Off Grid Photovoltaic System with Seven Level Inverter for THD reduction

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Abstract- *Solar Photovoltaic (PV) system requires an effective controller to support maximum power tracking (MPPT) and maintaining output voltage levels. In this study, Incremental Conductance (I&C) method is applied for MPPT operation. The operation is attained with an effective DC/DC Boost converter which provides the final output DC voltage depending on system load. The loads used being AC, this report suggests the use of 7-level inverter, to keep low harmonic profile. The inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade.*

In this way, the system under study generates a sinusoidal output current that is feeding the AC load. The effectiveness of system in terms of performance and harmonic profile is verified using MATLAB simulation studies.

Keywords- *Photovoltaic System (PV), Incremental and conductance (I&C) algorithm, DC/DC Boost Converter, Multilevel Inverter (MLI), 7-level inverter, Pulse width modulation (PWM)*

I. INTRODUCTION

The global demand for electric energy has increased continuously over the last few decades. Energy and the environment have become serious concerns in the today's world [1]. Alternative sources of energy generation have drawn increasing attention in recent years. Clean and renewable energy sources such as photovoltaic (PV) power generation can reply to that demand as the one of key technologies to mitigate global warning [2]. As one of distributed sources, photovoltaic (PV) power generation can be used for grid connected system or either stand alone system to reduce consumption of conventional energy [3].However the PV system has low efficiency because of the power generated from PV system depends on the environmental condition i.e. variation in insolation and temperature may affect the output characteristics of the PV modules. A lot of research has been done to improve the efficiency of the PV modules. A number of methods to track the maximum power point of a PV module have been proposed to overcome the limitation of efficiency [4].

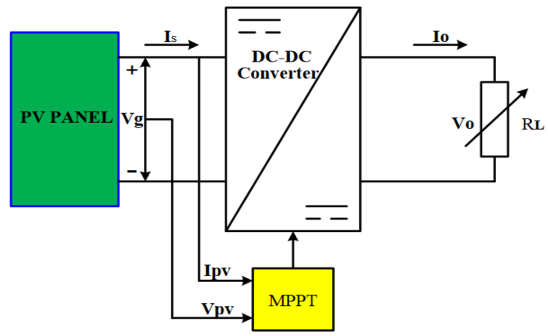

Fig 1- PV system with MPPT controller

MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. DC-DC converter acts as an interface between the load and the PV module as it serve the purpose of transferring maximum power from the solar PV module to the load. By changing the duty cycle the load impedance is matched with the source impedance to attain the maximum power from the PV panel [5], [6]. Fig. 1 shows the DC-DC converter for operation at MPP.

II. SYSTEM MODELLING

The complete system comprises of the following equipments:

a. Photovoltaic System:

Equivalent circuit model of PV cell defines the entire I-V curve of a cell, module, or array as a continuous function for a given set of operating conditions. As per figure below, the current equation derives to be:

$$I = I_L - I_D - I_{sh}$$

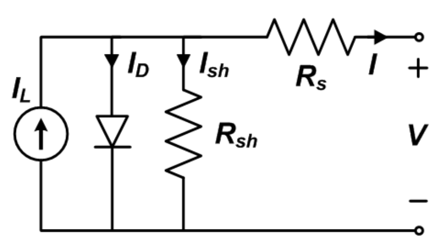

Fig 2- Solar PV Cell Model

Here, I_L represents the photo-generated current in the cell, I_D represents voltage-dependent current lost to recombination, and I_{sh} represents the current lost due to shunt resistances. I_D is modeled using the Shockley equation for an ideal diode:

$$I_D = I_0\left[\exp\left(\frac{V + IR_S}{nV_T}\right) - 1\right]$$

where, n is diode ideality factor, I_0 is saturation current, and V_T is the thermal voltage.

