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Single Phase Hybrid Cascaded H-Bridge and Flying Capacitor Multilevel Inverter with Capacitor Voltage Balancing

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***Abstract*—In this paper a single-phase hybrid cascaded H-Bridge and Flying capacitor multilevel inverter with capacitor voltage balancing is proposed. Flying capacitor and cascaded H-Bridge multilevel inverters are the two main multilevel inverter topologies. Cascaded H-bridge multilevel inverters require separate DC sources, whereas flying capacitor multilevel inverters contain capacitors that require balancing of their voltages. So, a hybrid-topology inverter, comprising of single-phase five level flying capacitor and five level cascaded H-bridge inverter with their outputs connected in series so as to reduce the total harmonic distortion (THD) is developed. This method gives fast and good control with minimum acceptable amount of harmonics. The proposed system is being simulated in MATLAB/Simulink software.**

Index Terms— H-bridge, multilevel inverter, Flying capacitor multilevel inverter, Harmonics, Simulink software.

I. INTRODUCTION

The multilevel inverter concept was introduced in the year 1975 to meet the demands of industrial applications as an alternative to high and medium power applications. The major challenge of multilevel inverter is to meet requirement for isolated power supplies, design complexity and switching control circuits to reduce the harmonics particularly the lower order harmonics. So various topologies of different combinational multilevel inverter are being designed to overcome the problems such as improving the efficiency, reducing total harmonic distortion, and also improving the power factors. One of the main combinational multilevel topologies is single phase hybrid cascaded H-bridge and diode clamped multilevel inverter was used [1]. Since the multilevel inverter was introduced to overcome the limitation and restriction in normal two-level inverter. So different methods of balancing of voltages can be done [2]. So, the main strategies used are to increase the power level by addition of power semiconductor devices to improve the THD, power quality and to reduce the voltage stress on semiconductor devices.

Since there are basically three foundational types of multilevel inverters, they are mainly Flying capacitor MLI, Diode clamped MLI and H-Bridge multilevel inverter. All these multilevel inverter works on the semiconductor switching pattern but the inputs to these switches depends on the type of MLI used. These multilevel inverters can be used as interface for renewable energies and also to maintain THD [3][4]. Different redundant states are used in flying capacitor [5], diode clamped and H-bridge [6]. Many research work is being carried out in hybrid clamped system [7-9]. The proposed method finds application in grid interface for wind power generation [10]. In this paper a new nine level combinational cascaded H-bridge and flying capacitor multilevel is being proposed with five level of flying capacitor multilevel and five level of cascaded H-bridge multilevel is being connected in cascaded fashion as it provides reliable operation with less voltage stress on semiconductor switches with minimum THD.This method requires balancing of capacitor voltages so different combination of switches from H-bridge and flying capacitor are turned ON and OFF to obtain different output voltages. By simulating this type of proposed inverter, we can obtain a considerable amount of THD.

II. PROPOSED CONVERTER OPERATION

The proposed cascaded converter consists of five level flying capacitor multilevel inverter and five level H-bridge multilevel inverter with four switches from flying capacitor multilevel are chosen common for both flying capacitor and H-bridge so as reduced the complexity and also reduce the losses. The H-bridge consists of four switches for controlling purpose, these switches may be IGBT or MOSFET. The H-Bridge and flying capacitor are placed in cascaded fashion and the output of both is connected in series so as to reduce the THD.

The proposed circuit consists of two H-bridge and a flying capacitor multilevel inverter which are connected in cascaded manner. The combination of single-phase hybrid cascaded H-Bridge and flying capacitor multilevel inverter is connected with two types loads such as R load and RL load to compare different THD's. Flying capacitor is most commonly used method for different application for voltage balancing. In case of flying capacitor there are three ways of balancing the voltages the first method is by algorithm based method, second is by reducing the duty cycle to get the desired output and third is by modifying modulation index [2]. Both the flying capacitor and H-bridge multilevel inverter connected in cascaded and the whole combination is connected with resistive load as shown in Fig. 1.

