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Hybrid Multilevel Inverter Topology with an Independent Control for Photovoltaic System

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ABSTRACT*:* The paper describes a high efficiency photovoltaic system using a hybrid multilevel inverter circuit with multi-string boost converter topology. The proposed inverter circuit is built by connecting a line-frequency three-phase bridge inverter in series with three high-frequency single-phase H-bridge inverters. The multi-string topology with separate MPPT control achieves maximum power available from the PV which maximizes the efficiency. This inverter circuit can achieve high efficiency and low harmonics and it can reduce the voltage stress on the power switches. Since the circuit is modularized and having independent voltage control, it can be controlled easily. This paper includes the study of photovoltaic system with independent MPPT control, inverter topology, principle of operation, switching states and its control circuit design. Simulation of a three phase proposed inverter with multistring boost converter photo-voltaic system is carried out using MATLAB-Simulink software and the result shows the viability of the proposed topology.

Keywords*:* Multilevel Inverter, Photo Voltaic (PV) Cell, Multi-String Topology, Cascaded multilevel inverter

I. INTRODUCTION

Electrical energy crisis is an important issue. Inorder to overcome, renewable energy particularly solar and wind has been the certain choice. Solar energy is one of the favourable renewable energy source due to its distinctive advantages - simple configuration, easy allocation, free of pollution, no noise, low maintenance cost, etc [1]. Photovoltaic (PV) generation is the technique which uses photovoltaic cell to convert solar energy to electric energy. Different types of photovoltaic system are available-centralized topology, string topology and multi-string topology. Centralized inverter topology is simple and provides connections in series and parallel according to the required voltage and power. But to achieve high power demand purpose, we need large space requirements; connections provide to the PV system become complex and high rating equipments are necessary. One of the important limitations is the single control for the whole photo-voltaic system. This paved the way for the string inverter topology. It is not possible to extend the rated power of single strings by connecting more PV modules to the PV strings. So the next step in the evolution of string inverter topology is multistring inverters. It is considered as the state of art. Multistring topology is the symbiosis of two main competitors in the PV system-the central and string topology [2],[3].

A step-up converter is used for voltage amplification and regulation purpose. To attain the maximum power from a PV system, MPPT tracker is inevitable. By using multi-string inverter topology separate MPPT tracking can be possible. Different MPPT tracking algorithms are present- Perturb and Observe method (P&O), incremental conductance method (INCond.), feedback voltage or current, fuzzy logic method and neural network method [4]-[6]. P&O method is widely applied in the MPPT controllers due to their simplicity and easy implementation.

An inverter which is an important element in the PV system is used to convert dc power from the solar panels into ac power. The performance of the power inverter depends on the control strategy adopted to generate the gate pulses. Multilevel inverters have gained much attention in the field of medium voltage and high power applications due to their many advantages, such as low voltage stress on power semiconductor, low harmonic distortions, good electromagnetic compatibility, reduced switching losses and improved reliability on fault tolerance. Multilevel inverter is useful to reduce the cost and size of power filter. Such inverter requires several number of dc power sources depending on the number of level and voltage ratio of dc buses. Multiple power sources can be easily be obtained by dividing the photovoltaic modules in groups. As a result, multilevel inverters are becoming increasingly popular in photovoltaic applications. Though, there is a lot of challenge to use multilevel inverter in photovoltaic system. As the number of level of the inverter increases, the number of device also increases. The challenge of using multilevel inverter in

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photovoltaic application is to reduce the number of switches without compromising with power quality (number of levels) [7]-[9].

Different types of multilevel inverters have been studied- diode clamped (neutral clamped) inverter, flying capacitor (capacitor clamped) inverter and cascaded inverter with separate dc source [4],[5],[7]. Compared with the other multilevel inverters, cascaded multilevel inverter has lower total harmonic distortion; it requires only less number of components comparative to the diode clamped or the flying capacitor. In addition, dc sources can be added or subtracted which can increase the number of output levels. But it needed separate H-bridge according to the increase in output voltage levels. So the number of switching devices required is more. In effect the switching losses are more, efficiency is reduced, and expense and complexity is increased. Hence a novel cascaded multilevel inverter topology is introduced.

