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Three Phase 11-Level Single Switch Cascaded Multilevel Inverter

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ABSTRACT

Application of multilevel inverter for high power equipments in industry has become popular because of its high-quality output waveform. In this paper, a three phase 11 level is proposed with reduced number of switches. An algorithm has been generated on the basis of optimized harmonic stepped waveform technique to find out firing angle for multilevel inverter to reduce harmonic content present in output. The proposed multilevel inverter has been validated using MATLAB R2009a software and firing angle was calculated using program executed by MATLAB R2009a.

KEYWORDS: *Three phase inverter, single switch cascaded multilevel inverter, total harmonic distortion.*

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I. INTRODUCTION

Many industrial applications have begun to use high power apparatus in recent year. Medium power motor drives and utilities require medium voltage and higher power level. In a medium voltage grid, connecting only one power semiconductor switch directly will create problem. To overcome this problem, a multilevel inverter topology has been introduced as an alternative in medium voltage and high power situations. A multilevel inverter use renewable energy as source and can achieve high power rating. So, renewable energy sources such as solar, fuel cells and wind can be easily interfaced to a multilevel inverter structure for a high power application. The multilevel inverter concept has been used since past three decades. The multilevel inverter begins with a three-level inverter. Thereafter, many multilevel inverter topologies have been developed. However, the main concept of a multilevel inverter is to achieve high power with use of many power semiconductor switches and numerous low voltage dc sources to obtain the power conversion that lookalike a staircase voltage waveform. The dc voltage sources for multilevel inverter are given by battery, renewable energy and capacitor voltage sources. The proper switching of the power switches combines these multiple dc sources to achieve high power output voltage. The voltage rating of the power semiconductor devices depends only upon the total peak value of the dc voltage source that is connected to the device. Three major classification of multilevel inverter structures [1-3] are cascaded H-bridge inverter with separate dc source, diode clamped (neutral-clamped), and flying capacitor (capacitor clamped).

II. THREE PHASE SINGLE SWITCH CASCADED MULTILEVEL INVERTER

A new multilevel inverter topology has proposed and illustrated in Fig. 1.The Single switch cascaded multilevel inverter consists of a full bridge inverter that is used to change the direction of current through the load to obtain an alternating current flow across the load. It consist of parallel connection of switches connected parallel to full bridge inverter with a single DC voltage source in between them.

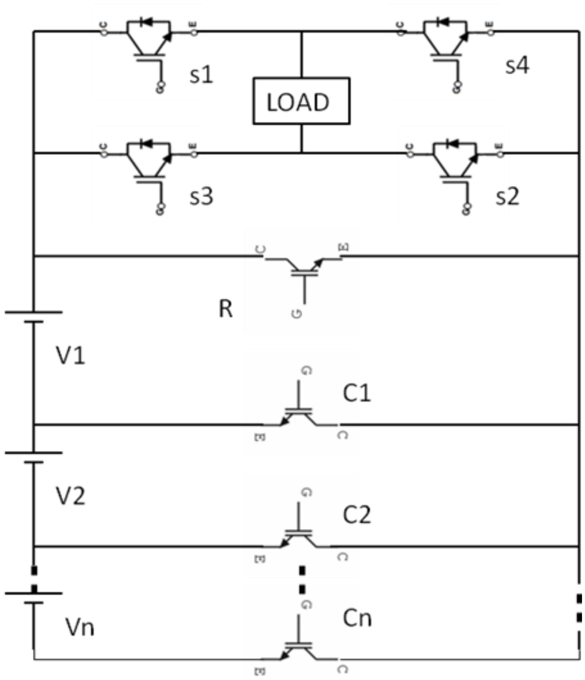

Figure 1. Single switch cascaded multilevel inverter

Initially, switch s1 and s2 are turned on for supplying power in the positive direction across load. After positive cycle is finished switches s1 and s2 are turned off. Now for reversing the direction of flow of power across load, switches s3 and s4 are turned on. At the end of negative cycle, switches s3 and s4 are turned off. There is a period of gap is left between positive to negative cycle and negative to positive cycle, in that period switch R is turned on and turned off for continuous conduction of current across the load that is stored in the load if its inductive and this switch is useful in reducing voltage ripple that occur in between cycles due to inductive loads.

