Simulation and Harmonics Analysis of Modified Cascade H- Bridge Multi-level Inverter

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Abstract - In Multilevel Inverters- Cascaded multilevel inverters synthesize a medium-voltage output based on a series connection of power cells which use standard low-voltage component configurations. This characteristic allows one to achieve high-quality output voltages and input currents and also outstanding availability due to their intrinsic component redundancy. Due to these features, the cascaded multilevel inverter has been recognized as an important alternative in the medium-voltage inverter market. Cascaded H bridge converters are considered to be the most preferred form of converters. But in these converters as the number of staircase levels in output voltage increases the dc source requirement also increases, thereby limiting its application. This paper tries to address the above mentioned problem by developing a Modified version of Cascaded Multilevel Converters which require less number of switching devices compared to conventional cascaded converters and produce lesser harmonics in the output voltage. The harmonics and THD at the output of Modified cascaded H-bridge inverter of different levels i.e. five-level, seven- level, nine-level and eleven-level are studied and compared. In this paper, the developed Modified Cascaded Converters are simulated in MATLAB/ SIMULINK.

Keywords— D.C Voltage Source, Harmonics, Modified Cascade H-Bridge Multilevel Inverter, MOSFETs, THD.

I. INTRODUCTION

The consumption of electricity is growing day by day. Due to deficiency in fossil fuels and problems in the environment caused by traditional power generation, renewable energy becomes very popular and demanding. The search for a stable, reliable and efficient power has always been the main concern in energy conversion from renewable resources. This has encouraged researchers to design more efficient conversion systems. Among energy conversion systems, Multilevel Inverters (MLI) have shown several advantages and benefits such as reduced stress on switches, lower change in voltage with respect to time at inverter output voltage higher efficiency and less harmonic distortion. To connect the renewable energy sources with the electricity grid there should be matching in voltage and frequency with the help of inverters. To achieve this multilevel inverter is employed. A multi-level inverter achieves high power ratings.

II. MULTI-LEVEL INVERTER

A multi-level inverter is an electronically operated device. Which synthesize the AC voltage from several different levels of DC voltages. Each additional DC voltage level adds a step to the AC voltage waveform.

Abundant MLI configurations have been matured and few are proposed during the last few years. Basically multilevel inverters can be classified into three types described below.

- Diode Clamped MLI
- Flying Capacitor MLI
- Cascade H-Bridge MLI

***Advantages of Multilevel Inverter*-1-**It can generate better output waveforms with a lower dv/dt as compared to standard converters (power quality issue).

2-It can be directly connected to high voltage sources without using any transformers or voltage conversion devices which leads to the reduction of implementation and costs.

Diode Clamped MlI Firstly, it was projected by "Akagi, Takashi and Nabae in 1981 and also known as neutral point converter. Diode clamped or neutral point inverter requires large number of diodes. Clamping diodes are used by the diode clamped multi-level inverters to bound voltage stress of the devices. A m level inverter requires 2(m-1) switching devices,(m-1) input voltage source and(m-1)*(m-2) operating diodes.

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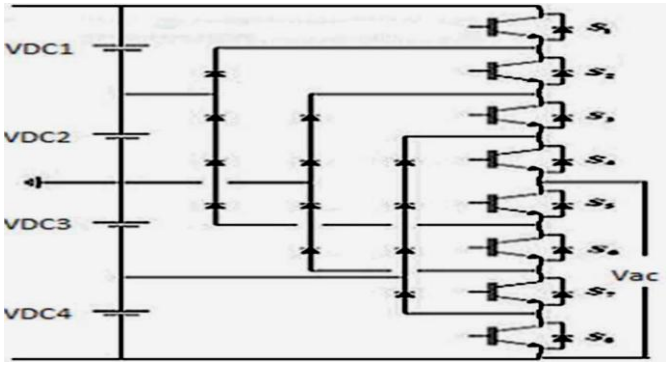

Fig.1-Diode Clamped Multilevel Inverter

***Advantages*-1-**It has a very high efficiency for the fundamental switching frequency.
2-The capacitors can be pre-charged at the desired voltage level thus reduces the complexity.
3-All phases shares a common DC link therefore the capacitance requirement of the inverter is minimized.

***Disadvantages*-1-**Packaging of inverters for a high number of levels can be a problem due to the quadratic relation among the number of levels and diodes.
2-Rating in the diodes needed for the converter is uneven.

Flying Capacitor MLI The flying capacitor topology is some way derived from diode clamped predecessor by its simplification through elimination of the clamping diodes. Such inverter uses additional capacitors which are oppositely charged to be included in series with dc supply. m level inverter requires 2(m-1) switching devices,(m-1) input voltage source and zero operating diodes.The flying capacitors inverter (FCI) is a multilevel pulse width modulated inverter whose internal architecture guarantees the voltage balancing property automatically for passive loads.

