Multilevel Inverter Configuration with Boost converters in a Photovoltaic System using MATLAB/SIMULINK

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Abstract: The paper presents the analysis of multilevel inverter configuration with boost converters using the source as photovoltaic cells. The PV array is used for the DC output voltage. The Boost converters are used to develop the voltage and to deliver the DC power to the Multilevel Inverter. The input parameters of PV array like Sun Irradiance and temperature conditions are given through MATLAB/SIMULINK. The testing of the proposed framework is tried just with standard test condition (STC). The standard test condition incorporates Cell temperature 25 ^{0}C, irradiance 1000 W/m^2. This configuration of multilevel inverter reduces the value of total harmonic distortion (THD). The higher output voltage level is generated with lesser number of power semiconductor switches compared to conventional configuration, thus reducing the total harmonic distortion and switching losses. This paper is implemented in MATLAB/SIMULINK environment. Selective experimental results are presented to prove the effectiveness of the system

Keywords — Boost Converter, Cascaded H-Bridge, Dc Filter, Integration of Renewable Source, Multi Level Inverter, Solar PV Module.

I. INTRODUCTION

Solar PV cells are more familiar with all electrical sources because they are used in many of the appliances, businesses and small industries. In general, these solar cells are used to develop the DC electrical power. The generated voltage from the Solar PV will be then used to convert into AC electrical power. The main motto of the paper is to boost the DC power produced by the Solar PV by using the Boost converter and filters, also to convert the DC electrical power to AC electrical power by use of the Inverter Preferably Cascaded H- Bridge Multilevel Inverter. In this the modeling of the multilevel inverter with boost circuit and Solar PV was created in a MATLAB/SIMULINK file environment and The PV Cell used in the MATLAB is 1Soltech 1STH – 215-P. 1Soltech 1STH – 215-P is manufactured by 1 Soltech company with a Maximum Power of 213.15W, Open circuit voltage of 36.3V and Short circuit current of 7.84A.

In Boost converters, the values of energy storage elements such as Inductor and Capacitor are designed. In Booster circuit, the filters are also crucial because the filters placed after the circuit will maintain the constant voltage output. Since the DC voltage is boosted it is convenient to supply DC power to the Inverter and which in turn delivers AC electrical power to the AC load and the AC power is delivered to the AC load. This paper is to design the multilevel inverter output using Solar PV array.

II. SOLAR PV SYSTEM

Based on the electric energy production, PV modules can be arranged into arrays to increase electric output. Solar PV systems are generally classified based on their functional and operational requirements and configurations of components present. It can be classified into grid-connected and stand-alone systems [1]. Here, Stand-Alone Solar PV System is used.

Stand-alone PV systems or direct coupled PV systems are designed and sized to supply DC and/or AC electrical loads [2]. It is called direct coupled systems because, the DC output of a PV module or array is directly connected to a DC load and has no electrical energy storage (batteries) in Stand-Alone systems as because of that, the load only operates during sunlight hours.

A. 1Soltech 1STH – 215-P SOLAR PV MODULE:
1Soltech 1STH – 215-P is the Solar PV Module used. The parameters of 1Soltech 1STH – 215-P module is shown in table 1.1

S.No	PARAMETER	VALUE
1	Maximum power (W)	213.15
2	Cell per module (Ncell)	60

3	Open circuit voltage V_{oc}(V)	36.3
4	Short circuit current I_{sc}(A)	7.84
5	Voltage at maximum power pointVmp(V)	29
6	Current at maximum power point Imp(A)	7.35
7	Temperature coefficient of Voc (%deg.C)	-0.36099
8	Temperature coefficient of Isc (%deg.C)	0.102

Table 1.1 1Soltech 1STH – 215-P Module Parameters

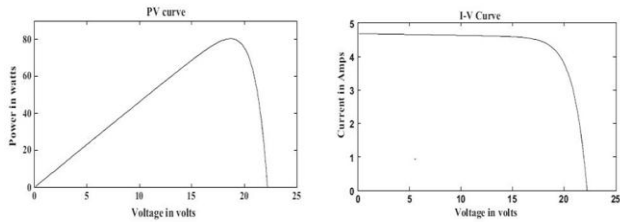PV and IV curves i.e. Power Vs Voltage and Current Vs Voltage curves for a solar PV cell are shown in figure 1.1.

