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SIMULATION OF INVERTER TOPOLOGY TO DRIVE MULTIPLE AC LOADS USING MATLAB SOFTWARE

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Abstract: In this paper we are specially focused on simulation of Cascaded H-bridge with Reduce Switch Count inverter topology to drive multiple AC loads with zero sequence signal injection PWM technique and observe performance of inverter between the shared loads for common frequency as well as different frequency modes using MATLAB/Simulink software. We have analyzed mathematical model of switching angle and simple harmonic elimination equation with the help of Newton-Raphson Method and calculate the firing angle. We have been analyzed the virtual load for the maximum current and voltage as per the requirement.

Keywords: *Cascaded H-bridge, Reduce Switch Count, Zero Sequence Signal Injection, Simple Harmonic Elimination, Newton-Raphson.*

I INTRODUCTION

An Inverter is an electrical power device which is used to convert direct current (DC) into alternating current (AC). We can get alternating current at any required voltage and frequency, using appropriate control circuit. It can be used to convert DC power coming from solar panels, batteries, supercapacitors, micro-grid or medium that provide DC voltage source to AC power for appropriate loads. Reduce Switch-Count (RSC) inverter topology has been proposed in the resent era. As the number of switches required producing a set of voltage using RSC topology in a certain system reduces size and cost to drive multiple AC loads. We have proposed an integration of the H-Cascaded switching mechanism with reduced switch count inverter topology for optimizing the switching time, size and cost to driven the loads.

II METHODOLOGY

The focus on inverter capability to drive multiple loads and observe the performance of inverter between the shared loads at their maximum requirement of current and voltage for common frequency (CF) as well as different frequency (DF) using MATLAB/Simulink Software. The Simulink model of Reduced Switch Count with H- cascaded inverter topology to drive multiple AC loads has been implemented. The Zero Sequence Signal Injection PWM technique for switching operation of inverter has been used. These RSC with H-Cascaded inverter and Zero Sequence Signal Injection PWM module implemented using MATLAB/Simulink.

III CASCADED H-BRIDGE INVERTER WITH RSC TOPOLOGY

A number of H-bridge inverter units with separate DC source for each unit are connected in cascade or series.

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For each switching operation of IGBT/MOSFET RC, RI, RI, RC is required. Due to this, the overall cast increases. To reduce cost RSC topology is used. Here one RC combined inductor- based diode are used for switching operation with IGBT/MOSFET. Each H-bridge can produce three different levels as +Vdc, 0, -Vdc by connecting the DC source to AC output side by different combinations of the four switches S1, S2, S3 and S4. Depending on firing pulses to four switches, which me be MOSFET or IGBT. So that particular level of output voltage can be obtained. The graph below shows the firing pulses given to S1, S2, S3 and S4. When switches S1 and S4 are ON, we get +Vdc at output, while when switches S2 and S3 are ON, we get -Vdc at output. When either S1 and S2 are ON or S3 and S4 are ON, then we obtain 0 Volt as an output. This is how we obtain 3 levels of voltage from a single H-Bridge. The block diagram for single H-bridge and its wave form as shown in fig.1 and fig.2, also at all times the firing pulses issued to the switch S1 and S3 will be compliment of each other. Similarly, for switch S2 and S4 as well. This is done to prevent short circuit of source voltage Vdc.