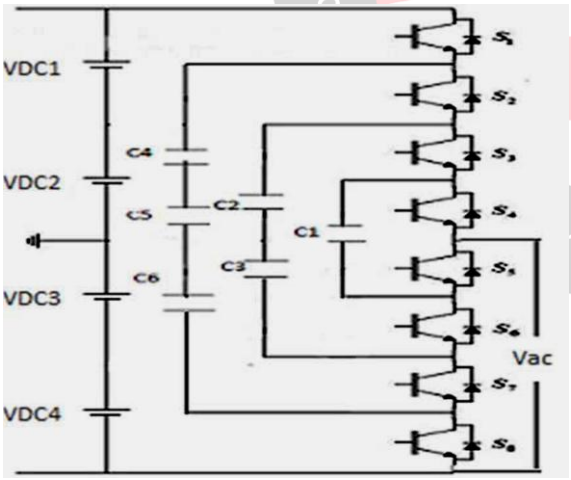

Fig.2-Flying Capacitor Multilevel Inver ter

***Advantages*-1-** Balancing the voltage levels of the capacitors by phase redundancies. These voltage-level redundancies can be used as degree of freedom for control and optimization purpose.
2-Flow of real power can be controlled.

***Disadvantages*-1-** Flying capacitor required more number of capacitors for voltage balancing therefore increase the cost of inverter.
2-Flying capacitor multilevel inverter are very bulky in size.

Cascade H-Bridge MLI The idea of this kind of inverter is grounded on connections of H-bridge inverters in cascaded manner to produce a sinusoidal output voltage. H- Bridge inverter is based on the fact that sine wave can be approximated to steeped waveforms which are having large number of steps. The voltage at output is the addition of the voltages produced by all cells .Each cell of CHB-MLI operate with separate DC voltage source. A m level inverter requires 2(m-1) switching devices,(m-1)/2 input voltage source and zero operating diode.

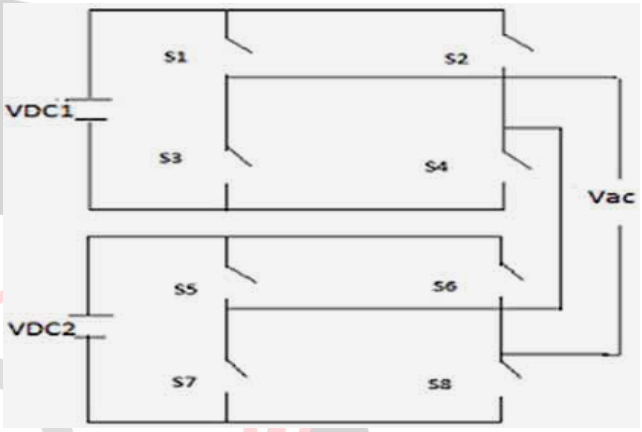

Fig.3-Cascade H- Bridge Multilevel Inverter

***Advantages*-1-** As more steps are included in the waveforms, the harmonics distortion of the output wave decrease proportionally and can approach zero if the number of levels increases to infinity..
2- All H-bridge cell will be available in a single module..
3-The high volt-ampere rating are possible with these inverters.

***Disadvantages*-1-**Middle ranges of modulation index, High voltage stage will supply more power than load requires, under these operating conditions, to operate in a rectification mode the low voltage stage will be required, which imply that the dc link must be capable of a bidirectional power flow.

2-It's more complexity in operation than standard inverter, in case of grid supply, additional transformers windings and rectifies are required by different DC sources.

III. Simulation Work

The simulation work is done in the MATLAB SIMULINK. We have made the five-level, seven-level, nine level, eleven-level and thirteen-level inverter in MATLAB by using MOSFET as a switch device. it works according to gate pulse which is given through pulse generator. We have connected the 4 MOSFETs in such a manner to make an H-bridge cell. According to the formula of cascaded H-bridge multi-level inverter we can produce desired levels as the formula is(2m+1) where m is no. Of cells. So that we can

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produce desired levels just by adding the H-bridge cells according to our desired levels.

Five Level Modified Cascade H-Bridge Inverter-five level Modified Cascade H-bridge inverter consists of Six MOSFETS, that provide five level output voltage at the output end.

