Design and implementation of photovoltaic module using multilevel inverter and boost converter

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Abstract- *This paper presents the design of photovoltaic module, where the panel is constructed by series and parallel connection of solar cell. The power obtained from the solar panel is boosted up by feeding it to dual stage boost converter and then the output is fed to multilevel cascaded H-bridge inverters. The utilization of multilevel inverter in power electronics has been increased since last decades. Multilevel cascaded H-bridge inverters have high conversion efficiency, easily interfaced with renewable energy sources such as solar panel. In this paper comparisons have been made of THD of voltage waveform obtained from 3,5,7,9 and 11 level cascaded H-bridge inverter, using shifted pulses technique for switching. Also comparisons has been made of THD of sinusoidal voltage waveform obtained from T-LCL type LPF filter used for 3,5,7,9 and 11 level inverters to get voltage with minimum harmonics. This paper demonstrates that as the level of cascaded H-bridge inverter used increases the Total Harmonic Distortion (THD) decreases.*

Key Words: Cascaded H-bridge multilevel inverter (CHB), Solar Panel, Dual Stage Boost Converter, Total Harmonic Distortion (THD), Prototype LPF Filter.

I. INTRODUCTION

With the increasing demand of energy the focus is shifting towards the use of conventional sources. Solar energy is the most readily available form of energy. It is the most important form of non-conventional energy because it is nonpolluting and thus helps in reducing greenhouse effect. It is also free of cost. It can be harnessed and used for different purposes with help of solar panel. Solar panel can be constructed by series and parallel connection of solar cells. They produce electricity due to quantum mechanical process known as "photovoltaic effect". The major drawback of these PV modules is their cost is high and efficiency is low. Solar power system requires DC-DC dual stage boost converter to increase the voltage level and reduce the cost of solar array to deliver the required power to the electrical grid system followed by multilevel inverters and LPF filters, to get sinusoidal voltage waveform so that system can remain in synchronization.

Here a complete design of solar power system in open loop has been done to feed required power in grid system with appropriate number of solar module connected in series and parallel .Also different level of inverters have been used to reduce the harmonics and filter, to achieve sinusoidal waveform of appropriate frequency for feeding energy in grid.

Different studies have been conducted regarding feeding energy harnessed by solar array to grid system. Also research is going on how to become more dependent on renewable energy sources by connecting the solar power plants to power grid in close loop system with more efficiently, minimum cost and minimum harmonics in voltage.

II. SOLAR POWER SYSTEM.

Considering the increasing demand of electrical energy day by day throughout the world and people's more dependency on conventional energy sources which will not last for longer time, a simple module of solar power system consisting of solar arrays, a dual stage boost converter to boost up the voltage level obtained from solar modules, inverters of different level to reduce the harmonics and low pass filter to achieve sinusoidal waveform has been introduced here.

III. COMPONENTS OF SOLAR POWER SYSTEM.

The major components of solar power system are:-

Solar PV Array

Solar array consists of solar module connected in series and parallel. A single solar module is constructed with a number of cells depending upon the capacity of module. The cells operate at a low voltage, ranging from less than 1V (PV cell) to 3 or 4V (Li-Ion cell).These low voltages do not interface well to existing high power systems, so the solar cells are series connected to create a battery or a PV module with a higher voltage terminal. [1-2].The output power of solar array depends upon solar irradiance (in KW/sq.), cell temperature and area of array. Here total 4 modules have been used (2-2 connected in series and then in parallel) each having 36 solar cells and Irradiance 675 kW/m^2 has been taken. The rating of solar panel is tabulated in Table I.

Table I: Solar Panel Rating

Voltage	36.0 V
Current	9.02 A
Power	325 Watt
Irradiance	675 W/m^2

Dual Stage Boost Converter

A DC-DC converter converts DC voltage from one level to another by storing input energy momentarily and then releasing that energy at a different voltage. The energy is stored either in electric field component or magnetic field component.[3] In this paper boost converter is used to amplify the output voltage of solar panel.