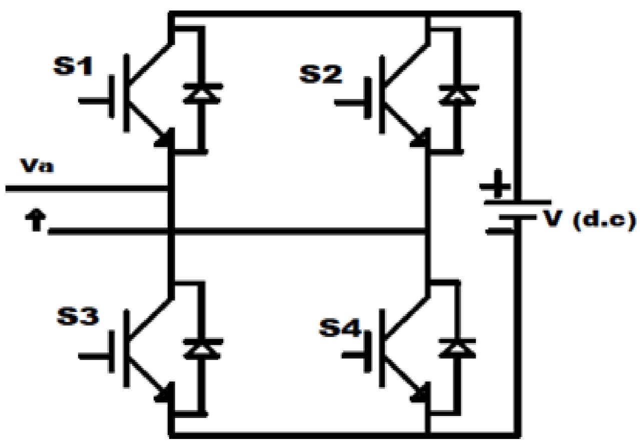

Fig.1: H-bridge unit

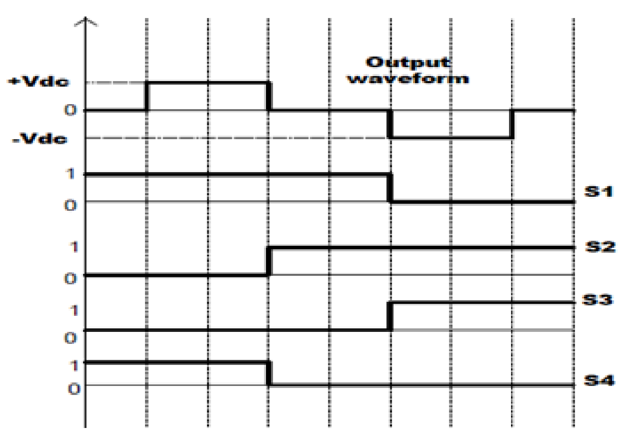

Fig.2: Waveform of Single H-bridge unit

In Cascaded H-bridge circuit, several H-bridge connected in series such that the synthesize output voltage waveform of Cascaded H-bridge is the sum of individual H-bridge output. For 11-level output phase voltage waveform using five H-bridge which is cascaded in series. The magnitude of the AC output phase voltage is given by,

Van = Va1 + Va2 + Va3 + Va4 + Va5

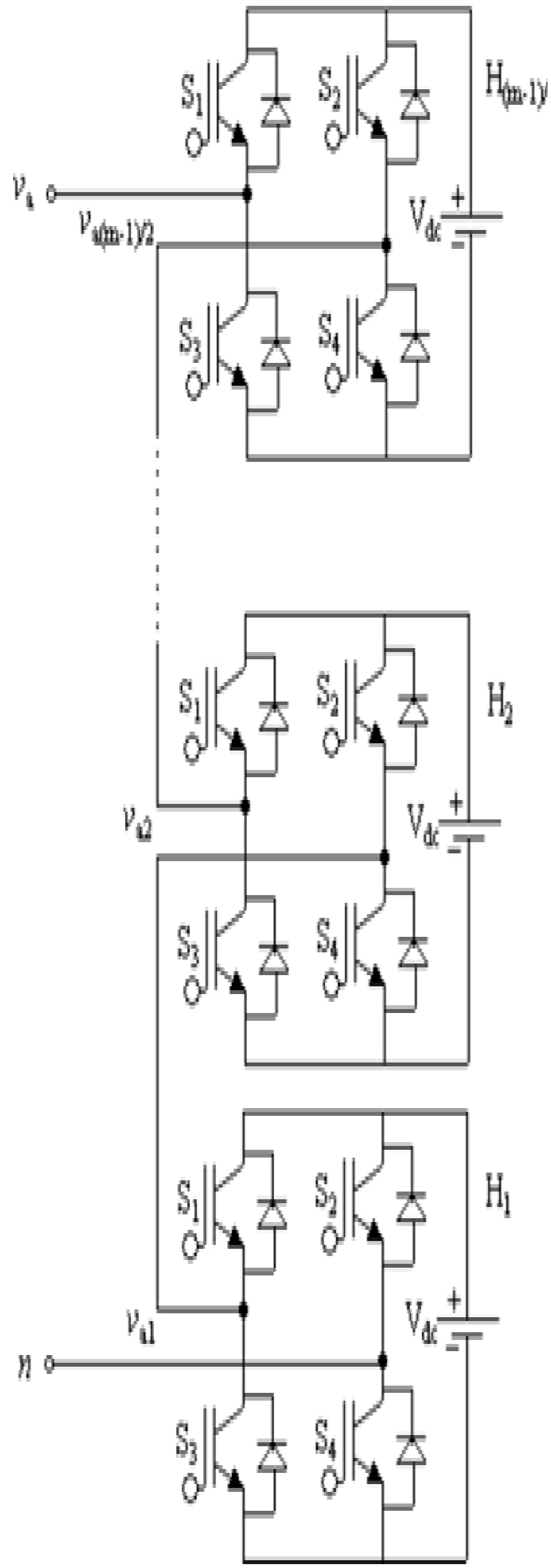

Fig.3: Cascaded H-Bridge unit

Every switch (MOSFET/ IGBT) is ON for 180o of the cycle i.e., half of the time period as shown in fig.4. For an 11 Level inverter, we have five H-bridge unit which are cascaded. We fire this H-bridge with five different firing angle α1, α2, α3, α4 and α5; these have been calculated using Newton-Raphson Method.