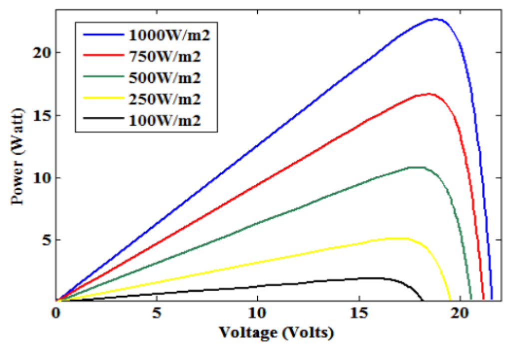

Fig 3- P-V Characteristic of curve

b) DC-DC Boost Converter

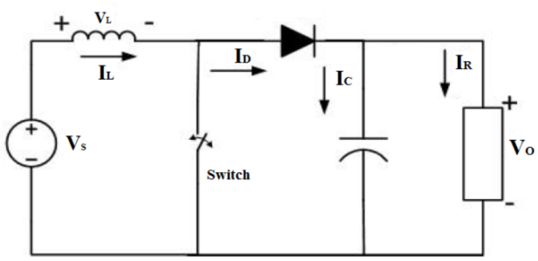

Fig 4- DC/DC Boost converter

The DC-DC Boost converter's function is to step up DC voltage to bring it to a desired level. If the switch is turned on and off repeatedly at very high frequencies and assuming that in the steady state the output will basically be DC (large capacitor), than:

$$I_C = 0$$

$$I_L = I_R - I_{switch} = I_R - DI_L$$

$$\text{So, } I_L = \frac{V_O}{R(1-D)}$$

The DC component of voltage across the inductor has to be zero if losses are neglected. The average voltage across the inductor is given by:

$$V_L = 0$$

$$\frac{1}{T}\left(\int_{DT} V_{ON}\,dt + \int_{(1-D)T} V_{OFF}\,dt\right) = 0$$

$$\frac{1}{T}[V_S DT + (V_S - V_O)(1-D)T] = 0$$

$$V_S - (1-D)V_O = 0$$

Solving,

$$\frac{V_o}{V_S} = \frac{1}{1-D}$$

c) Incremental Conductance MPPT Scheme

The maximum power supplied by the photovoltaic panels never stable and fixed in the same operating point due to the continuous variation in radiation level and load conditions. To operate at the MPP level, MPPT schemes are used which dynamically adjusts the extraction of the power. Convergence speed is one of the most important features among all different MPPT algorithms. Any improvement in the rise time of MPPT improves the reliability of the system and increases the power extraction and efficiency of the whole system. In our study, Incremental Conductance (I&C) scheme is used.

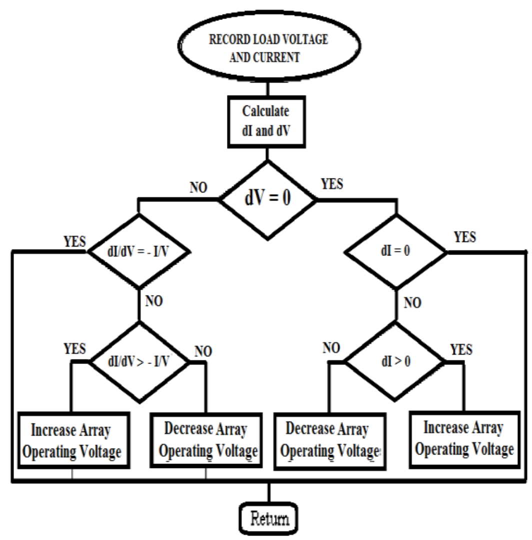

Fig 5- I&C MPPT

The I&C algorithm is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero:

$$\frac{dP}{dV} = \frac{dVI}{dV} = I + V\frac{dI}{dV} = 0$$

$$\frac{dI}{dV} = -\frac{I}{V}$$

Thus, at the MPP, left and right side quantities must be equal in magnitude, but opposite in sign. These relationships are summarized as:

$$\frac{dI}{dV} = -\frac{I}{V}; \left(\frac{dP}{dV} = 0\right)$$

$$\frac{dI}{dV} > -\frac{I}{V}; \left(\frac{dP}{dV} > 0\right)$$

$$\frac{dI}{dV} < -\frac{I}{V}; \left(\frac{dP}{dV} < 0\right)$$

These are used to determine the direction in which a perturbation must occur to move the operating point toward the MPP, and the perturbation is repeated until MPP is achieved, where the system continues to operate until a change in current is detected due to change in irradiance.

III. MULTILEVEL INVERTER

Multilevel inverters (MLI) are important aspect here as most loads used by us are designed for AC. The technology for high-switching-frequency inverters (typically 20 kHz or higher) is achieved by power MOSFETs.

a) 3 Level MLI: Single phase Three level Cascaded H-Bridge inverter consisting of single isolated DC source, four IGBT switches& R-L load. The result of output voltage waveform of 3-level multilevel inverter consists of three levels 0, $+V_{dc}$, $-V_{dc}$.