Boost converter steps up the voltage to a desired value without the use of a transformer. The main components of boost converter are a diode, inductor and a high frequency switch. The output can be controlled by varying the duty ratio. The components are designed based on input voltage, output voltage and current, ripple. The assumptions to be considered while designing boost converters are: [4]

1. All the elements are ideal and current is assumed to be continuous.

2. Supply voltage is constant.

3. The converter operates at high switching frequency.

The advantage of using boost converter over transformer is that transformer is bulky while converter is light in weight. [3] The output voltage of solar array is fed to the converter to get the voltage at much more level. In this panel output of 326V is obtained from an input of 36V.The circuit diagram of boost converter is shown in Fig.1-

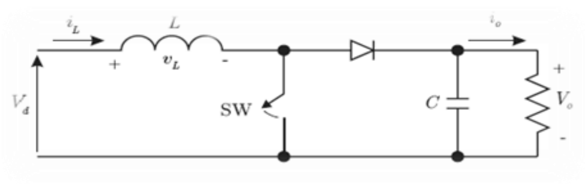

Fig.1: Boost Converter

The value of various parameters of dual stage boost converter is calculated by the following formulae: [3-4]

$$L=V_{in}(V_o-V_{in})/(F_s*\Delta I*V_o)$$

$$C=(I_{out}*D)/(F_s*\Delta V)$$

The values of different parameters for 1st stage boost converter are given in table II and for 2nd stage in table III.

Table II: Design Parameters for 1st Stage DC-DC Boost Converter

Input Voltage, V_{in} (O/P Of Solar Array)	36 V
Output Voltage, V_{out}	85 V
Switching Frequency, F_s	25 kHz
Duty Cycle, D	0.58
Resistance, R	20 Ω
Output Current, I_{Out}	4.25 A
Current Ripple, ΔI	20% of I_{out} = 0.85 A
Voltage Ripple, ΔV	0.144% of Vo=0.1224 V
Inductance, L	0.977 mH
Capacitance, C	0.805mF

Table III: Design Parameters for 2nd Stage DC-DC Boost Converter

Input Voltage, V_{in}(O/P Of 1st Stage Boost)	85 V
Output Voltage, V_{out}	326 V
Switching Frequency, F_s	25 kHz
Duty Cycle, D	0.74
Resistance, R	30 Ω
Output Current, I_{out}	10.87 A
Current Ripple, ΔI	20% of I_{out}=2.17 A
Voltage Ripple, ΔV	0.50% OF Vo =1.63 V
Inductance, L	1.158 mH
Capacitance, C	0.197

Cascaded H-Bridge Multilevel Inverter

Multilevel Inverter achieves high power ratings and also enables the use of renewable energy sources. Renewable energy sources such as Photovoltaic can be easily interfaced to a multilevel converter system for high power applications.

The concept of multilevel converter has been introduced since 1975.Multilevel starts with three (3)-level inverter. Then by cascaded connection of 3-level H-bridge inverters and giving them switching pulses at appropriate firing angle to reduce the harmonics , higher level such as 5,7,9 and 11 level inverter can be obtained.[5-6]

Some important features of multilevel inverter are as followings:-

i) The voltage waveform obtained from cascaded H-bridge inverters is staircase. And as the level of inverters increases, total harmonic distortion (THD) decreases.

ii) Also they can draw input current with low distortion. [5-7]

The 3-level, H-bridge inverter with four power electronic switches (IGBT) has been shown in fig.2:

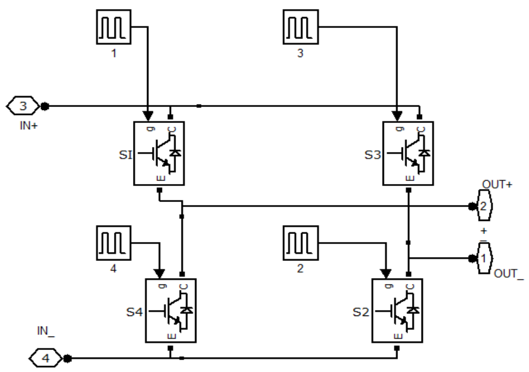

Fig.2: 3-Level H-Bridge Inverter.

