A THIRTEEN LEVEL INVERTER WITH REDUCED NUMBER OF SWITCHES FED FROM PV SYSTEM

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***Abstract*: This paper deals with the multilevel inverter with reduced switch count fed by renewable energy sources. The inverter circuit is designed with the help of T-type topology. The inverter is fed from a solar panel which generates a dc output. MPPT technique is employed to get the required output from solar panel. The output of solar panel is passed to a dc-dc converter and then to inverter. Thirteen level output voltage waveform is produced using eight switches in inverter. LC filter is used to avoid harmonics. Space vector pulse width modulation technique is used to generate pulses for the switches used in inverter. The transistors used will be MOSFET in case of low power applications and IGBT in case of high power applications. The proposed system has several advantages like less number of switches, lower switching frequency and reduced harmonics. The performance of the proposed system is simulated in a Matlab/Simulink environment and its output waveform is verified.**

***Keywords*-Solar Energy System, MOSFET, 13 Level inverter, Space Vector PWM (SVPWM), MPPT**

1. INTRODUCTION

The advancement in technology around the world has been increased in the past decade and seen tremendous changes/development in all aspects. The governments all over the world are struggling to supply the electricity as per the increased demand and taking it as challenge. The following reasons: mostly the electricity generation is with depleting fossil fuels, global warming due to carbon emissions, ozone layer depletion, ever increasing population and energy consumption, increased awareness of environmental protection, centralized power system that can't supply power to the remote areas etc. drive the world to search for the alternate sources for the power generation i.e renewable energy sources like solar, wind, tidal, biomass, geothermal energy, etc…The literature suggests that the plenty of energy can be extracted through sunlight, even wind also helps for the same. In this paper solar cells are used to extract dc output power using MPPT technique.

In the last few decades, multilevel voltage-source inverters have emerged as a viable solution for high-power DC-AC conversion applications. Commercially available for multilevel voltage output are neutral point clamped (NPC), cascaded H-bridge (CHB), and flying capacitor (FC) converters. A multilevel inverter (MLI) is a linkage structure of multiple input dc levels (obtained from dc sources and/or capacitors) and power semiconductor devices to synthesize a staircase waveform. Voltage stresses experienced by the power switches are lower as compared to the overall operating voltage level. In addition, the multilevel waveform has a better harmonic profile as compared to a two-level waveform obtained from conventional inverters. Other advantages of MLIs are reduced dv/dt stress on the load and possibility of fault-tolerant operation. The quality of the multilevel waveform is enhanced by increasing the number of levels. However, it inadvertently leads to a large number of power semiconductor devices and accompanying gate driver circuits. This increases system complexity and cost and tends to reduce the system reliability and efficiency. For a high-resolution waveform, therefore, practical considerations necessitate reduction in the number of switches and gate driver circuits. This necessitates focusing on reducing the component count in multilevel topologies through various approaches. The main disadvantage is the increase in number of power switches that normally contributes to the complexity in controlling the power switches. This paper proposes a thirteen-level inverter with only eight switches. Space vector pulse width modulation (SVPWM) technique is used in the inverter

2. CONFIGURATION OF PROPOSED CIRCUIT

Solar panel consists of large number of photovoltaic cells which generates dc output when sunlight is incident upon them. The dc output is then passed to the dc-dc converter to get required output. Then the output of dc-dc converter is passed to the T-type cascaded multi-level inverter which generates a thirteen level stepped ac output voltage. Then its output is passed to filter and then to load. Single phase induction motor can be used as a load in this project but to confirm the stepped output voltage a CRO is connected in place of load. Driver circuit and controller are given supply as shown

