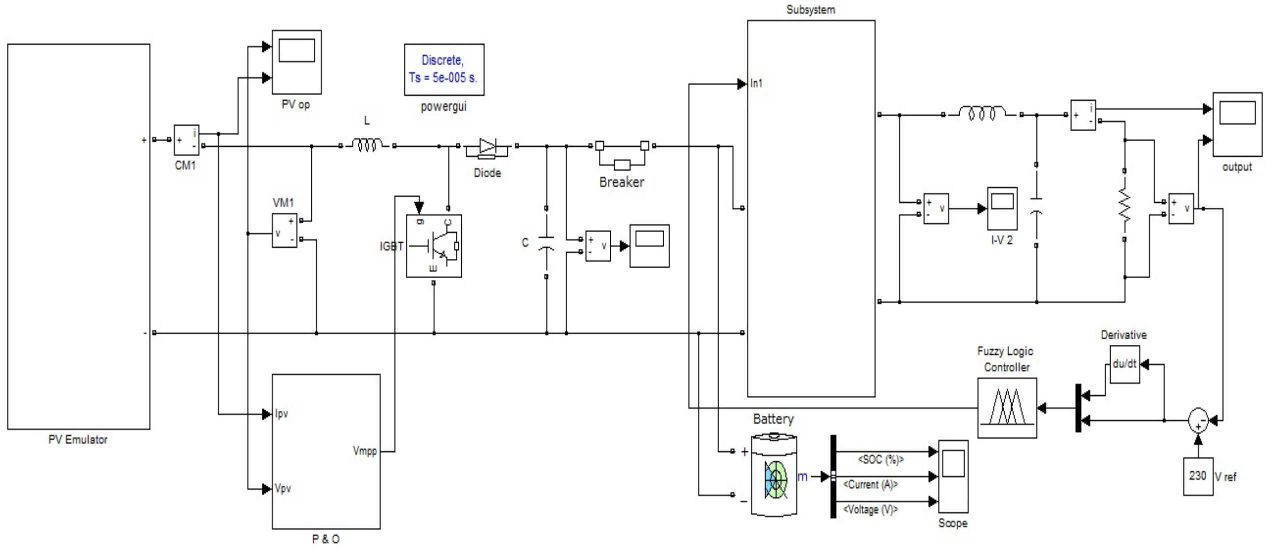

Fig.24 over all Simulation

VII.CONCLUSION

In the paper ,a new single phase cascaded H-Bridge Nine –level inverter with boost converter and fuzzy logic controller using solar power source was simulated using MATLAB/SIMULINK and sinusoidal pulse width modulation control technique was used to control this inverter. By tuning the fuzzy logic controller required RMS voltage with less harmonic distortion obtained in closed loop configuration hence we could achieve the improved efficiency of the system and better performance over cascaded H-bridge seven level inverter.

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