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Selective Harmonic Elimination of Single Phase PWM Inverter by Particle Swarm Optimization and Newton Raphson Method

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ABSTRACT: In recent years there has been an increased demand for integration of renewable energy into the electricity grid. This has amplified research into power converter solutions required to integrate renewable technology into the electricity supply. One such converter is a H-Bridge Converter. This paper reports particle swarm optimization (PSO) technique and Newton Raphson method for selective harmonic elimination (SHE) in pulse width modulated inverter. To minimize the THD of the output voltage of PWM inverter A PSO optimization technique and NR method is proposed to find best switching angles. This method is applied for the unipolar switching in single phase inverter for five switching angles. The switching angles are calculated to completely eliminate the lower order harmonics. The result of the unipolar case using five switching angles are compared with that of a recently reported work, based on PSO technique, And is observed that the proposed method is effective in eliminating the lower order harmonics specially 3rd, 5th,7th,9th order harmonics and THD is reducing to a greater extent than the previously reported work.

KEYWORDS: Selective harmonic elimination (SHE), particle swarm optimization (PSO), pulse width modulation (PWM)., Total Harmonic Distortion (THD),Newton Raphson (NR) method.

I. INTRODUCTION

Renewable power generation has been an underlying trend in the energy sector during the last decades. The intermittent nature of such resources necessitates an effective power electronic interface. Different configurations have been reviewed previously to overcome the conversion challenges associated with solar panels. In comparison to 2-level inverters, multilevel ones are proved to provide superior performance in the reduction of harmonic distortions, torque pulsations and voltage stress across the switching devices. Decreased switching loss and Total Harmonic Distortion (THD) are indices of satisfactory performance and they cause further compact design and filters.

One of the most important problems in power quality aspects is that the harmonic contents within the electrical system. Generally, harmonics could also be divided into two types: 1) voltage harmonics, and 2) current harmonics. Current harmonics is usually generated by harmonics contained in voltage supply and depends on the type of load such as resistive load, capacitive load, and inductive load. Both harmonics are often generated by either the source or the load side. Harmonics generated by load are caused by nonlinear operation of devices, for example power converters, arc-furnaces, gas discharge lighting devices, etc. Load harmonics results the overheating of the magnetic cores of transformer and motors windings. On the opposite hand, source harmonics are mainly due to power supply with non-sinusoidal voltage waveform. Harmonic actually cause power losses, pulsating torque in AC motor drives also electromagnetic interference. A periodic waveform can be represented by superposition of a fundamental and a group of of harmonic components. By applying Fourier transformation, these components can be extracted. The frequency of every harmonic component is an integral multiple of its fundamental. There are several methods to point of the number of harmonics contents. The THD is mathematically Represented by

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$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} H_{(n)}^{2}}}{H_1}$$

Where H_1 is fundamental component and H_n is harmonic content, n is integer.

II. LITERATURE REVIEW

V.Joshi Manohar, V. Lakshmi Devi, and Adinarayana, "SHE Controlled CHB 7-Level Inverter with Unequal DC Sources using MPSO Algorithm," 2018 IEEE this paper [1] In this work, the optimum switching angles have been determined for a three phase 7- level CMLI with unequal DC sources by implementing Selective Harmonic Elimination Technique and optimize by MPSO. Author calculates THD for different modulation index also uses solar panel output unequal voltage to the input for inverter.

A. Sharma, D. Singh, and S. Gao, "Harmonic Elimination in Three Phase Cascaded Multilevel Inverter using Genetic Algorithm," 1st IEEE 2019 In this paper [2] In this work, the appropriated switching angles have been determined for a three phase 15- level CMLI with equal DC sources by implementing Selective Harmonic Elimination Technique and optimize by Genetic Algorithm method. Author calculates dominant order of harmonics for different load.

M. Kumari et al., "Genetic Algorithm based SHE-PWM for 1- ø and 3- ø Voltage Source Inverters," 2019In this paper [3]in solving of system of SHE equations. The computational results are verified with simulation for single phase and three phase VSI. Hardware is also developed and the correctness of computational and simulations results have been tested Author uses Genetic algorithm for optimization of switching angle.