Fig 1.1 PV and IV curves of PV Solar Cell

III. BOOST CONVERTERS (DC-DC)

A boost converter (dc-dc) is shown in Fig. 1.2 Only a switch is shown, for which a device belonging to transistor family is generally used. Diode is used in series with the load. The load is of the same type as used earlier. The value of the load inductor is small. An inductance, L is series with the input supply. The position of the switch and diode in this circuit may be noted, as compared to their position in the buck converter [3].
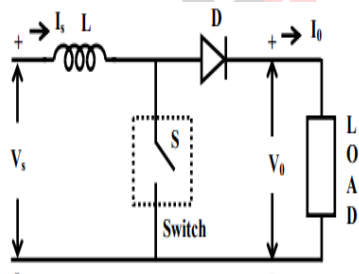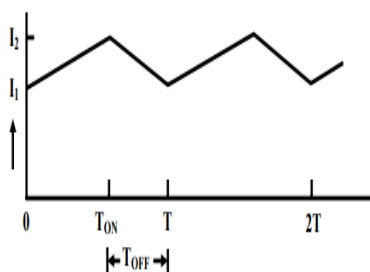

Fig.1.2. Boost converter

Fig.1.3. waveforms of source current

The operation of the circuit is explained. Firstly, the switch, S (i.e., the device) is put ON (or turned ON) during the period, $T_{ON} \geq t \geq 0$, the ON period beingT_{ON}. The output voltage is zero (Vo = 0), if no battery (back emf) is connected in series with the load and as stated earlier, the load inductance is small. The current from the source (i_s) flows in the inductance L .The value of current increases linearly with time in this interval, with (d i/ d t) being positive. As the current through L increases, the polarity of the induced emf is taken as say, positive, the left-hand side of L being +ve. The equation for the circuit is,

$$V_s = L \frac{di_s}{dt} \qquad \frac{di_s}{dt} = \frac{V_s}{L}$$

The switch, S is put OFF during the period, $T \geq t \geq T_{ON}$, the OFF period being $T_{OFF} = T - T_{ON}$. $(T = T_{ON} + T_{OFF})$ is the time period. As the current through L decreases, with its direction being in the same direction as shown (same as in the earlier case), the induced emf reverses, the left-hand side of L being -ve. So, the induced emf (taken as –ve in the equation given later) is added with the supply voltage, being of the same polarity, thus, keeping the current ($i_s = i_0$) in the same direction. The current ($i_s = i_0$) decreases linearly in the time interval, T_{OFF}, as the output voltage is assumed to be nearly constant.

The equation for the circuit is,

$$V_s = V_0 + L \frac{di_s}{dt} \quad \text{or} \quad \frac{di_s}{dt} = \frac{(V_s - V_0)}{L}$$

The source current waveform is shown. As stated earlier, the current varies linearly from I 1 (I_{min}) to I 2 (I_{max}) during the time interval, T_{ON} .So, by using the expression for di_s /dt during this time interval,

$$I_2 - I_1 = I_{max} - I_{min} = \left(\frac{V_s}{L}\right) T_{ON}$$

Similarly, the current varies linearly from I 2 (I max) to I 1 (I min) during the time interval, T_{OFF} .So, using the expression for d i s/ d t during this time interval,

$$I_2 - I_1 = I_{max} - I_{min} = ((V_0 - V_s)/L)T_{OFF}$$

Equating the two equations, (V s / L) $T_{ON} = [(V_0 - V_s) /$ L] T_{OFF}, from which the average value of the output voltage is,

$$V_0 = V_s \frac{T}{T_{OFF}} = V_1 \frac{T}{T - T_{ON}} = V_s \frac{1}{1 - \left(\frac{T_{ON}}{T}\right)} = V_s \frac{1}{1 - k}$$

The time period is T = $T_{ON} + T_{OFF}$, and the duty ratio is, k = (T_{ON} / T) = [T_{ON} / ($T_{ON} + T_{OFF}$)], with its range as $1.0 \geq k \geq 0.0$. The ON time interval is $T_{ON} = k$ T. As stated in the previous case, the range of k is reduced. This is, because the minimum value is higher than the minimum (0.0), and the maximum value is lower than the maximum (1.0), for reasons given there, which are also valid here. As shown, the source current is assumed to be continuous.