In this paper, the principle of operation of the proposed system and its control part is included in section II. Simulation works of a three phase novel system using MATLAB-Simulink software is included in section III. Conclusions are given in section IV. The analytical and simulated results show the superiority of the proposed system compared with conventional system.

II. PROPOSED SYSTEM & ITS CONTROL STRATEGY

A new inverter topology is introduced with double frequency control for photo-voltaic application. Proposed system shown in fig.1 consists of separate PV strings as DC source and each string is connected to a boost converter. Boost converter reduce the series-connected numbers of PV modules, to maintain a constant dc bus voltage for the inverter utilization, and to decouple and simplify the inverter control design. Since multi-string topology is used the boost converters are connected in parallel. Maximum available power from PV strings is extracted by P & O MPPT algorithm shown in fig.2.

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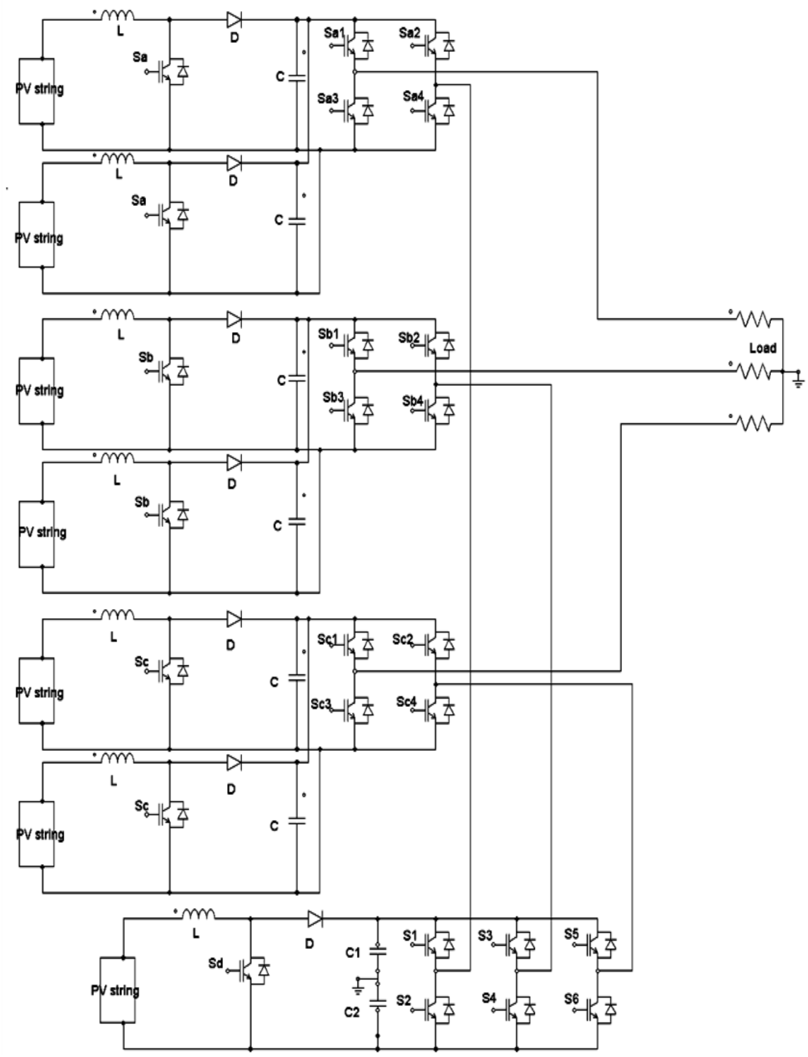

Fig. 1: Proposed inverter

According to the structure of MPPT system shown in fig. 2, the required parameters of the power-feedback type MPPT algorithms are only the voltage and current of PV modules. Power is calculated from the measured voltage and current and algorithm is operated by perturbing (ie. incrementing or decrementing) the array terminal voltage periodically and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. Compared with Incremental Conductance algorithm, Perturb and Observe algorithm is preferred due to its simplicity and easy implementation. Once maximum power attained, then the operating point oscillate around MPP [6],[10]-[13].