If V is the input then output voltage will be obtain in 3-level like V, 0 and –V. Switching pattern of the switches is shown in the table IV:

Table IV- Switching Sequence for 3-Level Inverter

Switches Turn On	Voltage
S1 ,S2	+V
S1,S3 OR S2,S4	0
S3,S4	-V

If S1 is fired at 0 degree then S2, S3 and S4 will be fired at 90,180 and 270 degree respectively to get 3 level staircase output with minimum harmonic. [6-9]

Phase delay of the pulses can be calculated from this formula:-

Delay time (t) = [(firing angle)]/[360*output frequency]

Corresponding delay time for 3- level H-bridge inverter is calculated and given in the table V

Table V- Firing Angle for 3-Level Inverter

Switches	Firing Angle (Degree)	Time Delay (Sec)
S1	0	0
S2	90	0.005
S3	180	0.010
S4	270	0.015

The circuit for 5-level inverter is obtained by cascaded connection of two 3 level inverter and the output voltage will be of 5-level that is (V2+V1), V2, 0, V1 and - (V2+V1).The circuit is shown below in the fig.3

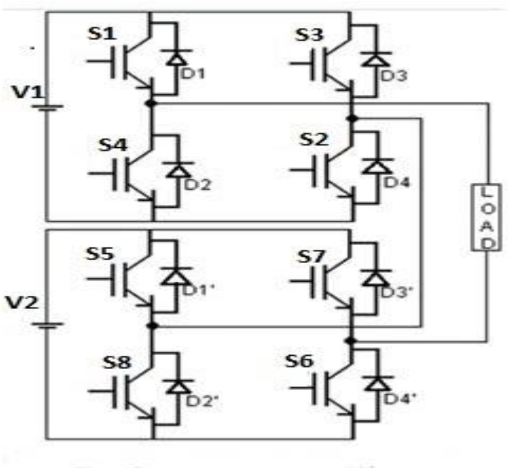

Fig.3: 5-Level Cascaded H-Bridge Inverter

The switching pattern of the switches to get 5-level is maintained in the table VI.

Table VI: Switching Sequence for 5-Level Inverter

Switches Turn On	Voltage
S1,S2,S6,S8	V2
S1,S2,S5,S6	(V2+V1)
S5,S4,S2,S6	V1
S3,S4,S7,S8	-(V2+V1)
S1,S3,S6,S8	0

To calculate the firing angle it is assumed that V1=V2.Firing angle and corresponding time delay for the switches is also calculated and maintained in the table VII.

Table VII: Firing Angle for 5-Level Inverter

S.No.	Switches	Firing Angle (degree)	Time Delay (sec)
1	S1	0	0
2	S2	90	0.0050
3	S3	180	0.0100
4	S4	270	0.0150
5	S5	45	0.0025
6	S6	135	0.0075
7	S7	225	0.0125
8	S8	315	0.0175

Similarly 7, 9 and 11 level inverters are obtained by cascade connection of three, four and five 3-level H-bridge inverter respectively.

T-LCL Type Filters

Filters are frequently used in numerous fields for selecting a particular band or frequency from a wide range of frequency spectrum. Here prototype low pass filter has been used to eliminate the undesired frequency component resulting from thyristor controlled circuits also to reduce the harmonics. [3]

For designing of the parameter, we have assumed the Design Resistance Ro =20 ohm, and cut off frequency 50 Hz.

