HARMONIC ANALYSIS OF NR & ELITIST TLBO ALGORITHMS IN CONTROL OF SOLAR FED CASCADED MULTILEVEL LEVEL INVERTER

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Abstract: Selective harmonic elimination technique is one of the extensively used methods for low thermal losses and high converter efficiency in medium and high voltage application. The nonlinear transcendental trigonometric SHE equations are highly nonlinear character in multilevel inverter; hence it is very difficult to obtain feasible solution at desired value of modulation index. This paper presents comparative analysis of NR method with random initial guess and new algorithm such as elitist teaching learning based optimization technique to solve SHE equation set at different values of modulation index. To confirm the proposed technique, a single phase 27 level Cascaded Multilevel Inverter has been considered and the developed algorithms are tested at different modulation index. MATLAB programming and SIMULINK model has been developed to validate the proposed optimization methods. A 5kW solar photo voltaic power plant has been designed and implemented with 27 level Cascaded Multilevel Inverter with the SHEPWM algorithm.

Key-words: cascaded multilevel inverter; NR method; selective harmonic elimination technique; elitist teacher learning based optimization; THD analysis.

1. Introduction

The multilevel inverters are most suitable application in the area of high power rating and medium voltage applications. The multilevel inverter designed to overcome the limitations of conventional two voltage level converters. The advantages of the multilevel inverter are low electromagnetic interference, higher power quality, lower switching losses and higher voltage capability.

J. Rodríguez et al, (2002) analyzed the most important topologies like diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor), and cascaded multicellular with separate DC sources. Emerging topologies like asymmetric hybrid cells and soft-switched multilevel inverters are also discussed. This paper also presents the most relevant control and modulation methods developed for this family of converters: multilevel sinusoidal pulse width modulation, multilevel selective harmonic elimination, and space-vector modulation. Special attention is dedicated to the latest and more relevant applications of these converters such as laminators, conveyor belts, and unified power-flow controllers [1].

J. Napoles et al, (2012) developed the cascaded H-bridge converter (CHB) is a multilevel topology which is formed from the series connection of H-bridge cells. Optimized pulse width modulation techniques such as selective harmonic elimination or selective harmonic mitigation (SHM-PWM) are capable of preprogramming the harmonic profile of the output waveform over a range of modulation [2].John N. Chiasson et al, (2004) presented the analysis of the complete solutions for both unipolar and bipolar switching patterns to eliminate the fifth and seventh harmonics are given. Finally, the unipolar case is again considered where the fifth, seventh, 11th, and 13th harmonics are eliminated along with corroborative experimental results[3].J.Sun and H.Grotstollen,(1992) presented the method of Solving Nonlinear equations for Selective harmonic eliminated PWM using predicted initial values for CHB [4]. J.Chiasson et al,(2005) developed the Elimination of harmonics in a multi-level converter using resultant theory of symmetric polynomials and resultants[5].Reza S et al,(2011) analyzed the Elimination of Low order harmonics in Multilevel Inverter using Genetic Algorithm for CHB[6]. Ozpineci B et al,(2005) presented the Harmonic Optimization of Multilevel Converters Using Genetic Algorithms[7]. Tarafdar M et al,(2009) analyzed the model of Harmonic Minimization in Multilevel Inverters Using Modified Species- Based Particle Swarm Optimization technique[8]. Venkata Rao R and Vivek P,(2012) analyzed the teaching-learning based optimization algorithm for solving complex constrained optimization problems [9]. Samir Kouro et al, (2009) developed the model of Predictive control based selective harmonic elimination with low switching frequency for multilevel converters Energy Conversion Congress and Exposition [10]. H. S. Patel and R. G. Hoft, (1973) developed the Generalized harmonic elimination and voltage control in thyristor inverters [11]. Jagdish Kumar, Biswarup Das and Pramod Agarwal, (2008) presented the Selective harmonic elimination technique for a multilevel inverter[12].Venkata Rao R and Vivek P, presented the elitist teaching-learning based optimization algorithm for solving complex constrained optimization problems[13].