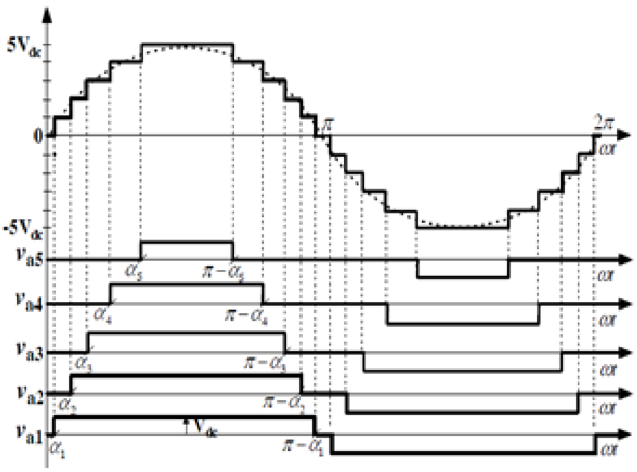

Fig.4: Waveform when 5 units of H-bridge are cascades For a single-phase inverter -

Number of levels in output waveform for single phase Cascaded H-bridge inverter is equal to 2n+1. Example, if n=5, we obtain 11 levels in single phase cascaded H-bridge inverter waveform as shown in fig.5

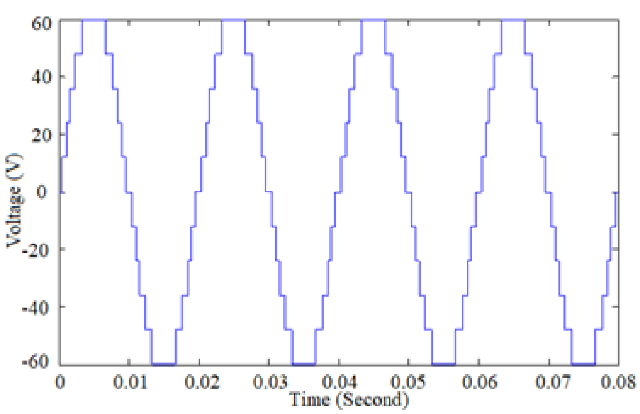

Fig.5: 11 Level 1-Phase Cascaded H-bridge Inverter For a three-phase inverter -

Number of levels in output waveform for three phase cascaded H-bridge inverter is equal to 4n+3. For example, if n=5, we obtain 23 levels in a three-phase cascaded H-bridge inverter waveform as shown in fig.6 required to determine the switching angles such that 0 < α1 < α2 < α3…< α5 < Pi/2 and some predominant lower order harmonics of phase voltage are zero. In 3-Phase power system, triplen harmonics are cancel out automatically in line-to-line voltage as a result only non-triplen odd harmonics are present in line-to-line voltage. The modulation index 'm1', is the ratio of the fundamental output voltage V1 to the maximum obtainable fundamental voltage V1(Max). The maximum fundamental voltage is obtained when all the switching angles are zero i.e.

$$V_{1max} = \frac{4sV_{dc}}{\pi} \qquad \text{--------- (2)}$$

$$m_1 = \frac{\pi V_1}{4sV_{dc}} \qquad \text{----------(3)}$$

For an 11-Level cascaded H-bridge inverter, there are five H- bridges per phase i.e., s = 5 or five degrees of freedom is available.

$$\cos(\alpha_1) + \cos(\alpha_2) + \cdots + \cos(\alpha_5) = 5m_1$$
$$\cos(5\alpha_1) + \cos(5\alpha_2) + \cdots + \cos(5\alpha_5) = 0$$
$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cdots + \cos(7\alpha_5) = 0$$
$$\cos(11\alpha_1) + \cos(11\alpha_2) + \cdots + \cos(11\alpha_5) = 0$$
$$\cos(13\alpha_1) + \cos(13\alpha_2) + \cdots + \cos(13\alpha_5) = 0$$

-------(4)

In general, (4) can be written as

$$f(\alpha) = b(m)$$

-----------(5)

The equation (4) is a system of five transcendental equations known as Selective Harmonic Elimination (SHE) equation in term of α1, α2, α3, α4 and α5. For the given values of m1 from (0 to1), it is required to get complete and all possible solutions for many numbers of levels can be computed by proper implementation of Newton-Raphson method without knowing any specific initial guess, the range of modulation index for which solution exist.

