COMPARATIVE STUDY OF H-BRIDGE MULTI LEVEL INVERTERS

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Abstract - *Now a days, usage of the power electronic devices for conversion of electric power from DC-AC conversion or vice-versa increased drastically because of advantages with power electronic converters. But, due to the switching actions involved in conversion of DC-AC, the output waveforms are having discontinuous wave shapes. These waves consists of not only fundamental component but also the harmonics w.r.t. to fundamental wave. The control of the switches in all inverters are using PWM technique to get uniqueness in comparison.*

This work analyses the Harmonic content in the output wave using Fast Fourier Transform (FFT) when 2KVA at u.p.f., load is connected. Also analysis the output active, reactive power delivered to load when some fault occurs in the conversion process like battery source disconnected, one of the switch fails to operate, etc. In all the cases the harmonic content in the output wave in the 5-level ,7-level,9-level and 11-level inverters and compared the results with each other. The comparison will be carried out by using FFT analysis in MATLAB/SIMULINK software.

Power loss, voltage transients also calculated across the each switch when the load is at u.p.f. in the 5-level ,7-level,9-level and 11-level inverter and compares the results. Calculation of power loss, design of heat sink for proper dissipation of heat are also considered. Whereas the OFF state voltage across the switch to design the size of the switch.

***Key Words*:** Comparison, power loss, Analysis of active power, PWM technique, Cascaded H-Bridge, Voltage transients.

1.INTRODUCTION

In power converters, energy conversion is a function of switching states of the converter. Based on the application, power converters with optimal modulation techniques need to be identified and developed to deliver maximum output power. This research work aims at comparing the output voltages, Total Harmonic Distortion (THD), predominant harmonics of a single phase cascaded multilevel inverter of various levels and validating the performance of the inverter as using PWM switching control technique.

The main objectives of this research work are, to study, the calculation of pulse width and duty ratios of switches in Multi-Level Inverters and implement PWM strategies with cascaded multilevel inverter based on control degrees of freedom combinations and to obtain Total Harmonic Distortion in each Level of CHB based inverter it helps to design the physical filters based on the harmonics exist.

2. FIVE LEVEL INVERTER

In this inverter, two H-bridges are connected as cascade and two DC sources of 150 v each are connected to each bridge. And 8 switches IGBT switches with individual gate control.

Simulation

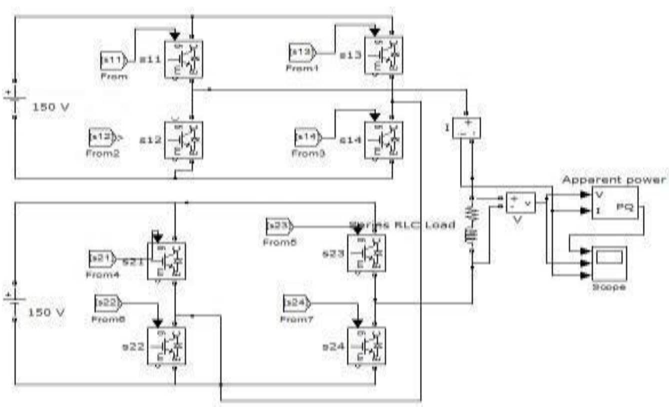

Figure 2.1 simulation of five level inverter

Fig 2.1 shows the 5 level inverter and its duty ratio depends on the pulses produced by the pulse generator. Inverter consists of two legs, in each leg two IGBT switches are connected back to back. Output of pulse generator is connected to each switch and NOT gate output is connected to the another switch which is placed on same leg.

2.1 LOAD AT U.P.F:

At unity power factor, the 2kva is connected at load terminals for analyzing the performance of inverter. At load terminals the active power transmitted from the source is 1814w at fundamental frequency. Reactive power transmitted from source is zero. Figure2.2 shows the waveforms of voltage, current and apparent power at load terminals. Voltage and current wave forms in stepped in nature. It consists of five level voltage magnitudes 0v, 150v, 300v, -150v, -300v.

