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# GHNN based Selective Harmonic Elimination Implementation for Single Phase Inverter

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***Abstract* — In this paper, Generalized Hopfield Neural Network (GHNN) based Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) is implemented to single phase inverter. Different order of harmonics can be eliminated by using this projected work. This proposed technology tries to eliminate fifth, seventh, eleventh and thirteenth order harmonic. Performance analysis is carried out in the form of simulation using MATLAB/Simulink. To get the continuous switching instants for corresponding modulation indices M, these system is solved by Ordinary Differential Equation's (ODE's) by fourth order of Runge Kutta i.e. RK-4. With the help of Fast Fourier Transform (FFT) Analysis, Output voltage verifies the effectiveness of proposed technique. Hence, it proves that SHEPWM is applicable in industrial application.**

***Keywords— Selective Harmonic Elimination Pulse Width Modulation (SHEPWM), Artificial Nueral Network (ANN), Generalized Hopfield Neural Network (GHNN), Ordinary Differential Equetion (ODE) .***

## I. INTRODUCTION

To converting the DC voltage to AC voltage waveform, the high switching frequency is the considerable task while pulse width modulation inverter contains lower order harmonics. The occurrence of harmonics is one of the major drawback with inverters. However, high switching frequency leads to more switching losses in the inverter switches. Also high switching frequency is limited by the switching capability and dead time of the switches.

There are several techniques of switching the inverter switches such as hysteresis controller, Sinusoidal Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM) & Selective Harmonic Elimination Pulse Width Modulation (SHEPWM). Each technique has its own upside and downside. The Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) technique helps to reduce the harmonics more as compared to other techniques [1] & it can be preferred for high switching frequency application to maintain the switching losses within the acceptable tolerance.

Controlling action is very important role to find the accurate switching instants & to reduce the lower order harmonics. This can be solve by using non linear algebraic equations by two trendy approach as

i. Numerical iterative technique such as Newton – Raphson [2]
ii. Employ the analytical equations as in the situation of optimization problem [3-6]

## II. GENERALIZED HOPFIELD NEURAL NETWORK

### A. *Outline of GHNN*

With the assumption of continuous variable, the continuous time single layer feedback networks are called as 'gradient type networks'. The gradient type networks are nothing but the Generalized Hopfield Neural Network (GHNN) in which the computational energy decreases incessantly with time [7].

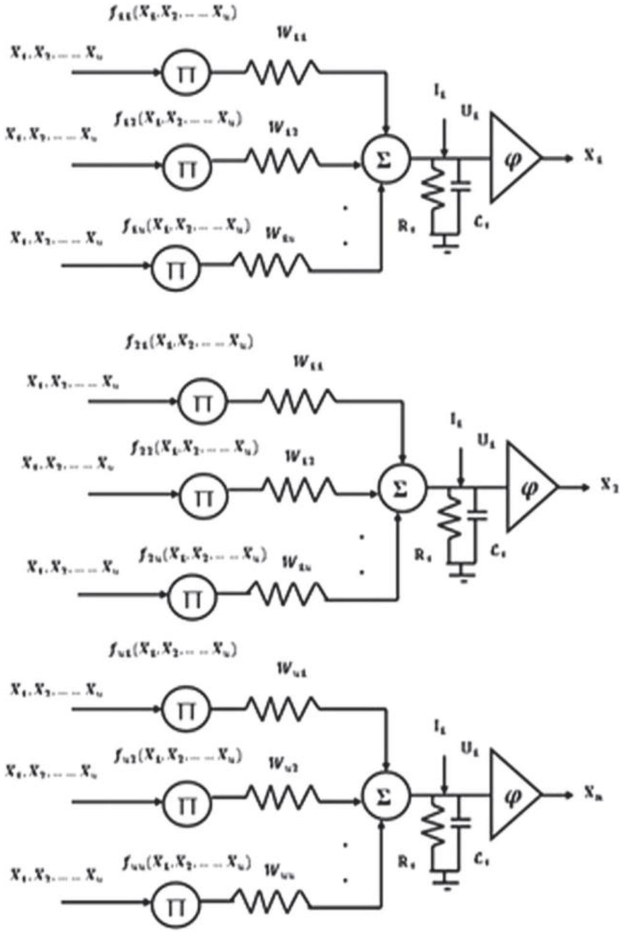


Fig. 1. Architecture of Generalized Hopfield Neural Network

The evolution of system is negative gradient of energy function for general direction. For optimization problem, when GHNN is used then the energy function is made equivalent to a certain objective function that needs to be minimize. The GHNN generalized electrical equivalent architecture is shown in fig. 1.

