Solar Application for Grid Tied 3-Level Diode Clamp Inverter Using Sinusoidal Pulse with Modulation

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***Abstract*—The Renewable energy sources are nowadays in demand and very well-liked. Here, Solar energy which gives DC output and to convert it into AC to fed the AC LOADs is a big challenge. Solar energy DC output can be converted in to AC by using DC to AC converters. 3-level diode clamped multilevel inverter is used to convert DC into the AC and the PV system which is used as a renewable energy source is obtained DC by means of MPPT using P&O technique (Maximum power point tracking-Perturb & Observe method). Obtained DC is fed to multilevel inverter and the inverter switches made turn ON and OFF frequently by using Sinusoidal PWM. The output AC obtained from multilevel inverter than fed to LOAD and the system is interfaced with GRID by generating new modulation index for SPWM technique. After that %THD (total harmonic distortion) analysis of the system is done. The entire system modelling and simulation is done by using MATLAB/Simulink.**

***Index*Terms—MATLAB, Pulse Width Modulation (PWM), Three Level Diode Clamp Inverter,**

I. INTRODUCTION

Demand of renewable energy sources like solar energy, wind energy and fuel cell is progressively greater than before because of the expensiveness and limited availability of conventional energy sources like coal, gas and oil. Recent year energy policies and global warming have become a main topic on the international agenda. Today developed countries are trying to mitigate the greenhouse effect. [1] In this circumstance, generation of photovoltaic power has an important role to play due to the fact that it is a green source. Basic idea about the grid connected solar photovoltaic system is composed of solar photovoltaic array, boost converter, power inverter and utility grid as illustrate in Fig. 1. Solar photovoltaic array generates DC power at its maximum by using boost converter with help of Maximum Power Point Tracking (MPPT) algorithm while power inverter converts this DC power to AC power and feeds to utility grid.

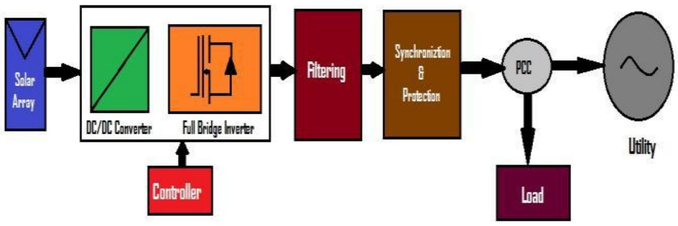

Fig 1 Grid connected solar Photovoltaic system

Requirement of renewable energy sources is rapidly increasing because of the high cost and limited conventional energy sources as gas, oil, coal and multilevel inverters are more reliable to interface with renewable energy sources than a conventional two-level inverter for a high power application in aspects of better power quality, as well as multilevel Inverters have become more popular over the years in electric power application with the promise of less disturbances outputs and the possibility to function at higher switching frequencies than ordinary two-level inverter. In multilevel inverters not only two voltage levels of DC input is obtained but several voltage levels are obtained to make the system more reliable and with better quality output fed to LOAD.

There are three topologies for multilevel inverter:

- Cascaded H-Bridge Multilevel inverter,
- Flying Capacitor Multilevel inverter and
- Diode Clamped Multilevel inverter.

In diode clamped topology has been used which is the best suitable topology for each kind of renewable energy source. Diode clamped topology also known as neutral point clamped topology because the neutral point has been clamped to obtain 0 v magnitude level.

To control multilevel inverters, different types of pulse width modulation (PWM) techniques are used:

- Sinusoidal PWM and
- Space Vector PWM

In Sinusoidal Pulse width modulation (SPWM) the gating signals generated by comparing sinusoidal reference signal with a triangular carrier wave.[5] In Space Vector pulse width Modulation (SVPWM) rotating phase is obtained by adding all the three voltages. SVPWM technique is mostly used for multilevel inverters compared to SPWM. SVPWM modulation technique was actually developed as a vector approach to PWM for 3-phase inverters. It is an advanced and computation method and it is quite different from SPWM method and other PWM methods.