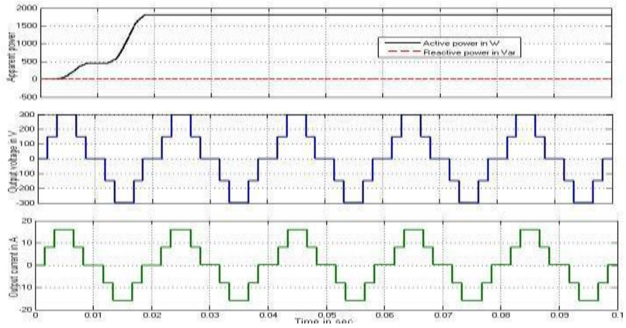

Figure 2.2 output waveforms of Five level inverter at u.p.f.

FFT analysis

RMS value of Output voltage is 193.8 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency is 184.7v. And the waveform consists of 31.52%(THD) at fundamental frequency. The predominant harmonics are3^{rd}-24.48%, 5^{th}-5.60% 7^{th}-3.57% and th-8.00%. Fundamental RMS current 9.835A.

2.1.1 Power loss across switches

Average power loss can be calculated by multiplying the voltage across and current through the switch . The figure 2.3 shows the waveforms of power loss, voltage and currents in a switch. Each switch causes the power loss of 0.225W And in Five level inverter 8 no's of switches are used

.So total average power loss in the bridge circuit is 1.8w. we conclude that the average power loss is same for all the power factors.

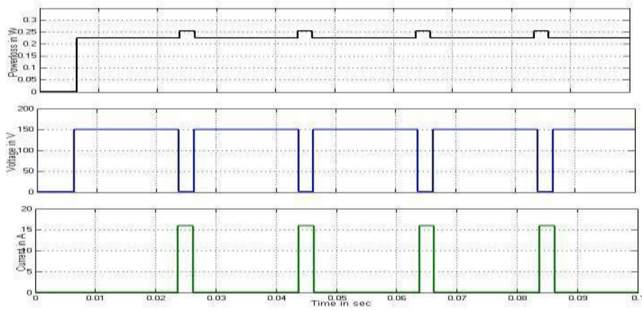

Figure 2.3 power loss across switch

Off state voltage

Voltage across the switch when it is in OFF 150v i.e. the switch capable to withstand this voltage during turn off state. The forward break over voltage should be more than this voltage to avoid automatic turn on. Figure 2.3 shows the voltage transients across the switch.

2.1.2 One battery source disconnected

Figure 2.4 shows the apparent (active, reactive) powers delivered to load, when the battery is disconnected from one of its bridge. In both cases the power can be transmitted from another Even though the battery removed or suddenly disconnected from the bridge there is continuity of power to the load with reduction in power. In this case active power drawn by the load is 725 w and reactive power is zero.

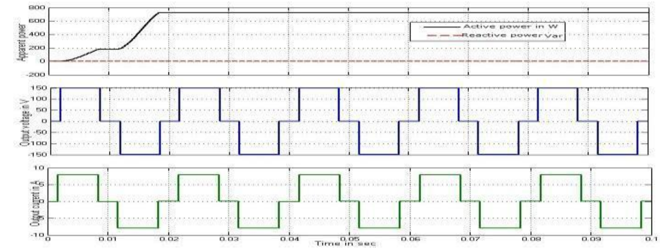

Figure 2.4 waveforms when one battery source disconnected

FFT analysis

RMS value of Output voltage is 122.3 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 116.7 v. And the waveform consists of 30.54%(THD) at fundamental frequency. The predominant harmonics are 5^{th}-20.10%,7^{th}-14.19% and 11^{th}-9.00%. Fundamental RMS current 6.221 A.

2.1.3 Switch failed to turn on

If the pulse generator failed to generate the gate pulse to IGBT or IGBT failed to turn on, in both the cases IGBT will not turn on. In this circumstances analyze parameters at load terminals like output voltage, currents and harmonics. The active power delivered to load is 848 w. Figure 2.5 the output voltage, current, apparent power at output terminals.