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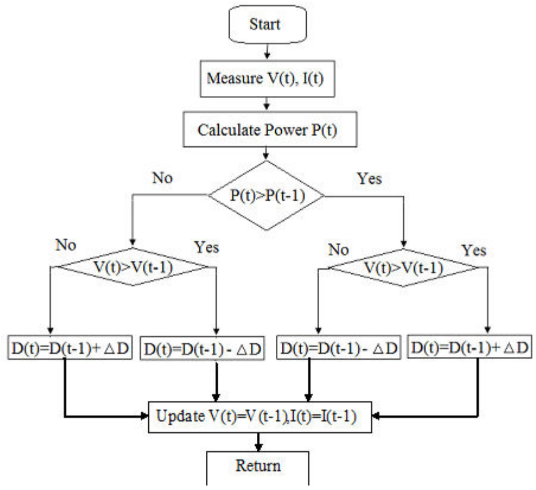

Fig. 2: Flowchart for P& O algorithm

The boosted dc supply [14] is fed to three phase five level novel cascaded H-bridge multilevel inverter. An H-bridge is connected to each leg of the three phase inverter and the output is connected to the load. Three-phase inverter circuit works at line-frequency, which provides the main output power [15]. Since the switches of the three phase inverter work at line frequency, the switching loss is small and the efficiency of output system is high.

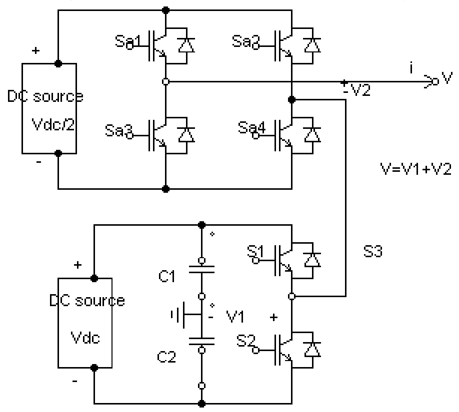

Fig. 3: Single phase structure of proposed inverter [16][17]

Fundamental switching scheme is used to do modulation control for the main inverter and an independent voltage control is used for H-bridges. Considering the figure 3, the switch S1 is ON for positive half cycle produces +Vdc/2 and S2 is ON for negative half cycle which produces-Vdc/2. Similarly other switches in the main inverter conducts for 180 degree in turn in each cycle. For each H-bridge inverter, when Sa1 and Sa4 is ON produces +Vdc/2 and when Sa2 and Sa3 is ON produces –Vdc/2. Main inverter uses dclink voltage to generate a modulated voltage at the output terminals. The total output voltage for proposed inverter is obtained by the sum of each individual output voltage. Thus proposed inverter is able to produce five output voltage levels, such as, +Vdc, +Vdc/2, 0, -Vdc/2 and –Vdc[15][17].

Table I: Output voltages and switching states of single phase structure

Main inverter switches	H-bridge inverter switches	Output voltage
S_1	S_{a2},S_{a3}	0
S_1	S_{a3},S_{a4}	$V_{dc}/2$
S_1	S_{a1},S_{a4}	V_{dc}
S_2	S_{a1},S_{a4}	0
S_2	S_{a1},S_{a2}	$-V_{dc}/2$
S_2	S_{a2},S_{a3}	$-V_{dc}$

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The output voltages attained and the switching sequence are shown in table I. For the same operation in conventional cascaded inverter needed four switches. In proposed inverter topology, only three switches are conducting at a time. Thus the switching losses are reduced. As the number of switches reduced, the efficiency of the system is improved. At the same time distortions are reduced. This will reduce the filter requirements. Since double mode frequency control is carried out, this makes the inverter control simple. The same principle of operation is employed in the other two phases.

