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A Novel Control of a Cascaded H – Bridge Converter Based Solid State Transformer for Microgrid Applications

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ABSTRACT: A cascaded H-Bridge Multilevel Inverter (CHMI)-based Solid-State Transformer (SST) topology can be applied to Microgrid Applications. This we investigates the application of the 3-phase SST and its controller with the energy flow from the distributed renewable energy resources to the grid under unbalanced conditions. The control scheme resolve the power and voltage unbalanced problems of 3-phase SST including the unbalanced of different modules (DAB+CHMI) in each phase and finally inject a purely sinusoidal balanced three-phase current into the ac grid. To reduce load on the controller and simplify modulation algorithm, a master-slave control (MSC) strategy is designed for the dual active bridge (DAB) stage. The master controller executes all control and modulation calculations, and the slave controllers manage only device switching and protection. The three-phase grid currents and dc-link voltage in each module can be simultaneously balanced by using multilevel inverter with reduced number of switches. The proposed balance strategy is characterized for producing high quality grid currents and reactive power compensation. The simulation circuit is analyzed and results are presented for the system.

I. INTRODUCTION

Basically Inverter is a device that converts DC power to AC power at desired output voltage because of other advantages such as high power quality , lower order harmonics, lower switching losses, and better electromagnetic interference, and frequency. Demerits of inverter are less efficiency , high cost, and high switching losses. To overcome these demerits, were going to multilevel inverter. Multilevel inverter output voltage produce a staircase output waveform, this waveform look like a sinusoidal waveform. The multilevel inverter output voltage having less number of harmonics compare to the conventional bipolar inverter output voltage. If the multilevel inverter output increase to N level, the harmonics reduced to the output voltage value to zero. The multilevel inverters are mainly classified as Di ode clamped, Flying capacitor inverter and cascaded multi level inverter. The cascaded multilevel control method is very easy when compare to other multilevel inverter because it doesn't require any clamping diode and flying capacitor. Moreover, abundant modulation techniques have been developed i n cascade multilevel inverter and reducing the power losses. The most attractive features of multilevel inverters are as follows.

1. They can generate output volt ages with extremely low distortion and lower order harmonics.
2. They draw input current with very low distortion.
3. In addition, using sophisticated modulation types of methods, CM voltages can be eliminated.
4. They can operate with a less switching frequency.

Multilevel inverter output voltage produce a staircase output waveform, this waveform look like a sinusoidal waveform. The multilevel inverter output voltage having less number of harmonics compare to the conventional bipolar inverter output voltage. If the multilevel inverter output increase to N level, the harmonics reduced to the output voltage

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value to zero. The multi level inverters are mainly classified as Diode clamped, Flying capacitor inverter and cascaded multi level inverter.

The cascaded multilevel control method is very easy when compare to other multilevel inverter because it doesn't require any clamping diode and flying capacitor. There are two PWM methods mainly used in multilevel inverter control strategy. One is fundamental switching frequency and another one is high switching frequency. For high switching frequency classified as space vector PWM, Selective Harmonics Elimination PWM and SPWM. Among these PWM methods SPWM is the most used for the multilevel inverter, because it has very simple and easy to implemented. In this work present SPWM method with the different carrier based disposition PDPWM, PODPWM and APODPWM has been analyzed. It is generally accepted that the PD strategy gives rise to the lowest harmonic distortion for the line -to-line voltage. Any semiconductor switches have already been used. In this conventional concept uses the MOSFETs semiconductor switches. MOSFETs are preferred in: High frequency applications (1MHZ), Wide line or load variations, Long duty cycles, and Low-voltage applications (500V). Mainly selected the MOSFET switches are used because of its fast switching capability.

A cascaded multilevel inverter made up of from series connected single full bridge inverter,each with their own isolated dc bus.This multilevel inverter can generate almost sinusoidal waveform voltage from several separate dc sources,which may be obtained from solar cells, fuel cells,batteries,ultra capacitors, etc.This type of converter does not need any transformer or clamping diodes or flying capacitors.Each level can generate five different voltage outputs +2Vdc, +vdc, 0 ,–2Vdc and –vdc by connecting the dc sources to the ac output side by different combinations of the four switches.The output voltage of an M-level inverter is the sum of all the individual inverter outputs.Each of the H-Bridge's active devices switches only at the fundamental frequency, and each H-bridge unit generates a quasi- square waveform by phase-shifting its positive and negative phase legs switching timings.Further, each switching device always conducts for 180˚ (or half cycle)regardless of the pulse width of the quasi-square wave so that this switching method results in equalizing the current stress in each active device.This topology of inverter is suitable for high voltage and high power inversion because of its ability of synthesize waveforms with better harmonic spectrum and low switching frequency.