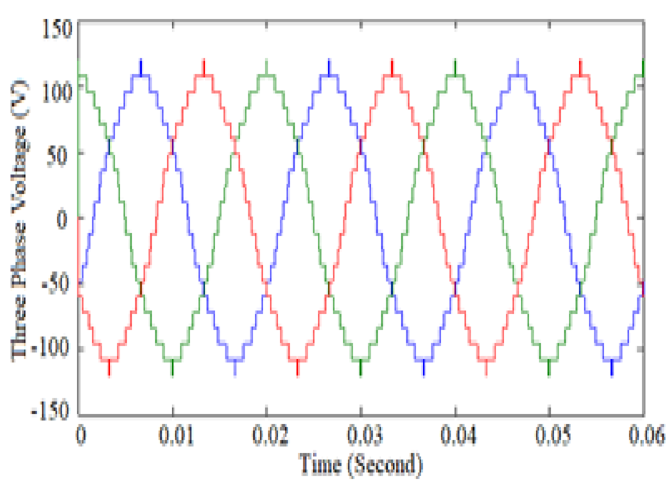

Fig.6: 11 Level 3-Phases Cascaded H-bridge Inverter

Where, n = no. of H-bridge which are cascaded in the circuit. As we increasing 'n' i.e., number of H-bridge in series, we obtain a greater number of levels in the output waveform and Total Harmonic Distortion (THD) less.

IV MATHEMATICAL MODEL OF SWITCHING ANGLE AND SHE EQUATION

In general, the Fourier series expansion of the staircase output voltage waveform is given by,

$$V_{an}(\omega t) = \sum_{k=1,3,5\ldots}^{\infty}\left(\frac{4V_{dc}}{k\pi} + (\cos(k\alpha 1) + \cos(k\alpha 2) + \cdots + \cos(k\alpha s))\sin(k\omega t)\right)$$

---------- (1)

Where‘s’ is the number of H-bridge connected in cascade per phase. For a given desired fundamental peak voltage V1, it isThe equation (4) is a system of five transcendental equations known as Selective Harmonic Elimination (SHE) equation in term of α1, α2, α3, α4 and α5. For the given values of m1 from (0 to1), it is required to get complete and all possible solutions for many numbers of levels can be computed by proper implementation of Newton-Raphson method without knowing any specific initial guess, the range of modulation index for which solution exist.

A. Newton-Raphson Method

Let there be ‘n’ unknown variable x1, x2, x3………xn given as,

$$\begin{aligned} f_1(x_1, x_2, \ldots \ldots x_n) &= b_1 \\ f_2(x_1, x_2, \ldots \ldots x_n) &= b_2 \\ \vdots \qquad\qquad & \vdots \quad \vdots \\ \vdots \qquad\qquad & \vdots \quad \vdots \\ f_n(x_1, x_2, \ldots \ldots x_n) &= b_n \end{aligned}$$

....(A.1)

To solve equation, first we take an initial guess of the solution. Subsequently firdt order Taylor’s series expansion (neglecting the higher order terms) is carried out for these equation around the4 initial guess of solution.

V MATLAB SIMULATION MODEL

$$f_1\left(x_1^{(0)}, x_2^{(0)}, \cdots x_n^{(0)}\right) + \frac{\partial f_1}{\partial x_1}\Delta x_1 + \frac{\partial f_1}{\partial x_2}\Delta x_2 + \cdots + \frac{\partial f_1}{\partial x_n}\Delta x_n = b_1$$

$$f_2\left(x_1^{(0)}, x_2^{(0)}, \cdots x_n^{(0)}\right) + \frac{\partial f_2}{\partial x_1}\Delta x_1 + \frac{\partial f_2}{\partial x_2}\Delta x_2 + \cdots + \frac{\partial f_2}{\partial x_n}\Delta x_n = b_2$$

$$\vdots \qquad\qquad\qquad \vdots \quad \vdots$$

$$\vdots \qquad\qquad\qquad \vdots \quad \vdots$$

$$f_n\left(x_1^{(0)}, x_2^{(0)}, \cdots x_n^{(0)}\right) + \frac{\partial f_n}{\partial x_1}\Delta x_1 + \frac{\partial f_n}{\partial x_2}\Delta x_2 + \cdots + \frac{\partial f_n}{\partial x_n}\Delta x_n = b_n$$

