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Performance Analysis of Seven Level Multilevel Inverter Using Renewable Energy Systems

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Abstract - **With the increasing concerns on energy issues, the development of renewable energy sources is becoming more and more attractive. A new kind of wind-PV hybrid generated system that comprises of wind and photovoltaic generation subsystems as input to a cascaded H-bridge multilevel inverter is developed in this paper. In conventional methods the inverter with solar and wind energy sources are used. In this method a seven level multilevel inverter with wind–PV hybrid generation system as input are proposed for application to remote and isolated areas. The wind and the solar light are captured in greatest degree, as well as the multilevel inverter using pulse width modulation technique is adopted. The objectives of this hybrid system are, to satisfy the load power demand and, presence of high number of output levels in inverter to maintain the dc output voltage level of the inverter to produce a nearly sinusoidal output. This reduces harmonics in inverter output voltage. This paper discusses about the control of seven-level H-bridge cascaded multilevel inverter with Fast Fourier Transform analysis in inverter output voltage through simulation. The simulated wind-PV system consists of an AC-to-DC boost converter, a DC-to-AC inverter, a photovoltaic module, and wind module. Its shown by the simulations that a multilevel inverter utilizing renewable resource has lower Total Harmonics Distortion in output voltage. In this paper comparison of conventional inverter and proposed seven level cascaded H-bridge multilevel inverter using solar and wind energy sources are presented.**

Keywords-**Harmonics, MATLAB, Pulse Width Modulation (PWM), PhotoVoltaic array (PV), Wind Turbine**

I. Introduction

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronic techniques. Solar technologies tap directly into the infinite power of the sun and use that energy to produce heat,light and power. Wind is one of the most environment friendly, clean and safe energy resources.

The development of solar power generation should be integrated with that of the wind power generation systems since both forms of renewable energy have inherently random property and they can compensate the lack of energy for each other. Hence, the hybrid wind -PV power system therefore has higher reliability to deliver continuous power than either individual source.

Usually, two separated inverters for the PV array and the wind turbine are used for the hybrid wind-PV power system. An alternative approach is to use the multilevel inverter for combining these renewable energy sources in the dc end instead of the ac end. It can simplify the hybrid wind-PV power system and reduce the costs. This paper is focused on hybrid inter connection of solar and wind source for seven level multilevel inverter control.

II. Conventional Inverter Topology

The general structure of the inverter for single phase output is shown in Figure 1and the output voltage of the inverter is shown in Figure 2. The voltage source V_{dc1} connected as shown in Figure1 and this circuit consists of four active switching elements that can make the output voltage source in positive or negative polarity; or it can be simply zero volts depending on the switching condition of the switches in the circuit [1-3]. A conventional inverter topology employs multiple link voltage of equal magnitudes. It is fairly easy to generalize the number of distinct levels.

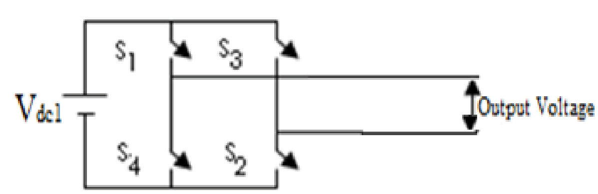

Fig. 1 Topology for conventional inverter

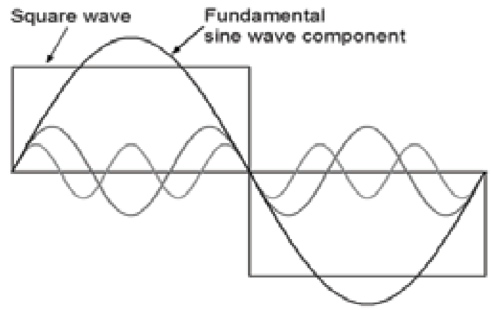

Fig. 2 Output voltage of conventional inverter

III. Proposed Multilevel Inverter Topology

The proposed seven level multilevel inverter block with wind and photovoltaic generation systems as input sources block diagram is shown in Figure 3. The block diagram consists of a boost DC–DC converter and a full bridge DC–AC inverter. The DC-DC converter can draw maximum power from both the PV array and the wind turbine. Diode rectifier is used at the wind output to convert ac power obtained from wind module into dc power to be fed to the DC-DC converter. Two cascaded H-bridge inverters are used. Each H-bridge is a standalone bridge with the necessary signal conditioning/ processing circuitry and gate drivers.

