SIMULATION OF 1KW MULTI-LEVEL SWITCH MODE POWER AMPLIFIER

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Abstract-The main aim of a large signal amplifier, otherwise called a power amplifier is to deliver a substantial amount of power to the load. Its ultimate power decides the type of operation of an amplifier. A multi-level switch-mode power amplifier is designed and classified under class S configuration. The input to the amplifier is 8Vpp of few milliamps and frequency from 3 to 6 kilohertz, the output obtained is of 1KW and frequency set at the input. A new multi-level inversion topology approach achieves this output with less distortion and reduced harmonics.

Keywords - Multi-Level Switch, Power Amplifier, Voltages, Control, Circuit

1. INTRODUCTION

The output of the conventional single-phase and three-phase inverters is non-sinusoidal and contains harmonics. So, for medium and low power application, this is acceptable, but for high power applications, low distortion sinusoidal waveforms are required. Multilevel inverters have a significant advantage over the conventional one because of the capability of operating the load with linearly sinusoidal current waveforms of high output voltages.

Here the available single-phase 220V AC is given to a transformer's primary, and seven different voltages are produced by the multiple secondary's. One output is used as the power supply for the control circuit. The other six outputs are given to the full-bridge rectifiers, thus corresponding six dc voltages are produced. These voltages are given to IGBT switches which are made to operate either in cut off or saturation regions (hence the name switch mode) with different time intervals to generate a stepped waveform with six voltage levels of dc. An appropriate sinusoidal waveform is then generated by using an H bridge inverter.

It may be easier to produce high power, high voltage, using the multilevel structure because of how the device voltage stress is controlled in this structure. Increasing the number of inverter levels without requiring higher ratings on individual devices can increase power ratings. This unique structure of the amplifier with multilevel inversion topology allows us to reach high amplified voltages with lower harmonics. [1-10].

2. OVERVIEW OF MULTILEVEL SWITCHED MODE AMPLIFIER

Amplifiers are of in general linear and switched-mode type. Class A, Class B, Class AB, Class C is classified under linear amplifiers. But Here class S mode of operation is used were IGBT is made to operate as a switch either in cutoff or saturation regions. The drop taking place across the collector to emitter region is nearly significantly less of nearly 1 volt. Class S amplifier is made to operate with multilevel inversion topology. Hence the name multilevel switch-mode power amplifier. [5]

The major components used in the above circuit is IGBT's which act as switches and are turned on and off appropriately to obtain the required output voltage waveform.

Six rectifiers are connected to the secondary of the transformer supplying the six DC voltage sources, at the input of inverter circuit.Fig 1 shows that Basic block diagram of a six-level inverter.

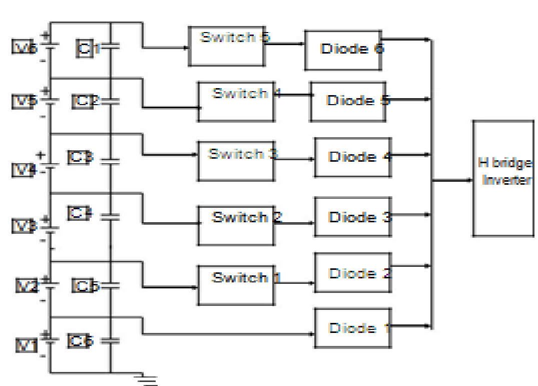

Fig 1. Basic block diagram of a six-level inverter

Fig 2. The waveform of the amplified output

The waveform of the amplified output is shown in Fig 2.

3. DESIGN AND IMPLEMENTATION OF SWITCHED MODE POWER AMPLIFIER

Here available single-phase 220V ac has been given to a transformer's primary. Seven different voltages are produced by the multiple secondary's in which one output has been used as the power supply for the control circuit. The other six outputs were given to the full-bridge rectifiers and corresponding six dc voltages were produced. These voltages were given to the filter circuit to reduce ripple then voltages were given to IGBT switches. It is made to operate either in cut off or saturation regions (hence the name switch mode) with different time intervals to generate a stepped waveform with six voltage levels of dc. An appropriate sinusoidal waveform is then generated by using an H bridge inverter. Fig 3 shows complete block of the amplifier circuit. Fig 4 shows Control circuit and block diagram. Fig 5 shows circuit configuration of the multilevel switch mode amplifier.