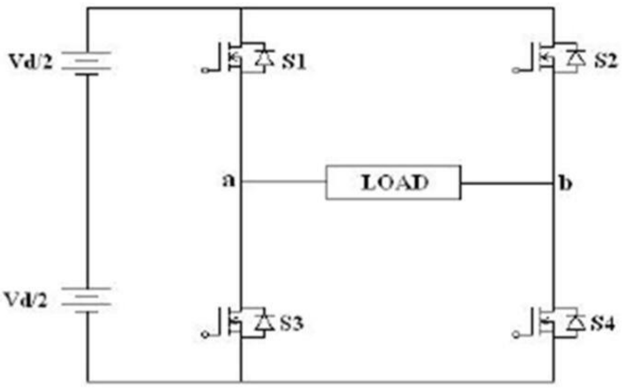


Fig. 2. Single phase full bridge inverter

This architecture consists of '*n*' neurons. The single phase inverter as shown in fig. 2 & it can be represented as nonlinear amplifier which has input activation and output activation function as φ(.):Ɽ→[0 1]. The sigmoid function is the most common function of activation and it is given by,

$$x = \varphi(u)=1/1+e^{-u/\theta} \qquad (1)$$

Where, '*θ*' is the positive parameter which controls the slope of activation function.

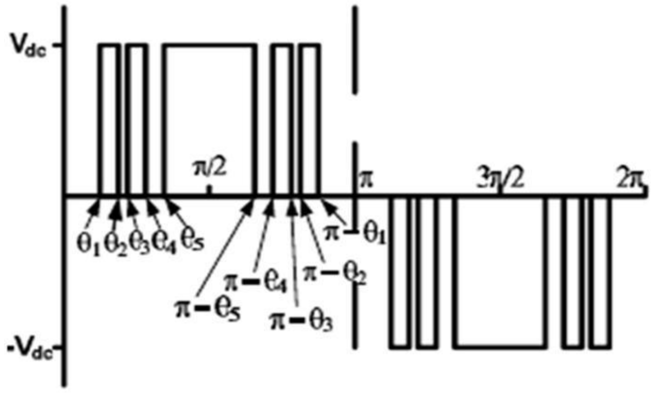


Fig. 3. Output voltage waveform of inverter

It can be observed from fig. 3 which produces the function *f*ij(.), where *i* ϵ [1,….,n] & '*j*' represents the number of product terms. The output obtained from that product which is linearly dependent on the synaptic weight *Wij*. By applying the Kirchhoff's current law at the inputs of every amplifier, it domino effects as,

$$C_i\frac{du_i}{dt}+\frac{u_i}{R_i}=\sum_i W_{ij}f_{ij}(x_1,x_2,\ldots\ldots,x_n)+I_i \qquad (2)$$

The outputs of network is,

$$x=\varphi(u)$$

This function is invertible so it can be write as,

$$u=\varphi^{-1}(x) \qquad (3)$$

Eq. (2) can be writing as,

$$C_i\frac{d\varphi^{-1}(x_i)}{dt}+\frac{\varphi^{-1}(x_i)}{R_i}=\sum_i W_{ij}f_{ij}(x_1,x_2,\ldots\ldots,x_n)+I_i \quad (4)$$

The energy function for proposed work is given by,

$$E=\left(\sum_i\int_0^{xi}\frac{\varphi^{-1}(s)}{R_i}ds\ \sum_i\sum_j W_{ij}f_{ij}(x_1,x_2,\ldots\ldots,x_n)x_i+\sum I_i x_i\right) \qquad (5)$$

By using conventional methodology we can show that the derivative for the proposed energy function is always less than or equal to zero.