P. K. Kar, A. Priyadashi, and S. B. Karanki, "Harmonics Mitigation of Single-Phase Modified Source Switched Multilevel Inverter Topology Using OHSW-PWM Technique," Proc. 2018 IEEEIn this paper [4]In this paper, a modified 7-level source switched MLI has been presented. In order to obtain good output response with reduced harmonic contains in output the proposed topology OHSW switching technique has been operated .Author calculate THD for different multilevel inverter.

S. Kundu, S. Bhowmick, and S. Banerjee, "An Optimized Selective Harmonic Minimization-PWM Scheme for Cascaded H-Bridge Inverter Fulfilling NRS 048-2:2003 Grid code," Proc. 2018 IEEEHere in this paper [5]This paper presents, an optimized pulse width modulation (PWM) scheme for a five-level cascaded H-bridge(CHB) inverter that reduces some selective harmonics to satisfy the grid code NRS 048-2:2003 for medium-voltage level three-phase applications.

III. PROPOSED METHODOLOGY

Selective Harmonic Elimination Pulse Width Modulation (SHE -PWM)

The Selective Harmonic Elimination PWM (SHE PWM) method is applied in conventional three-level single phase inverter circuits. The conception of the SHE PWM technique will be presented in this chapter. It required to be compared to the harmonic stepped-waveform technique is optimized in several aspects. Mainly, the harmonic components and the harmonic individuality will be focused.

The SHE PWM method is used to synthesize an output waveform of a full-bridge inverter. In this thesis, a three-level optimized SHE PWM full-bridge or H-bridge VSI voltage source inverter, which consist four switches and single dc source, is depicted in Fig. 4.1. Three different level of an output waveform shows such as positive, negative, and zero, can be obtained. Fig 4.2 shows a stepped three-level SHE PWM waveform, which is synthesize by using the inverter circuit shown in Fig 4.1. The output waveform which shows is chopped N times per quarter. Each switch is, therefore, switched N times per cycle to show such a waveform.

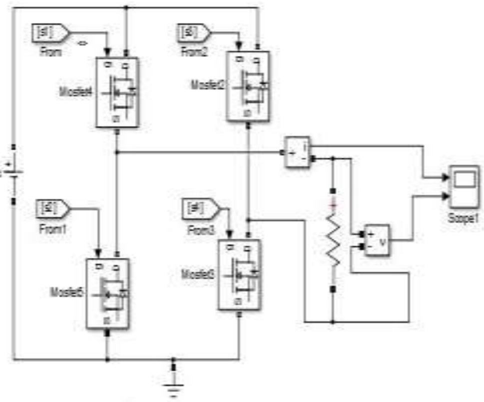

Figure 3.1 A full-bridge voltage source inverter.

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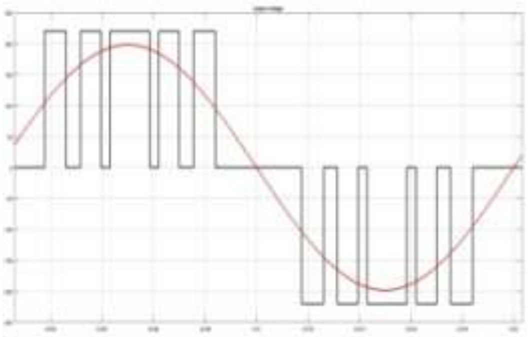

Fig 3.2 Five switching angle three-level SHE PWM waveform

A three-level stepped five-switching angle use in SHE PWM waveform, which is shown in Fig. 4.3, and Newton-Raphson method is apply to solve equation for such SHE PWM switching angles. In this case, a single-phase system is considered and modulation index of output voltage, MI 0.85 taken.

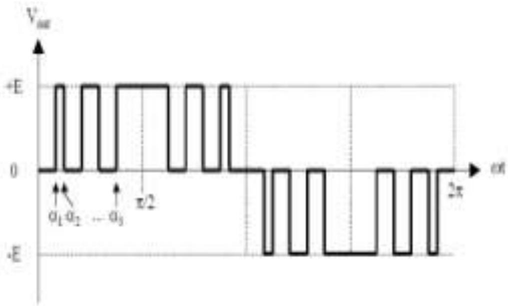

Figure 3.3 Output voltage waveform of a stepped three-level five-angle SHE PWM.