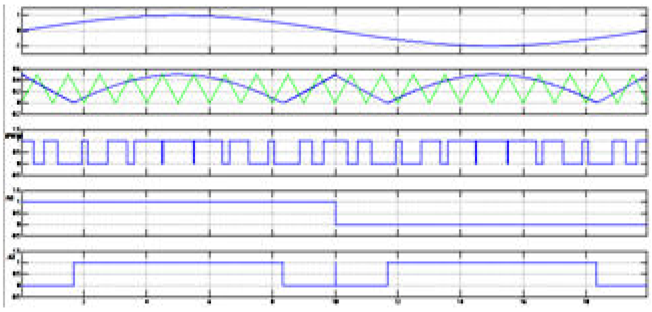

Fig. 4: Modulation signal used to fabricate gate pulses for main and H-bridge inverter

In proposed system, the three phase inverter works at line frequency and at the same time three single-phase H-bridge inverters work at high frequency Consider the fig. 4, the modulating signal shown has to be formed to attain the switching pulses for the proposed inverter and it is obtained from the sinusoidal waveform. The gate pulses for one leg of the main inverter switches S1 and S2 are achieved by comparing the sine wave with a relational operator and obtained the pulse A1 and $\overline{A1}$. The same procedure is repeated for the other two phases. The modulating wave in fig.4 is compared with triangular carrier wave with equal amplitude and frequency and obtains the PWM signal [17]. Also the modulation or reference signal of sinusoidal PWM (SPWM) used for the H-bridge inverter is modified by using following equations (1)-(4) and the multiplexing signals from equation (3) and (4) are used to fabricate PWM signal.

$$f(t) = \mathrm{m_a}\sin(wt) \tag{1}$$

$$\frac{Tp}{Tc} = \begin{cases} 2\left(\frac{1}{2} - f(t)\right) : 0 \le |f(t)| \le \frac{1}{2} \\ 2\left(f(t) - \frac{1}{2}\right) : \frac{1}{2} \le |f(t)| < 1 \end{cases} \tag{2}$$

$$\text{A1}=\begin{cases} 1 : f(t) \ge 0 \\ 0 : f(t) < 0 \end{cases} \tag{3}$$

$$\text{A2}=\begin{cases} 1 : |f(t)| \ge \frac{1}{2} \\ 0 : |f(t)| < \frac{1}{2} \end{cases} \tag{4}$$

Where f(t) is a reference signal.

$\mathrm{m_a}$ is modulating index.

A1 and A2 are multiplexing signals.

$\frac{Tp}{Tc}$ is pulse width of PWM.

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Thus the driving signals for the high frequency switches Sa1, Sa2, Sa3 and Sa4 are obtained as shown in the table II and the switches logic connections are shown in fig.5 [17]. By providing such a control signal to the inverter, the regulation is achieved.

Table II: Fabricated PWM signal for hybrid multilevel inverter [17]

Switches	PWM Mixing Operator
S1	A1
S2	$\overline{A1}$
Sa1	$PWM \bullet ((A2 \bullet A1) + (\overline{A2} \bullet \overline{A1}))$
Sa2	$\overline{PWM} + \overline{((A2 \bullet A1) + (\overline{A2} \bullet \overline{A1}))}$
Sa3	$PWM \bullet \overline{((A2 \bullet A1) + (\overline{A2} \bullet \overline{A1}))}$
Sa4	$\overline{PWM} + ((A2 \bullet A1) + (\overline{A2} \bullet \overline{A1}))$