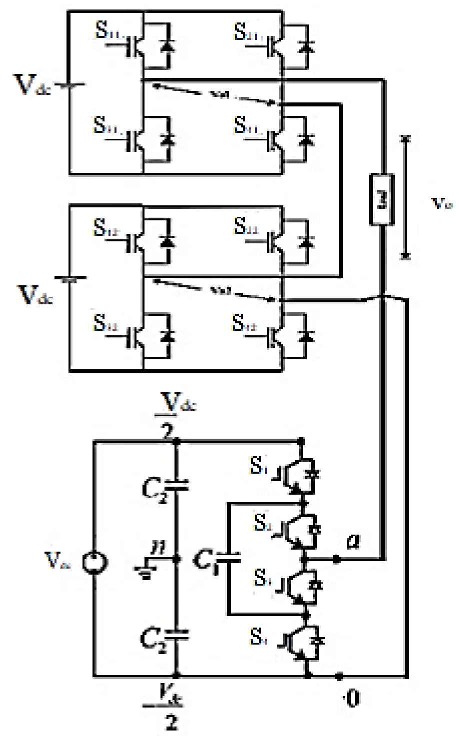

Fig .1. Proposed hybrid cascaded five level H-Bridge and five level flying capacitor multilevel inverter.

TABLE I
SWITCHING TABLE FOR PROPOSED MULTILEVEL INVERTER

S1	S2	S3	S4	S11	S21	S31	S41	S12	S22	S32	S42	OUTPUT
0	0	0	0	0	0	0	0	0	0	0	0	ZERO
0	1	0	1	1	0	0	1	0	0	0	1	$V_{dc}-V_{c1}$
0	0	1	1	1	0	0	1	0	0	0	1	V_{dc}
0	1	0	1	1	0	0	1	1	0	0	1	$2V_{dc}-V_{c1}$
0	0	1	1	1	0	0	1	1	0	0	1	$2V_{dc}$
1	0	1	0	0	0	1	0	0	0	1	0	$-(V_{dc}-V_{c1})$
1	1	0	0	0	0	1	0	0	0	1	0	$-V_{dc}$
1	0	1	0	0	1	1	0	0	0	1	0	$-(2V_{dc}-V_{c1})$
1	1	0	0	0	1	1	0	0	0	1	0	$-2V_{dc}$

From the Table I, we can see that the various output voltages are obtained when different combination of switches are turned ON and OFF to produce different output voltages both for positive dc supply and for negative dc supply. The different operational modes for proposed multilevel inverter is being proposed below.

Mode 1: In this mode no switches are turned ON and the load is disconnected from the source. Zero current passes through the load and hence the voltage across the load is zero.

Mode 2: In this mode the switches S2 and S4 of FCMLI (flying capacitor multilevel inverter) is turned ON and hence the capacitor C1 is charging and the switches S11, S41 and S42 of cascaded H-bridge(CHBMLI) is turned ON to provide path for load. Here since the flying capacitor is being not attached directly with the switches. So, voltage from the H-Bridge 1 flows from voltage source to S11 switch through the load to the switch S2 through the capacitor C1 then through the switch S4 then through the switch S42 through the body diode D32 then through S41 then back to the source as shown in Fig. 2. Hence the voltage across the load is V_{dc}-V_{c1}.

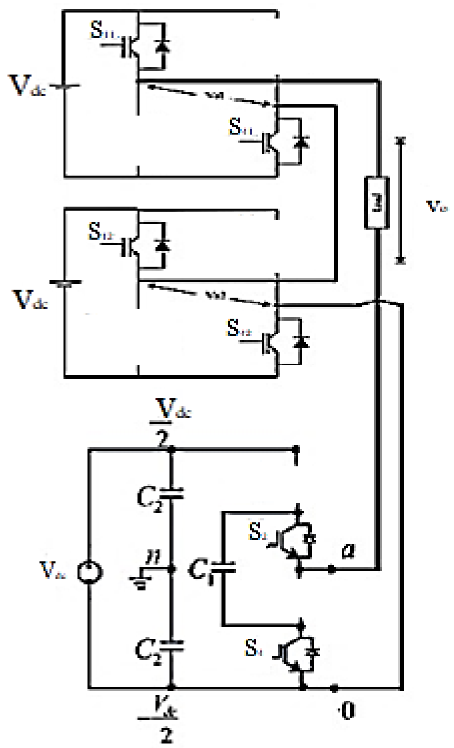

Fig. 2. Mode 2 Equivalent circuit.