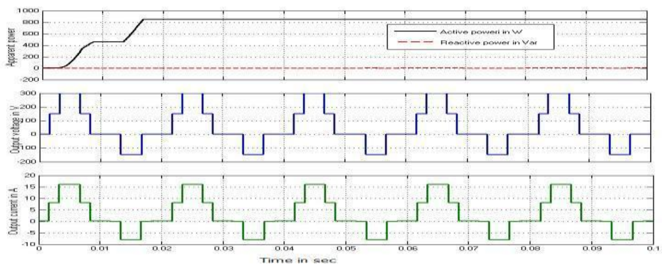

Figure 2.5 Output waveforms when switch failed to turn on

FFT analysis

The RMS value of Output voltage is 150.2 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency (50 HZ) is 126.3

v. And the waveform consists of 50.44%(THD) at fundamental frequency. The predominant harmonics are DC-28.1%, 2nd-23.1%,3rd-35.71%, 4th-11.52% and 5th- 1.11%.

3 SEVEN LEVEL INVERTER

In this inverter, three H-bridges are connected as cascade and three equal DC sources of 100 v each(namely dc1, dc2, dc3) are connected to each bridge, and 12 switches IGBT switches with individual gate control.

Simulation

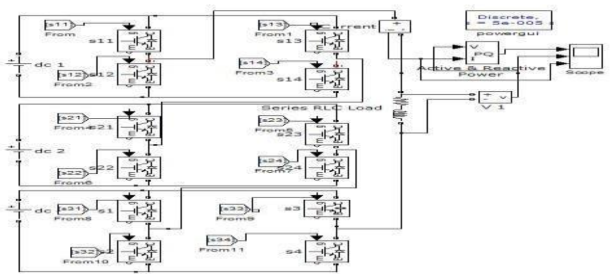

Figure3.1 Simulation of seven level inverter

Fig 3.1 shows the seven level inverter and its duty ratio depends on the pulses produced by the pulse generator. Inverter consists of two legs , in each leg two IGBT switches are connected back to back. With same configuration seven level inverter consists of 3 bridges. Output of pulse generator is connected to each switch and NOT gate output is connected to the another switch which is placed on same leg.

3.1 LOAD:2KVA@UPF

At unity power factor, the 2kva is connected at load terminals for analyzing the performance of inverter. At load terminals the active power transmitted from the source is 1879w at fundamental frequency. Reactive power transmitted from source is zero. Voltage and current wave forms in stepped in nature. It consists of 7 voltage magnitudes 0v, 100v, 200v, 300v, -100v, -150v, -300v.Figure 3.3 shows the voltage levels of inverter.

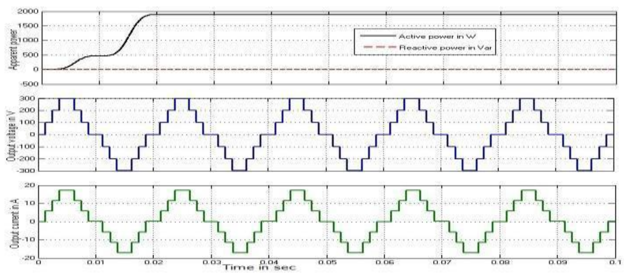

Figure 3.2 output waveforms of Seven level inverter at u.p.f.

FFT analysis

RMS value of Output voltage is 187 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency is 181.3v. And the waveform consists of 25.47 %(THD) at fundamental frequency. The predominant harmonics are 3rd-20.67%, 5th-1.65% 7th-4.25% and 9th- 3.31%.Fundamental RMS current 10.37 A.

3.1.1 Power loss across switches

Average power loss can be calculated by multiplying the voltage across and current through the switch . The figure3.3 the waveforms of power loss, voltage and currents in a switch. Each switch causes the power loss of 0.1w and in Seven level inverter 12 no's of switches are used .So total average power loss in the bridge circuit is 1.2w.We conclude that the average power loss is same for all the power factors.