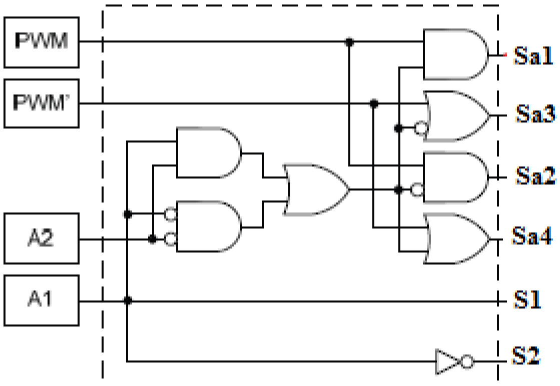

Fig. 5: Logic diagram [17]

III. SIMULATION RESULTS AND ANALYSIS

The Sun Power MSX327, 327W PV module was chosen for modeling and simulation using MATLAB/SimuLink. The module has 96 mono-crystalline cells which are connected in series. The electrical specifications are shown in Table III. The configuration of PV system built in Simulink consists of a set of PV module model, a set of boost converter, MPPT algorithm and PWM generator. Simulation is carried out for three phase system. The inputs of the PV module are the solar irradiance and the ambient temperature.

Table III: Specification of sunpower E20/327model

At temperature	25^0C
Open circuit voltage, V_{oc}	64.9V
Short circuit current, I_{sc}	6.46A
Voltage at maximum power, V_{mpp}	55.87V
Current at maximum power, I_{mpp}	5.85A
Maximum power, MPP	326.8W

The output produced by the PV module is the PV current, which acts as a controlled current source for the input of the boost converter. The input capacitance of the converter is 2.082mF, the inductance, L is 4.06mH and the output capacitance is set to be 56.4 μF. The load resistance, R is 61.16Ω. The MPPT block consists of MPPT algorithm, namely perturb and observe algorithm. The PWM generator provides a triangle waveform for pulse width modulation.

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The switching frequency, fs was set to be 1 kHz in this simulation. The sampling time of the simulations is assumed to be 0.2s. The incremental and the decremental perturbation step size of P&O algorithm is 0.01. Algorithm was tested at temperature of 25^{o}C and solar irradiance of 1 kW/m2. The maximum PV power generated by algorithm is 327W, which is the expected maximum power, MPP of SunPower MSX327 as shown in TABLE III. Figure 6 shows the simulated V-I characteristics and V-P characteristics of the PV model at temperature-25^{o}C and irradiance -1kW/m^{2}. The maximum power attained from the PV model is 306.7W with Vmpp-50.2V and Impp- 6.11A

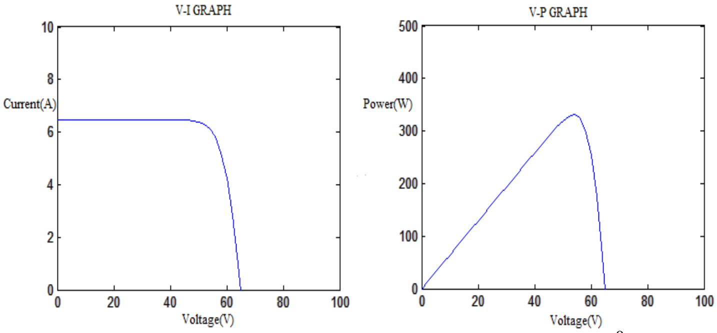

Fig. 6: V-P and V-I output characteristics of PV module at T-25^{0}C and s=1kW/m^{2}

For two-stage PV generation system, boost converter circuit is used as the dc-dc converter. The simulation results of PV fed multi-string boost converter is shown in fig.7.The converter is designed for boosting the PV model voltage-50V to 200V with total output power 654W. The values obtained are output power, Po – 576.6W, output voltage Vo – 200V, output current, Io – 2.882A. By using multi-string topology the voltage becomes steady, current is doubled and the power is increased. The obtained input voltage and current from PV system are Vd – 50.2V and Id – 12.22A. By providing separate MPPT control, maximum power can be attained and its value is 306.7W. The obtained result is shown in fig. 8.