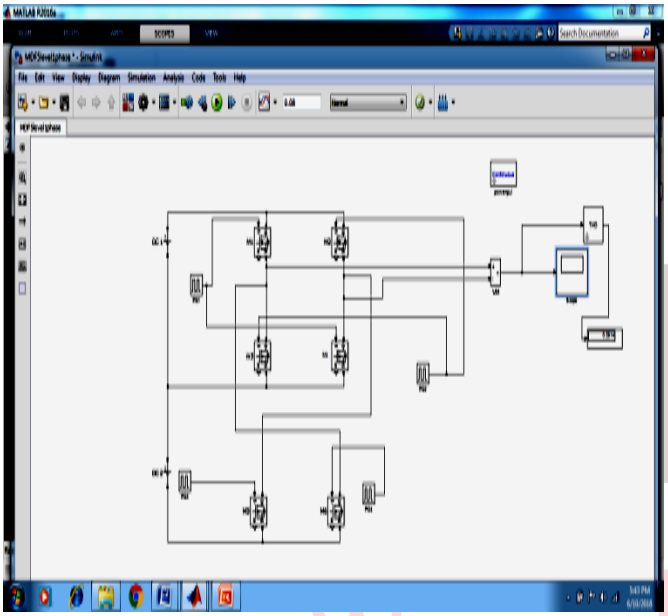

Fig .4-simulink model of single phase five- level Modified cascade H-bridge inverter

We have provided an operating time period of 0.02seconds by using a pulse generator to the all MOSFETs. Phase delay for MOSFETs (M_1,M_4) are 0.0016 And Phase delay for MOSFETs(M_2,M_3) are 0.0116. Phase delay for MOSFET (M_5) is 0.0033.Phase delay for MOSFET(M_6) is 0.0133.

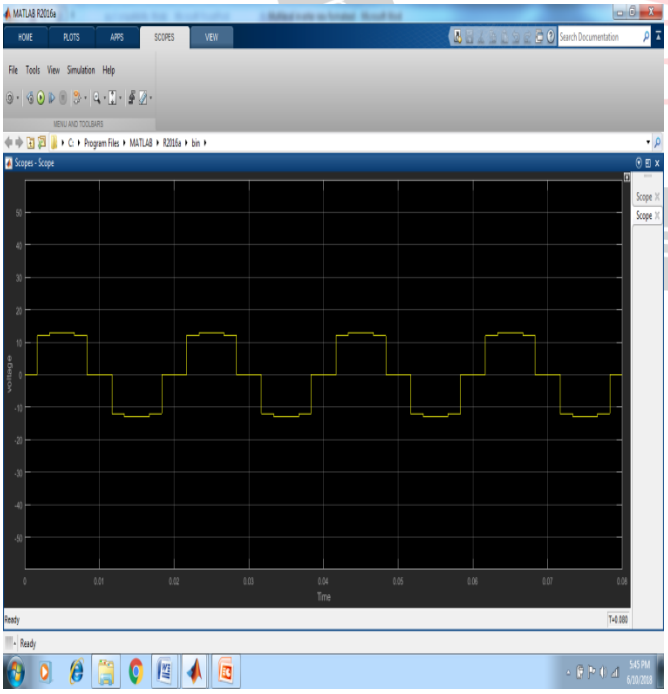

Fig .5-Output waveform of single phase five level Modified Cascade H-bridge inverter

We have provided an operating time period of 0.02seconds by using a pulse generator to the all MOSFETs. Phase delay for MOSFETs (M_1,M_4) are 0.0016 And Phase delay for MOSFETs(M_2,M_3) are 0.0116. Phase delay for MOSFET (M_5) is 0.0033.Phase delay for MOSFET(M_6) is 0.0133.

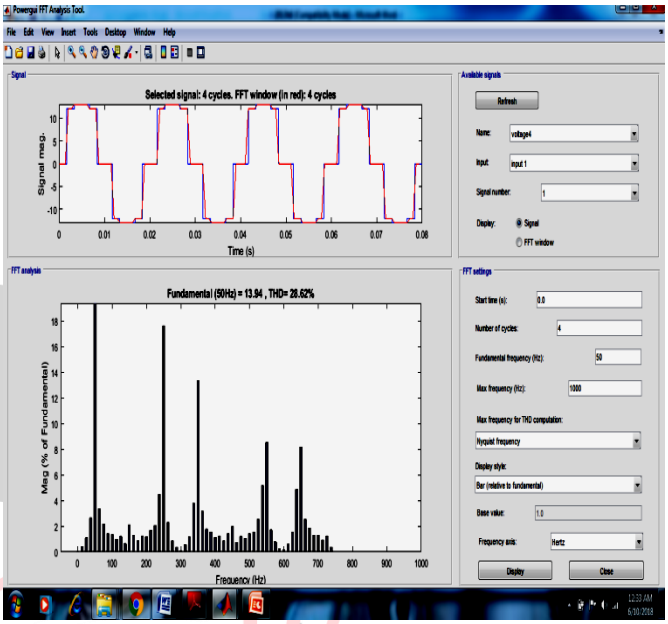

Fig .6-Total Harmonics Distortion of single phase five- level modified cascade H-bridge inverter