Since,

Ro= √(L/C);…………………………………………(i)
Fc =[(1/Π)]/√ t(L*C)…………………………(ii)

From equation (i) and (ii) we get

Inductance L=(Ro/Π)/(fc)
Capacitance C=1/(Π*Ro*fc)

The circuit diagram of T-LCL type filter is shown in fig 4

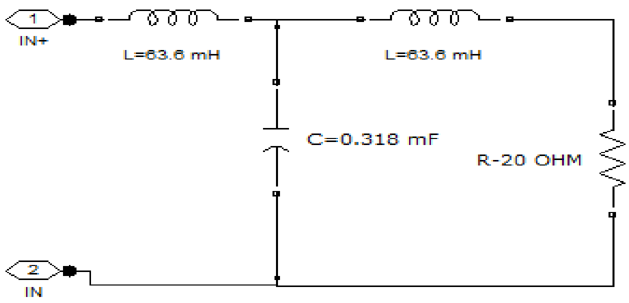

Fig.4: T-LCL Type Prototype Filter

The complete block diagram of the whole system is shown in fig.5

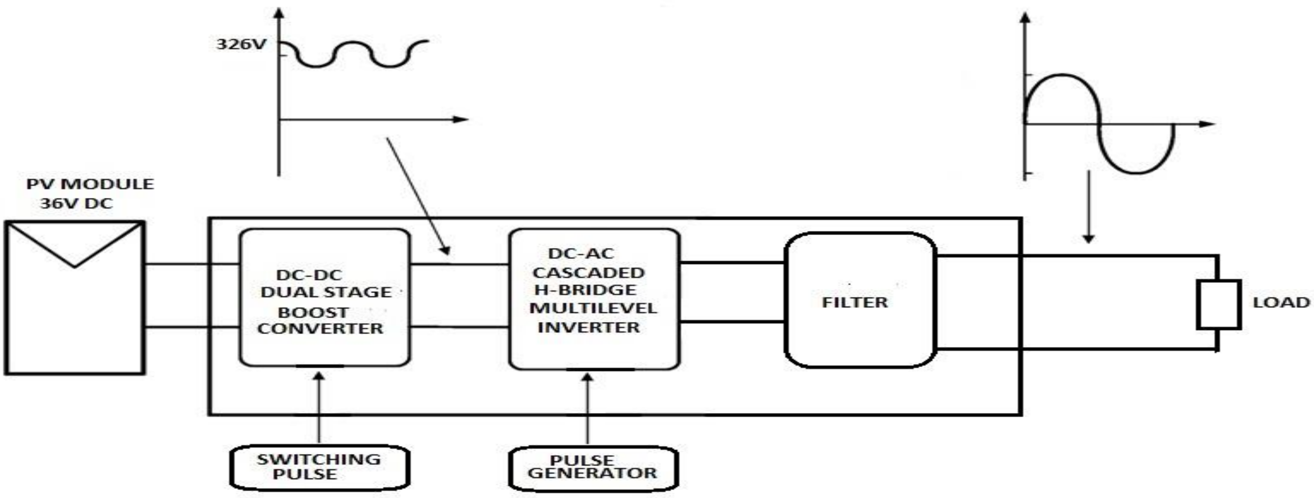

Fig 5: Complete solar power system in open loop with DC–DC dual stage boost converter and cascaded H-bridge multilevel inverter.