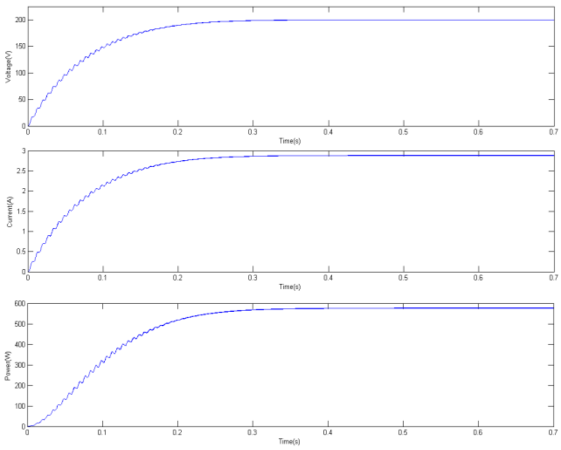

Fig. 7: Output voltage, current and power of multi-string PV boost converter

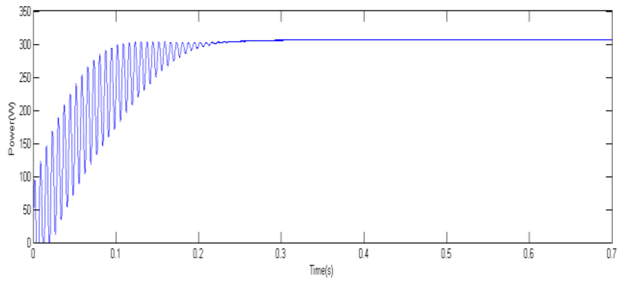

Fig. 8: Maximum power obtained from MPPT

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The simulink model of conventional cascaded H-Bridge multilevel inverter consists of six subsystems for the inverter design and six subsystems for its controlling techniques. Subsystems which specify inverter design consists of six H-bridge inverters and its dc input is multi-string boost converter. The controlling section subsystem includes the phase opposition pulse width modulation control pulses.The output phase voltage obtained is shown in fig.9 and FFT analysis is carried out to find the THD of the conventional system. The power obtained for conventional system is 1072.4W. FFT analysis result for 'phase a' of conventional inverter is shown in fig. 10.The obtained THD value is 27.17%.

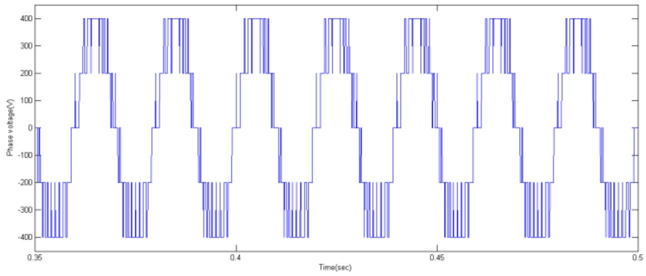

Fig. 9: Output phase voltage of conventional cascaded inverter

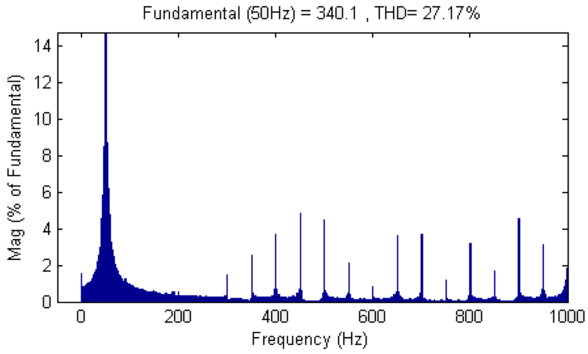

Fig. 10: FFT analysis of conventional cascaded inverter

The proposed cascaded H-bridge multilevel inverter with multi-string boost converter is simulated. Separate MPPT is given to each PV string. Four PV fed boost converters are necessary for the proposed inverter. It consists of four subsystems for the proposed inverter design and four subsystems for its controlling techniques. Subsystem which specifies inverter design consists of three H-bridge inverter and a main inverter. The controlling section subsystem includes the fundamental switching frequency control pulses and the high switching frequency control pulses. The proposed inverter is fed to a three phase load. Each phase consist of five output levels- 0, 200V,-200V, 400V, -400V.