### B. *Solution of nonlinear equation using GHNN*

The Hopfield Neural Networks (HNN) have been used as application for solving the set of linear and non linear equations. Tank and Hopfield established the first model of HNN for linear programming problems [8]. Chua and Kennedy introduced the second model of Hopfield neural networks (HNN) [9]. A dynamic model describing the GHNN had a set of nonlinear ordinary first order ODE's are derived by using the energy function. To get the solution, the derived Ordinary Differential Equations (ODE's) are solved by suitable techniques. The above technique is used to solve the set of non linear transcendental SHEPWM equations to implement the proposed work in real time.
Let us consider the following nonlinear algebraic equations,

$$\begin{aligned}
f_1(x_1,x_2,\ldots,x_j,\ldots,x_n)&=P_1\\
f_2(x_1,x_2,\ldots,x_j,\ldots,x_n)&=P_2\\
&\vdots\\
f_j(x_1,x_2,\ldots,x_j,\ldots,x_n)&=P_j\\
&\vdots\\
&\vdots\\
f_n(x_1,x_2,\ldots,x_j,\ldots,x_n)&=P_n
\end{aligned} \qquad (6)$$

In equation (6), $f_j(.)$ is a function of variables $x_1,x_2,\ldots,x_j,\ldots,x_n\ \epsilon$ Ɽ. Our goal is to find the values for variables $x_1,x_2,\ldots,x_j,\ldots,x_n$ in such way that it satisfies the equation (6). To get the solution, the energy function has to be formulated for above set of equations & derived as follows:

$$E=\sum_j^n\left(g_j(.)\right)^2 \qquad (7)$$

Where,

$$g_j(.)=\left(f_j(x_1,x_2,\ldots,x_j,\ldots,x_n)-P_j\right) \qquad (8)$$

For designing the proposed network, equation (7) and (8) have been used. In the given network, we have '*n*' number of neurons or variables. The network dynamics are directed by following differential equation:

$$\frac{du_j}{dt}=-\frac{\partial E}{\partial x_j} \qquad (9)$$

and

$$x_j=\varphi(u_j)\ j=1\ldots\ldots.n \qquad (10)$$

Where, $u_j$ is the input to the $j^{th}$ neuron in the network, $x_j$ is the $j^{th}$ output for their respective input, $\varphi(.)$ is the activation function of the neurons. Hopfield equations will be obtained by calculating the partial derivatives of the equation (8) with respect to $x_1, x_2, \dots, x_j, \dots, x_n$. The coefficients and constants of these equations give the value of weight and bias for the network respectively.

## III. IMPLEMENTATION OF SHEPWM AS APPLICATION OF GHNN

A standard single phase inverter is shown in Fig. 2 and the unipolar output voltage waveform is shown in Fig. 3. There are four switches in the circuit. As per $2^4=16$, there are sixteen switching states. Out of that only four switching combinations are useful to get the output waveform across the load.

### A. *Transcedentan Equations formulation for SHEPWM*

Fourier series expansion of unipolar waveform is given by

$$V(\omega t) = \left(\frac{4V_{dc}}{\pi}\right)\left\{\sum_{n=1}^{\infty}\frac{\sin(n\omega t)}{n}(\cos(n\theta_1) - \cos(n\theta_2) + \cos(n\theta_3) - \cos(n\theta_4) + \cos(n\theta_5))\right\} \tag{11}$$

Here, the main task is that to calculate the switching angles $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, $\theta_5$ to eliminate the 5th, 7th, 11th and 13th harmonics and to achieve given desired voltage $V_1$, [11] in such that

$$\begin{gathered}\cos\theta_1 - \cos\theta_2 + \cos\theta_3 - \cos\theta_4 + \cos\theta_5 = M\\ \cos 5\theta_1 - \cos 5\theta_2 + \cos 5\theta_3 - \cos 5\theta_4 + \cos 5\theta_5 = 0\\ \cos 7\theta_1 - \cos 7\theta_2 + \cos 7\theta_3 - \cos 7\theta_4 + \cos 7\theta_5 = 0\\ \cos 11\theta_1 - \cos 11\theta_2 + \cos 11\theta_3 - \cos 11\theta_4 + \cos 11\theta_5 = M\\ \cos 13\theta_1 - \cos 13\theta_2 + \cos 13\theta_3 - \cos 13\theta_4 + \cos 13\theta_5 = M\end{gathered} \tag{12}$$

Where,

$$M = \frac{V_1}{\left(\frac{4V_{dc}}{\pi}\right)}$$

This is the system of nonlinear transcendental equations in the form of switching angles $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, $\theta_5$.