In literature several techniques have been proposed such as Newton Raphson Method, WALSH , Resultant theory, theory of systematic polynomials, all these techniques suffers long computational time, tedious calculations and unable to provide feasible solutions during complete range of modulation index from 0 to 1.Stochastic optimization techniques like, genetic algorithm, modified species based optimization technique and fire fly algorithms are used to provide the feasible solutions for SHE equation set. All these optimization techniques require initialization parameters such as alteration rate, social parameter, cognitive parameter, constriction factor etc. This paper compares the effectiveness of ETBLO algorithm with NR method in solving SHE equations set which are formed in control of single phase CHB 27-level inverter.

2 Problem Formation and SHE Technique in 27 level cascaded MLI

The block diagram of the proposed cascaded multilevel inverter is shown in fig.1. The proposed optimization techniques are used to solve the set of non-linear transcendental trigonometrically SHE equations. The output of solar panel array with adaptive MPPT output was given to bidirectional DC-DC converter. The bidirectional DC-DC converter operates in buck and boost mode. The output of DC-DC converter has been given to cascaded 27 Level MLI. Selective Harmonic Elimination method is applied to multilevel inverter to reduce THD of output voltage. The circuit diagram of the proposed 27 level inverter is shown in fig. 2.

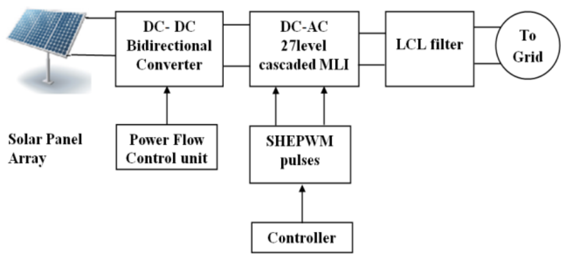

Fig. 1 Block Diagram of Proposed 27 level Multilevel Inverter

In the proposed system, variable dc source voltages from solar panel are used for the bridges of the multi-level inverter. Each bridge is energized by separate sources. The cascaded multilevel inverter consists of a series of full bridge inverter units.

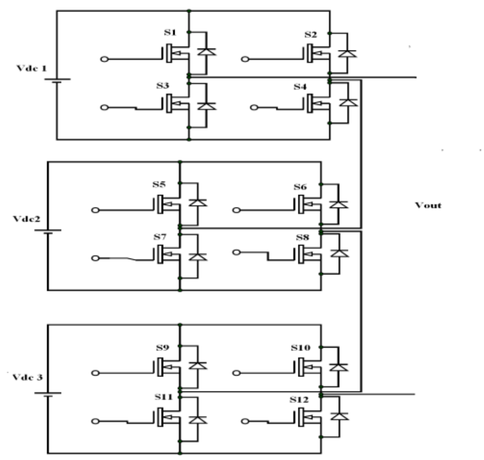

Fig.2. Circuit diagram of Proposed Cascaded 27 level Inverter

As shown in Fig.2, s H-bridge cells are connected in series. An output voltage waveform can be generated by summation of the output voltage of each cell, i.e.

$$\text{Vout} = \text{V1} + \text{V2}+\text{V3} \quad (1)$$

The Fourier series of the quarter-wave symmetric s bridge multilevel waveform is written as follows:

$$V_{out}(\omega t) = \sum_{n=1}^{\infty}\left[\frac{4E}{n\pi}\sum_{k=1}^{s}\cos(n\alpha_k)\right]\sin(n\omega t) \quad (2)$$

The voltage of the first level equals V1; the voltage of the second level equals V2 and so on. By considering the waveform in Fig. 3 there are three possible optimization techniques to reduce the voltage THD: 1) step heights are optimized with equally spaced steps; 2) step spaces are optimized with the steps of equal height; and 3) optimizing both heights and spaces.