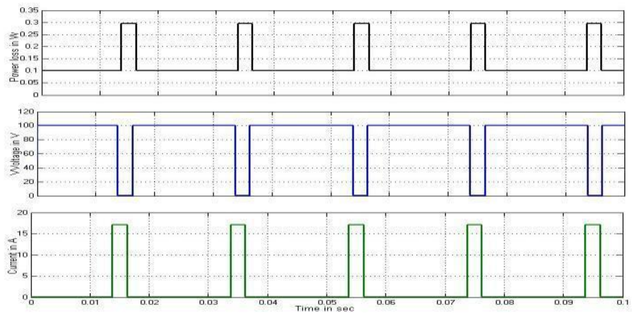

Figure 3.3 power loss across switch

Off state voltage

Voltage across the switch when it is in OFF 100v i.e. the switch capable to withstand this voltage during turn off state. The forward break over voltage should be more than this voltage to avoid automatic turn on. Figure 3.3 shows the voltage transients across the switch.

3.1.2 One battery source disconnected

Figure 3.4 shows the apparent (active, reactive) powers delivered to load, when the battery is disconnected from one of its bridge. In both cases the power can be transmitted from another Even though the battery removed or suddenly disconnected from the bridge there is continuity of power to the load with reduction in power. In this case active power drawn by the load is 550w. and reactive power is zero.

FFT analysis

RMS value of Output voltage is 115.2v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 98.2v. And the waveform consists of 54.38%(THD) at fundamental frequency. The predominant harmonics are 3rd-49.80%,5th-3.91%,7th-4.23%and9th-3.32%.Fundamental RMS current 6.221 A.

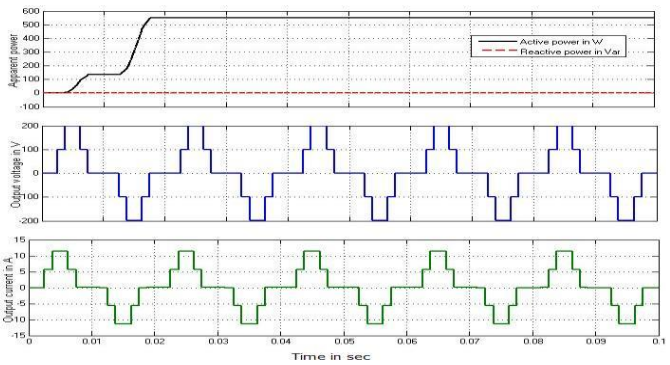

Figure 3.4 waveforms when one battery source disconnected

3.1.3 Switch failed to turn on

If the pulse generator failed to generate the gate pulse to IGBT or IGBT failed to turn on, in both the cases IGBT will not turn on. In this circumstances analyze parameters at load terminals like output voltage, currents and harmonics. The active power delivered to load is 1116w. Figure 3.5 the output voltage, current , apparent power at output terminals.

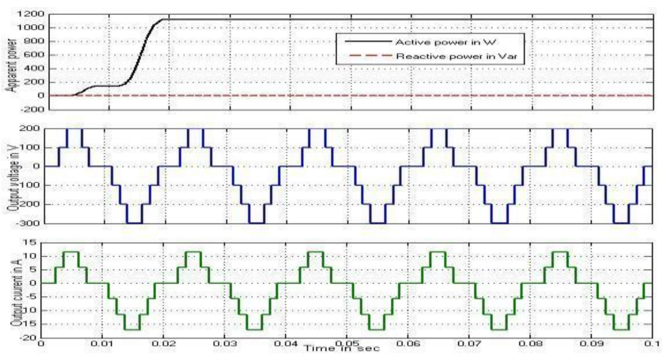

Figure3.5 Waveforms of seven level inverter (one switch fail)

FFT analysis

The RMS value of Output voltage is 154 v i.e. it consists of DC, fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 139v. And the waveform consists of 37.82%(THD) at fundamental frequency. The predominant harmonics are DC-18.98%, 2nd-11.36%, 3rd-30.84% and4th-8.05%.

4. NINE LEVEL INVERTER

In this inverter, three H-bridges are connected as cascade and three equal DC sources of 75 v each are connected to each bridge, and 16 switches IGBT switches with individual gate control.