From the output waveform shown in Fig. 4.3, five unknowns, switching angle □1 to □5, is to be solved. Because of a single-phase inverter system, the lowly four odd harmonics, i.e., the 3rd, 5th, 7th, and 9th will be reduced. five nonlinear consisting switching angle in cos term equations is given below will solve by NR method or PSO method

$$\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) - \cos(\alpha_4) + \cos(\alpha_5) = 0.85 \times \frac{\pi}{4}$$

$$\cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) - \cos(3\alpha_4) + \cos(3\alpha_5) = 0$$

$$\cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) - \cos(5\alpha_4) + \cos(5\alpha_5) = 0$$

$$\cos(7\alpha_1) - \cos(7\alpha_2) + \cos(7\alpha_3) - \cos(7\alpha_4) + \cos(7\alpha_5) = 0$$

$$\cos(9\alpha_1) - \cos(9\alpha_2) + \cos(9\alpha_3) - \cos(9\alpha_4) + \cos(9\alpha_5) = 0$$

To solve these (□1 to □5) switching angles, the Newton-Raphson (NR) method and Particle Swarm Optimization (PSO) are used.

Newton-Raphson method

In this method nonlinear equation is solved to find variable value in matrix form. Various steps are given below-

1) The switching angle matrix,

$$\alpha^j = \left[\alpha_1^j, \alpha_2^j, \alpha_3^j, \alpha_4^j, \alpha_5^j\right]^T$$

2) The nonlinear system matrix.

$$f^j = \begin{bmatrix} \cos(\alpha_1^j) - \cos(\alpha_2^j) + \cos(\alpha_3^j) - \cos(\alpha_4^j) + \cos(\alpha_5^j) \\ \cos(3\alpha_1^j) - \cos(3\alpha_2^j) + \cos(3\alpha_3^j) - \cos(3\alpha_4^j) + \cos(3\alpha_5^j) \\ \cos(5\alpha_1^j) - \cos(5\alpha_2^j) + \cos(5\alpha_3^j) - \cos(5\alpha_4^j) + \cos(5\alpha_5^j) \\ \cos(7\alpha_1^j) - \cos(7\alpha_2^j) + \cos(7\alpha_3^j) - \cos(7\alpha_4^j) + \cos(7\alpha_5^j) \\ \cos(9\alpha_1^j) - \cos(9\alpha_2^j) + \cos(9\alpha_3^j) - \cos(9\alpha_4^j) + \cos(9\alpha_5^j) \end{bmatrix}$$

and

$$\left[\frac{\partial f}{\partial \alpha}\right]^j = \begin{bmatrix} -\sin(\alpha_1^j) + \sin(\alpha_2^j) - \sin(\alpha_3^j) + \sin(\alpha_4^j) - \sin(\alpha_5^j) \\ -3\sin(3\alpha_1^j) + 3\sin(3\alpha_2^j) - 3\sin(3\alpha_3^j) + 3\sin(3\alpha_4^j) - 3\sin(3\alpha_5^j) \\ -5\sin(5\alpha_1^j) + 5\sin(5\alpha_2^j) - 5\sin(5\alpha_3^j) + 5\sin(5\alpha_4^j) - 5\sin(5\alpha_5^j) \\ -7\sin(7\alpha_1^j) + 7\sin(7\alpha_2^j) - 7\sin(7\alpha_3^j) + 7\sin(7\alpha_4^j) - 7\sin(7\alpha_5^j) \\ -9\sin(9\alpha_1^j) + 9\sin(9\alpha_2^j) - 9\sin(9\alpha_3^j) + 9\sin(9\alpha_4^j) - 9\sin(9\alpha_5^j) \end{bmatrix}$$

3) The related harmonic amplitude matrix,

$$T = \left[(0.85)\frac{\pi}{4}\ \ 0\ 0\ 0\ 0\right]^T$$

Thus, equations above can be rewrite in the following given matrix format:

$$f(\alpha) = T$$

By using application of matrices the Newton-Raphson method, the process of algorithm shown below:

1) initiate the initial values i.e. assigning for α^j with j=0

Assume

$$\alpha^0 = [\alpha_1^0, \alpha_2^0, \alpha_3^0, \alpha_4^0, \alpha_5^0]^T$$

2) Now compute the value of

$$F(\alpha^0) = T^0$$

3) Linearize equation about α^0

$$F^0 + \left[\frac{\partial f}{\partial \alpha}\right]^0 d\alpha^0 = T$$

And

$$d\alpha^0 = \left[d\alpha_1^0, d\alpha_2^0, d\alpha_3^0, d\alpha_4^0, d\alpha_5^0\right]^T$$