Considering the simplicity of the circuit and advantages, Cascaded H-bridge topology is chosen for the presented work. A multilevel inverter has four main advantages over the conventional bipolar inverter. First, the voltage stress on each switch is decreased due to series connection of the switches. Therefore, the rated voltage and consequently the total power of the inverter could be safely increased. Second, the rate of change of voltage (dv/dt) is decreased due to the lower voltage swing of each switching cycle. Third, harmonic distortion is reduced due to more output levels. Fourth, lower acoustic noise and electromagnetic interference (EMI) is obtained.

The features of multilevel cascade is given by

(1) It is much more suitable to high-voltage, high-power applications than the conventional inverters.

(2). It switches each device only once per line cycle and generates a multistep staircase voltage waveform approaching a pure sinusoidal output voltage by increasing the number of levels.

(3). since the inverter structure itself consists of a cascade connection of many single -phase, full-bridge Inverter units and each bridge is fed with a separate DC source, it does not require voltage balance circuits or voltage matching of the switching devices.

II. LITERATURE SURVEY

An inverter, also named as power inverter, is an electrical power device which is used to convert direct current (DC) into alternating current (AC). Using few control circuits and switches, one can get AC at any required voltage and frequency. Inverter plays exactly the opposite role of rectifiers as rectifiers are used for converting alternating current (AC) into direct current (DC). There are different types of inverters available these days. Few most commonly used inverter types are:

- Square wave inverters

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- Modified sine wave inverters
- Multilevel inverters
- Pure sine wave inverters
- Resonant inverters
- Grid tie inverters
- Synchronous inverters
- Stand-alone inverters
- Solar inverters

A multilevel inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltages as an input. Mostly a two-level inverter is used in order to generate the AC voltage from DC voltage. Now the question arises what's the need of using multilevel inverter when we have two-level inverter. In order to answer this question, first we need to look at the concept of multilevel inverter.

First take the case of a two-level inverter. A two-level Inverter creates two different voltages for the load i.e. suppose we are providing *Vdc* as an input to a two level inverter then it will provide +*Vdc*/2 and –*Vdc*/2 on output. In order to build an AC voltage, these two newly generated voltages are usually switched. For switching mostly PWM is used as shown in the Figure 2.1, reference wave is shown in dashed blue line. Although this method of creating AC is effective but it has few drawbacks as it creates harmonic distortions in the output voltage and also has a high dv/dt as compared to that of a multilevel inverter. Normally this method works but in few applications it creates problems particularly those where low distortion in the output voltage is required.

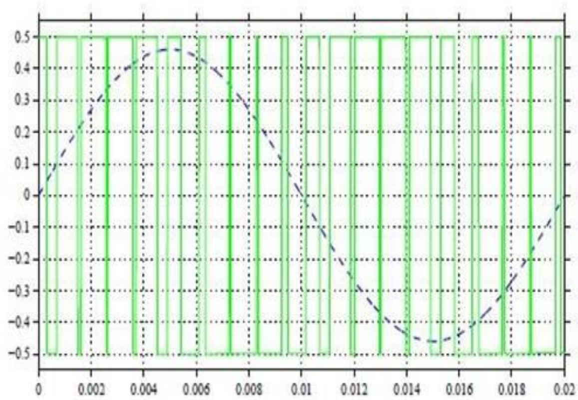

Fig. 2.1 PWM voltage output of a two-level inverter

The concept of multilevel Inverter (MLI) is kind of modification of two-level inverter. In multilevel inverters we don't deal with the two level voltage instead in order to create a smoother stepped output waveform, more than two voltage levels are combined together and the output waveform obtained in this case has lower dv/dt and also lower harmonic distortions. Smoothness of the waveform is proportional to the voltage levels, as we increase the voltage level the waveform becomes smoother but the complexity of controller circuit and components also increases along with the increased levels. The waveform for the three, five and seven level inverters is shown in the Figure 2.2 where we clearly see that as the levels are increasing, waveform becoming smoother.