Mode3: In this the switches S3 and S4 of FCMLI is turned ON and the DC source V_{dc} is connected directly as the capacitor C1 is disconnected from supply and the switches S11, S41 and S42 of CHBMLI is turned ON to provide path for load. Here since the flying capacitor is not attached directly with the switches So voltage from the H-bridge 1 flows from voltage source to S11 switch through the load to the switch S3 and S4 then through the switch S42 through the body diode D32 then through switch S41 then back to the source as shown in Fig. 3. Hence the voltage across the load is V_{dc}.

Mode 4: In this the switches S2 and S4 of FCMLI is turned ON and the DC source of V_{dc} is connected directly with one of the sources of CHBMLI in series as the switches S11, S41 S12 and S42 of CHBMLI is turned ON to provide path for load. Here since the flying capacitor is being not attached directly with the switches so voltage from the H-bridge 1 flows from voltage source to S11 switch through the load to the switch S2 through the capacitor C1 then through the switch S4 then through the switch S42 through voltage source V_{dc} then to switch S12 then through the switch S41 then back to the source as shown in Fig. 4. Hence the voltage across the load is $2V_{dc}$-V_{c1}.

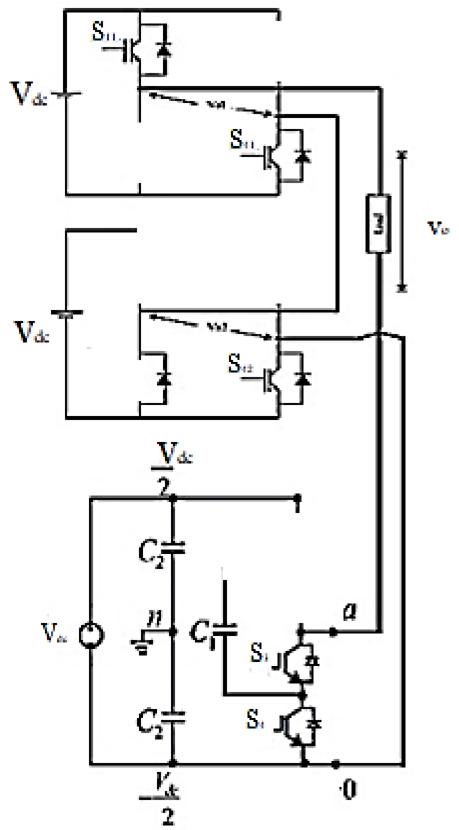

Fig. 3. Mode 3 Equivalent circuit.

Mode 5: In this the switches S3 and S4 of FCMLI is turned ON and the DC source of V_{dc} is connected directly with both sources of CHBMLI in series as the switches S11, S41, S12 and S42 switch of CHBMLI is turned ON to provide path for load. Here since the flying capacitor is being not attached directly with the switches so voltage from the H-bridge 1 flows from voltage source to S11 switch through the load to the switch S3 and S4 of the flying capacitor then through the switch S42 to the voltage source to the switch S12 and switch S41 and returns back to the source as shown in Fig. 5. So the voltage across the load is $2V_{dc}$.

Mode 6: In this the switches S1 and S3 of FCMLI is turned ON and hence the capacitor C1 is charging and the switches S31and S32 of CHBMLI is turned ON to provide path for load. The voltage from the flying capacitor multilevel flows through the switch S1 then through the capacitor C1 through the switch S3 then through the point 'a' through the load to the switch S31 then it passes through the body diode of D41 then through the second H-bridge switch S32 then through the body diode of D42 then it come back to the source of flying capacitor multilevel inverter as shown in Fig. 6. Here the voltage across the load is –(V_{dc} -V_{c1}).

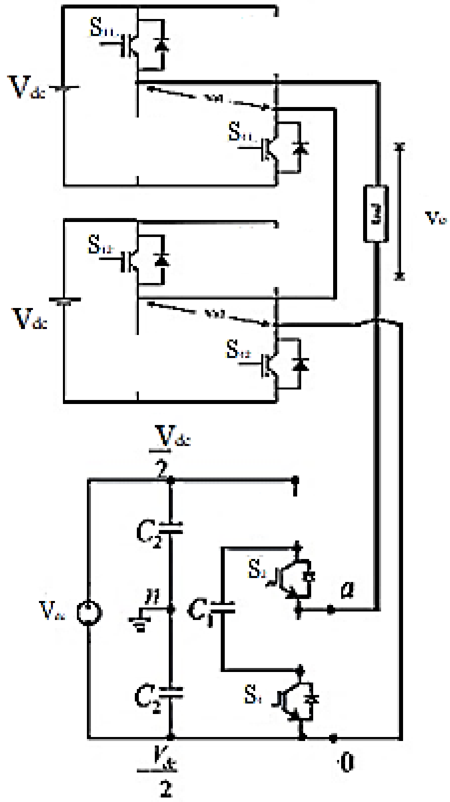

Fig. 4. Mode 4 Equivalent circuit.