VI. MULTILEVEL INVERTER

The Inverter is an electrical device which converts direct current (DC) to alternate current (AC). A multilevel inverter is a power electronic device which can provide

desired alternating voltage level at the output using multiple lower level DC voltages as an input [6].

A. NEED OF MULTI-LEVEL INVERTERS:

The need of multilevel converter is to give a high output power from medium voltage source with low power devices with a better reduction in dv/dt rating and Multi level Inverters will necessitates better quality. Multilevel inverters also has some other better features like,

- Increased number of voltage levels produces better voltage waveform.
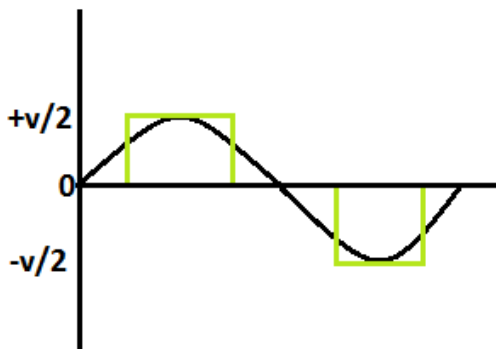- Switching frequency can be reduced for the PWM operation.

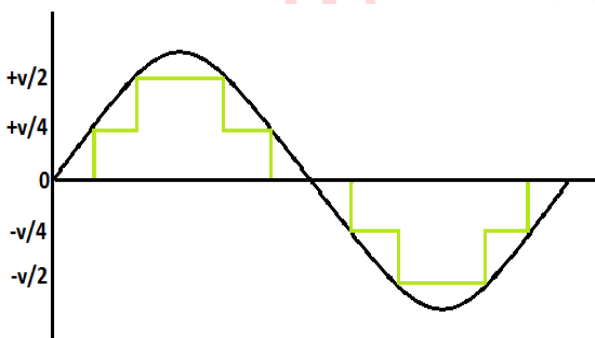**Fig 1.4 Three Level Output**

Fig 1.5 Seven Level Output

Although Multi level Inverter conversion of voltage is effective but it has some limitations as it causes disturbance in the output voltage. Normally, Multilevel Inverter method works but, in some applications, it creates problems specifically where high distortion in the output voltage is not required.

B. TYPES OF MULTILEVEL INVERTER AND APPLICATIONS:

There are a number of topologies of multilevel inverters. The change lies in the mechanism of switching and the source of input voltage to the multilevel inverters [8-9].

Three most commonly used multilevel inverter topologies are:

- Cascaded H-bridge multilevel inverters
- Diode Clamped multilevel inverters
- Flying Capacitor multilevel inverters

The proposed inverter uses a number of H-bridge inverters connected in series to deliver a sinusoidal output voltage. Each block contains one H-bridge and the output voltage generated by this multilevel inverter is actually the sum of all the voltages generated by each cell i.e. if there are k blocks in a H-bridge multilevel inverter then number of output voltage levels will be 2k+1. H-Bridge inverter has improvement over the other two as it requires less number of components as compared to the other two types of inverters and its overall weight and price is also less. Figure 1.6 shows cascaded H-bridge inverter.