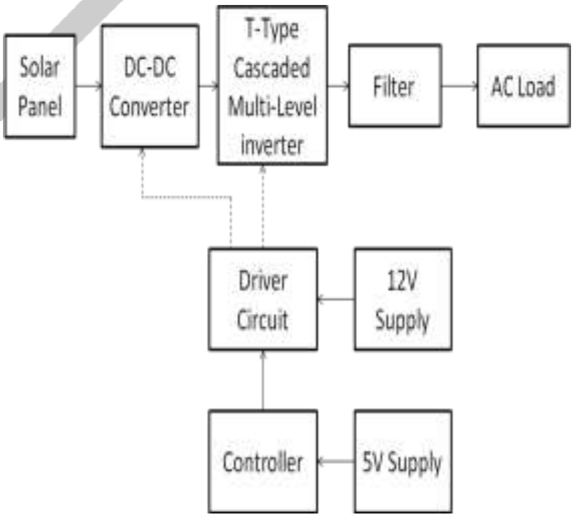

Fig 2.1 proposed configuration block diagram

A new class of multilevel inverters based on an MLDCL and a bridge inverter are used. Compared with the existing multilevel inverters, the new MLDCL inverters can significantly reduce the switch count as well as the number of gate drivers as the number of voltage levels increases. For a given number of voltage levels m , the new inverter requires m+3 active switches, roughly half the number of switches, clamping diodes, and voltage-splitting capacitors in the diode-clamped configuration, or clamping capacitors in the flying-capacitor configuration. Space vector modulation techniques are used for giving pulses to MOSFETs in inverter.

3. SOLAR PANEL

Solar panels absorb the sunlight as a source of energy to generate electricity or heat. A photovoltaic (PV) module is a packaged; connect assembly of typically 6x10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 Watts (W). The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 W module will have twice the area of a 16% efficient 230 W module. A single 5Watts solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes an array of photovoltaic modules, an inverter, a battery pack for storage, interconnection wiring, and optionally a solar tracking mechanism.

Fig 3.1 Solar Panel

Photovoltaic modules use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. The majority of modules use wafer-based crystalline silicon cells or thin-film cells. The structural (load carrying) member of a module can either be the top layer or the back layer. Cells must also be protected from mechanical damage and moisture. Most modules are rigid, but semi-flexible ones are available, based on thin-film cells. The cells must be connected electrically in series, one to another. Externally, most of photovoltaic modules use MC4 connectors type to facilitate easy weatherproof connections to the rest of the system. Modules electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. The conducting wires that take the current off the modules may contain silver, copper or other non-magnetic conductive transition metals. Bypass diodes may be incorporated or used externally, in case of partial module shading, to maximize the output of module sections still illuminated.

Efficiencies of solar panel can be calculated by MPP (maximum power point) value of solar panels. Solar convert the DC power to AC power by performing MPPT process: solar inverter samples the output Power (I-V curve) from the solar cell and applies the proper resistance (load) to solar cells to obtain maximum power.MPP (Maximum power point) of the solar panel consists of MPP voltage (V_{mpp}) and MPP current (I_{mpp}): it is a capacity of the solar panel and the higher value can make higher MPP.

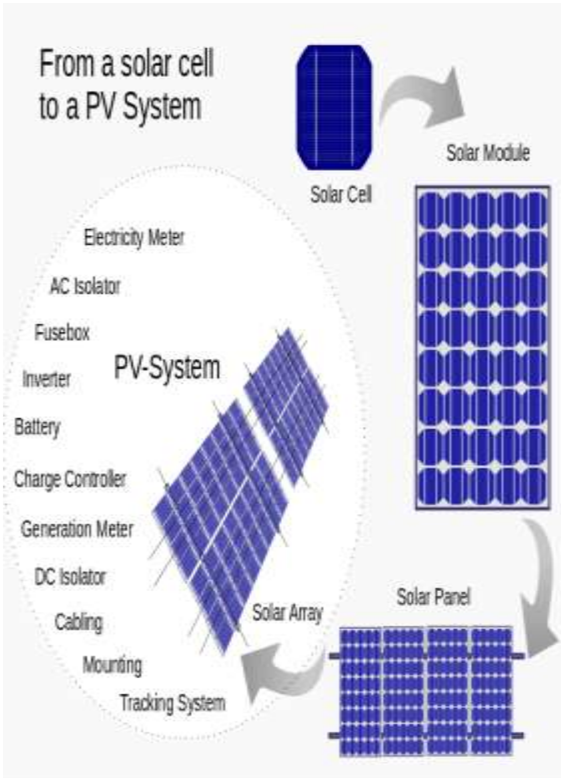

Fig 3.2 PV System

4. MAXIMUM POWER POINT TRACKING

Maximum power point tracking (MPPT) is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermophotovoltaics.PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load.