Mode 7: In this the switches S1 and S2 of FCMLI is turned ON and the capacitor C1 is disconnected and the switches S31 and S32 of CHBMLI is turned ON to provide path for load. The voltage from the flying capacitor multilevel flows through the switch S1 and S2 through the point 'a' through the load to the switch S31 then it passes through the body diode of D41 then through the second H-bridge switch S32 then through the body diode of D42 then it come back to the source of flying capacitor multilevel inverter as shown in Fig. 7. Hence the voltage across the load is -V_{dc}.

Mode 8: In this the switches S1 and S3 of FCMLI is turned ON and the sources of CHBMLI in series as the switches S21, S31 and S32 of CHBMLI is turned ON to provide path for load. Here the voltage from the flying capacitor multilevel inverter flows from the source to the switch S1 then it passes through the capacitor C1 then through the switch S3 then from the point 'a' through the load through the switch S31 then to the voltage source then through the switch S21 then passes through the switch S32 then through the body diode of D42 then back through the source as shown in Fig. 8. So the voltage across the load is –($2V_{dc}$-V_{c1}).

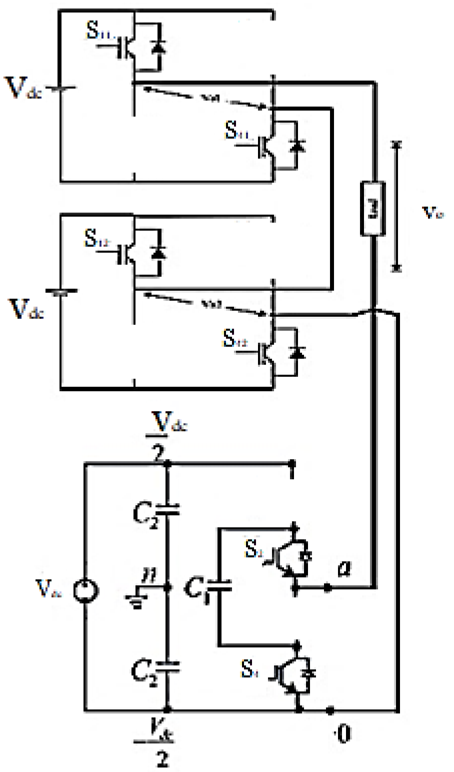

Fig. 5. Mode 5 Equivalent circuit.

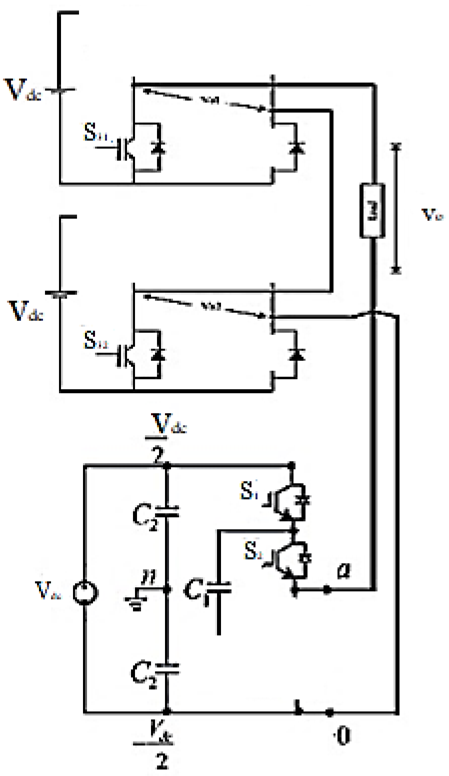

Fig. 7. Mode 7 Equivalent circuit.