In single phase inverter, each phase is connected to dc source. Different levels of inverters will generate three voltages which are positive, negative and zero voltages [10]. The voltage leveling can be obtained by connecting the AC source with the DC output and then using different arrangements of the four switches. The inverter will remain ON when two switches in opposite positions will remain ON. It will turn OFF when all the inverters switch ON or OFF. To minimize the total harmonic distortion, switching angles are defined and implemented. The switching angle calculations will remain the same.
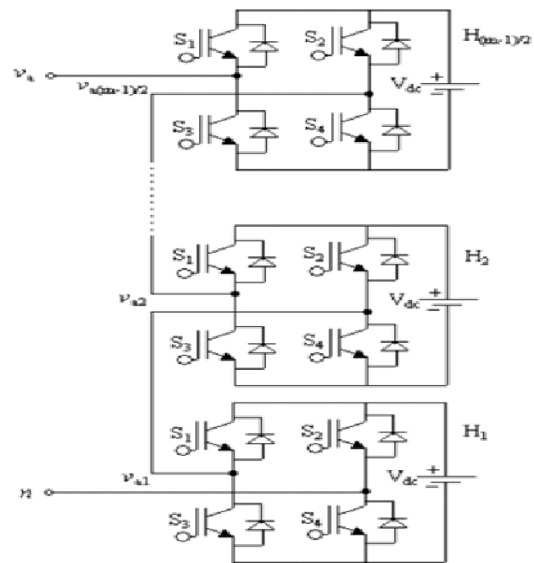

Fig.1.6 Cascaded H-bridge multilevel inverters

In 5 level cascaded H Bridge Multilevel Inverters, cascading of two H Bridge Inverters is done. It uses 8 switching devices to control the Inverter and has 5 levels of output levels, whereas in 9 level cascaded H Bridge Multilevel Inverters, cascading of four H Bridge Invertors is done. It uses 16 switching devices and has 9 output levels [4, 11, and 12].

C. ADVANTAGES OF CASCADE H BRIDGE MULTILEVEL INVERTERS:

➢ Output voltages levels are doubled the number of sources
➢ Manufacturing can be done easily and quickly
➢ Packaging and Layout is modularized
➢ Easily controllable with a transformer

D. DISADVANTAGES OF CASCADE H BRIDGE MULTILEVEL INVERTERS:

➢ Every H Bridge needs a separate dc source
➢ Limited applications due to large number of sources

E. APPLICATIONS OF CASCADED H BRIDGE MULT LEVEL INVERTER

➢ Active filters
➢ DC power source utilization
➢ Power factor compensators
➢ Inter facing with renewable energy sources

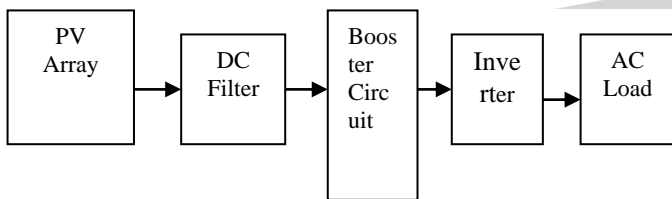## IV. PROPOSED MODEL

BLOCK DIAGRAM:

Fig.1.7 Block Diagram of Multilevel Inverter with Solar PV

The block diagram consisting of PV array, DC filters, Booster circuit, Inverter AC load as shown in Fig1.7. The inputs to the solar PV array are Sun Irradiance and temperature. From the Solar PV array DC output voltage is obtained. The produced DC output voltage has ripples. To reduce that ripples in the dc output voltage, DC filters are used before Booster circuit. That DC output voltage is not sufficient to drive the electrical load so that a booster circuit is required to drive the load [5, 7]. The boosted DC voltage is converted into AC voltage by multilevel inverter. The AC output voltage is driven with any kind of AC Load.