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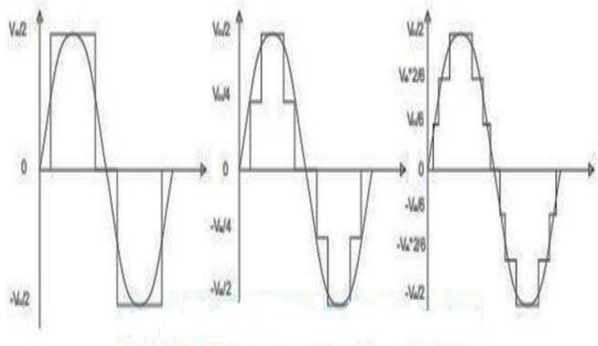

Fig. 2.1 A three-level waveform, a -ve-level waveform and a seven-level multilevel waveform, switched at fundamental frequency

There are several topologies of multilevel inverters available. The difference lies in the mechanism of switching and the source of input voltage to the multilevel inverters. Three most commonly used multilevel inverter topologies are:

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

This inverter uses several H-bridge inverters connected in series to provide a sinusoidal output voltage. Each cell 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 cells in a H-bridge multilevel inverter then number of output voltage levels will be 2k+1. This type of inverter has advantage over the other two as it requires less number of components as compared to the other two types of inverters and so its overall weight and price is also less. Figure 2.3 shows a k level cascaded H-bridge inverter.

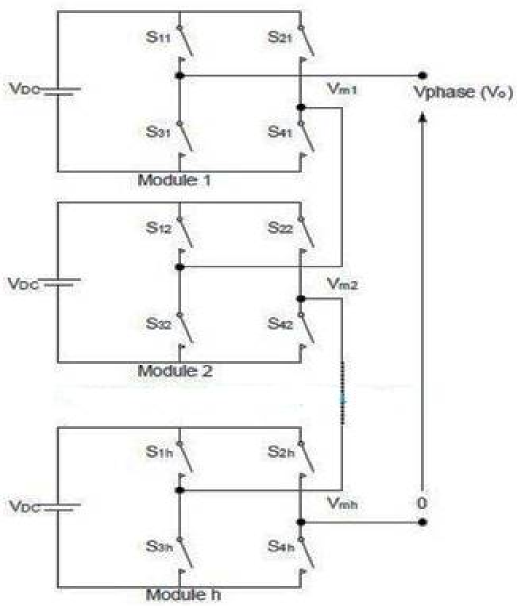

Fig. 2.2 One phase of a cascaded H-bridge multilevel inverter

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In single phase inverter, each phase is connected to single dc source. Each level generates three voltages which are positive, negative and zero. This can be obtained by connecting the AC source with the DC output and then using different combinations of the four switches. The inverter will remain ON when two switches with the 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 calculations for the measurement of switching angle will remain the same. This inventor can be categorized further into the following types:

- 5 levels cascaded H Bridge Multilevel Inverter
- 9 levels cascaded H Bridge Multilevel Inverter

In 5 level cascaded H Bridge Multilevel Inverters, Two H Bridge Inverters are cascaded. It has 5 levels of output and uses 8 switching devices to control whereas in 9 level cascaded H Bridge Multilevel Inverters, Four H Bridge Invertors are cascaded. It has 9 output levels and use and use 16 switching devices.

- Applications of Cascaded H-bridge Multilevel Inverters

Cascaded H Bridge Multilevel Inverters are mostly used for static var applications i.e., in renewable resources' of energy and battery based applications. Cascaded H Bridge Multilevel Inverters can be applied as a delta or wye form. This can be understood by looking at the work done by Peng where he used an electrical system parallel with a Cascade H Bridge. Here inverter is being controlled by regulating the power factor. Best application is when we used as photovoltaic cell or fuel cell. This is the example of Parallel connectivity of the H Bridge Multilevel Inverter.

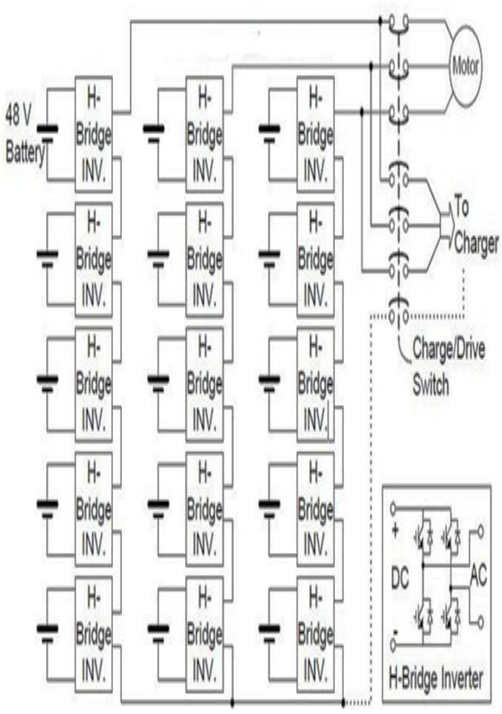

Fig. 2.3 Example of 3 phase Wye Connection

H Bridge can also be used in car batteries to run the electrical components of the car. Also this can be used in electrical braking system of the vehicles.