Voltage Conducting Table of Five Level Modified Cascade H-Bridge Inverter-

Time Period	Conducting MOSFETS	V_{out} (single phase)
0-30º	-	0
30º-60º	M_1, M_4	12 V
60º-90º	M_1, M_6	24 V
90º-120º	M_1, M_6	24 V
120º-150º	M_1, M_4	12 V
150º-180º	-	0
180º-210º	-	0
210º-240º	M_2, M_3	-12 V
240º-270º	M_2, M_5	-24 V
270º-300º	M_2, M_5	-24 V
300º-330º	M_2, M_3	-12 V
330º-360º	-	0

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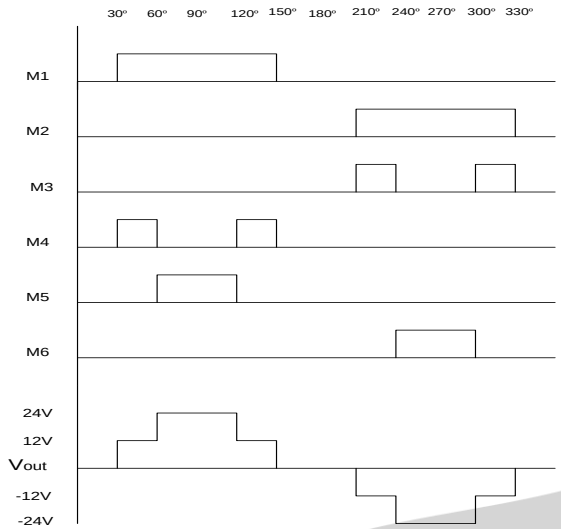

Fig. 7- Gate signal pattern for single phase five level Modified Cascade H-bridge inverter

Switching Table of Five Level Modified Cascade H-Bridge Inverter-

	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
M1	0	1	1	1	1	0	0	0	0	0	0	0
M2	0	0	0	0	0	0	0	1	1	1	1	0
M3	0	0	0	0	0	0	0	1	0	0	1	0
M4	0	1	0	0	1	0	0	0	0	0	0	0
M5	0	0	0	0	0	0	0	0	1	1	0	0
M6	0	0	1	1	0	0	0	0	0	0	0	0

Seven Level Modified Cascade H-Bridge Inverter-Seven level Modified Cascade H-bridge inverter consists of eight MOSFETS, that provide seven level output voltage at the output end.

We have provided an operating time period of 0.02seconds by using a pulse generator to the all MOSFETs.

Phase delay for MOSFETs(M_1,M_4) are 0.00125 And Phase delay for MOSFETs(M_2,M_3) are 0.01125.Phase delay for MOSFET(M_5) is 0.0025 and Phase delay for MOSFET(M_6) is 0.0125.

Phase delay for MOSFET (M_9) is 0.00375. Phase delay for MOSFET (M_{10}) is 0.01375.

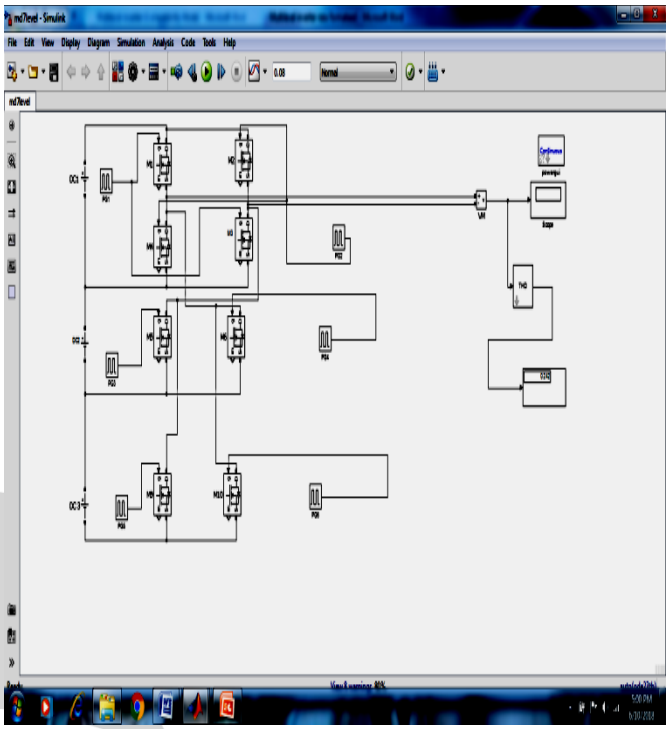

Fig .8-simulink model of single phase seven- level Modified cascade H-bridge inverter