Traditionally, each phase of a cascaded multilevel inverter requires *n* dc sources for 2*n* + 1 level, where n is the number dc sources. This paper allows the use of a single dc source such as solar cell as the first dc source with the remaining dc source being wind for the cascaded H-bridges multilevel inverter. Seven level output voltage will be regulated by the DC/AC inverter. Multilevel inverter is powered by wind-PV and is capable of achieving seven level stepped output phase voltage with a refined harmonic profile. The output waveform quality will be improved due to the increased number of levels. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of electromagnetic interference EMI generated by switching operation of the inverter.

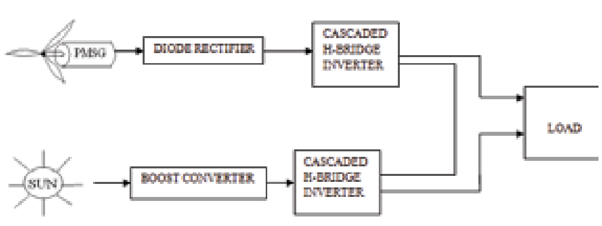

Fig. 3 Block Diagram of Seven Level Multilevel Inverter with PV and Wind as Input Sources

III. Design Of Systems

The most frequent combination of renewable energy sources for electric power supply is wind and solar energy source. They are used since they are environment friendly and they can replace non renewable energies like oil and coal.

A. Design of Solar Cell

Solar cells produce current when sunlight irradiates on them. In this paper the solar cell is simulated for any ambient temperature, sun light intensity and other internal parameters. An equivalent circuit is developed for easy analysis of solar cell [4]. The equivalent model is shown in Figure 4.

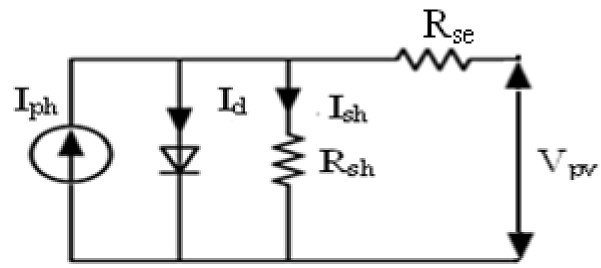

Fig. 4 Equivalent Circuit of a Solar Cell

From the equivalent circuit, the current produced by the solar cell is given by,

$$I = I_L - I_D - I_{SH} \quad (1)$$

where,

I = Output current (Amperes)
I_L = Photo generated current (Amperes)
I_D = Diode current (Amperes)
I_{SH} = Shunt current (Amperes)

The current through these elements is governed by the voltage across them,

$$V_j = V + IR_S \quad (2)$$

where,

V_j = Voltage across both diode and resistor R_{SH} (Volts)

V = Voltage across the output terminals (Volts)

I = Output current (Amperes)

R_S =Series resistance (Ω)

By the Shockley diode equation, the current diverted through the diode is,

$$I_D = I_O\left\{\exp\left[\frac{qV_j}{nkT}\right] - 1\right\} \quad (3)$$

where,

I_0 = Reverse saturation current (Amperes)

n = Diode ideality factor (1 for an ideal diode)

q = Elementary charge

k = Boltzmann's constant

T = Absolute temperature

By Ohm's law, the current diverted through the shunt resistor is,

$$I_{SH} = \frac{V_j}{R_{SH}} \quad (4)$$

Substituting these into the Equation 1 produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage,

$$I = I_L - I_O\left\{\exp\left[\frac{q[V+IR_S]}{nkT}\right] - 1\right\} - \frac{V+IR_S}{R_{SH}} \quad (5)$$

B. Design of Wind Turbine

A wind turbine is used to convert the linear motion of the wind into rotational energy that can be used to drive a generator. Wind turbines capture the power from the wind by means of blades and convert it into rotating mechanical power. These turbines require an average wind speed of about 2.5 m/s to 30 m/s velocity to generate power. The rotor is used to control the amount of energy extracted from the wind stream. Turbines cannot operate at wind speeds above 25 m/s because the generators could overheat. In this proposed system single phase Induction Generator (IG) is used to extract power from wind [5-9].