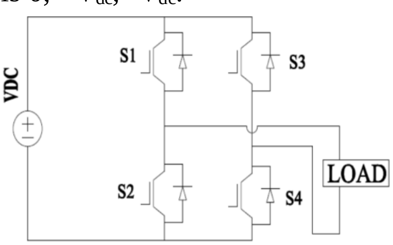

Fig 6- Three-Level MLI

b) 5-Level MLI

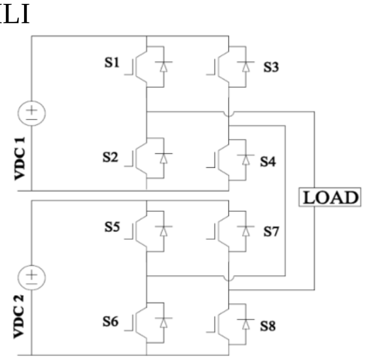

Fig 7- Five-Level MLI

Single phase cascaded H-Bridge multilevel inverter consisting of 2 H-Bridges with 8 IGBT switches, two DC sources and, R-L load. In this 8 IGBT switches are used. Two H-Bridges are connected in series to generate 5 level output voltage. The output voltage of H-Bridge inverter 1 is V_1 and H-Bridge 2 is V_2 & total output voltage of 5 level inverter is V=V1+V2.

c) 7-Level MLI

This topology is made of 7 switches and 3 DC sources. One H-bridge present in the topology is mainly for polarity change. Here, three switches conduct at a time for level generation. The table I below shows the switching status of 7 switches used for the 7-level inverter. To trigger the switches PWM modulated signals are used.

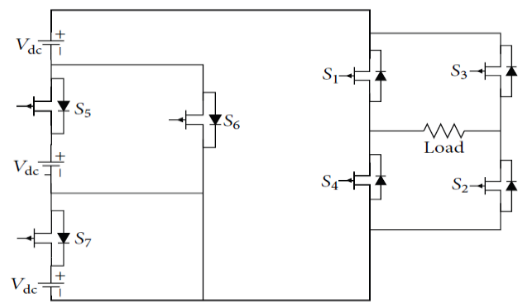

Fig 8- 7 level 7 switch MLI

Table I- Switching conditions for 7 levels

S. No	S4	S5	S6	S7	S1	S2	S3	V_{OUT}
1	ON	ON	ON	OFF	OFF	OFF	ON	+VDC
2	ON	ON	OFF	OFF	OFF	ON	OFF	+2VDC
3	ON	ON	OFF	OFF	ON	OFF	OFF	+3VDC
4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	0
5	OFF	OFF	ON	ON	ON	ON	OFF	-VDC
6	OFF	OFF	ON	ON	ON	OFF	ON	-2VDC
7	OFF	OFF	ON	ON	OFF	ON	ON	-3VDC

a) THD Calculations:

Converting DC to AC using MLI generates the problem of harmonics as the operation is performed by non-linear devices. Normally, amount of harmonics injected in the system is analyzed in terms of Total Harmonic Distortion (THD). The THD is usually calculated by taking the root sum of the squares of the first five or six harmonics of the fundamental. In MATLAB, the results of THD% can be obtained from FFT analysis of current and voltage waveforms obtained. The THD (%) is calculated by using the following formula:

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^2}}{M_1} X100$$

In IEEE standard 929-2000, the integration of PV systems to networks is covered in two main categories of safety and power quality. It states that the limits on the total harmonic distortion caused by the PV system at the point of common coupling (PCC) should be as per table II.