IMPLEMENTATION CIRCUITS

This paper explains the Five, Seven and Nine Level Inverter configurations. Here we will use the Solar PV Cell as a DC source and Capacitor is placed after the DC source in order to reduce the ripples produced from the PV Cell. The Boost converter is placed in order to boost the voltage from the DC Source (Solar PV cell), the switches here used in IGBTs and afterwards the capacitor is placed so that to maintain the DC voltage as a constant one. Later connection in the circuit is Inverter i.e. 9 level inverter as shown in figure 1.8

SIMULINK MODELS & RESULTS:

The Output Voltage waveform for 5 level inverters for a Booster converter with a duty cycle of 0.8 is shown in figure 1.9. The fundamental voltage and THD obtained are 506.4 volts and 32.73% respectively.
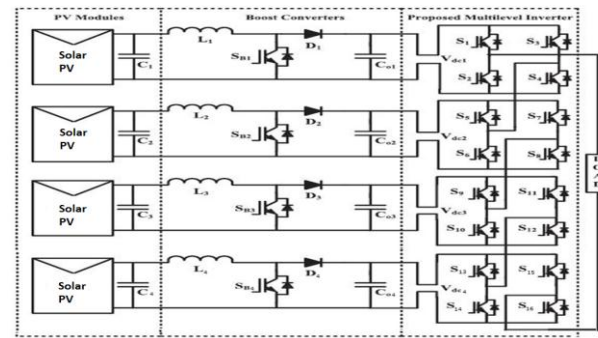

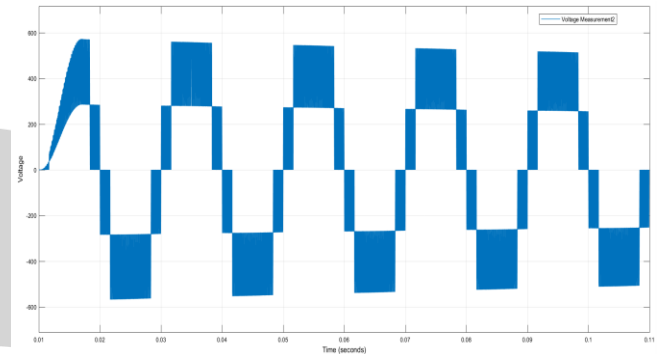**Fig 1.8 Nine level Inverter Configuration**

Fig 1.9 Output Voltage waveform of 5 level Inverter at 0.8 duty cycle

The Output Voltage waveform for 7 level inverters for a Booster converter with a duty cycle of 0.8 is shown in figure 1.10. The fundamental voltage and THD obtained are 742.8 volts and 26% respectively.
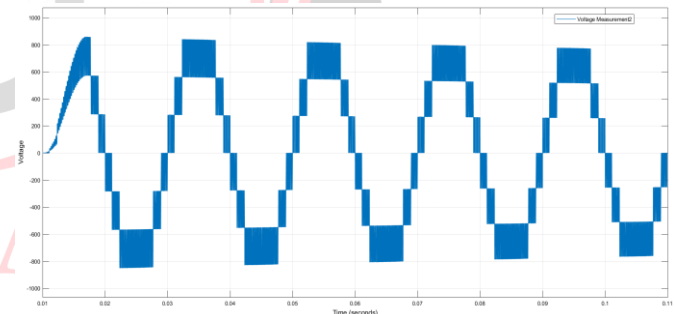

Fig 1.10.Output Voltage waveform of 7 level Inverter at 0.8 duty cycle

The Output Voltage waveform for 9 level inverters for a Booster converter with a duty cycle of 0.8 is shown in figure 1.11. The fundamental voltage and THD obtained are 990.8 volts and 23.03% respectively.
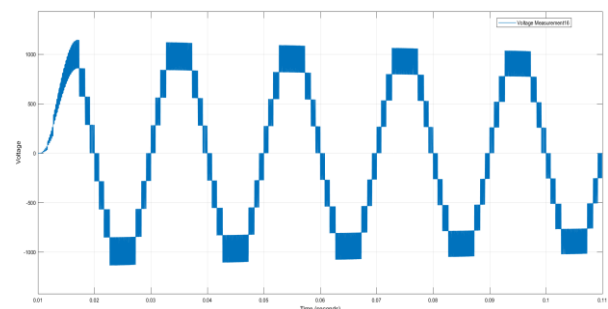