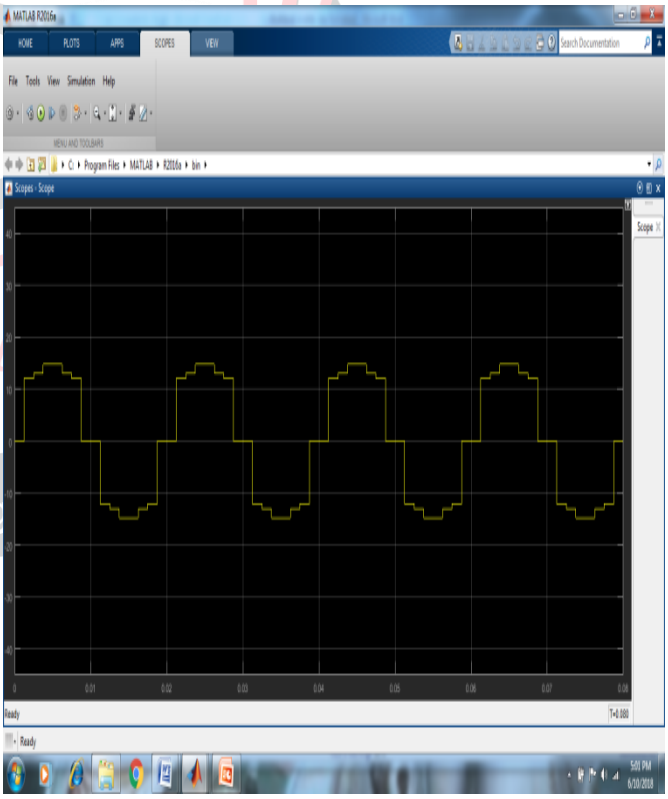

Fig.9-Output waveform of single phase seven-level Modified Cascade H-bridge inverter

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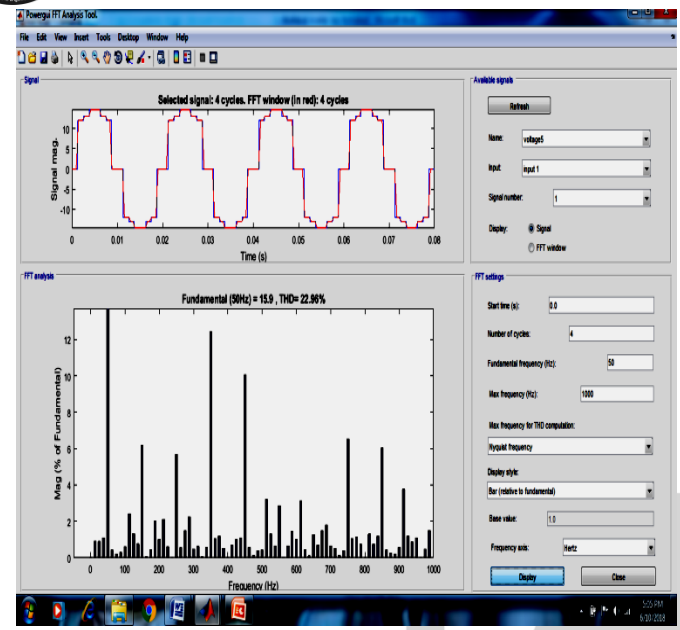

Fig .10-Total Harmonics Distortion of single phase seven- level modified cascade H-bridge inverter

Voltage Conducting Table of Seven Level Modified Cascade H-Bridge Inverter-

Time period	Conducting MOSFETS	V_{out} (Single phase)
0-22.5°	-	0
22.5°-45°	M1, M4	12V
45°-67.5°	M1, M6	24V
67.5°-90°	M1,M6, M10	36V
90°-112.5°	M1, M6,M10	36V
112.5°-135°	M1, M6	24V
135°-157.5°	M1, M4	12V
157.5°-180°	-	0
180°-202.5°	-	0
202.5°-225°	M2, M3	-12V
225°-247.5°	M2, M5	-24V
247.5°-270°	M2, M5,M9	-36V
270°-292.5°	M2, M5,M9	-36V
292.5°-315°	M2, M5	-24V
315°-337.5°	M2, M3	-12V
337.5°-360°	-	0

Nine Level Modified Cascade H-Bridge Inverter **-**Nine level Modified Cascade H-bridge inverter consists of ten MOSFETS, that provide nine level output voltage at the output end.