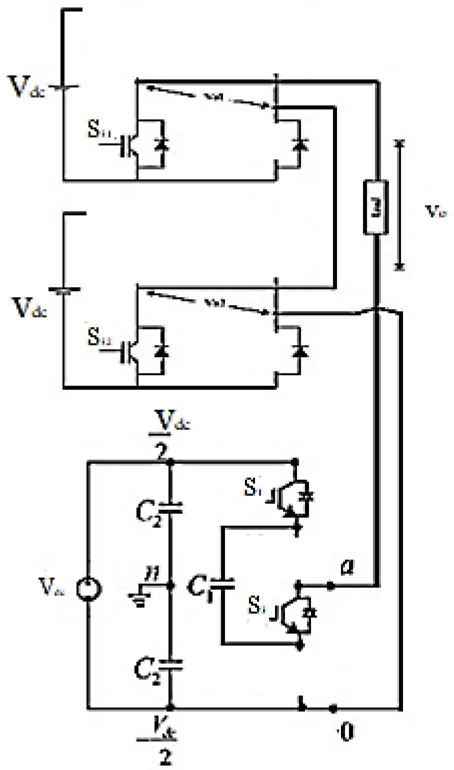

Fig. 6. Mode 6 Equivalent circuit.

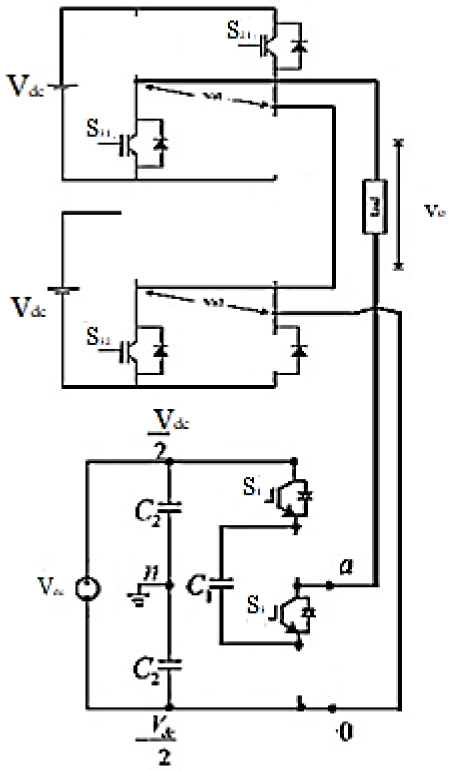

Fig. 8. Mode 8 Equivalent circuit.

Mode 9: In this the switches S1 and S2 of FCMLI is turned ON and the DC source of V_{dc} is connected directly with both sources of CHBMLI in series as the switches S31, S32 and S21 of CHBMLI is turned ON to provide path for load. Here the voltage from the flying capacitor multilevel inverter V_{dc} flows through the switch S1 and through the switch S2 through the point 'a' passes through the load then through the switch S31 through the V_{dc} to the switch S21 then through the switch from H-bridge 2 through the switch S32 then through the body diode D42 then back to the source as shown in Fig. 9. So, here the voltage across the load is -2V_{dc}.

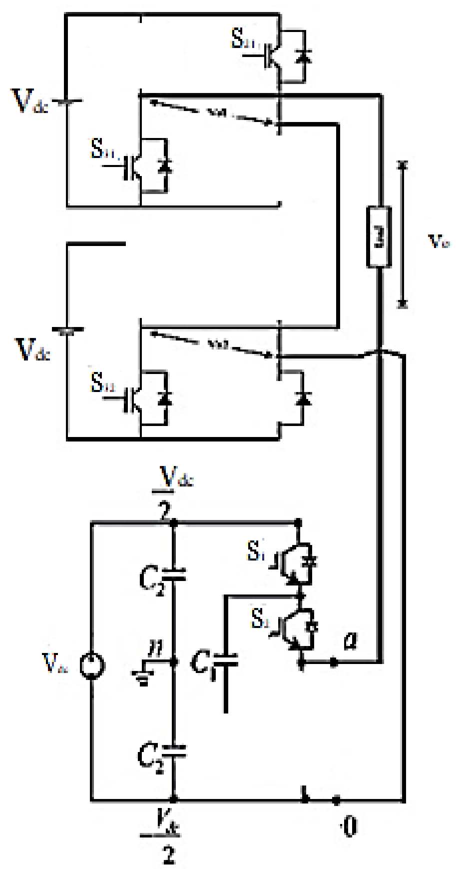

Fig. 9. Mode 9 Equivalent circuit.