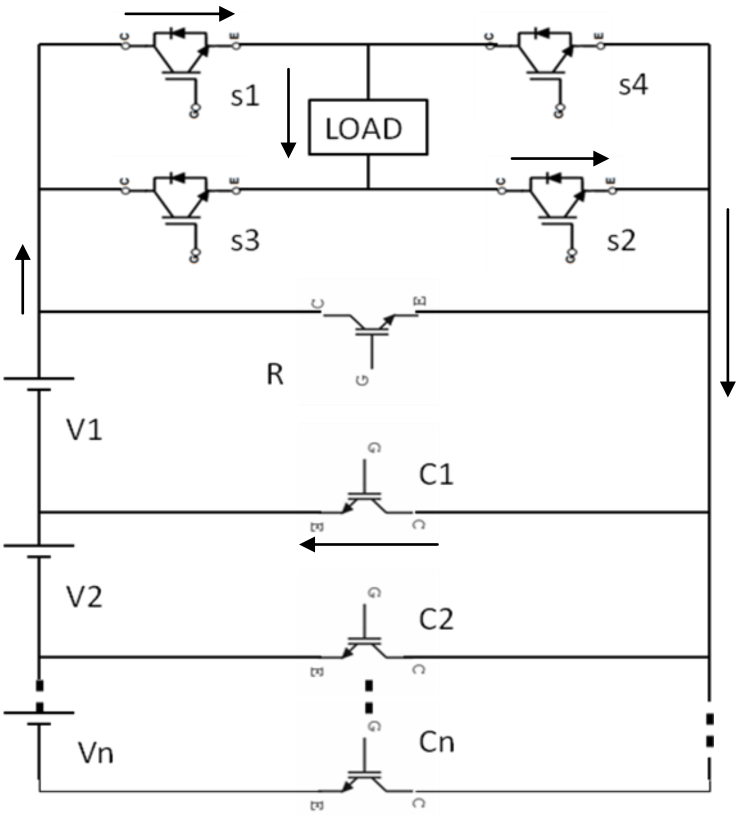

Figure 2. Positive cycle operation

In positive cycle operation, after the switches s1 and s2 are turned on, load is across the voltage sources and the amount of voltage to be present across it is decided by the switches c1, c2...cn. Switch c1 is turned on along with s1 and s2 to apply a voltage of E across load in positive direction which is showed in the Fig 2. Now, switch c1 is turned off and c2 is turned on to apply a voltage of 2E across the load. This operation is repeated until peak voltage nE is obtained; where n represent number of dc voltage source. Then switch cn is turned off and cn-1 is turned on to reduce the voltage level from peak to low to form a positive cycle.