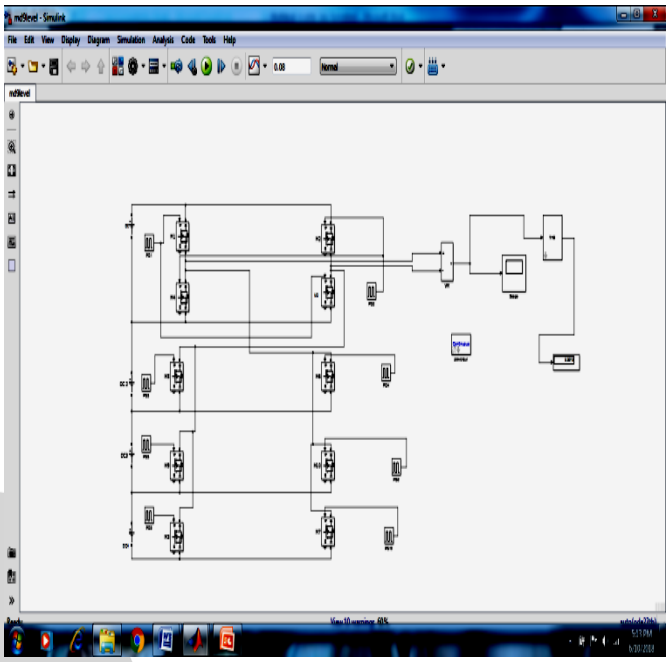

Fig .11-simulink model of single phase nine- level Modified cascade H-bridge inverter

We have provided an operating time period of 0.02seconds by using a pulse generator to the all MOSFETs.

Phase delay for MOSFETs(M_1,M_4) are 0.001 And Phase delay for MOSFETs(M_2,M_3) are 0.011.Phase delay for MOSFET (M_5) is 0.002 and Phase delay for MOSFET(M_6) is 0.012.Phase delay for MOSFET (M_9) is 0.003 and Phase delay for MOSFET (M_{10}) is 0.013. Phase delay for MOSFET(M_{13}) is 0.004 and Phase delay for MOSFET(M_{14}) is 0.014.

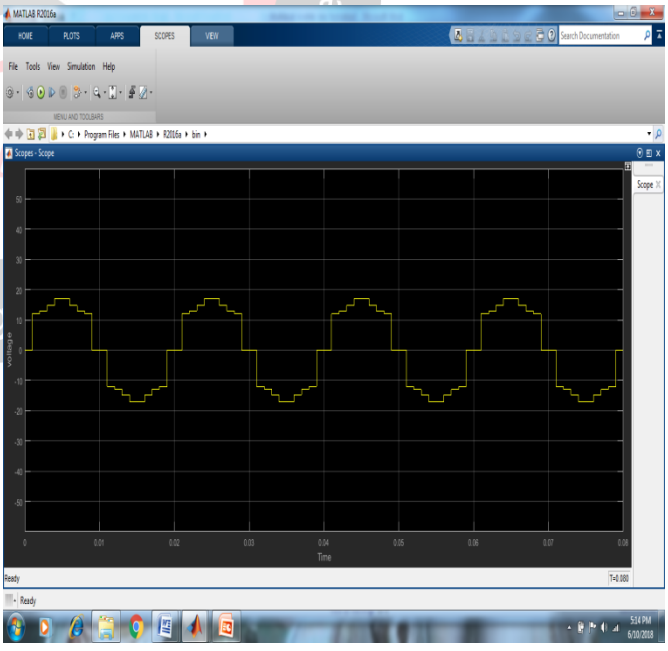

Fig.12-Output waveform of single phase nine-level Modified Cascade H-bridge inverter

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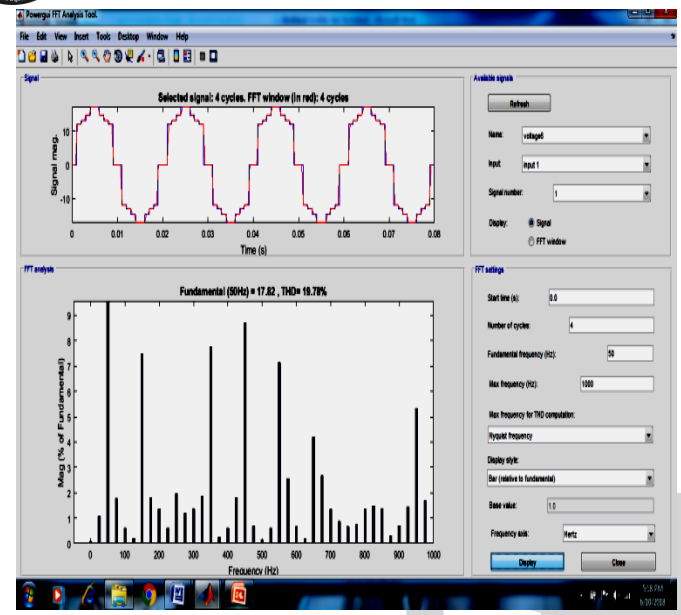

Fig .13-Total Harmonics Distortion of single phase nine- level modified cascade H-bridge inverter