$V_{max} = V_{dc}/2$: For sinusoidal/Sine triangular PWM

$V_{max} = V_{dc}/\sqrt{3}$: For Space vector PWM

II. PHOTOVOLTAIC CELL

The energy of solar rays can be converted directly into two different forms:

- Direct adaptation into the electrical energy that takes place in PV cells.
- Heat accumulation in the PV collectors.

The direct conversion of solar radiation into electrical energy is frequently known as a photo-voltaic (PV) energy conversion, [8]. So, the PV effect means the creation of a potential difference at the junction of two diverse materials in response to observable or other radiation. The entire procedure of solar energy conversion into electrical energy is thus denoted as the "photo voltaic".

The benefit of the PV system is that the solar panels are modular and can be united and can be attach together in a manner that they can bring exactly the required power. Equivalent circuit of photovoltaic and I-V Characteristics illustrate in fig. 2 and fig. 3 respectively

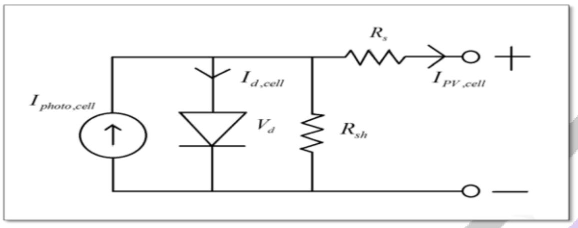

Fig 2 Equivalent circuit of Photovoltaic solar cell

The basic equations of ideal photovoltaic cell from the theory of the semiconductors is,

$$I = Ipv,cell - Id,cell.[exp\left(\frac{qV}{aKT}\right) - 1] \quad (1)$$

Where,
Ipv, cell=current generated through the incident light
T = temperature of p-n junction
a = diode ideality factor
Id = Shotckey diode equation
q = electron charge
K = Boltzmann constant

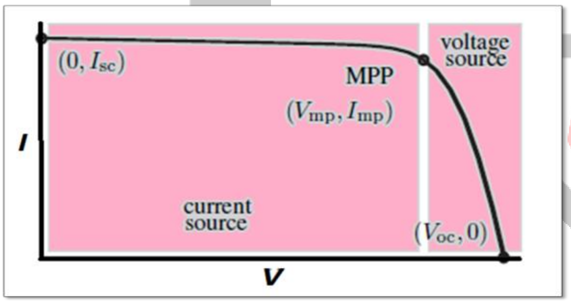

Fig 3 V-I characteristics of Solar cell

III. MAXIMUM POWER POINT TRACKING (P& O)

Solar energy is a better option of the other conventional energy sources because it can convert photo voltaic energy directly in to electrical energy. So for solar energy system there are many other responsibilities like better power quality output and efficient performance is required. So to full field these requirements MPPT can be used. by obtaining voltage at maximum power by means of MPPT the system will get maximum DC voltage from the solar cells and because of happening of this the system will became more efficient and with better power quality output[13].

MPPT can perform only with the help of other components like boost converter or other converters as required. MPPT can be perform on the availability of irradiation and the temperature. According to these parameters it can give the signals to boost voltage at maximum value of power.

MPPT Methods: Generally MPPT method have two basic kinds of methods: first one is Off-line method which have also two method like open circuit voltage method and short circuit current method, and other one is On-line methods which have also two method like perturb & observe method and Incremental conductance Method

A. *Perturb & Observe*

According to perturb and Observe method algorithm when the operating voltage of the given PV cell is perturbed by a little increment and the change in magnitude of power continuously is positive than it is known as the direction of maximum power point and it is necessary to keep it in the same direction.

When after some iterations the change in power will became negative than it shows that the maximum power point is already exist hence the sign of perturbation supplied should be changed. Figure. (4) Shows the detailed flowchart of this algorithm.