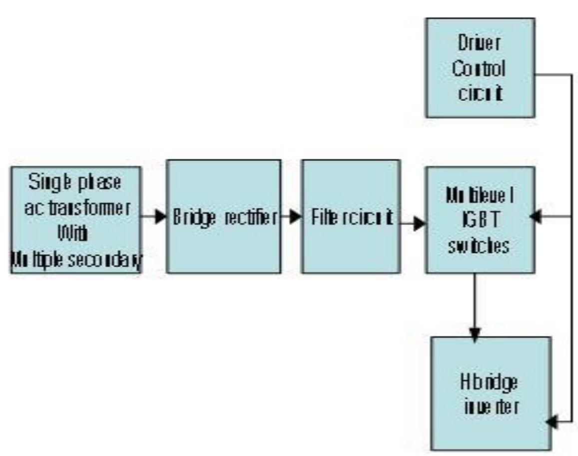

Fig 3. Complete block of the amplifier circuit.

The control circuit generates the gating signals for the corresponding IGBT's by comparing the sine wave, and it is rectified from with different DC levels to get the corresponding pulse widths.

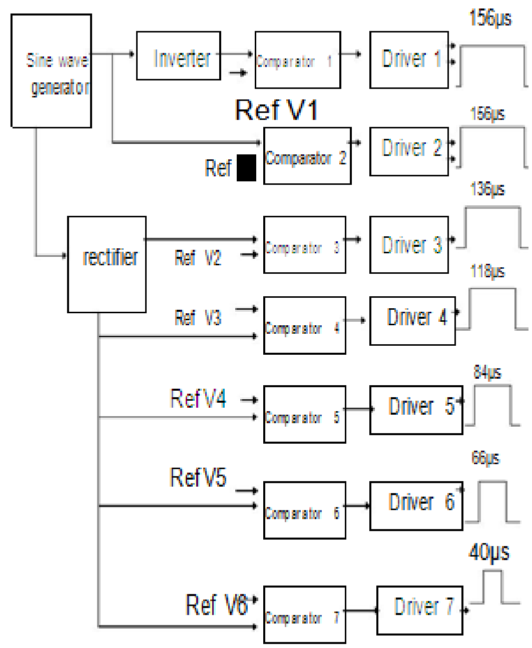

Fig 4. Control circuit and block diagram

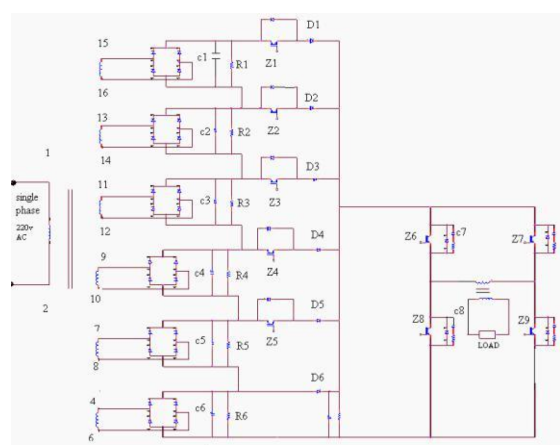

Fig 5. circuit configuration of the multilevel switch mode amplifier

If discrete multiple DC sources are used to synthesize the staircase waveform, it increases the hardware parts as the number of steps increases. Hence from available single-phase 220V ac source multiple, DC sources are obtained.

Multiple DC sources from available single phase Ac is obtained as shown in the block diagram above. The input 220V single phase Ac is utilized to get seven different voltages by multiple secondary transformers. Each ac voltage is converted into Dc voltage by connecting the bridge rectifier to all the seven secondary's. The output of the rectifiers is the Dc voltages which are given to the filter block which decrease the harmonics and give stabilized DC output, which is further used as the input DC voltage source required by the switch-mode power amplifier. Six outputs are used for generating staircase wave. The seventh output is used as a power supply source for the control circuit.

The working of the multilevel switch-mode power amplifier is explained regarding its output waveform as it can be seen from the output waveform of the inverter circuit as in fig 2. that there are six voltage levels. These voltages are the amplified output of the input signal of 8Vpp, with few milliamps and frequency depends upon the input it may be 3 to 6 KH. This input signal is compared with different dc voltages levels which decide the switching period of the IGBT's, which leads to receiving the stepped waveform output.