### B. *Energy Function formulation for SHEPWM*

The energy function is given by,

$$E = -0.5(\cos\theta_1 - \cos\theta_2 + \cos\theta_3 - \cos\theta_4 + \cos\theta_5 - M)^2 + (\cos 5\theta_1 - \cos 5\theta_2 + \cos 5\theta_3 - \cos 5\theta_4 + \cos 5\theta_5)^2 + (\cos 7\theta_1 - \cos 7\theta_2 + \cos 7\theta_3 - \cos 7\theta_4 + \cos 7\theta_5)^2 + (\cos 11\theta_1 - \cos 11\theta_2 + \cos 11\theta_3 - \cos 11\theta_4 + \cos 11\theta_5)^2 + (\cos 13\theta_1 - \cos 13\theta_2 + \cos 13\theta_3 - \cos 13\theta_4 + \cos 13\theta_5)^2 \tag{13}$$

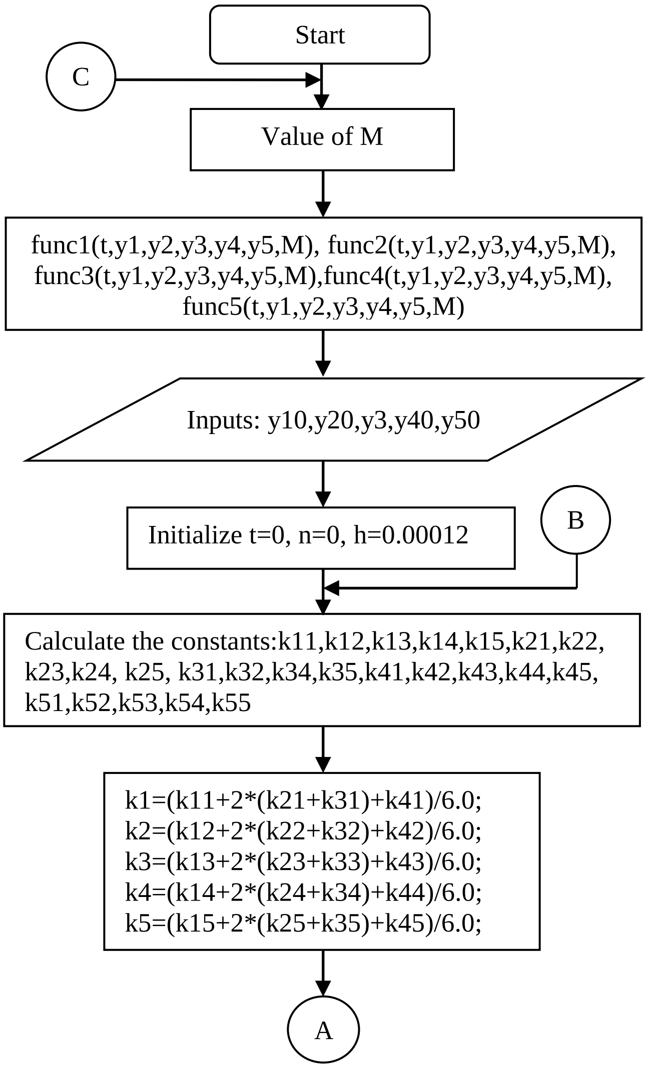
The network dynamics of the system is calculated using energy function as differential equation such that

$$\begin{gathered}\frac{d\theta_1}{dt} = -\frac{\partial E}{\partial\theta_1}\\ \frac{d\theta_2}{dt} = -\frac{\partial E}{\partial\theta_2}\\ \frac{d\theta_3}{dt} = -\frac{\partial E}{\partial\theta_3}\\ \frac{d\theta_4}{dt} = -\frac{\partial E}{\partial\theta_4}\\ \frac{d\theta_5}{dt} = -\frac{\partial E}{\partial\theta_5}\end{gathered} \tag{14}$$

### C. *Runge Kutta 4th order method for the solution of ODEs*

The five differential equations are describing the characteristics of the Generalized Hopfield Neural Network (GHNN) which is solved by Runge-Kutta 4 (RK4) method.