4) Solve $d\alpha^0$ i.e.

$$d\alpha^0 = INV\left[\frac{\partial f}{\partial \alpha}\right]^0 (T - F^0)$$

Where INV $\left[\frac{\partial f}{\partial \alpha}\right]^0$ is shows inverse matrix of $\left[\frac{\partial f}{\partial \alpha}\right]^0$

5) updated the assign initial values,

$$\alpha^{j+1} = \alpha^j + d\alpha^j$$

6) This process is repeated until $d\alpha^j$ is fulfilled to the required degree of accuracy, and the solutions must follow the condition:

$$\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \frac{\pi}{2}$$

By applying MATLAB program, by iteration tabulated the final solutions are tabulated, which are switching angles from 1to 5 in degree, are
By using these switching angles to the model, the 3rd, 5th, 7th, and 9th harmonics will be removed in greater extend from the output voltage stepped waveform. The output voltage THD, which is also simulated by MATLAB, is . The output results will be simulated and confirmed by simulink .

Particle Swarm Optimization (PSO) methodology

To find the best switching angles of non-linear given above transcendental SHE equations set during wide range of modulation index, MATLAB programming is used to develop the coding for the planned algorithm. Single phase 3-level inverter with equal DC sources is implemented in SIMULINK. The above algorithms are run at different modulation index and respective %THD is seen using FFT analysis tool.
Particle Swarm Optimization (PSO) algorithm was first introduced by Eberhart and Kennedy in his paper “PSO is also a population based Stochastic Optimization technique and is well adapted to solve complex optimization problems because of the advantages such as: with less computational effort, simplicity in computer coding, search techniques do not use gradient information but the values of objective function, initial guess is not needed like traditional iterative methods”[2].
PSO is an natured social behavior oriented based method which uses particles in a swarm to find various zones throughout the search space. For i^{th} particle the position and velocity vectors is define for iteration number j are as

$$x_i^j = (x_{i1}, x_{i2}, \dots \dots, x_{iD}) \quad 3\text{-}6$$

$$\Delta x_i^j = (\Delta x_{i1}, \Delta x_{i2}, \dots \dots, \Delta x_{iD}) \quad 3\text{-}7$$

Each particles are being updated it their position and velocity vector according to the objective function .Now Individual best found positions called $\mathbf{p_{best_i}}$by each particle and the best related global position called **Gbest**by swarm this is stored in memory to be treat as temporary target or object points. In the further iteration, four terms of x_i^j,Δx_i^j,p_{best_i},and G_{best} is find each particle in terms of position vector $x_i^{j+1}$and velocity vector Δx_i^{j+1}in such manner to reach optimum solution. The equations are given as

$$x_i^{j+1} = x_i^j + \Delta x_i^{j+1} \quad i=1,2,3,\dots\dots\dots P \quad 3\text{-}8$$

$$\Delta x_i^{j+1} = \Delta x_i^j + c_1 r_1 \lfloor p_{best_i} - x_i^j \rfloor + c_2 r_2 \lfloor G_{best} - x_i^j \rfloor \quad 3\text{-}9$$

whereP is the given by total number of particles in the swarm. The (j+1) index shows the next iteration. Acceleration coefficients term or weighting factors constant ofc1 and c2 are positive constants which resolve the extent of inclination in particles trajectory towards either of specified target points. Two different random numbers i.e. r1 and r2 with a flat giving out between zero and one. This process is done in the limit for this we have give limits so we get feasible solution
Incorporate this parameter to 3-9, the following expression will give one step ahead towards best solution.

$$\Delta x_i^{j+1} = w\Delta x_i^j + c_1 r_1 \lfloor p_{best_i} - x_i^j \rfloor + c_2 r_2 \lfloor G_{best} - xij \quad 3\text{-}10$$

PSO has ability to reach a good solution in a less number of iterations. This is achieve by 3-11.

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{J}\right) j \quad 3\text{-}11$$

wherew_{max} and w_{min} are the upper inertia weight and lower extremes of inertia weight, J shows the maximum iteration number.