IV. SIMULATION RESULTS

The results of simulation for different level are as shown in the figures

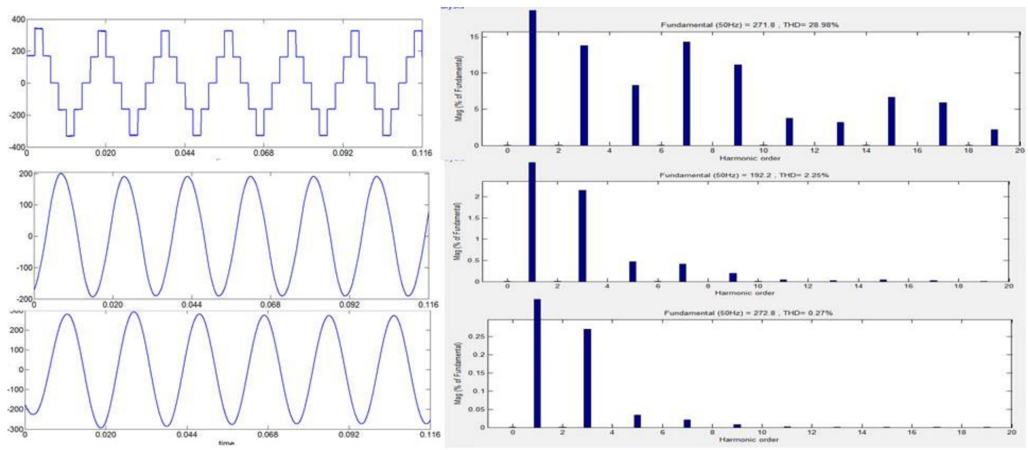

Fig. 6: Output waveforms and corresponding THD analysis of 5-level inverter

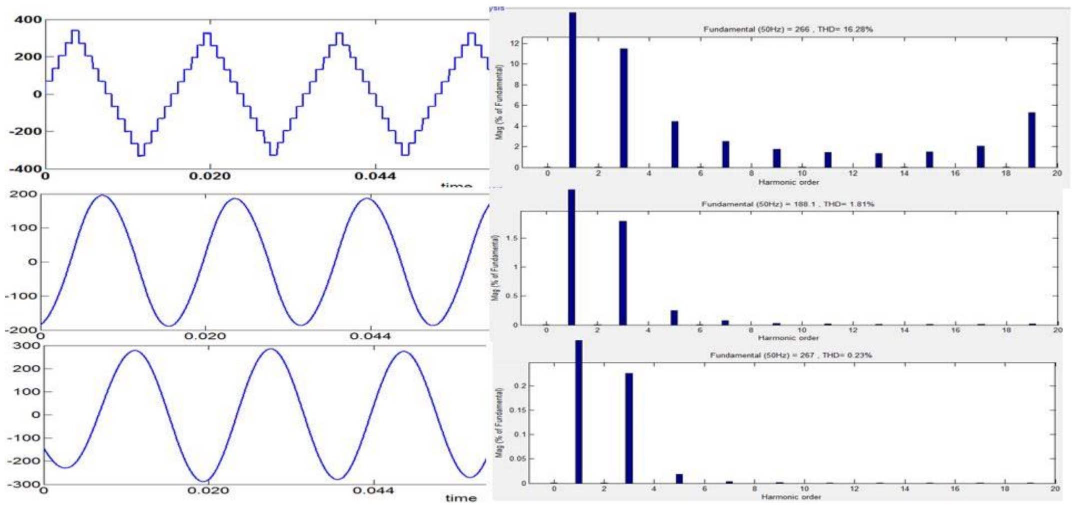

Fig. 7: Output waveforms and corresponding THD analysis of 11-level inverter

Table VIII: THD Analysis of Different Waveforms Obtained From Different Levels of Inverter

Total Harmonic Distortion			
Levels of Inverters	**Waveforms**		
	Staircase(O/P Of Inverter)	**Sinusoidal(O/P Of 2nd Order Active Filter)**	**Sinusoidal(O/P Of T-LCL Passive Filter)**
3RD	48.34%	5.35%	0.66%
5TH	28.96%	2.25%	0.27%
7TH	21.64%	1.87%	0.25%
9TH	18.17%	1.85%	0.23%
11TH	16.28%	1.81%	0.23%

V. CONCLUSION

In this paper solar panel output is boosted by dual stage boost converter and cascaded H-bridge inverters are used to convert DC output of boost converter to AC. The comparative THD analysis of a single phase cascaded H-bridge multilevel inverter is performed using shifted pulse technique. The results of simulation show that as the level increases THD decreases. Harmonics is reduced by the use of second order filter and T-LCL filter. The use of T-LCL filter reduces the THD to a greater extent and hence T-LCL is more efficient than active filter. Thus multilevel inverter improves output voltage, reduces output total harmonic distortion and voltage stress on semiconductors switches.

VI. REFERENCES

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