Simulation

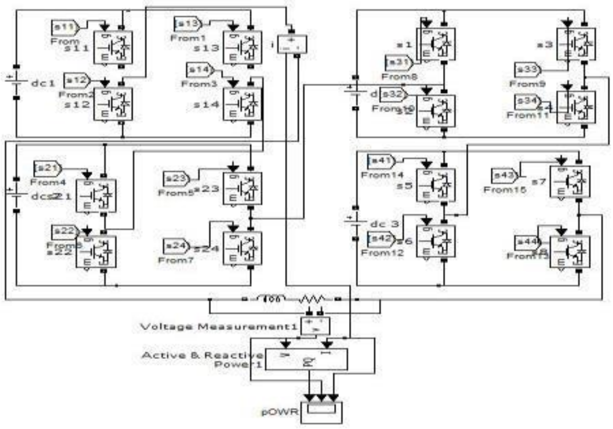

Figure 4.1 Simulation of nine level inverter

Figure 4.1 shows the nine level inverter and its duty ratio depends on the pulses produced by the pulse generator. Inverter consists of two legs , in each leg two IGBT switches are connected back to back. With same configuration nine level inverter consists of 4 bridges. Output of pulse generator is connected to each switch and NOT gate output is connected to the another switch which is placed on same leg.

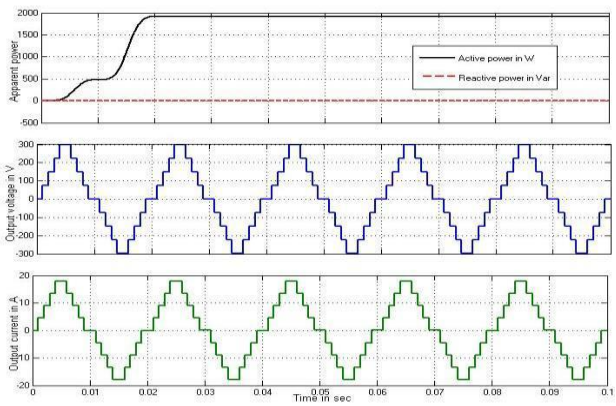

Figure 4.2 output waveforms of Nine level inverter at u.p.f.

4.1 LOAD:2KVA@UPF

At unity power factor, the 2kva is connected at load terminals for analyzing the performance of inverter. At load terminals the active power transmitted from the source is 1908w at fundamental frequency. Reactive power transmitted from source is zero. Voltage and current wave forms in stepped in nature. It consists of 9 voltage magnitudes 0v, 75v, 150v, 225v, 300v, -75v, -150v, - 225v, -300v.Figure 4.2 shows the voltage levels of inverter.

FFT analysis

RMS value of Output voltage is 183.6 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency is 179.3 v. And the waveform consists of 21.84 %(THD) at fundamental frequency. The predominant harmonics are 3rd-18.50%, 7th-4.40% and 9th- 1.76%. Fundamental RMS current 10.65 A.

4.1.1 Power loss across switches

Average power loss can be calculated by multiplying the voltage across and current through the switch . The figure shows the waveforms of power loss, voltage and currents in a switch. Each switch causes the power loss of 0.056w and in nine inverter 16 no's of switches are used .So total average power loss in the bridge circuit is 0.7w.We conclude that the average power loss is same for all the power factors.

Off state voltage

Voltage across the switch when it is in OFF 75v i.e. the switch capable to withstand this voltage during turn off state. The forward break over voltage should be more than this voltage to avoid automatic turn on. Figure 4.3 shows the voltage transients across the switch.

4.1.2 One battery source disconnected

Figure 4.4 shows the apparent (active, reactive) powers delivered to load, when the battery is disconnected to one of its bridge. In both cases the power can be transmitted from another Even though the battery removed or suddenly disconnected from the bridge there is continuity of power to the load with reduction in power. In this case active power drawn by the load is 786.5w. and reactive power is zero.