The theoretical available power from the wind is defined by the following equations,

$$P_r = \frac{1}{2}\rho s v^3$$

$$s = \pi R^2 \quad (6)$$

where

ρ is the air density in kg/m3,

s is the surface swept in meter,

υ is the speed of the wind in meter per second

R is the windmill radius in meter,

P is the total power available from wind in Watts

C. Design of DC-DC Converter

DC-DC boost converter is used for transferring power from the photovoltaic (PV) modules to a battery. By changing the duty cycle of switches in converter, the output voltage is regulated [10]. The circuit diagram of this converter is given in Figure 5.

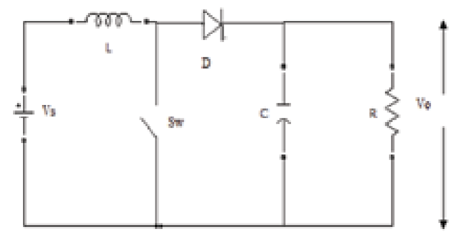

Fig. 5 Equivalent Circuit of Boost Converter

Open loop configuration of DC-DC converter will always result in poor efficiency. Hence instantaneously the output of the converter is measured and with an given reference, and the duty cycle of the switch should be changed. Hence for this digital controllers are most commonly used.

The boost converter is designed for boost mode of operation with solar cell voltage as input source. For open loop simulation the input voltage to the boost converter is taken from the solar cell. At the output of converter regulated voltage will be obtained. The duty cycle of the converter switch is calculated using the formula,

Output Voltage Vo=Vs/(1-D) (7)

where,

D =Duty Ratio

Vo=output voltage(volts)

Vs=input voltage(volts)

D. Seven Level Cascaded H-bridge Multilevel Inverter Configuration

The general structure of the cascaded H-bridge multilevel inverter for single phase stepped output is shown in Figure 6. Each of the separate voltage source V_{dc1}, V_{dc2} connected in cascade configuration. A conventional multilevel inverter topology employs multiple voltage levels of equal magnitudes [11-13].

The S number of stages or dc source and the associated number output level can be written as follows

$$N_{level} = 2^{S+1} - 1 \quad (8)$$

For example S=2, the output waveform has 7 levels (±7, ±6, ±5, ±4, ±3, ±2, ±1 and 0). The voltage on each stage can be calculated by using the equation,

$$V=2^{S-1}.V_{dc}(S=1, 2, 3……n.) \quad (9)$$

The number of switches used in this topology is expressed as,

$$N_{switch}=4\,S \quad (10)$$

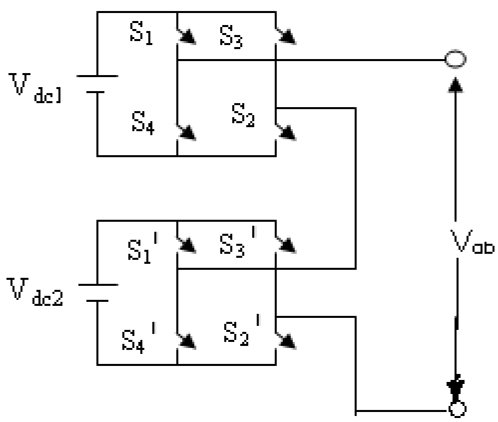

Fig. 6 Topology for Hybrid Multilevel Inverter

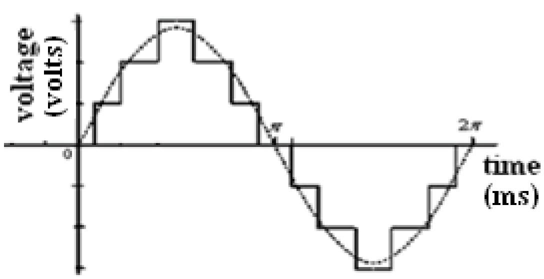

Fig. 7 Typical Output Voltage Waveform of Seven Level H-bridge Multilevel Inverter

Figure 7 shows the typical output voltage waveform of a seven level hybrid multilevel inverter with two separate dc sources.