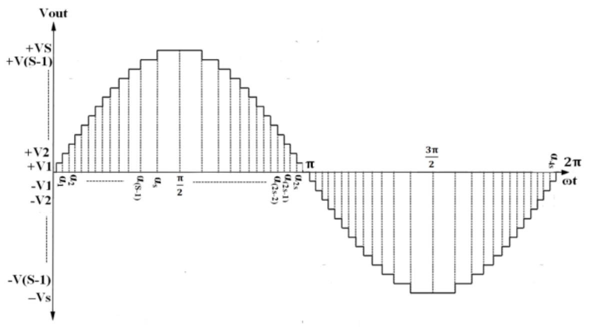

Fig. 3. Output voltage waveform of the s H-bridge cell series-connected multilevel inverter

In general, the modulation index of SHEPWM is the ratio of the modulating signal amplitude to the carrier signal amplitude. For the specified multilevel case, the modulation index is defined as follows:

$$M = V_{out}/sV_{dc} \quad (3)$$

Where

Vout is the amplitude of the output voltage at the fundamental frequency.

s is the number of dc sources or H-bridge cells per phase.

and *Vdc* is the amplitude of dc sources of solar panel.

From the waveform shown in Fig. 3, 13 unknowns, α1, α2, α3... and α13, need to be known. Because of a single-phase system, the lowest three odd harmonics, i.e., the 3rd, 5th, and 7th, should be eliminated.

To control the fundamental amplitude and eliminate the harmonics, four nonlinear equations can be set up as follows:

$$[\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) + \cos(\alpha_4) + \cdots + \cos(\alpha_{13})] = 0.8\frac{3\pi}{4} \quad (4a)$$

$$[\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3) + \cos(3\alpha_4) + \cdots + \cos(\alpha_{13})] = 0 \quad (4b)$$

$$[\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) + \cos(5\alpha_4) + \cdots + \cos(\alpha_{13})] = 0 \quad (4c)$$

$$[\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) + \cos(7\alpha_4) + \cdots + \cos(\alpha_{13})] = 0 \quad (4d)$$

3. Newton-Raphson Method

The Newton-Raphson method is used to compute the roots of an equation by successive-approximation procedure, which is suitable for implementation in a MATLAB program. Nonlinear equation system can be solved by using a linearization technique, which the nonlinear equations are linearized about an approximate solution.

In a multivariable nonlinear system, a set of independent variables is formed in matrix format and the statement of the algorithm of Newton's method can be shown as follows:

1. Guess a set of initial values for α with j =0

$$\alpha^j = [\alpha_1^j, \alpha_2^j, \ldots, \alpha_s^j]^T \quad (5)$$

2. Calculate the value of

$$F(\alpha_j) = F^j \quad (6)$$

3.Linearize equation 17 about α^j

$$F^j + \left[\frac{\partial f}{\partial \alpha}\right]^j d\alpha^j = K \quad (7)$$

Where

$$\left[\frac{\partial f}{\partial \alpha}\right]^j = \begin{bmatrix} \frac{\partial f_1}{\partial \alpha_1} & \frac{\partial f_1}{\partial \alpha_2} & \cdots & \frac{\partial f_1}{\partial \alpha_s} \\ \frac{\partial f_2}{\partial \alpha_1} & \frac{\partial f_2}{\partial \alpha_2} & \cdots & \frac{\partial f_2}{\partial \alpha_s} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_s}{\partial \alpha_1} & \frac{\partial f_s}{\partial \alpha_2} & \cdots & \frac{\partial f_s}{\partial \alpha_s} \end{bmatrix}$$

and

$$d\alpha^{j} = \left[d\alpha_1{}^{j} \quad d\alpha_2{}^{j} \cdots \quad d\alpha_s{}^{j}\right]^T$$

4.Solve $d\,\alpha^{j}$ from 7 by

$$d\alpha^{j} = INV\left[\frac{\partial f}{\partial \alpha}\right]^{j}\ (K - F^{j}) \qquad (8)$$

5.As updated the initial values

$$\alpha^{j+1} = \alpha^{j} + d\alpha^{j} \qquad (9)$$

6. Repeat the process, equations 6 to 9 until d α^{j} is satisfied to the desired degree of accuracy and the solutions must satisfy the following condition:

$$(\alpha_1, \alpha_{2,}\alpha_{3,}\alpha_4, \alpha_5, ---, \alpha_{13} < \frac{\pi}{2}) \qquad (10)$$

The proposed NR algorithm is developed in MATLAB programming and the value of proposed algorithm is tested in solving nonlinear transcendental SHE equation set.