III. SIMULATION AND ITS RESULT

The proposed single-phase hybrid five level cascaded H-Bridge and five level flying capacitor multilevel inverter is being simulated for both R load and RL load and compared its THD results with capacitance of 0.1µF resistance of 100Ω and inductance of 1mH with a DC voltage of 6v, IGBT switch.

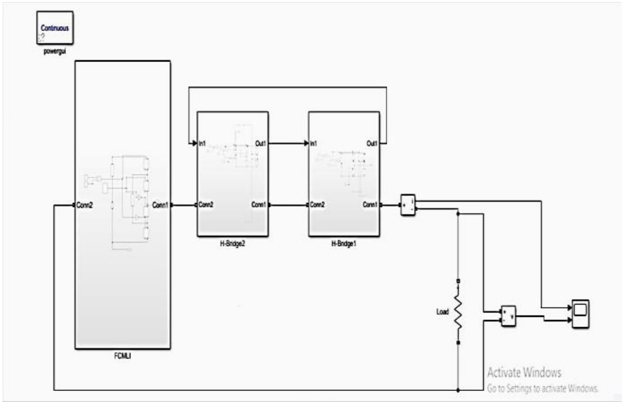

Fig. 10. Single phase hybrid cascaded H-bridge and Flying capacitor multilevel inverter simulation in Simulink software.

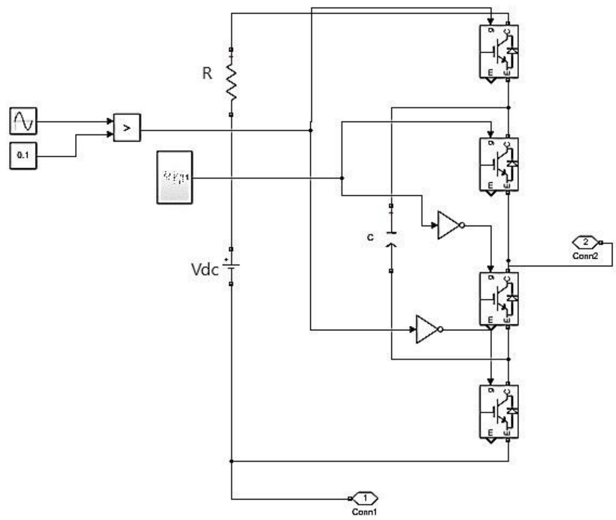

Fig 11. Simulation for flying capacitor multilevel inverter.

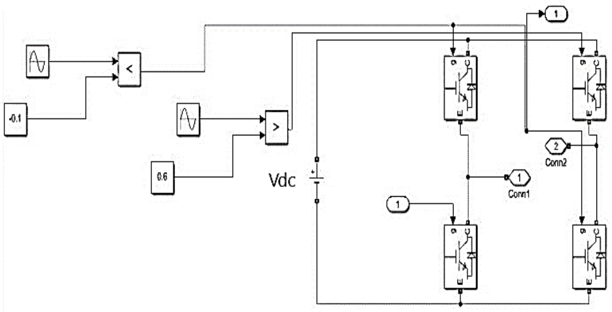

Fig. 12. Simulation for H-Bridge 1.