The output of the first level is = V1 = 29.2 V
The output of the second level is = V2 = 48.4V
The output of the third level is = V3 = 37 V
The output of the fourth level = V4 = 34V
The output of the fifth level = V5 = 31V
The output of the sixth level = V6 = 31V

These voltages (V) were measured across each rectifier

V = V1+V2+ V3+V4+V5+V6 = 192 volts dc is the voltage to the H bridge inverter. The transformer at the output is selected in such a wave that the output ac power is of 1KW at the first level, the DC voltage source V1 would be the input to the inverter, and the current path would be through the diode D6.

At the second level, IGBT Z5 is turned on. Hence the DC voltages V1 & V2 would be the input to the inverter, and the current path would be through diodes D6 & D5.

At the third level, IGBT Z5 & IGBT Z4 is turned on. Hence the DC voltages V1, V2 & V3 would be the input to the inverter and the current path would be through diodes D6, D5 & D4.

At the fourth level, IGBTZ5, IGBTZ4, & IGBTZ3 are turned on. Hence the DC voltages V1, V2, V3 & V4 would be the input to the inverter, and the current path would be through diodes D6, D5, D4 & D3.

At the fifth level, IGBTZ5, IGBTZ4, & IGBTZ3 ,IGBT2 turned on. Hence the DC voltages V1, V2, V3 & V4, V5. will be the input to the inverter, and the current path would be through diodes D6, D5, D4 D3 & D2.

At the sixth level, IGBTZ5, IGBTZ4, & IGBTZ3, IGBT2, IGBT1are turned on. Hence the DC voltages V1, V2, V3, V4, V5, V6 would be the input to the inverter, and the current path would be through diodes D6, D5, D4 D3, D2 & D1. Hence IGBT 6 and IGBT 9 would be conducting. During the next time, the output voltage across the load is decreasing. During the negative cycle, the working is the same as above, but the conduction path is reversed. Here IGBTZ 7 and IGBT 8 would be turned on. The pulses required to switch on the IGBT appropriately are generated using the control circuit. The pulses generated are given to IGBTs through driver circuit. Value of c1, c2, c3, c4, c5, c6 is 3600µf. Value of D1, D2, D3, D4, D5, D6 is 22kΩ. value of the snubber circuit capacitor and resistor of H bridge is 10µf and 50Ω, respectively.

4. TRANSFORMER DESIGN

This transformer has primary numbered 1and 2. current = 1.8amps and Voltage = 220Vac. secondary of the transformer numbered 3 and 5: current = 2.38A and voltage 36V, 4 and 6 current = 2.38 A and voltage = 36V, 7 and 8 current = 2.38 A and voltage 23V, 9 and 10 current = 2.38A and voltage = 23V, 11 and 12 current = 1.8A and voltage = 26V, 13 and 14 current = 1.8A and voltage = 26V, 15 and 16 current = 1.8A and voltage = 26V.

From the given data above, the appropriate core and winding should be selected.

Windings of the transformer are calculated. The equation relating the no of turns and the voltage is given by

Erms = (4fBmAcNK)/108, Where f = frequency =50Hz

Bm= maximum flux density =1.7T =17Kgauss Ac = effective core area =7.66cm2 for one loop. Since two loops are being used the Ac= 2x7.66 = 15.32 cm2, K = form factor = 1.11 for sine wave and 1 for square wave.

Hence the turns/volt ratio for primary from is,
Nprim /Eprim =
108/[4x1.11x50x1.7x10000x(7.66*2)]
Similarly Primary input voltage is of 220V

Nprim =1.73 * Eprim = 1.73*220 = 380.6 . Chosen as 384 turns/volt ratio for secondary
There are seven secondary's

Secondary numbered 3,5 and 4,6 = 36 * 1.73 = 61.92 chosen as 60 turns

Secondary numbered 7,8 and 9,10 = 23 * 1.73 = 40 chosen as 41 turns
Secondary numbered 11,12 ;13,14 and 15,16 = 26 *

1.73 = 45 turns chosen as 48 turns [2]

5. CALCULATION OF REFERENCE VOLTAGE LEVEL FOR DIFFERENT PULSE WIDTHS:

Since frequency f=3000Hz, Time period T = 333 µs, T/2 = 166.66 µs = 167 µs, V_m = 8Vpp

The main IGBTs require pulse width of 156 µs each and need to be switched once in a cycle complementarily

V_m = 8Vpp, t=(167-156) /2 µs = 5.5 µs
ω= 2πf =2π(2*3000) = 37699 rad/s

$V_{ref} = V_m \sin\omega t$

= 8 sin (37699* 5.5 µs) = 1.64V

The other multilevel switching IGBT s require to be switched for every half cycle with different pulse width