Extraction of decision variables

For each particle the layout is given by

$$x_i^j = (\theta_{i1}, \theta_{i2}, \dots \dots, \theta_{il}) \text{3-12}$$

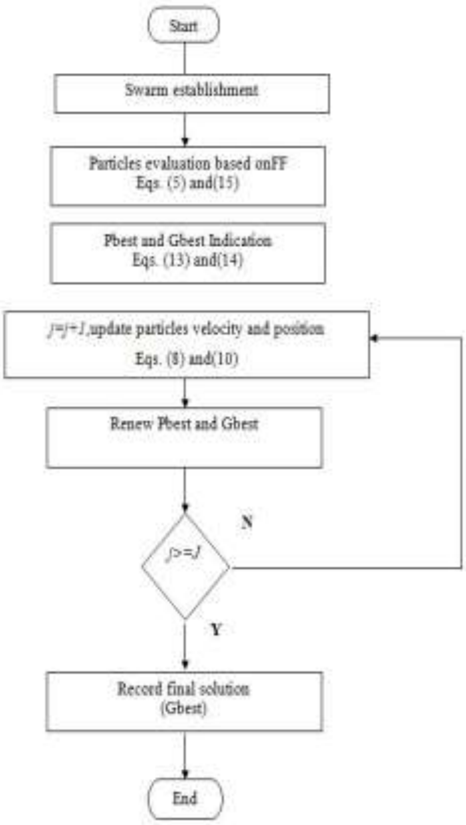

Figure 3.4 Flowchart associated with PSO algorithm All

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All particles are calculated on the basis of FF to determine **Pbest_i**and **Gbest**.

$FF(P_{best-i}) = \min_{k=1}^{j}\{FF(x_i^k)\} P_{best-i} \in Swarm$ 3-13

$FF(G_{best}) = \min_{i=1}^{p}\{\min_{k=1}^{j}\{FF(x_i^k)\}\} G_{best-i} \in Swarm$3-14

Velocity vector and positions vectors updated accordingly 3-8 and 3-10.

this programming for optimization best switching angle is coded in MATLAB environment. In this case subjected objective function is evaluated such that minimize the selective harmonics and Total harmonics Then, a appropriate FF can be defined as

$$FF = \left(100\left(\frac{V_1^* - V_1}{V_1^*}\right)\right)^4 + \sum_{s=2}^{l} \frac{1}{h_s}\left(50\,\frac{V_{h_s}}{V_1}\right)^2 \quad 3\text{-}15$$

where variables are limited to ranges given in 3-16 and 3-17, V1* is the required fundamental component , hs shows the order of sth harmonic in the given single phase output voltage, e.g. h2=5, h3=7 and h6=17 .

$0 \le \theta_i \le \frac{\pi}{2}$ 3-16

$0 \le V_i \le 1$ 3-17

IV. RESULT AND SIMULATION

Simulation is reduce development time and is power way to insure the proper fulfilment of critical steps. In this project, simulation work is done which allowed the observe of it behaviour under different operating condition and permitted study and control parameters together with optimization of the applying LCL filter component values. **MATLAB/SIMULINK** shown below and the power system block set in figure 5.1 were used as simulation tools in this development, models.

Simulation and Results:
Parameters of the Simulated System:

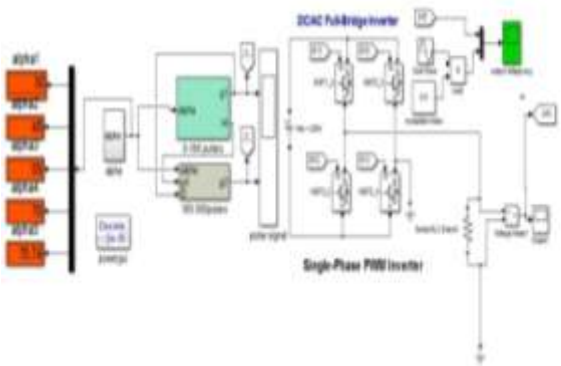

Fig 4.1: SHE-PWM single phase inverter without filter.

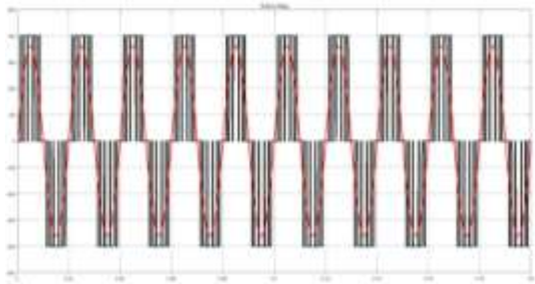

Fig 4.2: Output voltage waveform with sinusoidal sampling.