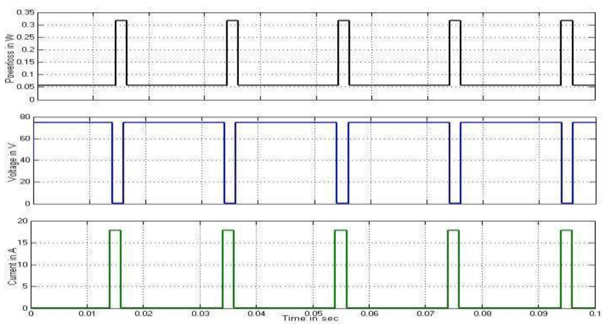

Figure 4.3 switching transients across the switch

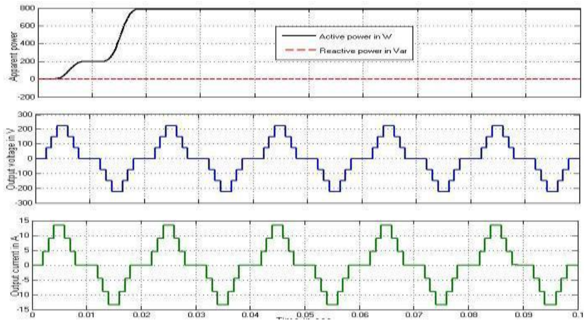

Figure4.4 waveforms of nine level inverter (one battery disconnected)

FFT analysis

RMS value of Output voltage is 125.4v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 115.2v. And the waveform consists of 43.05%(THD) at fundamental frequency. The Predominant Harmonics are 3rd-40.35 %, 7th-1.43 % and 9th- 3.43 %.Fundamental RMS current 6.8 A.

4.1.3 Switch failed to turn on

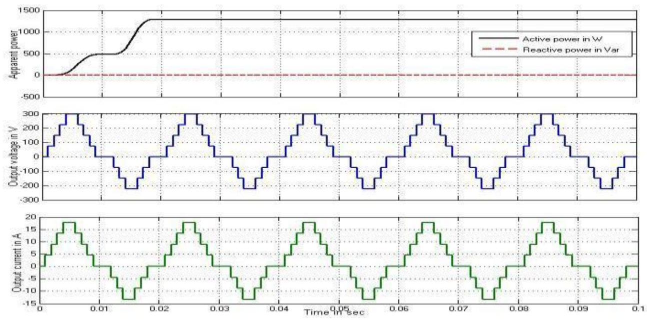

Figure 4.5 waveforms of nine level inverter (one switch fail)

If the pulse generator failed to generate the gate pulse to IGBT or IGBT failed to turn on, in both the cases IGBT will not turn on. In this circumstances analyze parameters at load terminals like output voltage, currents and harmonics. The active power delivered to load is 1286w. Figure 4.5 shows the output voltage, current, apparent power at output terminals.

FFT analysis

The RMS value of Output voltage is 154 v i.e. it consists of DC, fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 139v. And the waveform consists of 28.97%(THD) at fundamental frequency. The predominant harmonics are DC-11.78 %, 2nd 11.36%, 3rd-30.84% and4th-8.05%.

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5. ELEVEN LEVEL INVERTER

In this inverter, three H-bridges are connected as cascade and three equal DC sources of 60 v each are connected to each bridge, and 16 switches IGBT switches with individual gate control.

Simulation

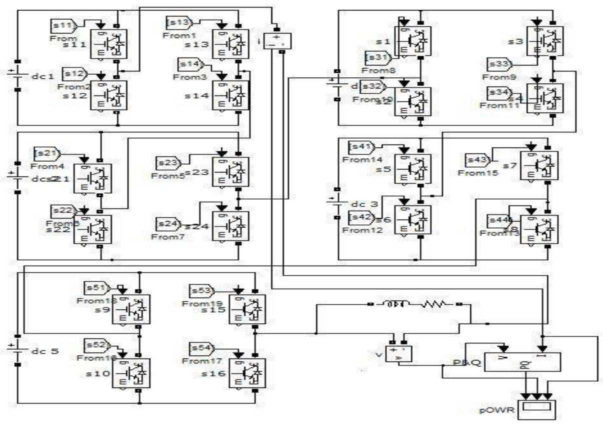

Figure 5.1 Simulation of nine level inverter

Figure 5.1 shows the eleven level inverter and its duty ratio depends on the pulses produced by the pulse generator. Inverter consists of two legs , in each leg two IGBT switches are connected back to back. With same configuration eleven level inverter consists of 4 bridges. Output of pulse generator is connected to each switch and NOT gate output is connected to the another switch which is placed on same leg.