For pulse width = 136 µs, t = (167 - 136)µs / 2 = 15.5 µs

ω=2π(3000)= 18849 rad/sec
$V_{ref} = V_m \sin\omega t$

= 8 sin (18849*15.5 µs) = 2.30V

For pulse width = 118 µs, t = (167 - 118) µs / 2 = 24.5 µs

ω=2π(3000)= 18849 rad/sec
$V_{ref} = V_m \sin\omega t$

= 8 sin (18849*24.5µs) = 3.56V

For pulse width = 66 µs, t = (167 - 84)µs / 2 = 41.5µs
ω=2π(3000)= 18849 rad/sec

$V_{ref} = V_m \sin\omega t$

= 8 sin (18849*41.5 µs) = 5.63V

For pulse width = 66 µs, t = (167 - 66)µs / 2 = 50.5µs
ω=2π(3000)= 18849 rad/sec

$V_{ref} = V_m \sin\omega t$

= 8 sin (18849*50.5 µs) = 6.51V

For pulse width = 136 µs, t = (167 - 40) µs / 2 = 63.5µs

ω=2π(3000)= 18849 rad/sec
$V_{ref} = V_m \sin\omega t$

= 8 sin (18849*63.5µs) = 7.44V

6. DESIGN OF COMPARATOR CIRCUIT

Fig 6 shows that the basic comparator. The pulse width of 156µs is obtained by comparing the respective Dc level with a sine wave, as shown in the fig below. The desired DC level is obtained, a voltage divider network is formed.

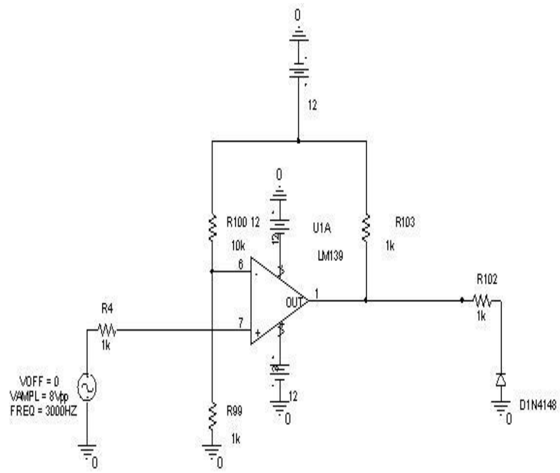

Fig 6. The basic comparator circuit is shown for example

For DC level $\mathbf{V_{ref} = 1.64V}$

V_{ref} = (12V*R99)/(R100+R99)

let **R100=10kΩ,**

1.64 = (12*R99)/(10k+R99)

R99= 1.583 kΩ **choose R99 =1KΩ**

Similarly, all other comparator circuits are designed to obtain the respective DC levels and the corresponding pulse widths. The multilevel inverter switches pulse widths are obtained by comparing rectified waveform with corresponding DC level.

7. DETAILS OF OUTPUT POWER TRANSFORMER DESIGN

The input voltage to the primary:400 Vpp
Output Voltage across the secondary:1000 Vpp
Core Data: Toroidal core Outer diameter = 80mm
Height = 27mm Winding Data:
Wire diameter :
Primary wire diameter: 1.6mm
Secondary wire diameter: 1.2mm
Number of turns
Number of turns in the primary = 90
Number of turns in the secondary = 200
Turns/layer
Primary Turns / layer = 90
Secondary turns / layer = 105
No of layers
No of layers in primary: 1
No of layers in the secondary: 2

Insulation details:
Interlayer insulation
2layers of yellow scotch tape in secondary Inter winding insulation:
2layers of yellow scotch tape in primary

8. CONTROL CIRCUIT OF THE AMPLIFIER

In multilevel switch-mode power, amplifier IGBTs are used as a switching device because of their switching frequency and various other advantages. These IGBTs require the triggering pulse to be given across the gate and source to initiate the conduction.

When the gate-source voltage VGE is less than the threshold voltage VGE (th), the device would operate in the cutoff region and is turned off.

When an enormous gate to source voltage VGE is applied the device is driving into the ohmic region and the device is turned on.

These triggering pulses are generated from the control circuit. The gate driver circuit would perform the following operations

It reduces the turn-on time of the IGBT.

It provides isolation between the power circuit and the control circuit.

The low magnitude pulses are pulled up to make it sufficient enough to drive the IGBT

Model of 1KW multilevel switch-mode power amplifier is shown 7.