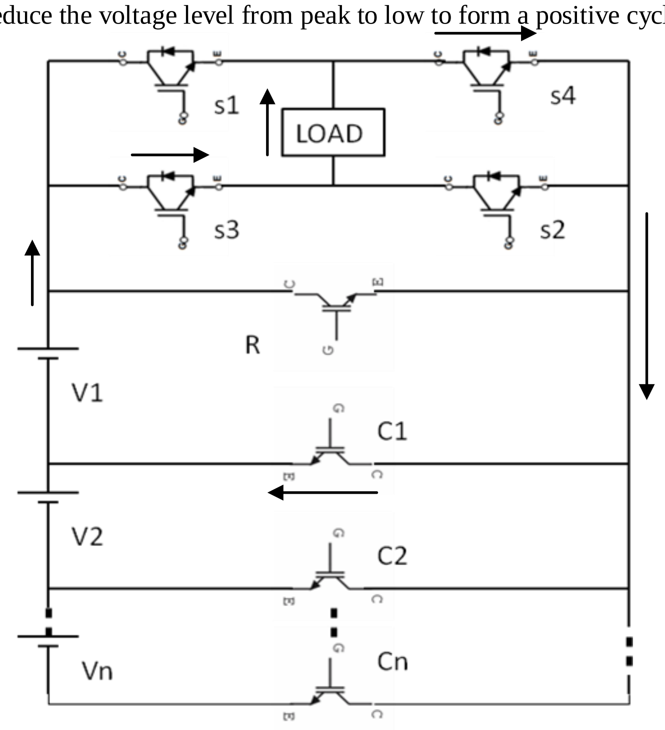

Figure 3. Negative cycle operation

Table I: Voltage Values and On State Switches for 11 Level Proposed Topology

level	Switches in on state		Voltage
5	s1,s2	C5	v5+v4+v3+v2+v1
4		C4	v4+v3+v2+v1
3		C3	v3+v2+v1
2		C2	v2+v1
1		C1	v1
0	R		0
-1	s3,s4	C1	v1
-2		C2	v2+v1
-3		C3	v3+v2+v1
-4		C4	v4+v3+v2+v1
-5		C5	v5+v4+v3+v2+v1

In negative cycle operation, switches s3 and s4 are turned on, then load is connected across the voltage sources and the amount of voltage to be present across it is decided by the switches c1, c2...cn. Switch c1 is turned on along with s3 and s4 to apply a voltage of E across load in negative direction which is showed in the Fig 3.

This process is repeated until the peak negative –nE is reached and then switch cn is turned off. Switches turned on in the reverse direction from cn to c1 to apply a voltage of nE to E in decreased way to form a complete negative cycle.

This single switch cascaded multilevel inverter is designed for 11 level and three set of topologies with a firing angle difference of 120 degree between them is used to produce R,Y and B phases to get three phase supply.

III. OPTIMIZED HARMONIC STEPPED WAVEFORM TECHNIQUE

The optimized harmonic stepped waveform technique [12, 13] was used in this paper. When OHSW technique is employed along with the multilevel topology, THD of output waveform is reduced without using any filter circuit is possible. Switching devices are turn on and turn off only one time in a complete cycle. Thus, switching loss and EMI problem can be overcome. Fig. 4 shows a symmetric 11-level optimized harmonic stepped-waveform.

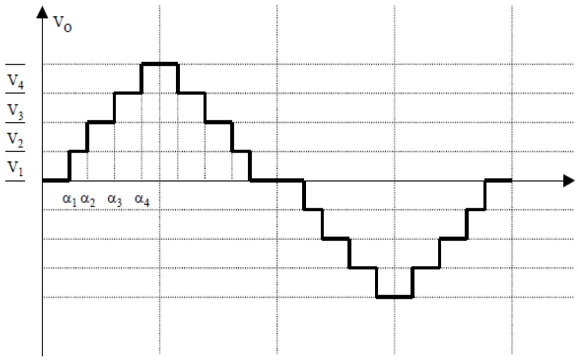

Figure 4. Eleven-level optimized harmonic stepped-waveform

In Fig. 4, V1 to V4 are dc voltage source, which are from either separated dc source or regulated capacitor. There are three types of techniques in OHSW for reducing the harmonics in waveform 1) step heights are changed with equal spaces between steps 2) step spaces are changed with the steps of equal height 3) Both step height and step space are changed.

The expression for the fundamental and all harmonic contents is given as:

$$V\ (\omega t) = \sum Hn\ (\alpha) sin\ (n\omega t) \qquad (1)$$

Where

$$H_n(\alpha) = \begin{cases} \frac{4E}{n\pi} \sum_{k=1}^{m} \cos(n\alpha_k) & for\ odd\ n \\ o & for\ even\ n \end{cases} \qquad (2)$$

E = DC voltage source.

m = Number of DC sources.

and α_k = switching angle of level k.

Lower order harmonics are needed to be eliminated. Equation (1) shows that odd harmonics (3rd, 5th…) and non-triplen odd harmonics (5th, 7th…) can be eliminated by solving it for required no. of harmonic order.