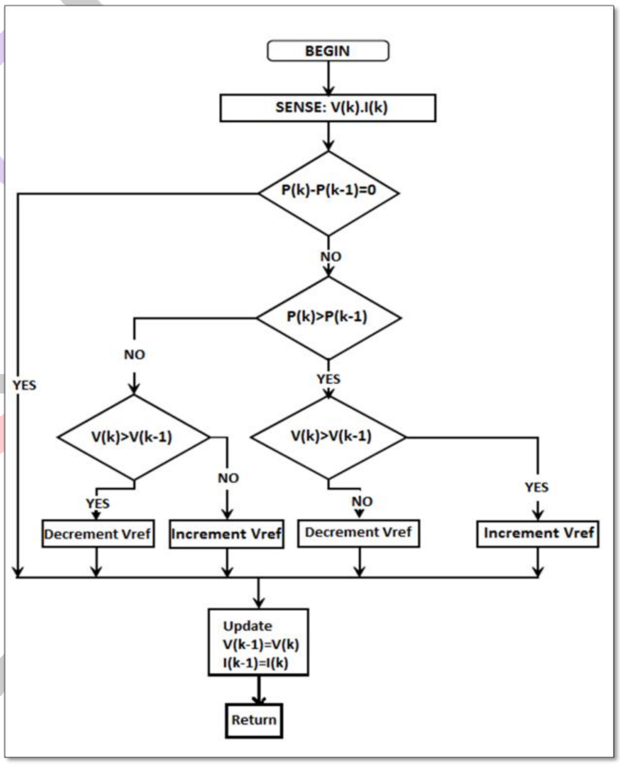

Fig 4 Flow chart algorithms for perturb & observe method

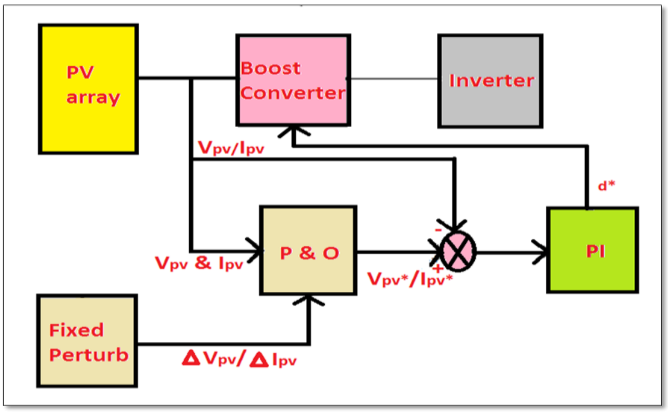

Fig 5 MPPT Circuit Arrangement for P&O Technique

There are some limitations which are responsible for reduction in MPPT's efficiency:

- It has been shown that it can exhibit abnormal performance in the cases of rapidly changed atmospheric situations as a result of moving of clouds or other humidity.
- It cannot be determine that when it has actually reached the MPP. Instead, it oscillates the operating point around the MPP after the each cycle and then slightly reduces PV efficiency under the constant irradiance situation.

The reasons for this problems can be shown in fig. 6 with the different set of PV curves at different irradiations. With the varying 'irradiance', according to fig. 6 the operating point is at the' point A' initially & at the irradiance of 500 W/m2 it will oscillating around the MPP. After that the radiation is changed suddenly to 600W/m2.

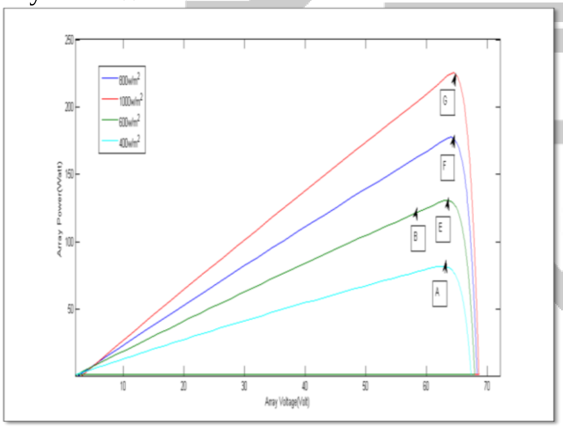

Fig 6 Wrong Detection of MPPT by P & O under Rapidly Changed Atmospheric conditions.

This condition can be take place on somewhat cloudy days, and MPP tracking will be the most complicated because of regular movement of the MPP. In this case the positive ΔP can be calculated when the operating voltage has been moving in the left side direction; The MPPT is fooled as if there is a MPP on the left side. If the irradiance is here still quickly rising, therefore the MPPT will once more observe the positive ΔP and again will assume that it is moving in the direction of the MPP, continuing to perturb to the left. From 'Points A, E, F and G' the operating point will continues to deviate from the actual MPP until the solar radiation is changing gradually or else settles down.