D.1 Control Circuit

The basic operation is when S_1 is turned on (S_2 and S_3 turn off) the output voltage is $+1V_{dc,}$ when S_2 is turned on (S_1 and S_3 turn off) produces the output of $+2V_{dc}$. Similarly other step output can be achieved by turning on the suitable switches at particular intervals. Table I shows the basic operation of proposed hybrid multilevel inverter.

TABLE I SWITCHING SCHEME FOR SEVEN LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER

S_1	S_2	S_3	S_4	S_1'	S_2'	S_3'	S_4'	V_{OUT}
1	0	0	1	1	0	0	0	1V
1	1	0	0	1	0	0	1	2V
1	0	0	1	1	0	0	1	3V
0	0	0	0	0	0	0	0	0V
0	1	1	0	0	0	1	1	-1V
0	0	1	1	0	1	1	0	-2V
0	1	1	0	0	1	1	0	-3V

where,
0 - OFF
1 - ON

D.2 Load

The seven level cascaded H-bridge multilevel inverter output is fed to a resistive load [11]. The resistive load has a resistance value which is set to get the required single phase output of seven level cascaded multilevel inverter.

IV. COMPARISON OF PROPOSED TOPOLOGY WITH CONVENTIONAL TOPOLOGY

The proposed simulation model consists of block diagram, MATLAB program and simulation model of cascaded seven level multilevel inverter. The block diagram describes the solar and wind input voltage block, output circuit block and also the switching device for cascaded H-bridge inverter. Pulse width modulation (PWM) strategies are used in a conventional inverter.

In this paper a novel multilevel inverter for the resistive load connected hybrid wind-PV power system is proposed in order to simplify the power system and reduce the cost. The multilevel inverter produce a seven level stepped output phase voltage with a refined harmonic profile. These multilevel inverter is powered by wind-PV and is capable of achieving seven level output. Due to the increased number of levels the output waveform quality is improved. A new wind–PV hybrid generation system for remote or isolated areas is proposed. And this new wind–PV hybrid generation system reduces the costs of energy. Simulation results will show the performance of the proposed and the conventional seven level multilevel inverter with desired features and they are shown in Figure 8 and Figure 9.