The RK4 algorithm to solve nonlinear ODEs is shown in the flowchart of Fig. 4. Here, y1, y2, y3, y4, y5 corresponds to $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, $\theta_5$.



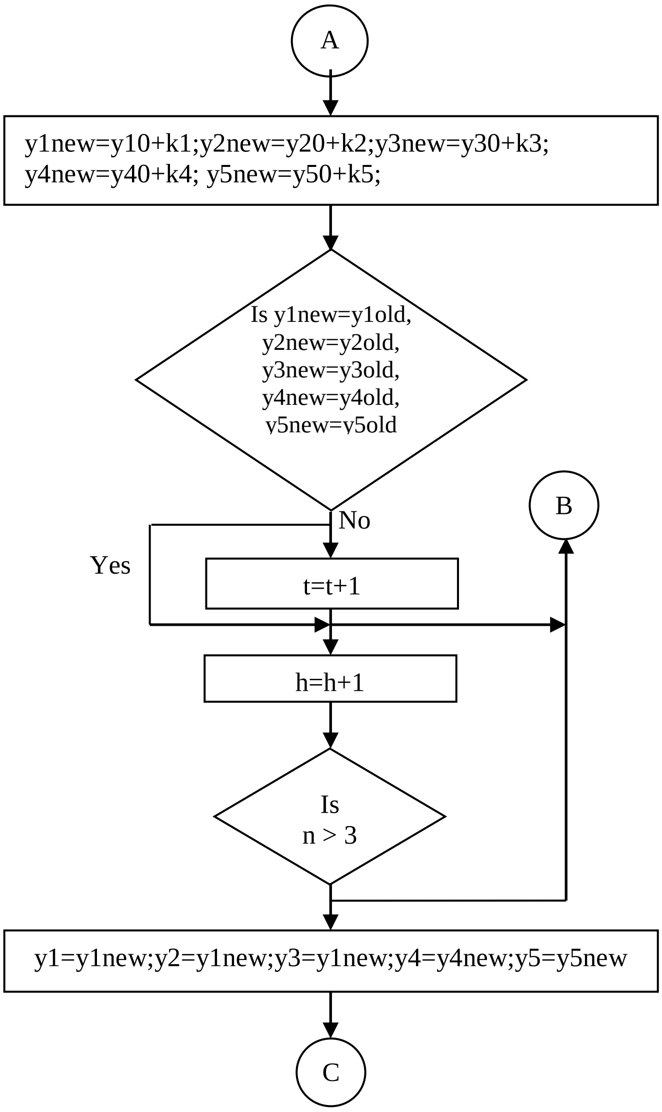


Fig. 4. RK4 algorithm flow chart to solve ODEs

## IV. IMPLEMENTATION OF SHEPWM USING MATLAB / SIMULINK

The proposed network is implemented using MATLAB R2014a. The simulation diagram is shown in Fig. 5.

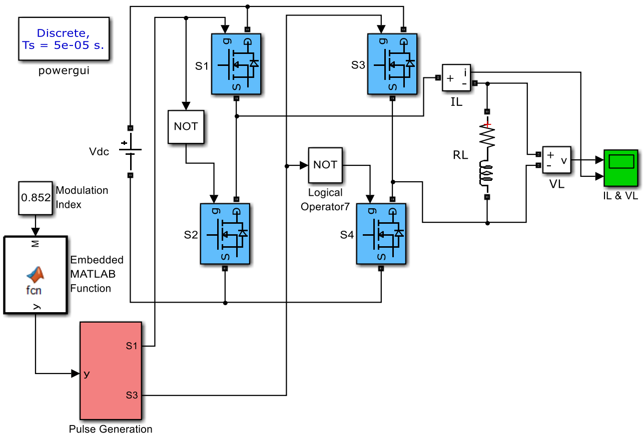


Fig. 5. MATLAB / SIMULINK of Proposed system

The propose work is simulated in MATLAB/ Simulink. A single phase full bridge is implemented using MOSFETs. The switching pulses are generated from the two subsystems which has the input of modulation index that lies between 0.05 and 0.95 with the resolution of ±0.01.