IV. INVERTER

A device which converts dc power into ac power at desired output frequency and voltage is called an inverter. When operated in the inverter mode, Phase controlled converters are called line-commutated inverters but line-commutated inverters need at the output terminal an accessible ac supply which is used for their commutation. This means that function of line commutated inverter cannot work as isolated ac voltage sources or as variable frequency generators with dc power at the input. As a result frequency, voltage level and waveform on the ac side of line commutated inverters cannot be changed; on the other side force commutated inverters provide an free from ac output voltage of adjustable frequency and adjustable voltage and have therefore much wider application. Basically, the inverters have four classifications: 1) the type of power de-coupling between the PV module(s) and the single-phase grid; 2) the number of power processing stages in cascade; 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 widely classified in to two types- voltage source inverter and current source inverter. In this paper, I explain the cascaded multilevel inverter, 3-level diode clamp inverter, SVPWM and SPWM method respectively.

V. THREE-LEVEL DIODE CLAMPED INVERTER

Usually simple two-level inverters are generally used to generate an AC voltage from a DC voltage. Working of the two-level inverter can create only two different output voltages for the load is +Vdc/2 and –Vdc/2 (This is consider when the inverter is fed with Vdc). The basic circuit diagram of 3-level diode clamped inverters as illustrate in fig. 6 does not depend on just two levels of voltage to generate an AC signal. When we get the smoother waveform, the more voltage levels generated in the inverter. However if many levels of voltage will make raise the complexity of the circuit, with more apparatus and a more complications the controllers for the inverter are required and being used [4].

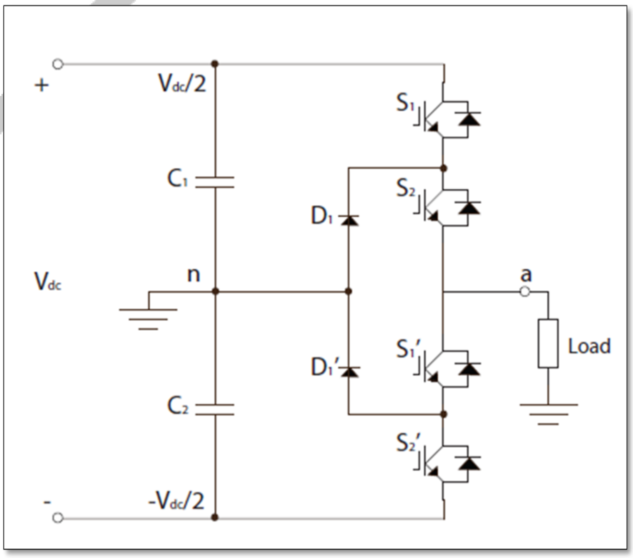

Fig 7 Circuit arrangement for Three-Level diode clamped inverter for single phasess

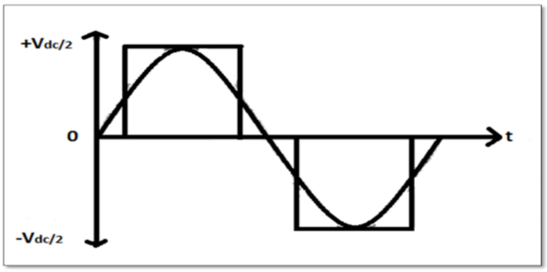

Fig 8 Output Voltage waveform by Three-level diode clamped Inverter

In 3-level diode clamp inverter, the duty cycle for switches ON/OFF is done shown in Table 1

TABLE I. SWITCHING MODES OF 3-LEVEL INVERTER.

MAGNITUDE OF VOLTAGE(VDC)	NO. OF SWITCHES TO BE ON/OFF			
	S1	S2	S3	S4
+VDC/2	ON	ON	OFF	OFF
0	OFF	ON	ON	OFF
-VDC/2	OFF	OFF	ON	ON

VI. PULSE WIDTH MODULATION TECHNIQUE

The inflection strategies can mainly divided into two strategies as: high switching frequency and Fundamental switching frequency pulse width modulation. Illustrate the fig. 9 present the different PWM techniques.