Scientist and engineers have also used the multiplicative factor on Cascade H Bridge Multilevel. It means that rather than using a dc voltage with difference in levels, it uses a multiplying factor between different levels of the multilevel i.e., every level is a multiplying factor of the previous one.

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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 as shown in the Fig 2.5
- Cheap

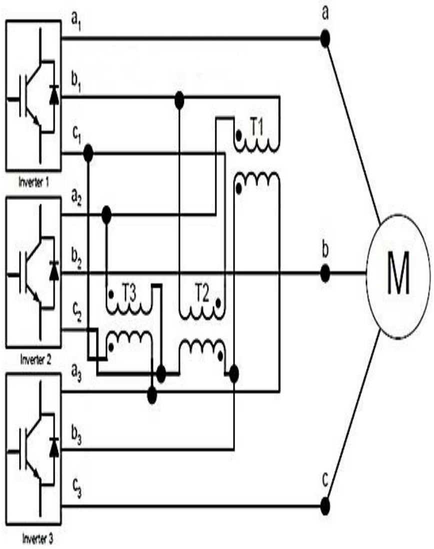

Fig. 2.4 Cascaded Inverter with transformer

Disadvantages of Cascade H Bridge Multilevel Inverters

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

III. METHODOLOGY

Generally the output voltages and input currents with low THD, the reduced switching losses due to lower switching frequency, good electromagnetic compatibility owing to lower di/dt and their better performance in high voltage due to lower voltage stress on switches , But those inverter configurations demand a higher dc requirements and switch counts .The requirement of multiple dc sources and the switch count may lead to increase the cost of the inverter, and more over the adaptation of the renewable sources would be tougher as they demand in multiple sources and the renewable are able to provide a single dc source at a time. The inverters demand in multistep dc to generate multilevel pattern as the PV systems are lack in generating of multiple dc voltages which cannot be used directly. Hence there should be an modifications to adopt multilevel inverters would need to reduce the operating cost and interfacing

3.1 Motivation towards Proposed scheme

The main motivation towards the proposed system is to generate a multiple voltage levels based on the single dc source, which could result in the adaptation of the single dc source from renewable can be included , these inverters are designed with the combination of the capacitor and the h bridges which can make their own self balancing based on the natural PWM scheme itself

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3.2 Multilevel Inverter Topology

The single-phase nine-level inverter was developed to generate nine levels inverter as shown in Fig below.

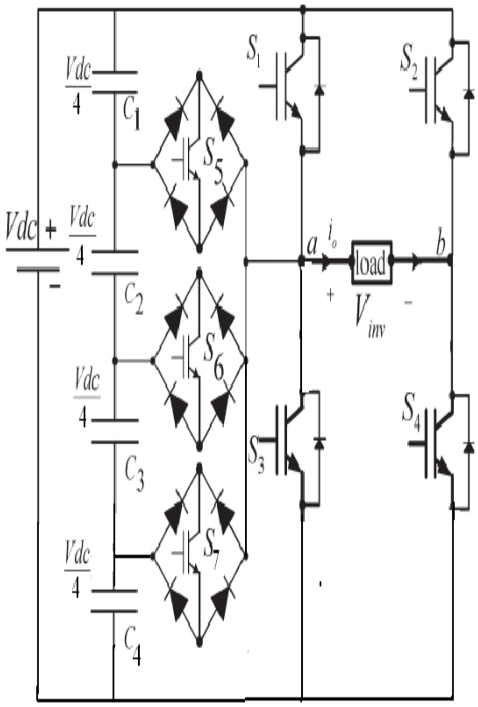

Fig. 3.1 Single-Phase Nine-Level Inverter

It comprises a single-phase conventional H-bridge inverter, three bidirectional switches, and a capacitor voltage divider formed by C1, C2,C3 and C4, as shown in Fig. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter. The power generated by the inverter is to be delivered to induction Motor.