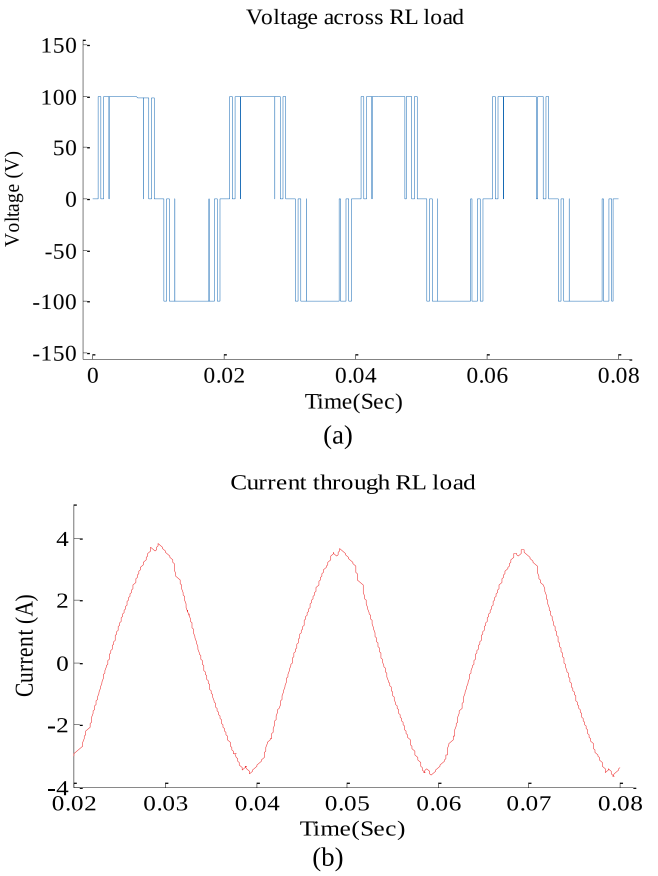
The first subsystem of switching pulses is built in MATLAB embedded function that contained RK4 algorithm. This subsystem has an input of modulation indices which gives the five switching instants namely $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, $\theta_5$. The second subsystem has logic gates system and triangular wave generation.

By comparison of triangular wave and switching instants produced by MATLAB embedded function, subsystem gives the pulses to drive the MOSFETs.

## V. SIMULATION RESULTS AND DISCUSSION

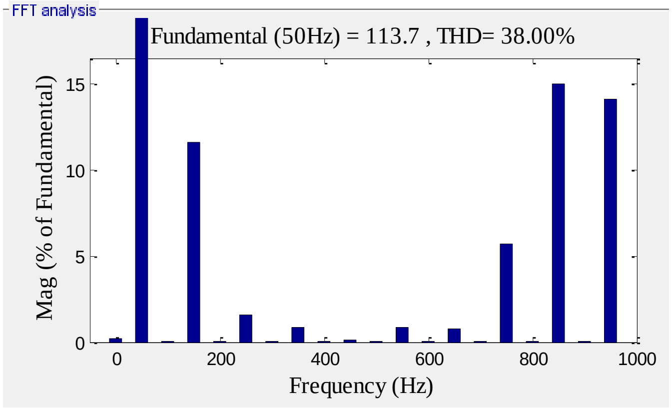
The SHEPWM inverter is developed in MATLAB Simulink with DC supply of 48 volts and RL load is connected with the values of R=10 Ω & L=100 mH. This simulation is developed in the environment of discrete domain with ode45 solver. To design the inverter, MOSFETs are used which has FET resistance of 0.1 ohm and internal diode resistance of 0.01 ohm.

The MATLAB simulated single phase full bridge inverter output voltage waveforms and load current waveform for 0.247as low, for 0.685 as medium, 0.852 as high modulation indices and their corresponding FFT analysis are shown in fig. 6, fig. 7 and fig. 8. From the figures 6 to 8, it is incidental that 5th, 7th, 11th harmonics are minimized while keeping hold on the fundamental.