By solving above equation 2 up to *n*th harmonic order we get following equations

$$\begin{aligned} \cos\alpha_1 + \cos\alpha_2 + \dots\dots + \cos\alpha_k &= \frac{mM}{4} \\ \cos 3\alpha_1 + \cos 3\alpha_2 + \dots + \cos 3\alpha_k &= 0 \\ \cos 5\alpha_1 + \cos 5\alpha_2 + \dots + \cos 5\alpha_k &= 0 \\ &\vdots \\ \cos n\alpha_1 + \cos n\alpha_2 + \dots + \cos n\alpha_k &= 0 \end{aligned} \qquad (3)$$

The above equations are solved to find the switching angle by using Newton Raphson method.

IV. RESULTS AND DISCUSSION

For simulation process MATLAB R2009a is used and MATLAB R2009a is used for programming. Proposed multilevel inverter was simulated for 11 levels. The switching angles are given below for positive cycle and 180° plus for negative cycle.

Table II: Switching Angle

R PHASE		Y PHASE		B PHASE	
α□	7.7805	α□	127.7805	α□	247.7805
α2	18.9234	α2	138.9234	α2	258.9234
α3	27.8261	α3	147.8261	α3	267.8261
α4	44.3132	α4	164.3132	α4	284.3132
α5	61.5421	α5	181.5421	α5	301.5421
α6	118.4579	α6	238.4579	α6	358.4579
α7	135.6868	α7	255.6868	α7	15.6868
α8	152.1739	α8	272.1739	α8	32.1739
α9	161.0766	α9	281.0766	α9	41.0766
α10	172.2195	α10	292.2195	α10	52.2195

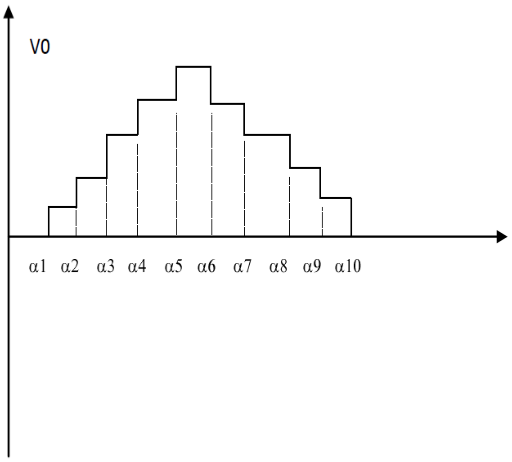

Figure 5. Switching Angle Representation

The simulation circuit of 11 level Three Phase Single switch cascaded multilevel inverter using MATLAB R2009a software is shown in following Fig. 6.