The Hardware diagram for this amplifier is shown in fig 7.

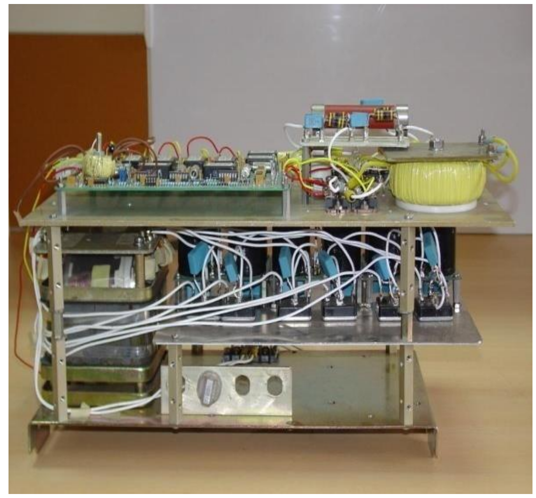

Fig 7. Hardware Diagram

9.SIMULATION RESULTS

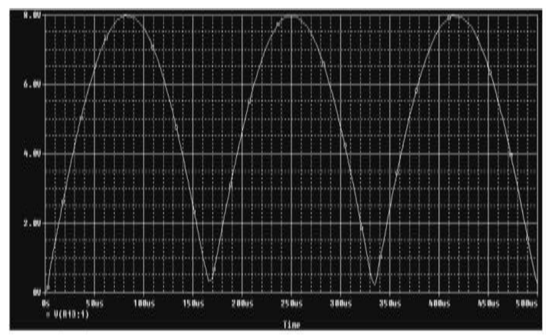

Fig 8. The output of the rectifier circuit

Figure 8 shows that the output of the rectifier circuit. Triggering input waveforms for the multilevel IGBT's to the gate of Z5 of 136 µs , Z4 of 118 µs , Z3 of 84 µs , Z2 of 66 µs , Z1 of 40 µs are shown in Fig 9,10,11,12 and 13.