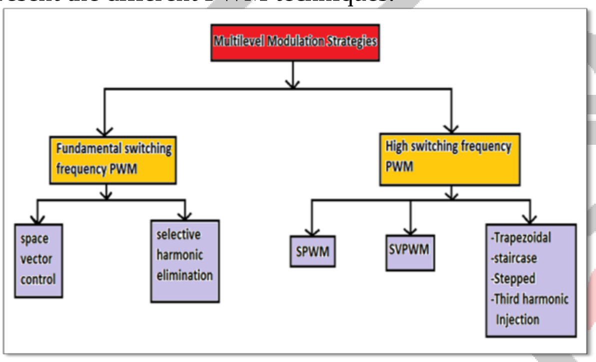

Fig 9 Different PWM techniques

Block diagram of different PWM techniques represents the overview of PWM techniques. Out of these techniques in this paper SPWM techniques are presented.

VII. SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

For the switching techniques inverters that use PWM techniques have a DC input voltage that is always constant in magnitude. The inverter will acquire this as an input voltage and output AC where the frequency and magnitude can be controlled as per the requirement. There are various ways by which PWM can be implemented to make the output to be AC. A widespread technique known as SPWM (Sinusoidal Pulse Width Modulation) has been used and discussed here. In order to get output as a sinusoidal waveform for 3-level inverter at a definite frequency a sinusoidal control signal (Vsine) at the definite frequency is compared with a (m-1) triangular waveform(Vtri) as illustrate in fig.9; here, m is number of inverter level(2,3,4,...,etc). The basic block diagram arrangement of the SPWM technique is illustrate in fig. 8. Usually the inverter will use than the frequency of the triangle wave as the switching frequency which is essentially kept constant [3][4][5].

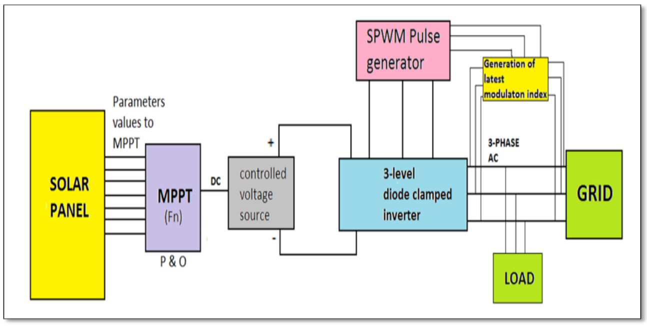

Fig 10 Block diagram arrangement of the entire system along with SPWM technique

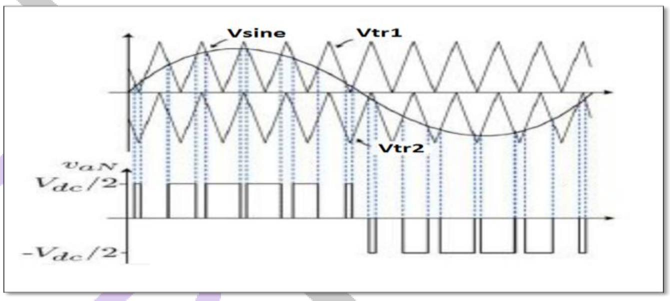

Fig 11 SPWM for 3-level inverter

In the fig.9 the triangle waveforms (Vtr1, Vtr2) are at the switching frequency (fs), this frequency is controls the speed at which the inverter switches can turn on and off. In this technique the control signal (Vsine) is used to adjust the duty ratio of the switch and has a frequency (f), which is recognized as fundamental frequency of the inverter output voltage. The inverter output voltage is affected by the switching frequency. One of the inverter switches duty cycle here is called as amplitude modulation ratio:

$$Ma = Vsin/Vtri \quad (2)$$

When,
Vsin > Vtr1 = +Vdc/2
When,
Vsin < Vtr2 = -Vdc/2
When,
Vtr2 > Vsine = 0

In SPMW for the 3-lelvel inverter the switches S+ and S- are controlled based on the comparison of signals Vtri and Vsine. Here, at the same time the two switches are never gets off which results in the output voltage fluctuating between +/- Vd/2 and the remaining switches will be output as 0 [3][4][5].