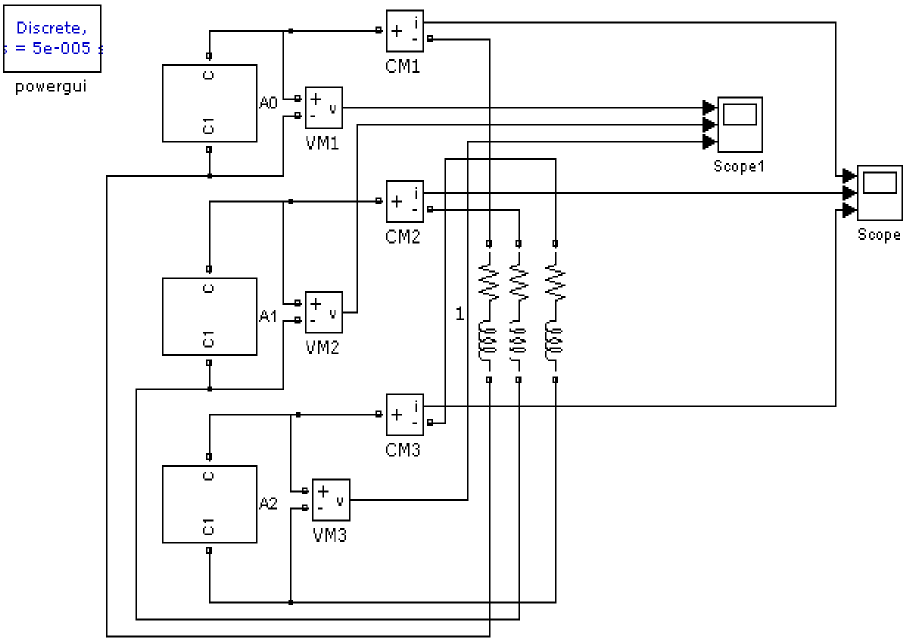

Figure 6. Simulation circuit of Three Phase Single switch cascaded multilevel inverter in MATLAB

Each subsystem A0, A1 and A2 consist of the circuit shown in Fig. 7.

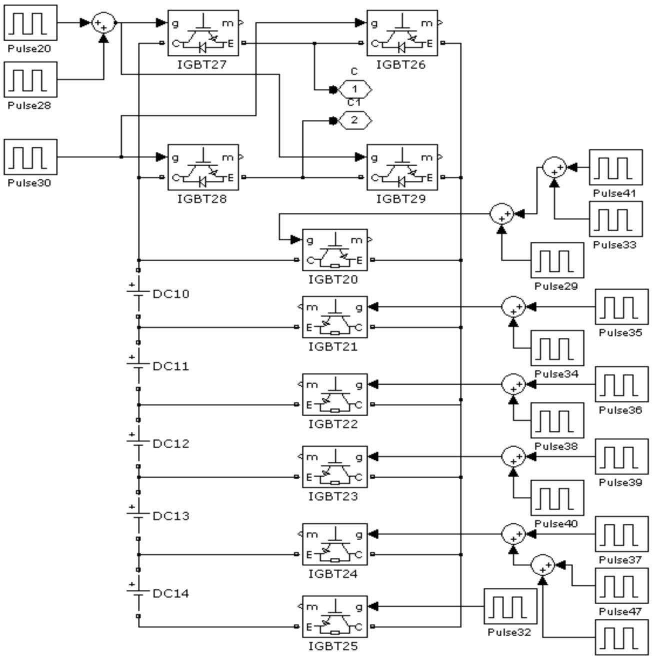

Figure 7. Circuit in Subsystem of Figure 6 in MATLAB

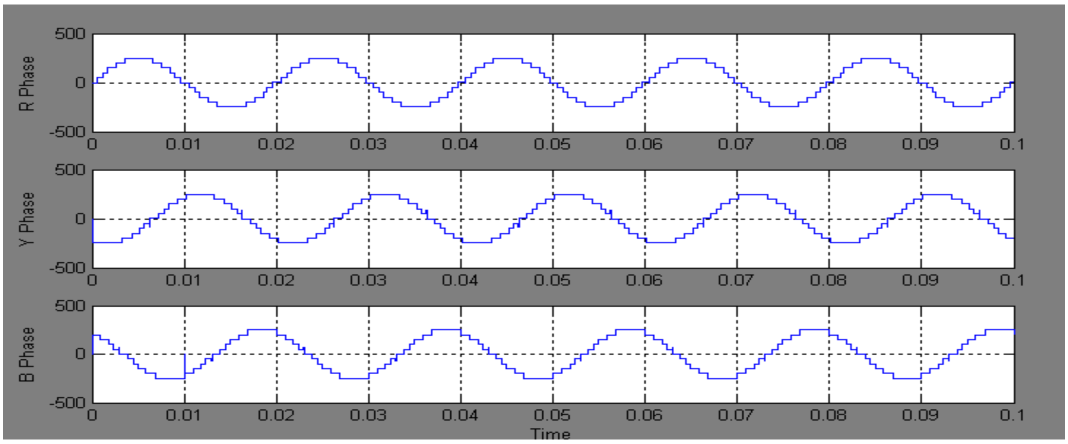

Figure 8. Output Voltage waveform of Three Phase Single switch cascaded multilevel inverter in MATLAB