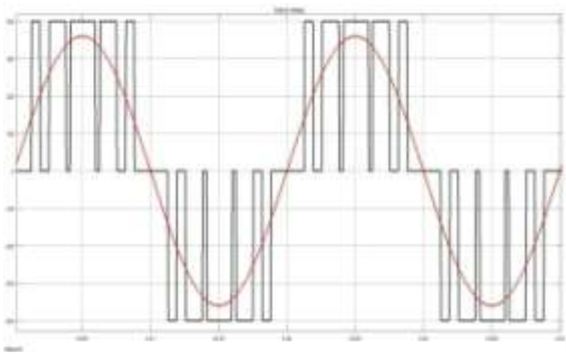

Fig 4.3: Output voltage waveform

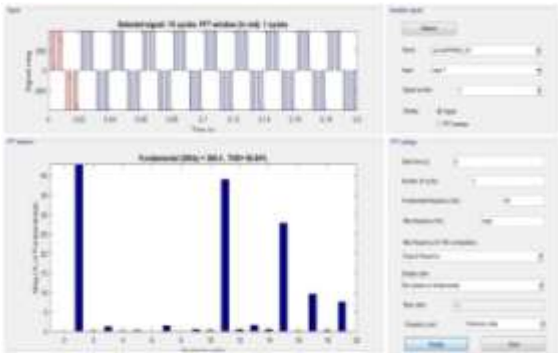

Fig. 4.4: FFT analysis for THD calculation

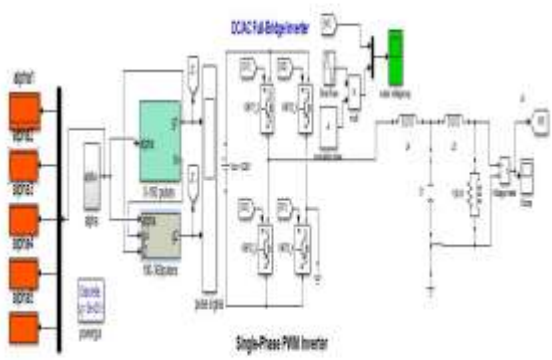

Fig 4.5: SHE-PWM single phase inverter with LCL filter.