Voltage Conducting Table of nine Level Modified Cascade H-Bridge Inverter-

Time period	Conducting MOSFETS	V_{out} (Single phase)
0-18°	-	0
18°-36°	M1, M4	12V
36°-54°	M1, M6	24V
54°-72°	M1,M6, M10	36V
72°-90°	M1, M6,M10,M14	48V
90°-108°	M1, M6, M10,M14	48V
108°-126°	M1, M6,M10	36V
126°-144°	M1,M6-	24V
144°-162°	M1,M4	12V
162°-180°	-	0
180°-198°	-	0
198°-216°	M2, M3	-12V
216°-234°	M2, M5	-24V
234°-252°	M2,M5,M9	-36V
252°-270°	M2,M5,M9,M13	-48V
270°-288°	M2,M5,M9,M13	-48V
288°-306°	M1,M5,M9	-36V
306°-324°	M2,M5	-24V
324°-342°	M2,M3	-12V
342°-360°	-	0

Eleven Level Modified Cascade H-Bridge Inverter- Eleven level Modified Cascade H-bridge inverter consists of twelve MOSFETS that provide eleven level output voltage at the output end.

We have provided an operating time period of 0.02seconds by using a pulse generator to the all MOSFETs.

Phase delay for MOSFETs(M_1,M_4) are 0.00083 And Phase delay for MOSFETs(M_2,M_3) are 0.010833.Phase delay for MOSFET (M_5) is 0.0016 and Phase delay for MOSFET (M_6) is 0.0116 .

Phase delay for MOSFET (M_9) is 0.0025 and Phase delay for MOSFET (M_{10}) is 0.0125. Phase delay for MOSFET (M_{13}) is 0.0033 and Phase delay for MOSFETs (M_{14}) is 0.0133. Phase delay for MOSFET (M_{17}) is 0.00416 and Phase delay for MOSFET (M_{18}) is 0.01416.

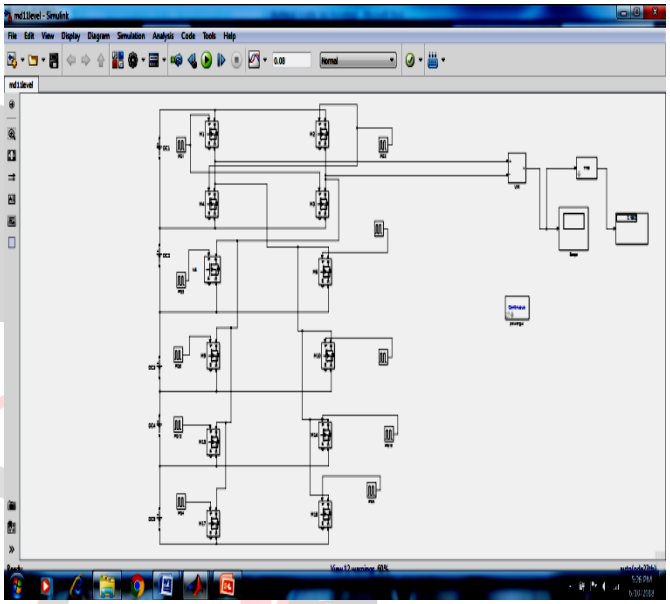

Fig .14-simulink model of single phase eleven- level Modified cascade H-bridge inverter

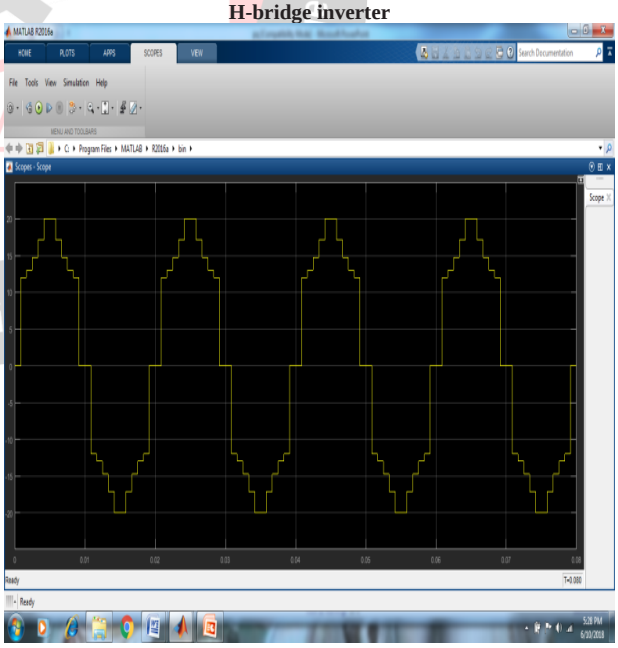

Fig.15-Output waveform of single phase eleven-level modified cascade H-bridge inverter