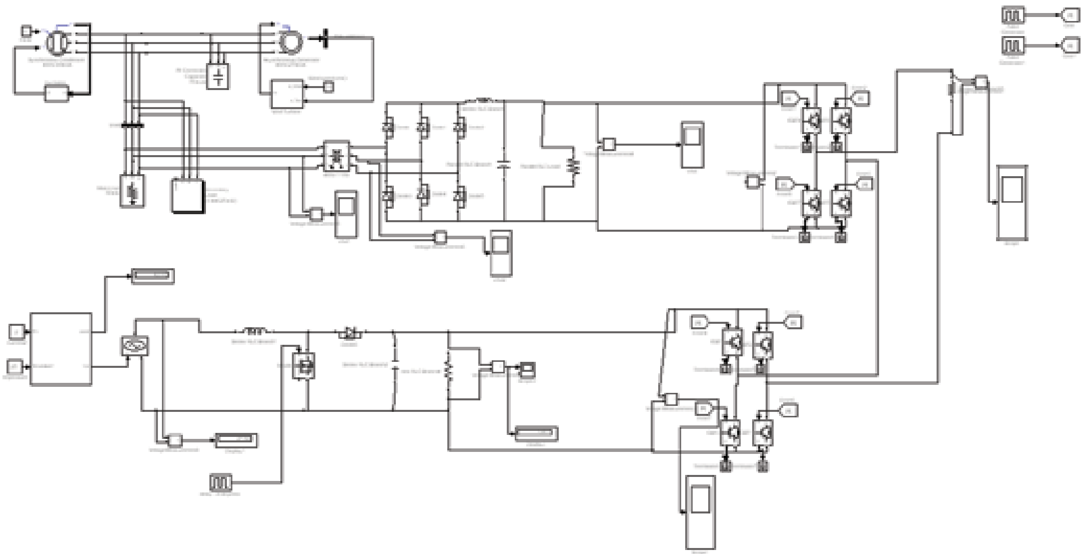

Fig. 8 Conventional Multilevel Inverter Circuit

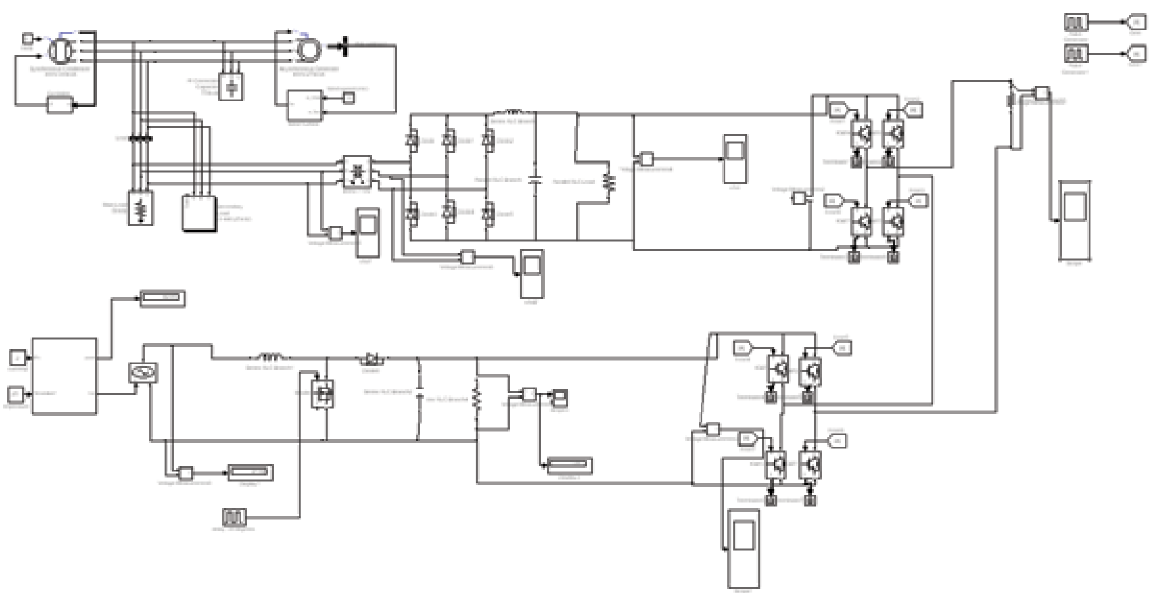

Fig. 9 Proposed Multilevel Inverter Circuit

A. Simulated Output of Boost Converter

In the case of boost converter the output is higher than the input. Whenever the IGBT is turned on energy is stored on the boost inductor. When the IGBT is turned off the voltage across the inductor reverses and adds to the input voltage to charge the output capacitor.

The output of boost converter is shown in Figure 10. Boost converter is used for wind installation system. The output of wind system is given to the boost converter. The output voltage varies with the input voltage. And this converter has advantages like reduced hardware and good output voltage regulation.

B. Simulated Output of Solar Energy System

The simplest model of a PV cell consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons, and its output is constant under constant temperature and constant incident radiation of light [14].

The output of the solar cells is shown in Figure 11.