As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

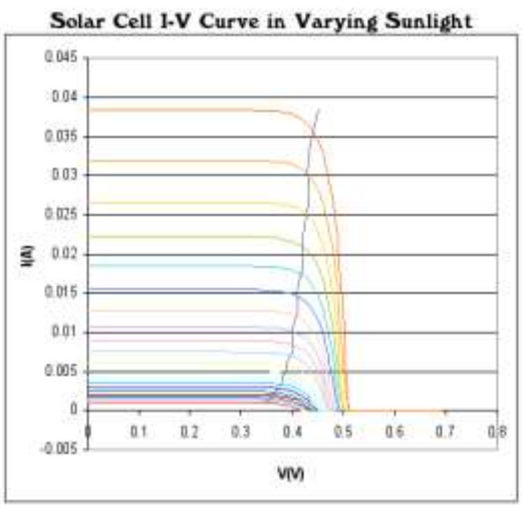

Fig 4.1 solar cell I-V curve

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

5. MULTILEVEL INVERTER

In recent years, industry has begun to demand high power equipment, which now reaches the megawatt level. Controlled AC drives in the mega watt range are usually connected to the medium-voltage network. Today it is hard to connect a single power semi-conductor switch directly to medium voltage grids .For these reasons a new family of multilevel inverters has emerged as the solution for working with high voltage levels.

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generates voltages with stepped waveforms with less distortion, less switching frequency, higher efficiency, lower voltage devices and better electro-magnetic compatibility. The commutation of the switches permits the addition of the capacitor voltages, which reach high voltages at the output, while the power semiconductors must withstand only reduced voltages. Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so they can be applied to higher voltage systems. The multilevel voltage source inverters unique structure allows them to reach high voltages with low harmonics without the use of transformers. The general function of the multilevel inverter is to synthesize a desired AC voltage from several levels of DC voltages. The advent of the transform less multilevel inverters topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. Multilevel power conversion technology is a very rapidly growing area of power electronics with good potential for further development. The most attractive application of this technology is in the medium-to-high-voltage range, and includes motor drives, power distribution, and power conditioning applications. In this paper thirteen level inverter with only eight numbers of switches are used. Space vector pulse width modulation technique is used to control the switching of power semiconductor devices.

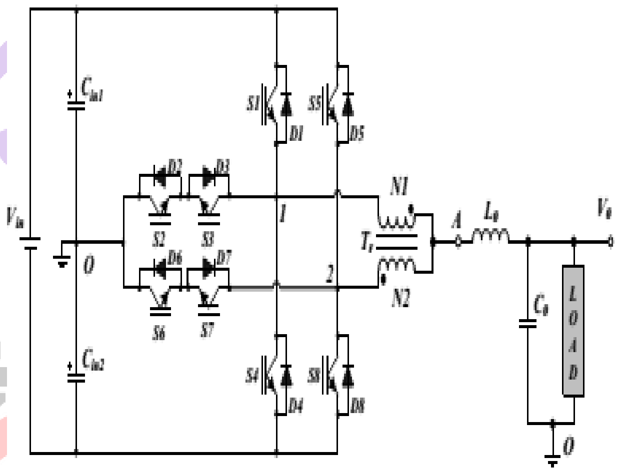

Fig 5.1 thirteen level inverter configurations

The switches in this converter are connected using T-type topology. The output of the inverter will be thirteen level stepped ac voltage. This stepped output voltage can be viewed using CRO connected at the load side. The connection of inductor and capacitor connected at the output side constitute the filter. The ac voltage, typically 220V rms, is connected to a transformer, which steps that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular regulator IC units. The potential transformers will step down the power supply voltage (0-230V) to (0-12V) level. Then the secondary of the potential transformer will be connected to the precision rectifier, which is constructed with the help of op–amp. The advantages of using precision rectifier are it will give peak voltage output as DC, rest of the circuits will give only RMS output.