5.1 LOAD:2KVA@UPF

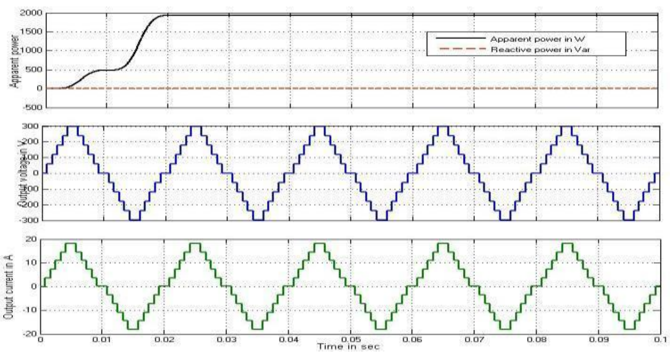

Figure 5.2 Output waveforms of eleven level inverter at u.p.f.

At unity power factor, the 2kva is connected at load terminals for analyzing the performance of inverter. At load terminals the active power transmitted from the source is 1921w at fundamental frequency. Reactive power transmitted from source is zero. Voltage and current wave forms in stepped in nature. It consists of 11 voltage magnitudes 0v, 60v, 120v, 180v, 240v, 300v, -60v, -120v, 180v, -240v, -300v.Figure 5.2 shows the voltage levels of inverter.

FFT analysis

RMS value of Output voltage is 181.5 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency is 178.1 v. And the waveform consists of 19.59%(THD) at fundamental frequency. The predominant harmonics are 3rd- 17.15 % and7th-3.64 % .Fundamental RMS current 10.8 A.

5.1.1 Power loss across switches

Average power loss can be calculated by multiplying the voltage across and current through the switch . The figure 5.3 shows the waveforms of power loss, voltage and currents in a switch. Each switch causes the power loss of 0.036w and in eleven inverter 20 no's of switches are used .So total average power loss in the bridge circuit is 0.648w.We conclude that the average power loss is same for all the power factors.

Off state voltage

Voltage across the switch when it is in OFF 60v i.e. the switch capable to withstand this voltage during turn off state. The forward break over voltage should be more than this voltage to avoid automatic turn on. Figure 5.3 shows the voltage transients across the switch.

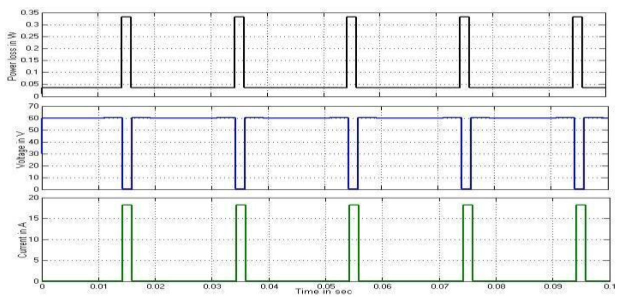

Figure 5.3 Voltage transients across switch

5.1.2 One battery source disconnected

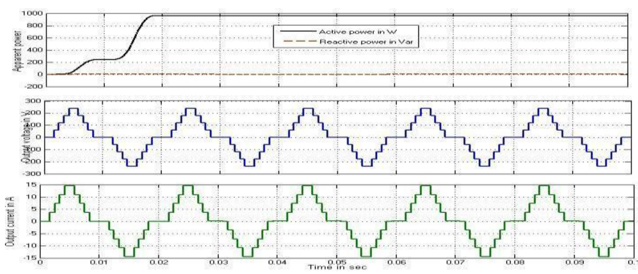

Figure 5.4 Waveforms of eleven level inverter (one battery disconnected)

Figure 5.4 shows the apparent (active, reactive) powers delivered to load, when the battery is disconnected from one of its bridge. In both cases the power can be transmitted from another Even though the battery removed or suddenly disconnected from the bridge there is continuity of power to the load with reduction in power. In this case active power drawn by the load is 960w. and reactive power is zero.