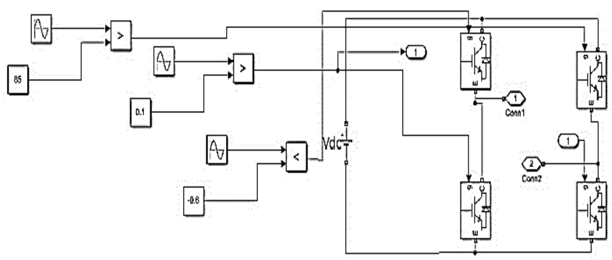

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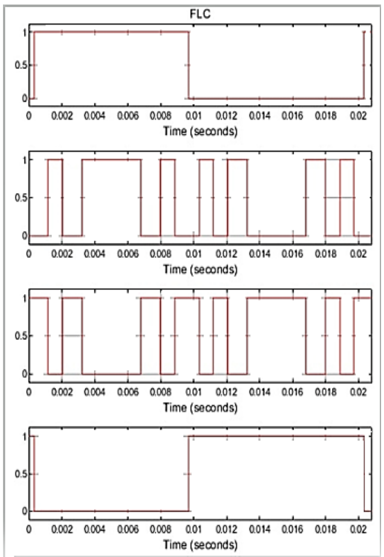
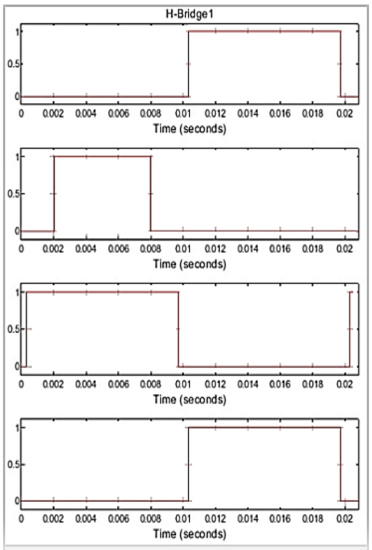
Fig. 13. Simulation for H-Bridge 2.

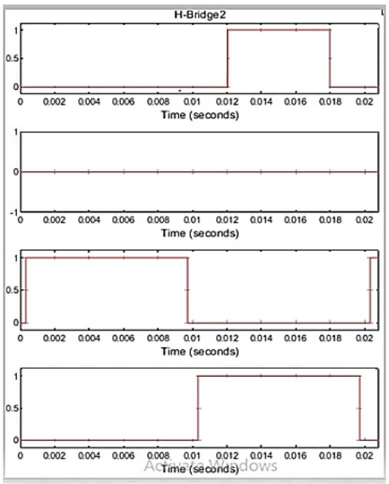
Switching Pulses for Flying capacitor and H-bridge multilevel inverter.



a



b



c

Fig. 14. Switching pulses for
(a) Flying capacitor multilevel inverter, (b) H-Bridge 1, (c) H-Brige2.

TABLE II
SIMULATION COMPONENTS AND ITS RATINGS

Components	Ratings
Resistance	100Ω
Capacitance	0.1µF
Inductance	1mH
DC voltage	6v

Simulation results for RL load

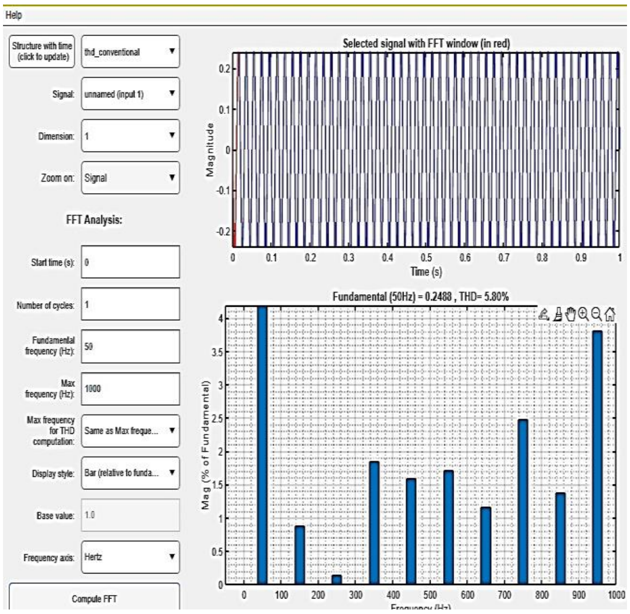


Fig. 15. Simulation results for single-phase hybrid cascaded H-bridge and Flying capacitor multilevel inverter for RL load THD is 5.80%.

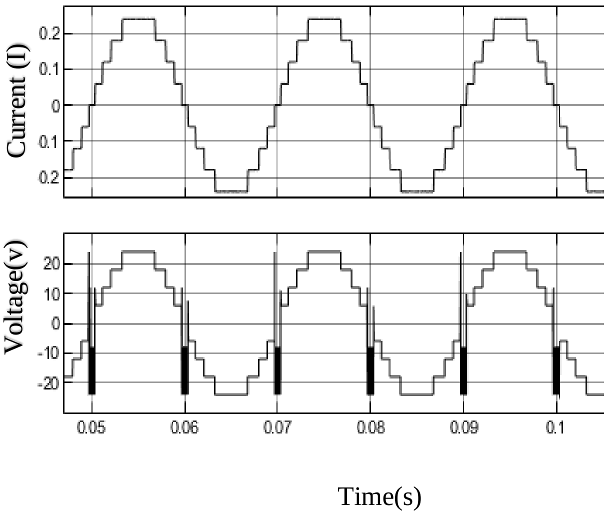


Fig. 16. Nine level Voltage and current waveform of single-phase hybrid cascaded H-bridge and Flying capacitor multilevel inverter for RL load.