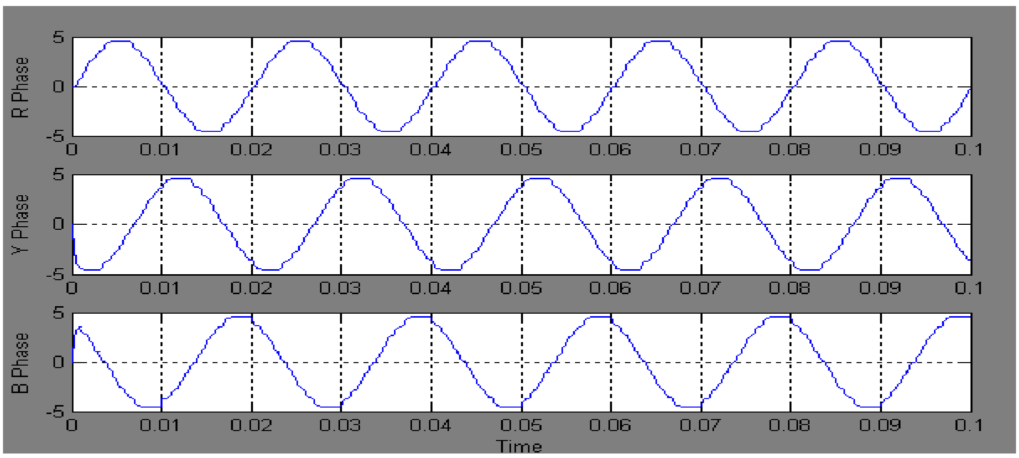

Figure 9. Output Voltage waveform of Three Phase Single switch cascaded multilevel inverter in MATLAB

The output voltage and current waveform for Single switch cascaded multilevel inverter in MATLAB is shown in the Fig. 8 and Fig. 9. FFT Analysis on output current waveform is shown in the Fig. 10 and Total Harmonic Distortion in MATLAB is 4.25%.

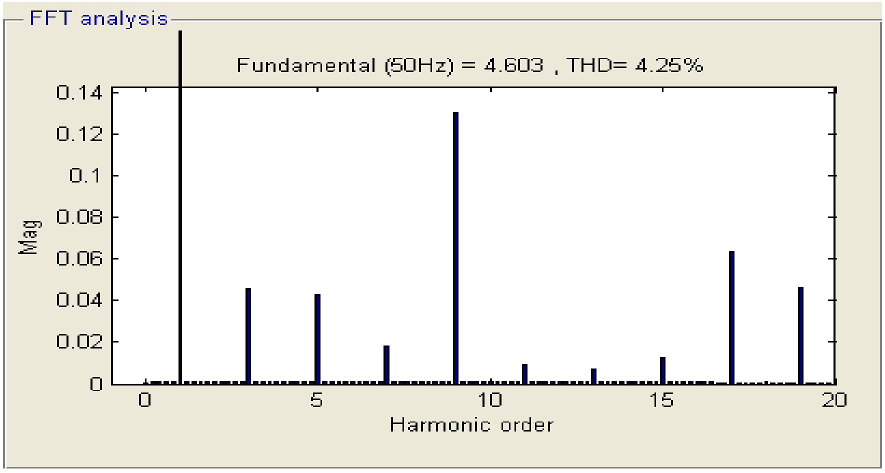

Figure 10. FFT analysis of Output Current

V. CONCLUSION

The need for efficient power conversion due to the explosive growth in renewable energy and reduced output ripple for sensitive devices has increased the demand for multilevel inverter. Multilevel inverter with more efficient output is needed. So a new topology with reduced switches and losses is needed. In this paper, a new topology has been designed with reduced number of switches; reduced switch count will result in reduced cost, complexity and losses. Harmonic contents present in the output were reduced using optimized harmonic stepped waveform technique. The output waveform of Three Phase Single switch cascaded multilevel inverter circuit was simulated using MATLAB. The total harmonic content present in the output current of proposed circuit after applying OHSW is 4.25% in MATLAB.

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