FFT analysis

RMS value of Output voltage is 134v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 125.9v. And the waveform consists of 36.42%(THD) at fundamental frequency. The Predominant Harmonics are 3rd-34.48 %, 5th 1.15% and 7th- 3.73 %.Fundamental RMS current 7.635 A.

5.1.3 Switch failed to turn on

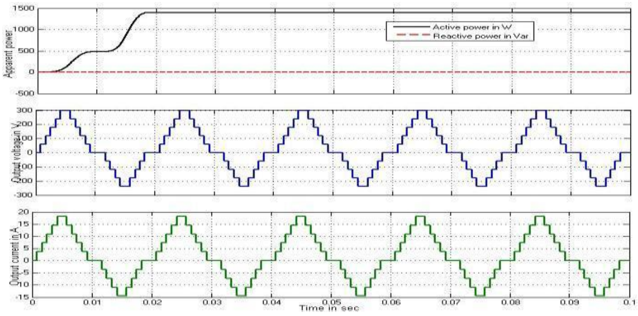

Figure 5.5 waveforms of eleven level inverter
(one switch fail)

If the pulse generator failed to generate the gate pulse to IGBT or IGBT failed to turn on, in both the cases IGBT will not turn on. In this circumstances analyze parameters at load terminals like output voltage, currents and harmonics. The active power delivered to load is 1399w. Figure 5..5 the output voltage, current , apparent power at output terminals.

FFT analysis

The RMS value of Output voltage is 159.5 v i.e. it consists of DC , fundamental and harmonics of voltages. The RMS value of output voltage at fundamental frequency(50 HZ) is 152v. And the waveform consists of 27.22%(THD) at fundamental frequency. The predominant harmonics are DC-11.50 %, 2nd-4.38%, 3rd-24.32%, 4th -8.05% and 6th-2.95%.Figure 3.56 shows the % magnitude of harmonics w.r.t. to fundamental frequency.

6. CONCLUSIONS

6.1 FOLLOWING ARE THE CONCLUSIONS DRAWN FROM THE PRESENT STUDY

As the level increases the Apparent (Active, Reactive) power transmitted at load increases at fundamental frequency, i.e., at 5 -level, 11- level active power loads are 1814w, 1921w respectively at unity power factor. Total Harmonic Distortion (THD) are 5-level, 7-level , 9- level , 11-level are 31.52%, 25.47%, 21.84% and 19.58% respectively. Concluded that THD decreases and power transmission increases with level of conversion at unity power factor.

Magnitude of 3rd harmonic (predominant one) content in five level- 24.48%, seven level-20.67%, nine level-18.50% and eleven level- 17.15%.Predominant harmonic magnitude decreases as the level increases. As the level increases the lower order harmonic content decreases , it is consideration of design the filter. Size of filter is low for 11 level converter.

Power loss in the switch for five level is 0.225w and total power loss is 1.8w, seven level power loss is 0.1w and total loss 1.2w , nine level power loss 0.056w and total loss0.7w and for eleven level power loss in each switch is 0.036w and total loss 0.648w. concluded that power loss also decreases in 11 level compared to five level inverter. Power loss is same in all inverters for any power factors. Proper heat dissipation methods need to be consider for five level because the power loss is high.

Voltage across each switch during off state for five level:150v, seven level:100v, ninelevel:75v, elevenlevel:60v. From above concluded that , the voltage across eleven level inverter is low. The size of the switch used in this inverter is low.

6.2 SCOPE FOR FURTHER STUDY

The present work can be extended by increasing number of levels, so that Total Harmonic Distortion (THD), magnitude of harmonics decreases and apparent power (active, reactive power) transmission increases at fundamental frequency.
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