S.No	S1	S2	S3	S4	S5	S6	S7	S8	Output voltage
1	1	0	0	0	0	0	0	1	Vdc/6
2	1	0	0	0	0	0	1	0	Vdc/5
3	1	0	0	0	0	1	0	0	Vdc/4
4	1	0	0	0	1	0	0	0	Vdc/3
5	1	0	0	1	0	0	0	0	Vdc/2
6	1	0	1	0	0	0	0	0	Vdc
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	1	1	Vdc
9	0	0	0	0	0	1	0	1	Vdc/2
10	0	0	0	0	1	0	0	1	Vdc/3
11	0	0	0	1	0	0	0	1	Vdc/4
12	0	0	1	0	0	0	0	1	Vdc/5
13	0	1	0	0	0	0	0	1	Vdc/6

Fig 5.2 Switching Table

When four diodes are connected in such a way to form a rectifier circuit, which is called as bridge rectifier. The input to the circuit is applied to the diagonally opposite corners of the network, and the output is taken from the remaining two corners. Let us assume that the transformer is working properly and there is a positive potential, at point A and a negative potential at point B. The positive potential at point A will forward bias D3 and reverse bias D4. The negative potential at point B will forward bias D1 and reverse D2. At this time D3 and D1 are forward biased and will allow current flow to pass through them; D4 and D2 are reverse biased and will block current flow. The path for current flow is from point B through D1, up through RL, through D3, through the secondary of the transformer back to point B. this path is indicated by the solid arrows. Waveforms (1) and (2) can be observed across D1 and D3.One-half cycle later the polarity across the secondary of the transformer reverse, forward biasing D2 and D4 and reverse biasing D1 and D3. Current flow will now be from point A through D4, up through RL, through D2, through the secondary of T1, and back to point A. This path is indicated by the broken arrows. The current flow through RL is always in the same direction. In flowing through RL this current develops a voltage corresponding to that shown waveform (5). Since current flows through the load (RL) during both half cycles of the applied voltage, this bridge rectifier is a full-wave rectifier.Regulator IC units contain the circuitry for reference source, comparator amplifier, and overload protection all in a single IC.The regulators can be selected for operation with load currents from hundreds of milli amperes to tens of amperes, corresponding to power ratings from milli watts to tens of watts. The series 78 regulators provide fixed positive regulated voltages from 5 to 24 volts. The series 79 regulators provide fixed negative regulated voltages from 5 to 24 volts. A fixed three-terminal voltage regulator has an unregulated dc input voltage, Vi applied to one input terminal, a regulated dc output voltage, Vo, from a second terminal, with the third terminal connected to ground. The series 78 regulators provide fixed positive regulated voltages from 5 to 24 volts. Similarly, the series 79 regulators provide fixed negative regulated voltages from 5 to 24 volts. For ICs microcontroller, LCD - 5 volts. For alarm circuit, op-amp, relay circuits.

The basic topology of three level T-Type converter. The conventional two level voltage source converter topology is extended with an active, bidirectional switch to the dc-link midpoint. In these conduction is takes place in the form of T shape to give the three level output voltage. The high side and the low-side switches (T1 /D1 and T4 /D4) would usually be implemented with 1200-V IGBTs/diodes as the full dc-link voltage has to be blocked. Differently, the bidirectional switch to the dc-link midpoint has to block only half of the dc-link voltage. It can be implemented with devices having a lower voltage rating, in the case at hand two 600-V IGBTs including anti parallel diodes are used. Due to the reduced blocking voltage, the middle switch shows very low switching losses and acceptable conduction losses, although there are two devices connected in series. An Additional benefits related to using single 1200-V devices to block the full dc-link voltage are reduced conduction losses, if bipolar devices are considered. Whenever the output is connected to (P) or (N), the forward voltage drop of only one device occurs, contrary to the NPC topology where always two devices are connected in series. The conduction losses are considerably reduced making the $3LT^2C$ an interesting choice even for low switching frequencies.

6. SPACE VECTOR MODULATION

Multilevel inverters generate sinusoidal voltages from discrete voltage levels, and pulse width modulation (PWM) strategies accomplish this task of generating sinusoids of variable voltage and frequency. Modulation methods for Hybrid Multilevel Inverter can be classified according to the switching frequency methods. Many different PWM methods have been developed to achieve the following: Wide linear modulation range, less switching loss, reduced Total Harmonic Distortion (THD) in the spectrum of switching waveform: and easy implementation and less computation time. The most widely used techniques for implementing the pulse with modulation (PWM) strategy for multilevel inverters are Sinusoidal PWM (SPWM) and space vector PWM (SPWM). The SVPWM is considered as a better technique of PWM implementation as it has advantages over SPWM in terms of good utilization of dc bus voltage, reduced switching frequency and low current ripple .SVPWM is considered a better technique of PWM implementation, as it provides the following advantages, (i) Better fundamental output voltage. (ii) Useful in improving harmonic performance and reducing THD. (iii) Extreme simplicity and its easy and direct hardware implementation in a Digital Signal Processor (DSP). (iv) SVPWM can be efficiently executed in a few microseconds, achieving similar results compared with other PWM methods.A three dimensional (3-D) space vector has been defined for cascaded H-bridge multilevel inverter which is capable of dealing with zero-sequence component caused by unbalanced load.