---------(A.2)

The equation (A.2) can be written as,

$$\begin{bmatrix} f_1(x^{(0)}) \\ f_1(x^{(0)}) \\ \vdots \\ f_n(x^{(0)}) \end{bmatrix} + \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \frac{\partial f_2}{\partial x_n} \\ \vdots & \vdots & & \vdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \Delta x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

The matrix containing partial derivative terms is known as the Jacobin matrix (J). As we can converted into square matrix as,

$$\begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \Delta x_n \end{bmatrix} = [J]^{-1} \begin{bmatrix} b_1 - f_1(x^{(0)}) \\ b_2 - f_2(x^{(0)}) \\ \vdots \\ b_n - f_n(x^{(0)}) \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta m_1 \\ \Delta m_2 \\ \vdots \\ \Delta m_n \end{bmatrix}$$

B. Algorithm for Newton-Raphson Method to calculate Firing angle

1) Assume any random initial guess for switching angle such as 0 < α1 < α2 < α3…< α5 < Pi/2.

2) Set m = 0.8 (Modulation index chosen for finding switching angles with low THD)

3) Calculate F(α0), B(m1), and Jacobian J(α0).

4) Compare correction Δα during the integration using relation

Δα=Jacobian (inverse of (α0)) × (B (m1)-F (α0))).

5) Update the switching angles i.e., α (k+1) = α (k) + Δα (k)

6) Perform α (k+1) = $\cos^{-1}$ ((abs (cos (α (k+1))))) transformation to bring switching angles in feasible range.

7) Repeat steps (3) to (60) for sufficient number of iterations to attain error goal of 0.001 radians.

The firing angle is calculated using above algorithmic code. So that we obtain the zero-sequence signal injection pulse width modulation. This firing angle is further used in the MATLAB model to provide firing pulse to the IGBT/MOSFET.

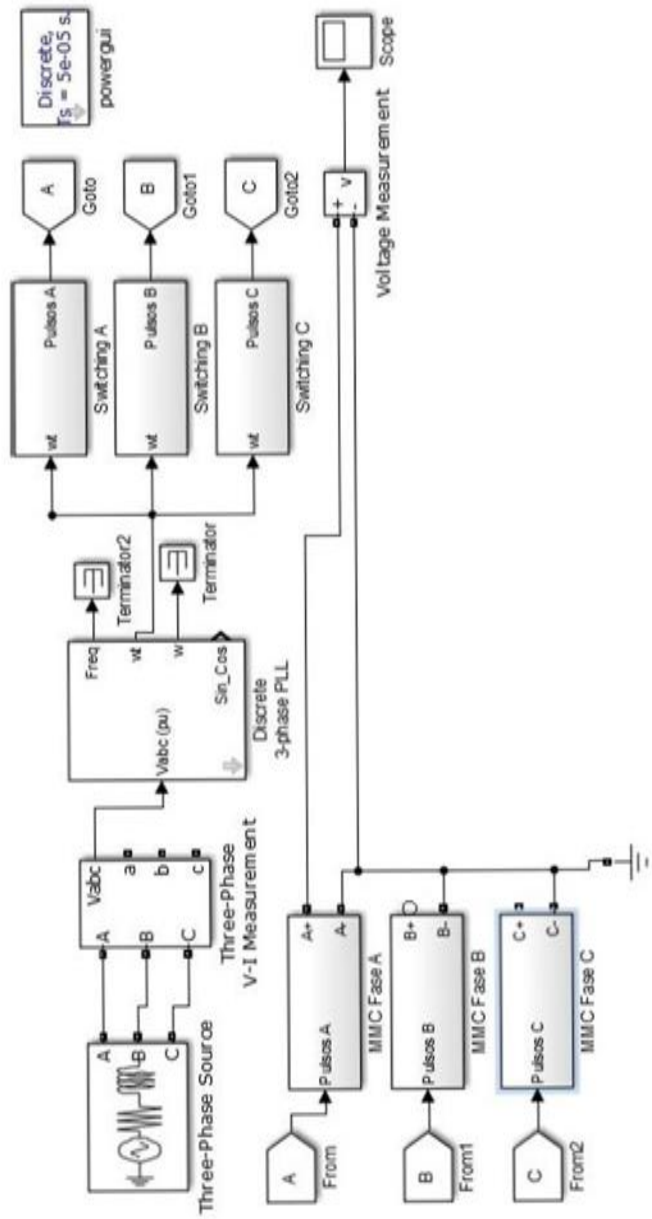

Fig.7: Cascaded H-bridge with RSC inverter Topology to drive virtual AC load simulation module.