The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the single-phase voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the single-phase induction motor. The LC-filter is modeled to obtain pure sine-wave and is given to drive a single-phase induction motor. Proper switching of the inverter can produce nineoutput-voltage-levels (Vdc, 3Vdc/4, Vdc/2, Vdc/4, 0,,–Vdc/4, –Vdc/2, -3Vdc/4,- Vdc) from the dc supply voltage.

3.3 Operation of the proposed Multilevel inverter

The proposed inverter's operation can be divided into nine switching states. The required nine levels of output voltage were generated as follows.

Maximum positive output (Vdc): S1 is ON, connecting the load positive terminal to Vdc, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc.

Three-fourth positive output (3Vdc/4): The bidirectional switch S5 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is 3Vdc/4.

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Half of the positive output (Vdc/2): The bidirectional switch S6 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/2.

One-fourth of the positive output (Vdc/4): The bidirectional switch S7 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/4.

Zero output: This level can be produced by two switching combinations; switches S3 and S4 are ON, or S1 andS2 are ON, and all other controlled switches are OFF; terminal ab is a short circuit, and the voltage applied to the load terminals is zero.

One-fourth negative output (−Vdc/4): The bidirectional switch S5 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to Vdc. All other controlled switches are OFF; the voltage applied to the load terminals is −Vdc/4.

Half of the negative output (−Vdc/2): The bidirectional switch S6 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is −Vdc/2.

Three-fourth negative output (−3Vdc/4): The bidirectional switch S7 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is −3Vdc/4.

Maximum negative output (−Vdc): S2 is ON, connecting the load negative terminal to Vdc, and S3 is ON, connecting the load positive terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is −Vdc.

Table shows the switching combinations that generated the nine output-voltage levels (Vdc, 3Vdc/4, Vdc/2, Vdc/4, 0, ,–Vdc/4, –Vdc/2, -3Vdc/4,- Vdc)

Table.1 Output Voltage According to the Switches' On Off Condition

Vo	S_1	S_2	S_3	S_4	S_5	S_6	S_7
V_{dc}	On	Off	Off	On	Off	Off	Off
3V_{dc}/4	Off	Off	Off	On	On	Off	Off
V_{dc}/2	Off	Off	Off	On	Off	On	Off
V_{dc}/4	Off	Off	Off	On	Off	Off	On
0	On	On	Off	Off	Off	Off	Off
V_{dc}/4	Off	On	Off	Off	On	Off	Off
-V_{dc}/2	Off	On	Off	Off	Off	On	Off
-3V_{dc}/4	Off	On	Off	Off	Off	Off	On
-V_{dc}	Off	On	On	Off	Off	Off	Off

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In order to validate the performances of the proposed inverter topology an inverter structure with eh balancing capacitors and the H bridges are designed and their operations are validated and the results are compared with the conventional H bridges are listed in the chapter 5 of this thesis.

IV. SIMULATION RESULTS

The proposed nine level multilevel pattern with the 7 switches and three capacitors are replaced with the existing 7 level configurations uses directly driven dc source from the solar panels and the capacitors takes care of voltage splitting and the controls scheme remains same as the existing system