Table II- IEEE 519 limits for odd harmonics

S. No	Harmonic Level	Distortion Level
1	3rd to 9th	< 4%
2	11th to 15th	< 2%
3	17th to 21st	< 1:5%
4	23rd to 33rd	< 0:6%
5	Above 33rd	< 0.3%

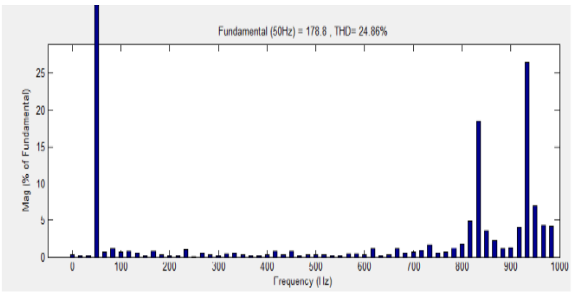

Fig 9- THD of 3-level MLI at 24.86%

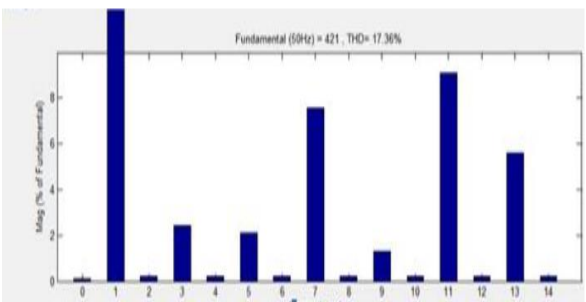

Fig 10- THD of 5-level MLI is 17.36%

It is very much clear that, in our application use of 7 level MLI is justified as the THD values for both 3-level and 5-level MLI is larger than limits.

IV. SIMULATION AND RESULTS

The system studied in previous section of this paper, promises an effective system of PV power generation. With higher step-up gain of the dc–dc power converter, there is lower power efficiency. Hence, the higher input voltage of solar power generation system results in better power efficiency.

AC side waveforms of the seven-level inverter are shown in figure 13. It has seven voltage levels. The supply is sinusoidal and in phase with the utility voltage, which means that the grid-connected power conversion interface feeds a pure real power to the utility.

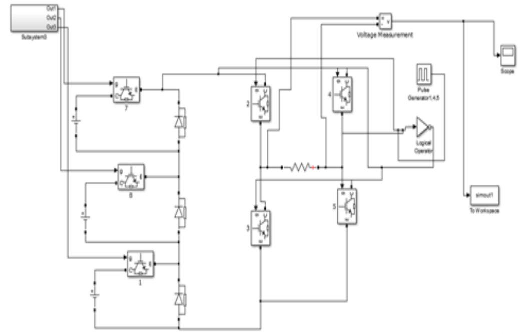

Fig 11- Simulation model of 7-level, 7 switch MLI

The total harmonic distortion (THD) of the output current of the seven-level inverter is 2.85%, as measured by FFT analysis of inverter current signal.

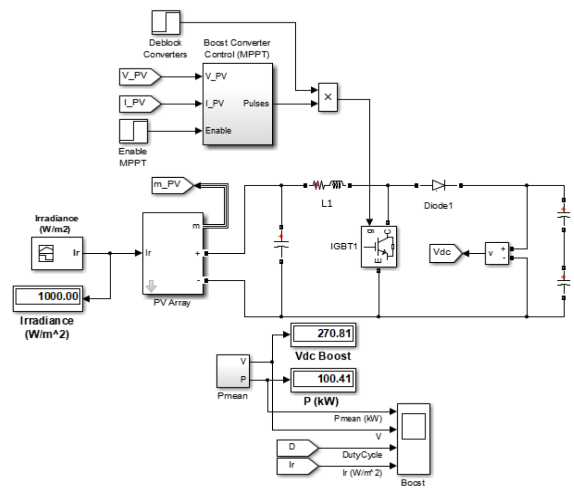

Fig 12-Simulation model of solar panels with MPPT and Boost Converter

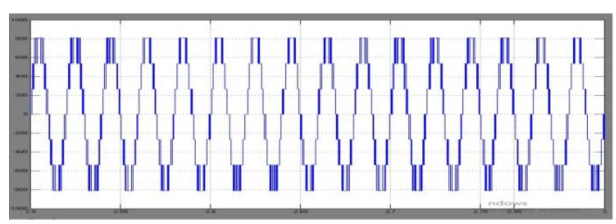

Fig 13- Inverter Output having 7 levels of voltage

V. CONCLUSION

The system under study consists of individual systems working together to provide efficient power generation. Generation through solar PV unit with Incremental conductance Maximum power point tracking algorithm, accomplishes the objective of tracing highest power extraction point. InC based MPPT system is interfaced with boost converter, whose output is given to 7-level inverter and produces inverted output voltage waveform. The switches are controlled through PWM technique. The THD in the output is also reduced due the use of 7-levels.

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