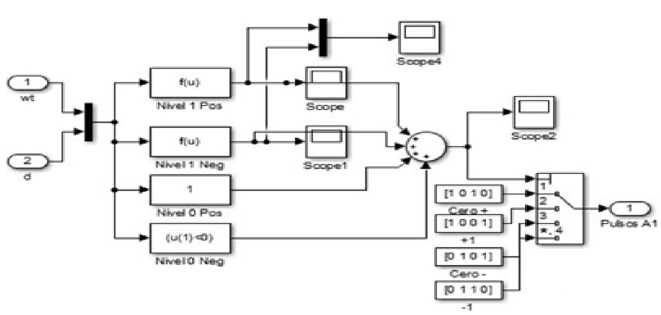

Fig.8: Nivel 1 module

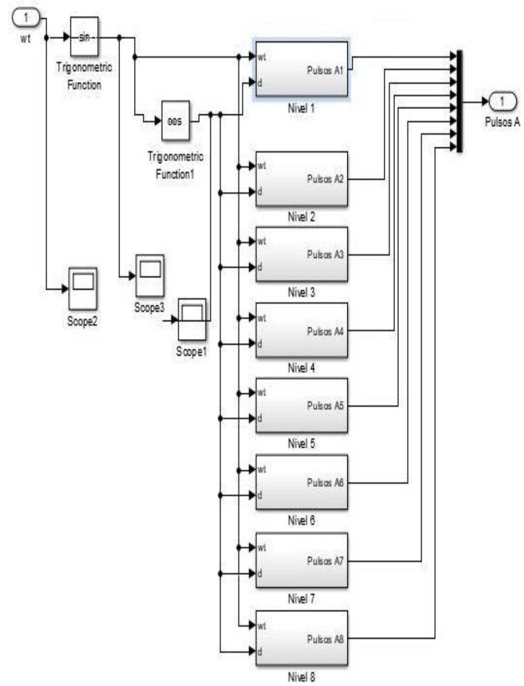

Fig.9: Integrated switching A module

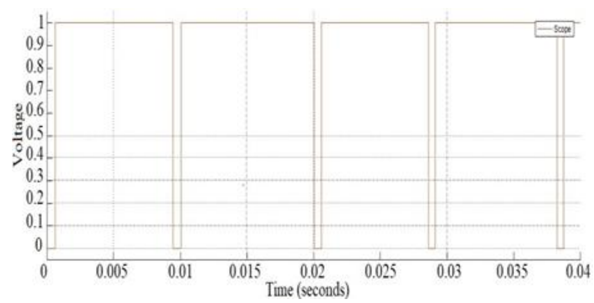

Fig.10: H-Bridge waveform

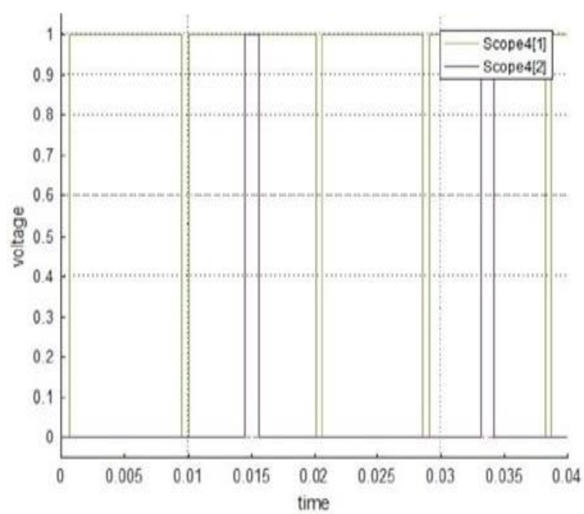

Fig.11: Cascaded H-bridge waveform

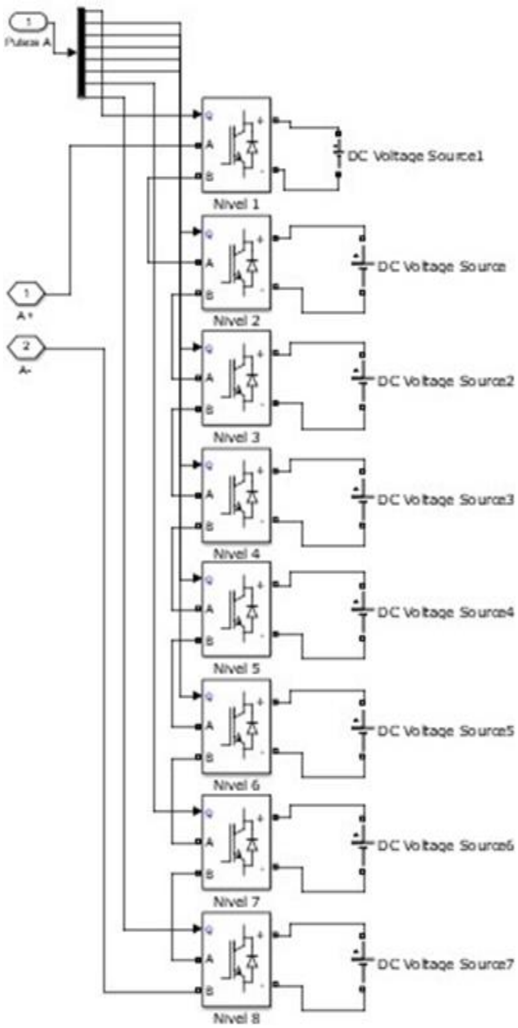

Fig.12: Migrating motor complex Phase A module

VI RESULT

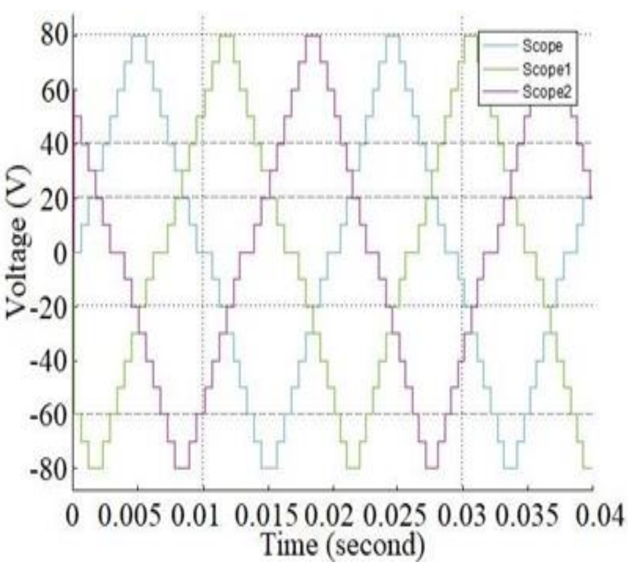

Fig.13: Final 3-phase output waveform of inverter

VI RESULT

The Reduced Switch Count integrated with cascaded H multilevel inverter structured topology is analyzed with Zero-Sequence-Signal Injection PWM technique to operate the four AC loads and observe the performance of Inverter between shared loads. The ideal and practical result was same. It can be operated easily at common frequency (CF) as well as different frequency (DF) using MATLAB software. The results were generated in MATLAB Simulink as per the generalized parameter and total harmonic distortion within a limit. The system shows compatibility with using advanced version of multi-level topology for increasing size and cost factor to be optimized.

VII CONCLUSION

We studied different types of literature review and got various research analyses on reduced switch count inverter topology, H type inverter topology and Cascaded H type inverter topology. We have studied benefit and drawback of each topology and tried to come up with an innovative topology to reduce the number of switching system, cost and size analysis. We have reduced the switching by using the RC combined inductor-based diode system at every stage we build the multi-level inverter topology. At each stage the concurrent analysis was benefited by the 3-phase switching mechanism build with initialized controlling voltage system. In future this inverter can be used with FACTS devices for large AC systems as well as HVDC transmission system. It can also use in the micro-grid application. In future we can also implement this real time inverter simulation model into hardware.

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