VIII. Simulation & Result

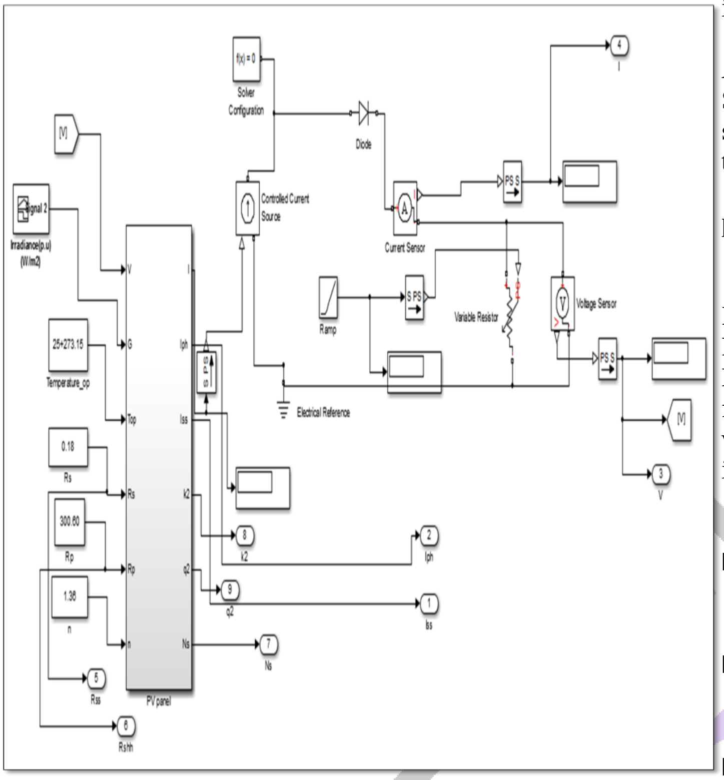

Fig 12 SPWM MATLAB modelling of Solar panel with Variable resistor

The given MATLAB modelling is for PV array. With the help of mathematical equations by applying some constant values the required parameter values can be obtained. The inputs in the given panel are the constant values and the outputs from the panel are the mathematic equation products and those values are than given to MPPT to make the system more efficient and accurate. In this modelling the variable resistor is used so the PV and IV curve should be obtained as given below.

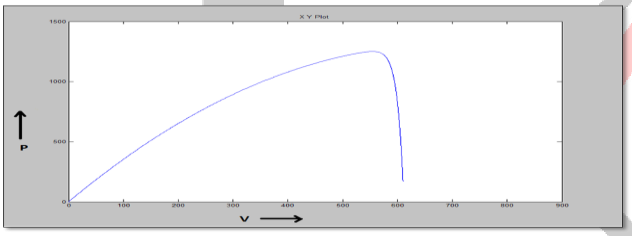

Fig 13 PV curve for the Solar panel

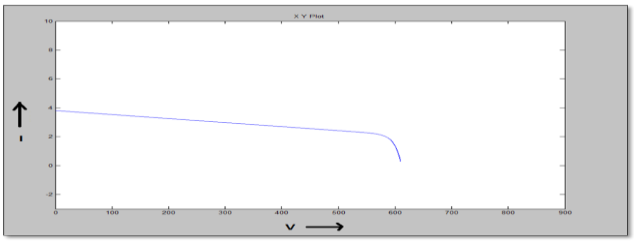

Fig 14 IV Curve for the Solar panel

IX. Conclusion

As we observed the results obtained by above discussion that multilevel (3-level) inverter gives enhanced and more proper output waveforms than the conventional 2-level inverter.

2-level inverters are not capable to convert DC voltage into AC as much efficiently as multilevel inverters can convert. SPWM technique is most suitable to the system because of its simplicity and better performance that it's generate gate pulses the way that it gives lesser THD.

P & O technique is required to achieve the maximum power point for the system to make the system more efficient.

X. Acknowledgment

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