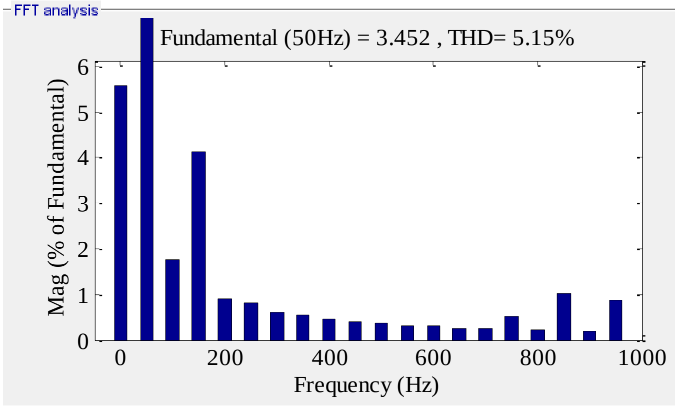


(a)

(b)

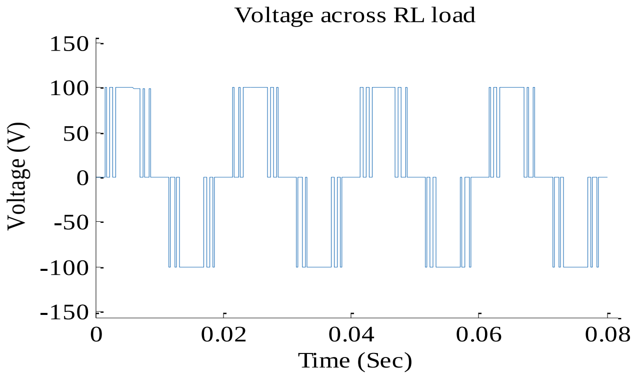


(C)

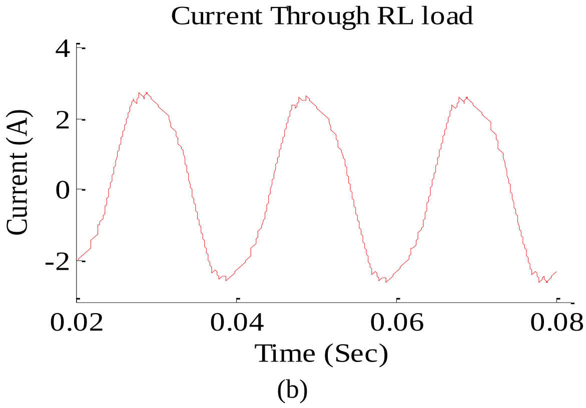


(d)

Fig. 6. Output waveforms at M=0.852 (a) Output Voltage waveform (b) Current waveform (c) FFT analysis of output voltage (d) FFT analysis of output current



(a)



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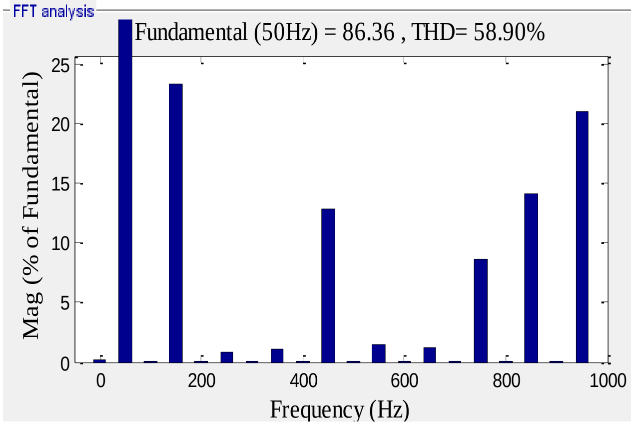
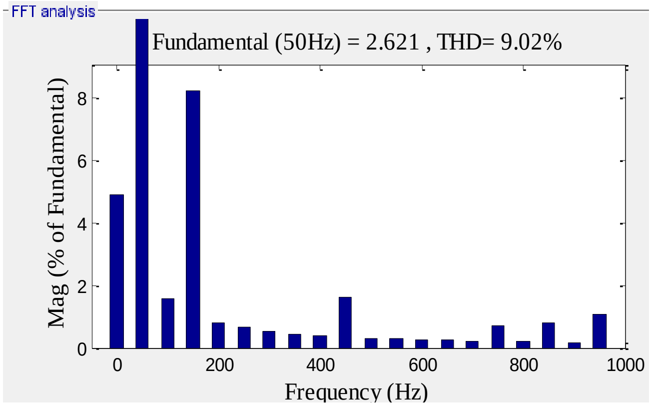
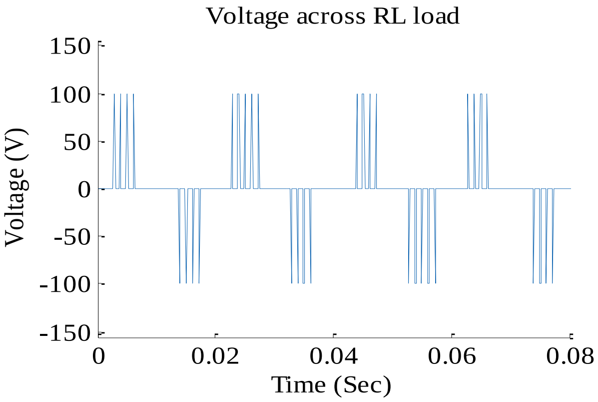