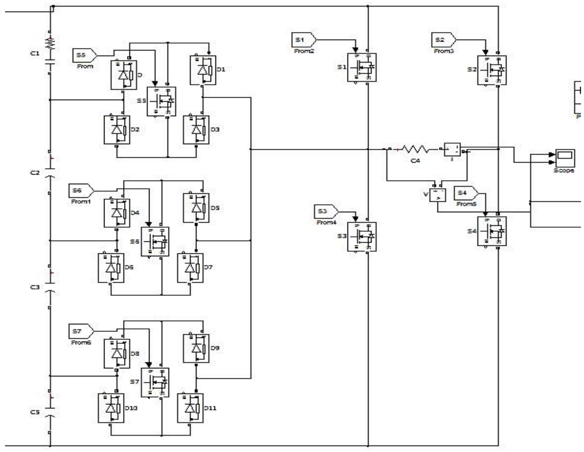

Fig. 4.1 Simulation of the proposed – 9 level inverter

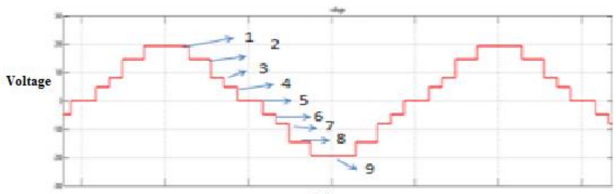

Fig. 4.2 9 level output of the inverter splits the main dc source

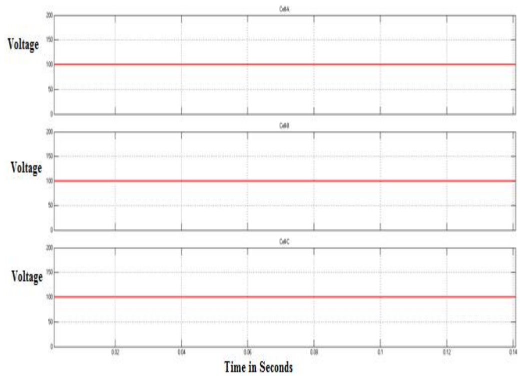

Fig. 4.3 9 level input capacitor balancing

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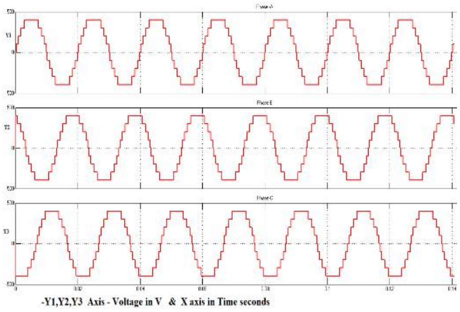

Fig. 4.4 9 level three phase output

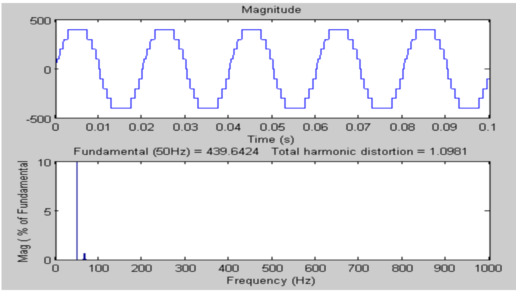

Fig. 4.5 Computed THD for Phase A

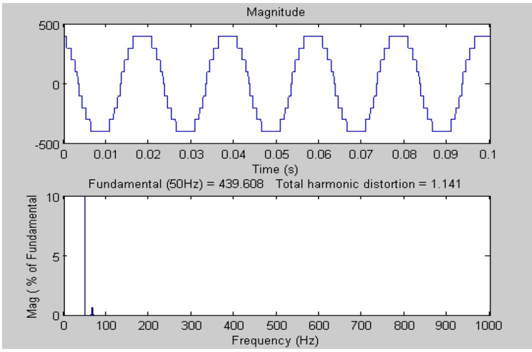

Fig. 4.6 Computed THD for Phase B

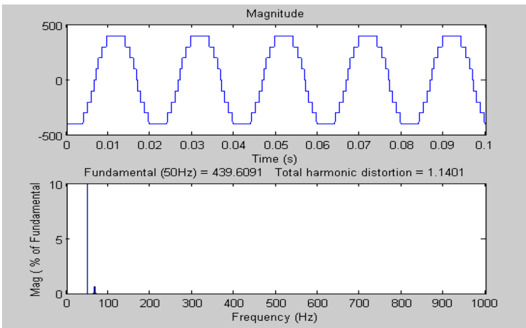

Fig4.7 Computed THD for Phase C

	Existing	Proposed
DC sources	3	1
No of switches	11	7
External dc source	1 for v1 generation	NO
Balancing	NO	Capacitor Balancing
THD	1.85	1.1

Table 2comparision of the modifications of existing and the proposed topologies

V. CONCLUSION

A multilevel inverter that operates in a single dc and the minimum number of switches has been proposed. The capacitor balancing modulation technique for the proposed scheme has been generated and validated to generate the multilevel pattern. The multilevel generated contains a three capacitors that balancing the voltage is done through the PWM modulation. This inverter uses a single dc sources and reduced number of dc sources which are minimal compared to the existing schemes, and also it can provides an additional space to modify the number of levels without touching the main circuit, with the addition of sub blocks and the capacitors the voltage level addition can be included and the addition of the such voltage levels without any modification in the modulation scheme too. As the system has the minimal switches the requirement of the hardware drivers are being reduced Therefore, construction cost of the proposed multilevel inverter is lower and it is not bulky.

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