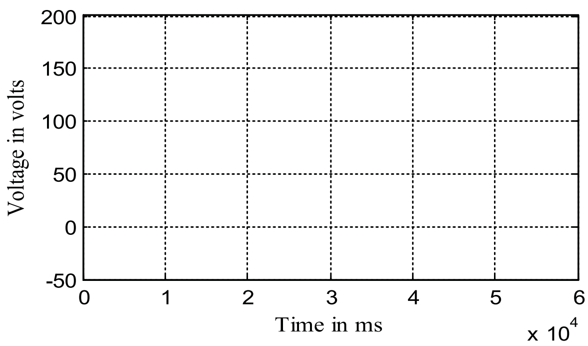

Fig. 10 Output of Boost Converter

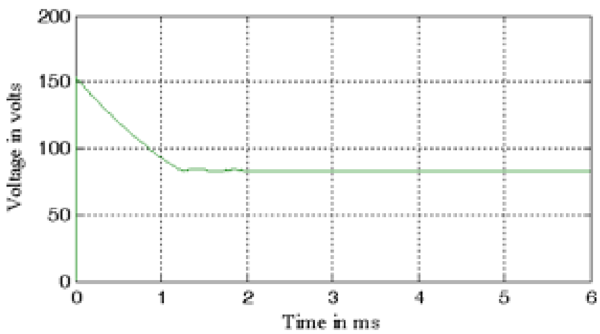

Fig. 11 Output of Solar Energy System

C. *Simulated Output of Wind Energy System*

The wind simulation model using Matlab / Simulink software comprises of the stator model, the rotor model, flux model and torque model. The amount of the wind power obtained by the vane is proportional to the cube of the wind speed. The output of wind energy system is shown in Figure 12 and Figure 13.

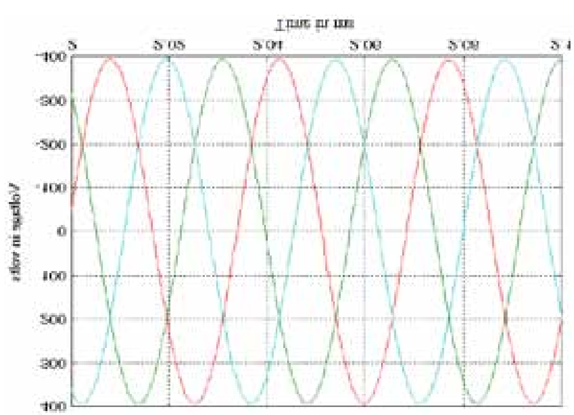

Fig. 12 Simulated Current Output at 10 m/s of Wind Energy System

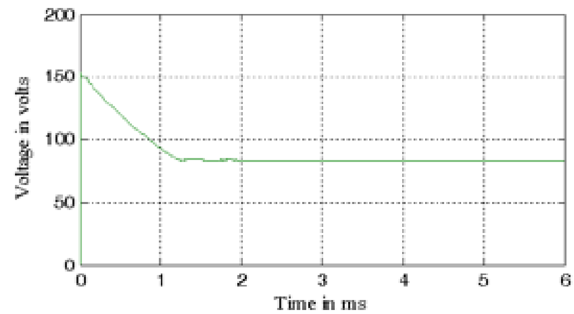

Fig. 13 Simulated Voltage Output of Wind Energy System after rectification at 10 m/s

D. Simulated Output of Conventional Inverter

The conventional inverter has been developed by using MATLAB, to operate a inverter using a solar and wind energy source and the single phase stepped output voltage is obtained [15].

The output of inverter is shown in Figure 14. The output voltage has one level. The total harmonic distortion of the inverter at fundamental frequency of 50 HZ is shown in Figure 15.