Fig 1.11 Output Voltage waveform of 9 level Inverter at 0.8 duty cycle

For 0.7 duty cycle	5 Level Inverter	7 Level Inverter	9 Level Inverter
Output Voltage of the Boost converter (in Volts)	177.4	177.1	173.4
Fundamental Voltage(in Volts)	378.3	554.8	739.6
THD (in %)	28.37	21.78	18.58

A. SIMULINK MODEL OF 9 LEVEL INVERTER:

Figure 1.12 shows the Simulink model of 9 level inverter with two cascaded single level inverter bridges. The Inverter is feeded by two solar PV cells and contains each individual Booster circuit for each leg.
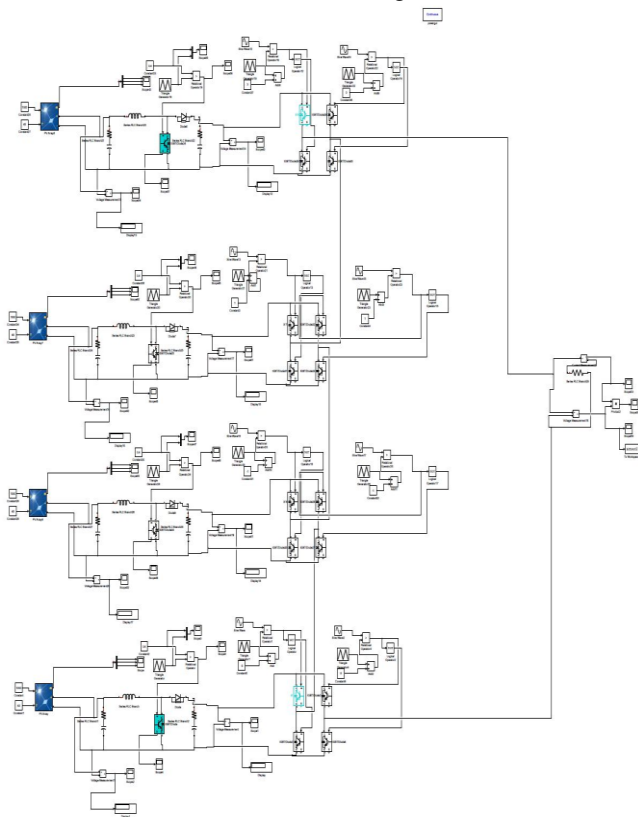

Fig 1.12 connection of 9- level inverter in the MATLAB/Simulink

COMPARISON OF DIFFERENT LEVELS WITH DUTY CYCLES:

For 0.8 duty cycle	5 Level Inverter	7 Level Inverter	9 Level Inverter
Output Voltage of the Boost converter (in Volts)	252.7	252.7	253
Fundamental Voltage(in Volts)	506.4	742.8	990.8

	5 Level Inverter	7 Level Inverter	9 Level Inverter
THD (in %)	32.73	26	23.03

For 0.6 duty cycle	5 Level Inverter	7 Level Inverter	9 Level Inverter
Output Voltage of the Boost converter (in Volts)	131.3	131.4	131.4
Fundamental Voltage(in Volts)	295.4	433.2	577.8
THD (in %)	27.14	19.94	16.34

The comparison tables which are shown above are practically proved in the MATLAB/Simulink. By seeing above tables, it is cleared that, by increasing levels of the inverter the Total Harmonic Distortion (THD) is reduced. So that by increasing levels of the inverter the loss percentage is less and the output voltage is more.

VI. CONCLUSION

This paper presented a method of producing AC electrical power by using Solar Arrays, Boost Converters and Inverters. From the convenience of the general power system, the user can be able to control and monitor the power delivered from the solar. The property and availability of the land and equipment makes this kind of power system useful and powerful.

The main objective is to increase the output voltage level and lesser % of THD. H-bridge multilevel inverters results were tested, and results were compared between 5, 7 and 9 level inverters with different duty ratios and their fundamental voltages. As the level of multilevel inverter increases, fundamental voltage increases and lesser the % of THD. So, the proposed perception is reliable and ease of control of electrical power. It also has wide range of applications in commercial and industrial areas. Found to be well suitable for PV applications.

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