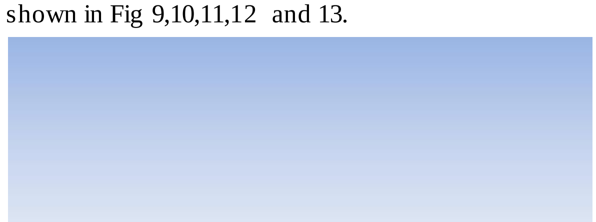

Fig 9. Input triggering pulse to the gate of Z5 of 136µs

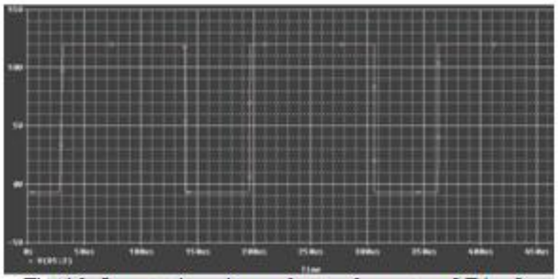

Fig 10. Input triggering pulse to the gate of Z4 of 118 µs

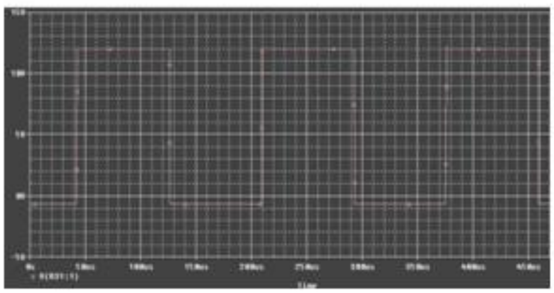

Fig 11. Input triggering pulse to the gate of Z3 of 84 µs

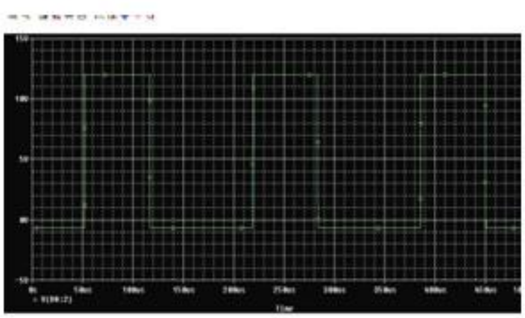

Fig 12. Input triggering pulse to the gate of Z2 of 66 µs

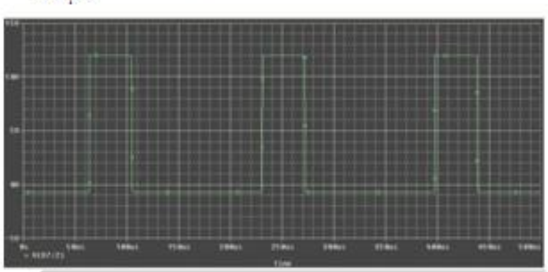

Fig 13.Input triggering pulse to the gate of Z1 of 40 µs

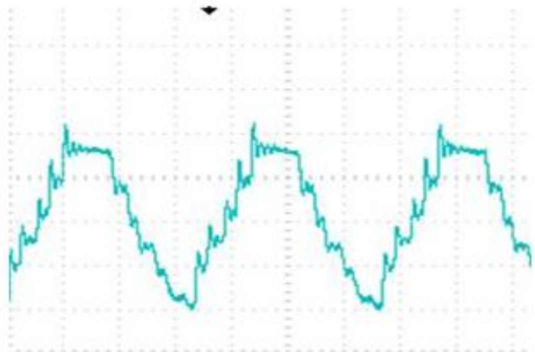

Fig 14. .DC output voltage waveform measured across the primary of the transformer

Fig 15 Output waveforms showing 2 steps at 4 Vp-p input signal

Fig 15 Output waveforms showing 2 steps at 4 Vp-p input signal

Fig 16. Output waveforms showing 3 steps at 5 Vp-p input signal.

Fig 14 shows that DC output voltage waveform measured across the primary of the transformer.

From fig 15 and 16, Output waveforms showing 2 steps at 4 Vp-p input signal and 3 steps at 5 Vp-p input signal.

Fig17. Output waveforms showing 4 steps at 6 Vp-p input signal

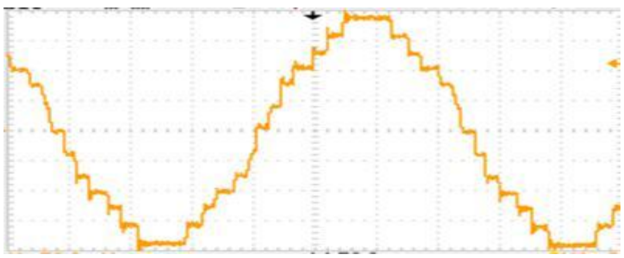

Fig 18. Output waveform showing 5 steps at 7 Vp-p input signal

Fig 19. Output waveform showing 6 steps at 8 Vp-p input signal

Output obtain at three different frequency levels across the load of 180Ω. The input from the power circuit is of 200V single phase ac and he signal to be amplified is of 8V pp.

Table 1 Efficiency of proposed work

Frequency in KHZ	Input current in amps	Output Voltage in Volts		Input power in watts	Output Power in Watts	Effecienc In %
		Vrms	Vpp			
3	2	252	816	400	352	88
4.5	2.1	265	864	420	319	92
6	2.2	273	872	440	414	94

Table 1 provides the result for Efficiency of proposed work. Advantages of this work are such as 1.Higher voltage capability. 2. Higher power quality. 3. Better electromagnetic compatibility. 4. It is suitable for medium to high power applications. 5.They can improve the power quality and dynamic stability for utility systems. 6. Switching stress and EMI are low. 7. Because of their modular and simple structure, they can be stacked up to an almost unlimited number of levels. 8. Low switching loss.

Limitations of this work are such as 1. Requires many high-power switching devices as then number of level increases. 2. A high voltage rating is required for switching devices. 3. There is potentially a voltage-balancing problem.

10. CONCLUSION

1k multilevel switch-mode power amplifier has been designed for a specific application as a power supply source for the transducers for sonar. Transducers in sonar are operated in echo ranging principle which is used to determine ocean depth, for the detection of underwater targets like submarines, fishes, obstacles on the sea bed. This equipment known as sonars is more complicated than echo sounder as it gives the information on the range and bearing of the target and the target velocity if it is a submarine. This amplifier output is given to the input of the piezoelectric transducer, which is of 1KW power with frequency ranging from 3 to 6 kHz then the output would be the sound waves used for the detection purpose. In this project, the control circuit has been implemented using all ICs, which has involved many hardware circuitry. Hence the hardware can be reduced by implementing the control circuit using any DSP based controller or any microcontroller or with the help of Genetic Algorithms.

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