(c)

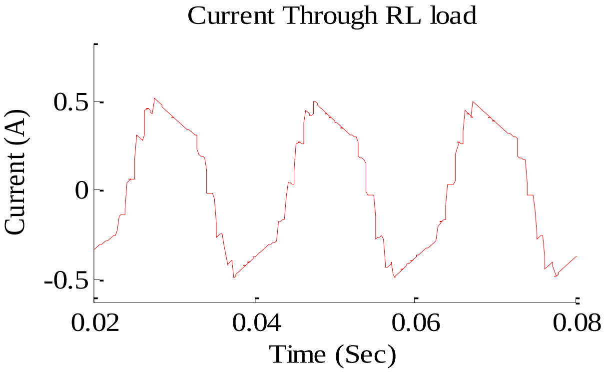


(d)

Fig. 7. Output waveforms at M=0.687 (a) Output Voltage waveform (b) Current waveform (c) FFT analysis of output voltage (d) FFT analysis of output current



(a)



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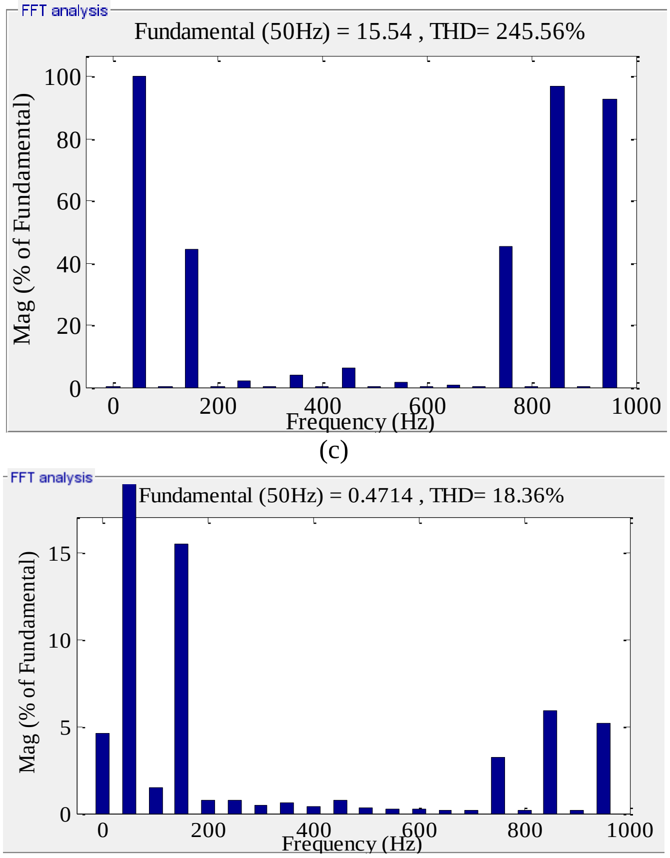

(c)

(d)

Fig. 8. Output waveforms at M=0.247 (a) Output Voltage waveform (b) Current waveform (c) FFT analysis of output voltage (d) FFT analysis of output current

## V. CONCLUSION

In the proposed technique, the harmonics in the order of 5th, 7th, 11th and 13th are eliminated in the waveform of output voltage of single phase full bridge inverter to keep holding on the desired fundamental. The knowledge of ordinary differential equations (ODEs) are sufficient to apply this technique that is Generalized Hopfield Neural Network (GHNN). This technique is highly reliable and it produces the consistent results. The proposed technique is one of the best alternative to optimization problem.

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