Voltage Conducting Table of Eleven Level Modified Cascade H-Bridge Inverter-

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Time period	Conducting MOSFETS	V_{out} (Single phase)
0-15°	-	0
15°-30°	M1, M4	12V
30°-45°	M1, M6	24V
45°-60°	M1,M6, M10	36V
60°-75°	M1, M6,M10,M14	48V
75°-90°	M1, M6, M10,M14,M16	60V
90°-105°	M1, M6,M10,M14,M16	60V
105°-120°	M1,M6,M10,M14	48V
120°-135°	5M1,M6,M10	36V
135°-150°	M1, M6	24V
150°-165°	M1, M4	12V
165°-180°	-	0
180°-195°	-	0
195°-210°	M2,M3	-12V
210°-225°	M2,M5	-24V
225°-240°	M2,M5,M9	-36V
240°-255°	M1,M5,M9,M13	-48V
255°-270°	M2,M5,M9,M13,M17	-60V
270°-285°	M2,M5,M9,M13,M17	-60V
285°-300°	M1,M5,M9,M13	-48V
300°-315°	M2,M5,M9	-36V
315°-330°	M2,M5	-24V
330°-345°	M2,M3	-12V
345°-360°	-	0

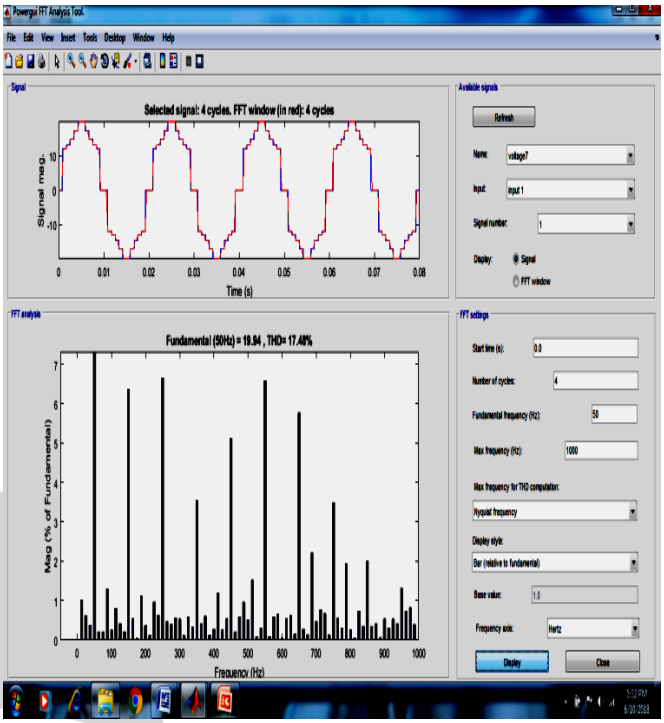

Fig .16-Total Harmonics Distortion of single phase eleven- level modified cascade H-bridge inverter

IV. CONCLUSION AND FUTURE SCOPE

In this paper we have designed and simulated the Modified Cascade H-Bridge Multilevel Inverter. The Total cost and the weight of the circuit is got reduced.

In the Modified cascaded H-bridge multi-level inverter the output voltage becomes more smooth and sinusoidal with an increase in levels then the number of power devices is get reduced as comparing to the conventional H-bridge multilevel inverter.

As we have seen in the results and output waveforms of 5, 7, 9,and 11 levels modified cascaded H-bridge inverters the THD has been reduced with an increase in levels.

Future perspective of the cascaded H-bridge inverter is that

with increase in the levels of the output voltage the THD

reduces, so that to achieve the lower THD and harmonics more than thirteen level inverter can be made viz. fifteen level, seventeen level and so on

FUTURE SCOPE

Through the number of switches has been reduced still some development is possible in Multilevel Inverter where number of power devices can still be reduced by using some other topologies as well as different modulation strategies can be implemented in multi level power conversion applications.

Three phase construction of cascade inverter is also possible.

Close loop control strategy can also be implemented. Control strategy can be applied in hardware also. Reduction

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in the switching losses of the power devices is also possible.

Advantages of Modified Cascade H-Bridge Multilevel Inverter

1- Use the Modified cascaded H-bridge multi-level inverter the number of power devices is reduced.
2- Low *dv/dt* stress.
3- Less EMI .
4- Reduced total harmonic distortion.
5- Size of the circuit reduced comparatively.
6- Low cost.
7- Output voltage becomes smoother.
8- Improvement in the efficiency of the system.
9- Better output waveforms.
10- Overall losses reduce.
11- Improvement in the reliability.
12- Weight of the circuit reduced comparatively.
13- Low switching losses.
14- Reduced the complexity of the circuit.

THD(Total Harmonics Distortion) percentage comparison Table for five, seven, nine and eleven level modified cascade h-bridge multi-level inverter

Serial No.	THD Percentage Comparison Of Different Level Inverters		
	Levels	*THD Percentage*	*THD Decreasing?*
1	5 level inverter	28.62%	Yes
2	7 level inverter	22.96%	Yes
3	9level inverter	19.78%	Yes
4	11 level inverter	17.48%	Yes

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