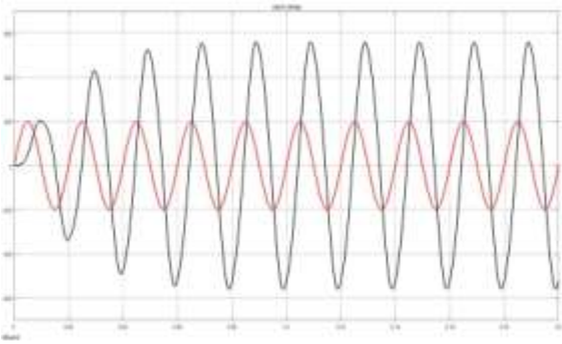

Fig 4.6: Output voltage waveform with LCL filter

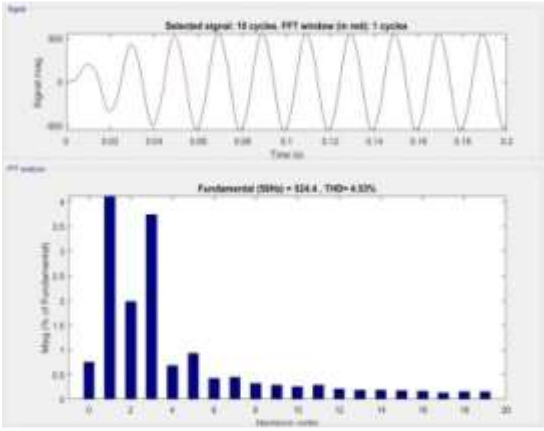

Fig. 4.7: FFT analysis NR method with filter

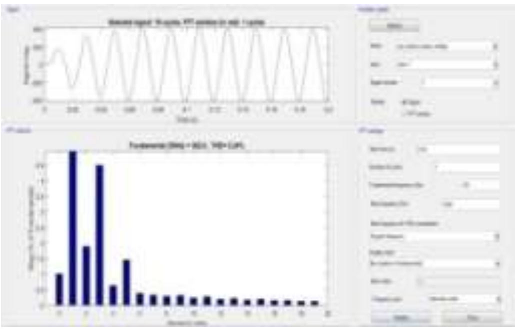

Fig. 4.8: FFT analysis pso method with filter

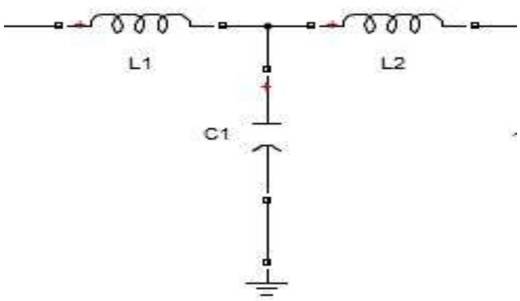

Fig. 4.9: LCL filter

Table 4.1 LCL Filter parameters

	L1	C	L2
Parameter	**0.04999 H**	**15.5e-5 F**	**0.04999 H**

V. CONCLUSION & FUTURE SCOPE

Conclusion:

MATLAB program has executed to find the switching angle for 3rd , 5th ,7th 9th (lower order harmonics)order harmonic elimination ie. Selective harmonic Elimination, this is reduce the total no of filter required and also by using appropriate filter higher order harmonic is also reduce which further reduce the total harmonic (THD),in this project two method is used and compare the result for different modulation index

- A model of single phase SHE-PWM inverter has been created in MATLAB/SIMULINK condition utilizing Power System Block-set.
- Newton Raphson method is use to solve nonlinear equation for selective harmonic elimination this is done by MATLAB program, MATLAB program has executed to find the switching angle for different modulation index , At 0.9 modulation index and harmonic order reduce up to 5,the THD is 4.53% and different optimized angle is $\alpha_1 = 22.0274551139915$, $\alpha_2 = 33.3203098068197, \alpha_3 = 45.4513489560173, \alpha_4 = 68.1122603626738, \alpha_5 = 73.3370323906526$.
- By Particle Swarm Optimization (PSO) method is use to for selective harmonic elimination ,this is done by MATLAB program, MATLAB program has executed to find the switching angle for different modulation index , the THD is 5.24% and different optimized angle is α_1 =5.49, α_2 =16.83, α_3 =28.99 α_4 =42.14, α_5 =60.72

Future Scope:

Different improvement strategies can be utilized to get the ideal inverter with low THD in the framework. Right now the optimizing technique is more efficient tool to get efficient output for high power inverter application. The exploration can be reached out for applying the comparable strategies to the different multilevel inverter which are excluded from the proposed investigation.

REFERENCES

[1] V.Joshi Manohar, V. Lakshmi Devi, and Adinarayana, “SHE Controlled CHB 7-Level Inverter with Unequal DC Sources using MPSO Algorithm,” 2018 IEEE Int. Conf. Syst. Comput. Autom. Networking, ICSCA 2018, pp. 1–6, 2018, doi:

10.1109/ICSCAN.2018.8541237.

[2] A. Sharma, D. Singh, and S. Gao, “Harmonic Elimination in Three Phase Cascaded Multilevel Inverter using Genetic Algorithm,” 1st IEEE Int. Conf. Sustain. Energy Technol. Syst. ICSETS 2019, pp. 213–218, 2019, doi: 10.1109/ICSETS.2019.8745125.

[3] M. Kumari et al., “Genetic Algorithm based SHE-PWM for 1- ø and 3- ø Voltage Source Inverters,” 2019 Int. Conf. Power Electron. Control Autom. ICPECA 2019 - Proc., vol. 2019-Novem, no. 978, pp. 0–5,2019, doi: 10.1109/ICPECA47973.2019.8975556.

[4] P. K. Kar, A. Priyadashi, and S. B. Karanki, “Harmonics Mitigation of Single-Phase Modified Source Switched Multilevel Inverter Topology Using OHSW-PWM Technique,” Proc. 2018 IEEE Int. Conf. Power Electron. Drives Energy Syst. PEDES 2018, pp. 1–6, 2018, doi: 10.1109/PEDES.2018.8707641.

[5] S. Kundu, S. Bhowmick, and S. Banerjee, “An Optimized Selective Harmonic Minimization-PWM Scheme for Cascaded H-Bridge Inverter Fulfilling NRS 048-2:2003 Grid code,” Proc. 2018 IEEE Int. Conf. Power Electron. Drives Energy Syst. PEDES2018,pp.1–6,2018,doi:10.1109/PEDES.2018.8707551.