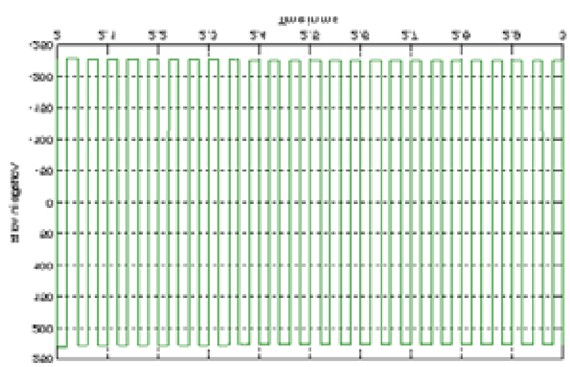

Fig. 14 Simulated Voltage Output of Conventional Cascaded H-Bridge Inverter

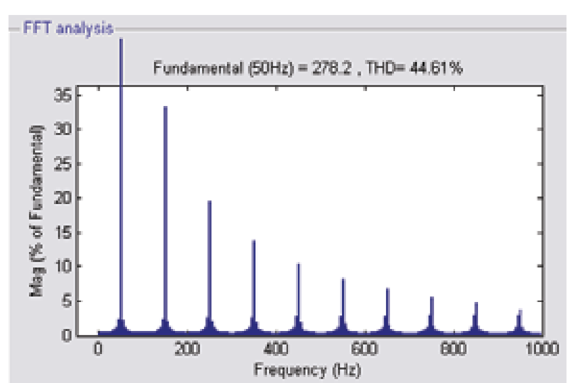

Fig. 15 Total Harmonic Distortion of Conventional Cascaded H-Bridge Inverter

E. Proposed Cascaded H-Bridge Multilevel Inverter

The seven level multilevel inverter has been developed by using MATLAB, to operate a cascaded multilevel inverter using a solar and wind source [16]. Considering a cascaded multilevel inverter with two H-bridges, the seven level stepped output voltage is obtained [17].

Simulation model of seven level cascaded multilevel inverter consists of pulse generator block which generates square wave pulses at regular intervals. The output of cascaded H-bridge seven level multilevel inverter is shown in Figure 16. The total harmonic distortion of the inverter at fundamental frequency of 50 HZ is shown in Figure 17.

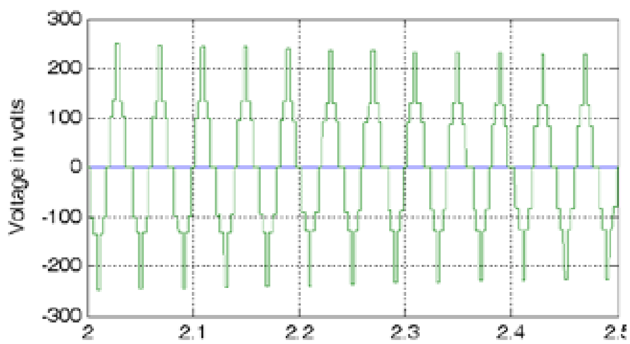

Fig. 16 Simulated Voltage Output of Proposed Cascaded H-Bridge Inverter

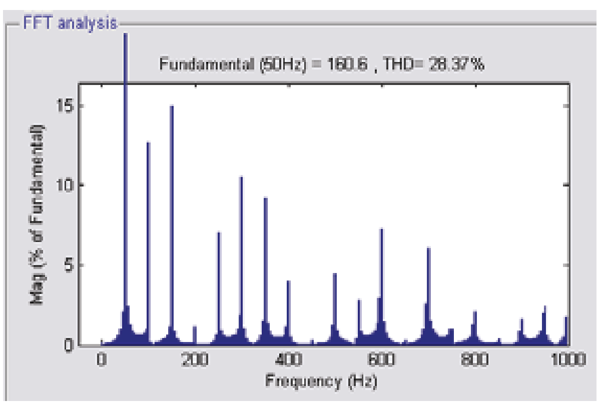

Fig. 17 Total Harmonic Distortion of Conventional Cascaded H-Bridge Inverter

V. Comparison In Thd

Table 1 Total Harmonic Distortion of Conventional and Proposed Method

Types of Inverter	Total Harmonic Distortion in %
Inverter with solar and wind sources	44.61
Cascaded H-bridge multilevel inverter with solar and wind energy sources	28.37

VI. Conclusion

In this paper seven level cascaded H-bridge multilevel inverter is used to get sinusoidal stepped output waveform and this also reduces harmonics in output voltage. The seven level cascaded H-bridge multilevel inverter fed by solar and wind energy source have been illustrated in simulation results by using MATLAB. PWM technique is used to improve the level of the inverter and extend the design flexibility and reduce the harmonics. The proposed control scheme have been verified analytically and demonstrated through simulation. In developing countries like India, wind power in combination with solar power can play more substantial role to dramatically improve the lifestyle of people in remote areas. In such remote or isolated areas, this stand-alone wind–PV hybrid generation system is particularly valuable and attractive. Since the cost of conventional energy resources are increasing every year, this system is going to be economical in future. Besides the cost, the environmental benefits are likely to facilitate the widespread use and acceptance of this system. Thus the above proposed system is reliable and economical for remote applications.

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