7. SIMULATION CIRCUIT DIAGRAM

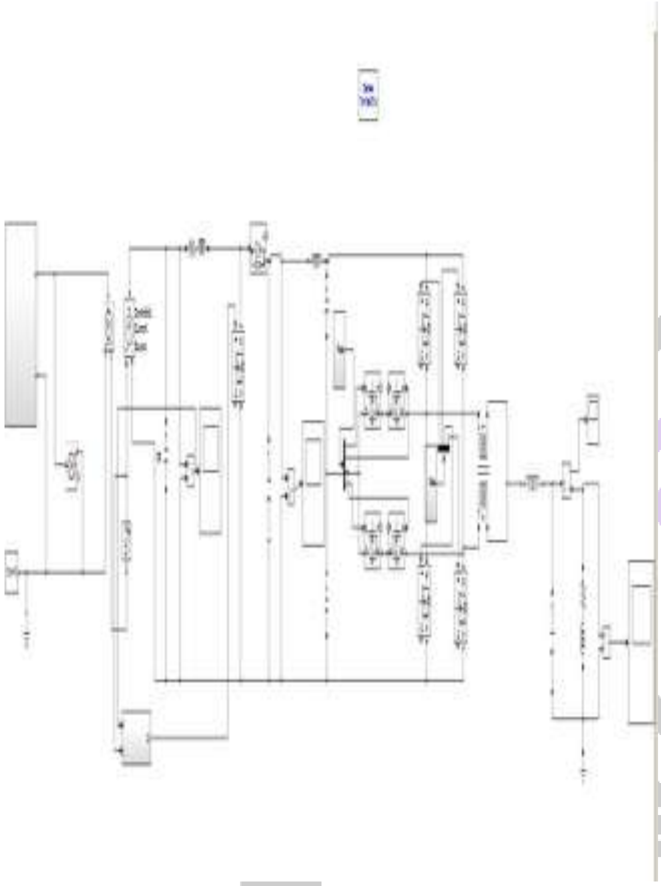

Fig 7.1 simulation diagram

8. SIMULATION RESULTS

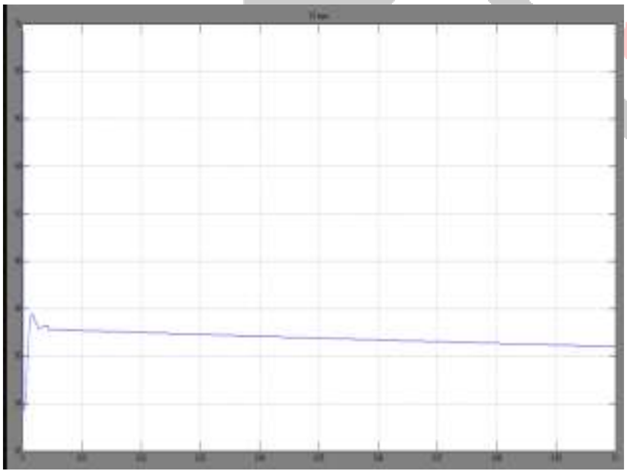

Fig 8.1Solar panel output

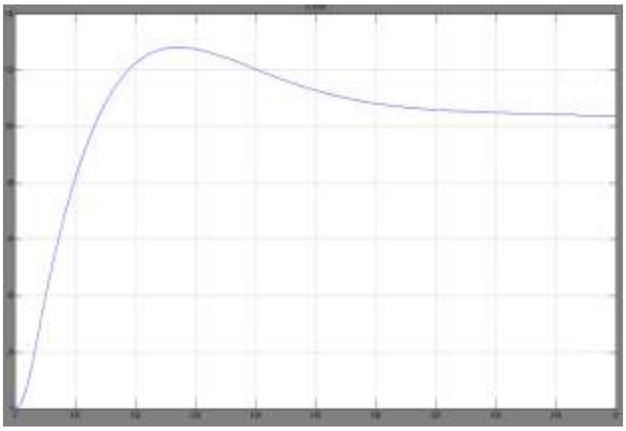

Fig 8.2 Boost converter output

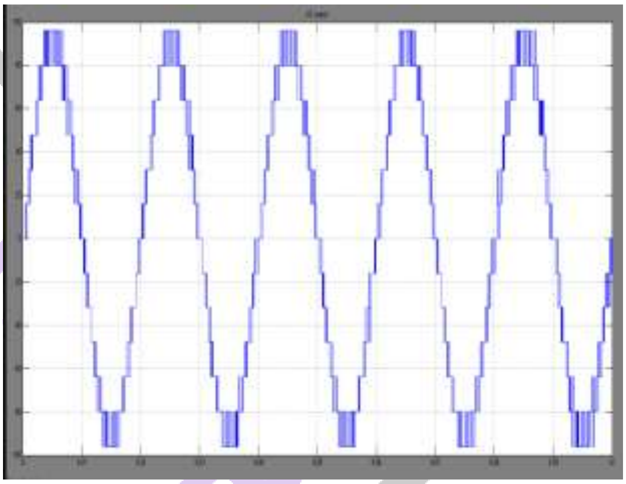

Fig 8.3 thirteen level inverter output

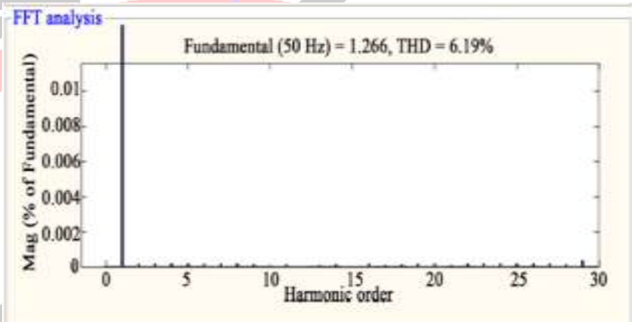

Fig 8.4 FFT analysis

9. EXPERIMENTAL RESULTS

Fig 9.1 prototype model

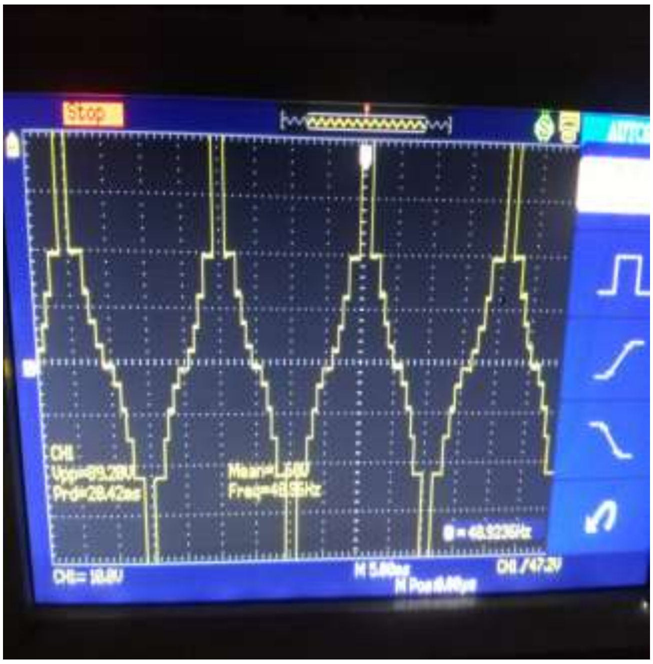

Fig 9.2 thirteen level inverter output

10. CONCLUSION

The proposed topology presents as advantage the presence of the 13 levels in the output voltage before the filter, providing lower content harmonic; and lower volume and weight of the magnetic components, reducing cost and volume of the converter. Furthermore, the 13L T-Type-MSSC presents low conduction losses due to current sharing between the semiconductors devices, resulting in high efficiency (above of 96.5 %) when compared with other multilevel inverters topologies. Finally, a 5 kW prototype was designed and built, and experimental results were obtained. The results have demonstrated the high performance of the propose converter. Due to its high performance, the proposed inverter is a competitive candidate for industrial applications in the field of low voltage and high power.

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