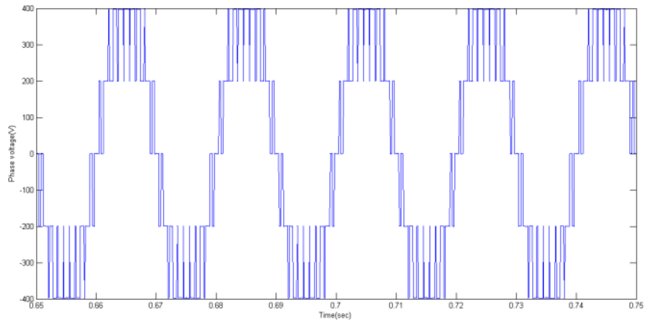

Fig. 11: Output phase voltage of proposed cascaded inverter system

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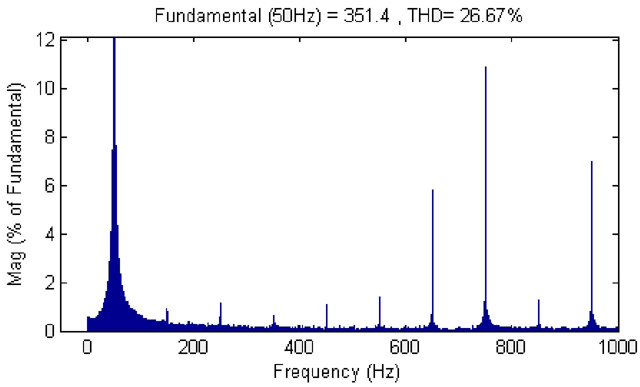

Fig. 12: FFT analysis of proposed cascaded inverter

The output phase voltage waveforms are shown in fig.11 and FFT analysis is carried out to find the harmonic distortion of the proposed system. FFT analysis result for phase a of proposed inverter is shown in fig.12.The obtained output power is 1041W and THD value is 26.67%.

Table IV: Comparison of five level proposed inverter with conventional cascaded inverter

	conventional inverter	proposed inverter
Number of switches	24	18
Switching losses	More	Less
Energy conversion efficiency	Less	More
Switching stress	More	Less
THD%	27.17	26.67

The conventional and proposed inverter topologies are designed and done simulations using MATLAB/Simulink software. Feasibility of the proposed inverter is verified through detailed FFT analysis and the table IV shows the effectiveness of the proposed inverter as compared with the conventional inverter. This inverter can be also applicable in electric vehicles and hybrid electric vehicles.

IV. CONCLUSION

An inverter is a vital element in the PV system which is used to convert DC power from the renewable energy resources into AC power. A study on photovoltaic system is done and different types of multilevel inverter topologies are studied to obtain an efficient three phase inverter topology that provide high efficiency and high quality outputs. Conventional three phase cascaded multilevel inverter circuit is more complex, expensive with high switching losses. Hence a novel three phase multilevel inverter with multi-string boost converter topology has been proposed. Circuit topology, operating principle, control algorithm of the proposed inverter have been analyzed. Maximum power tracking is achieved by using P&O algorithm having a maximum power of 306.6W. Compared with the conventional three phase topology, the new topology have lower THD-26.67% and switching losses, better efficiency, high quality voltage and current waveforms can be ensured from the simulation results. The simulation model of the proposed inverter is done using MAT LAB Simulink software.

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BIOGRAPHY

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