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The simulation results for RL load is given above with THD of 5.80%.

Simulation results for R load

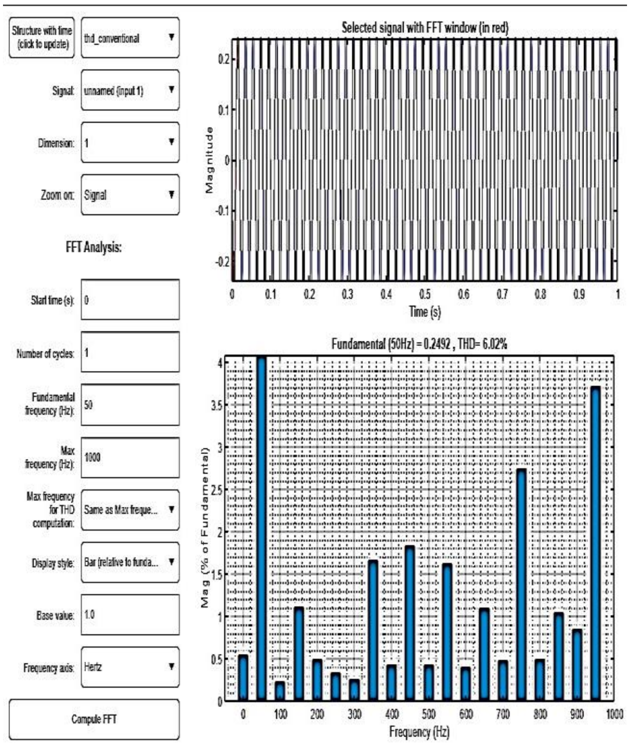

Fig. 17. Simulation results for single-phase hybrid cascaded H-bridge and Flying capacitor multilevel inverter for R load THD is 6.02%.

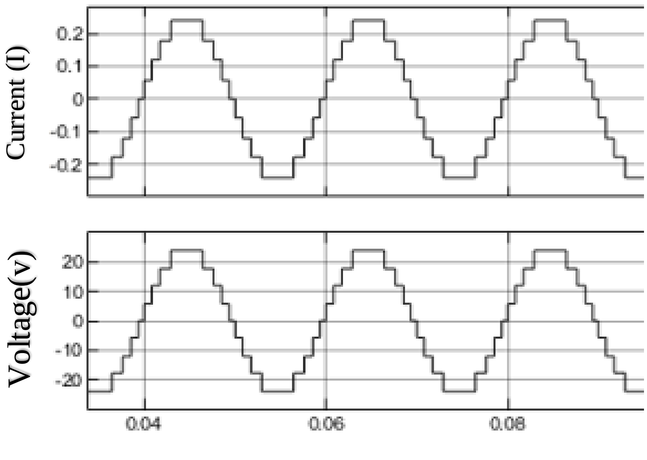

Fig. 18. Nine level Current and voltage waveform of single-phase hybrid cascaded H-Bridge and Flying capacitor multilevel inverter for R load.

The simulation results for R load are given above with THD of 6.02%.

TABLE III
COMPARISON OF THD'S WITH R AND RL LOAD

Type of load	THD in %
Resistive (R) Load	6.02%
Resistive indictive (RL) load	5.80%

Here are the two types of simulation results are provided and a brief comparison is made for THD's when the load is R load and RL load. The dc voltage of 12v is provided for both the bridges for nine level in which five level is single phase H-Bridge and five level for flying capacitor multilevel inverter. In Simulation, the obtained THD for R load is 6.02% and RL load is 5.80%.

IV. CONCLUSION

In this paper, a new hybrid topology with single-phase hybrid cascaded H-bridge and flying capacitor multilevel inverter for capacitor voltage balancing scheme is being proposed. This method is being implemented with different modes of operation for different outputs. Moreover, this scheme can be expanded to any required number of levels. The simulated results for both R load and RL load is being implemented and their corresponding THD's are being compared.

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