4. Elitist teaching learning based optimization technique

Elitist teaching-learning-based optimization (ETLBO) is a new optimization algorithm based on the practical teaching-learning process of the class. In this research, we recommend a feedback elitist teaching-learning-based optimization to solve the problem of low precision and poor stability of the ETLBO. Based on the ETLBO, a feedback phase is introduced at the end of the learner phase to increase the learning style and ensure the diversity of students so as to improve the algorithms global search ability. Meantime the feedback phase is for the slow students to speak with the teacher and enables them to be close to the teacher quickly, so that the algorithm uses the Fine local search and improves the precision. Six unconstrained and five constrained classic tests show that the FETLBO algorithm outperforms the other algorithms in precision and stability. Finally, the FETLBO algorithm is applied to the tension spring design problem and the 0-1 daypack problem, and obtains acceptable results.
The ETLBO algorithm that is introduced here is shown in the flow chart. The following steps provide explanations to the ETLBO algorithm.

Step1: Initialize the population design and termination criterion

Step2: Evaluate the initial population

Step3: Keep the elitist solution

Step4: Calculate the mean design variable

Step5: Select the best solution

Step6: Calculate the difference between and modify the solution

Step7: final value of solution

Termination criteria stop if the maximum generation is achieved; otherwise repeat from Teacher phase.

5. Simulation Results and Discussions

The planned techniques like NR method and ETLBO algorithms are used to resolve nonlinear transcendental SHE equations set which are formed in control of single phase 27level inverter. The MATLAB code has been developed for the proposed techniques and SIMULINK model is also developed to examine the THD & FFT analysis.

5.1 Newton Raphson method

The planned MATLAB algorithm has been programmed and run from modulation index value from 0.5 to 1 in steps 0.05.The switching angles from α1 to α13 with THD level for each value of modulation index are tabulated in Table1. From the analysis no solution for SHE equations set below the value 0.4 and above the value of 0.8. The phase voltage waveform of 27-level inerter output voltage is represented in fig.4. The flow chart for finding switching angle is shown in fig 5. Average computational time required to run the algorithm at selected values of modulation indices are 09.00 sec only. It is also found that the proposed NR method could not provide the feasible solution at the modulation index values of 0.85, 0.9, 0.95 and 1.0.

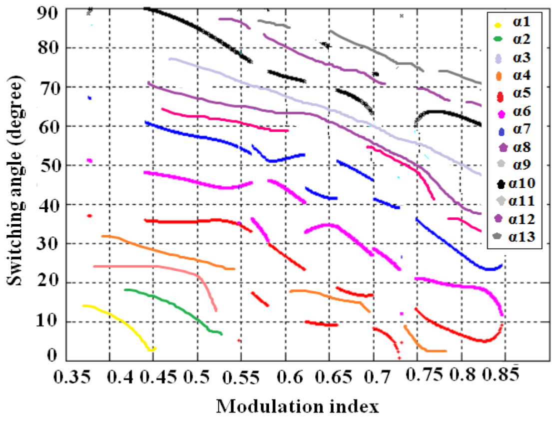

Fig.4. Switching angles Vs Modulation Index

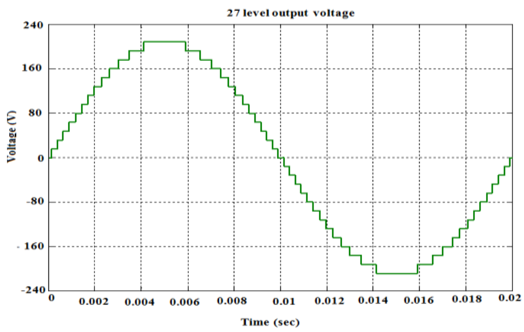

Fig.5.Output of 27 level Inverter

From the result of Table 1, it is found that %THD value gradually decreases as the modulation index increases and minimum %THD of value 3.02% has obtained at a modulation index of value 0.8. FFT analysis at the value of value of 0.8 MI is shown in Fig. 6; it is experimental that the targeted order of harmonics says 5th and 7th are minimized to that greater value.

Table 1. Switching angles in degrees & %THD

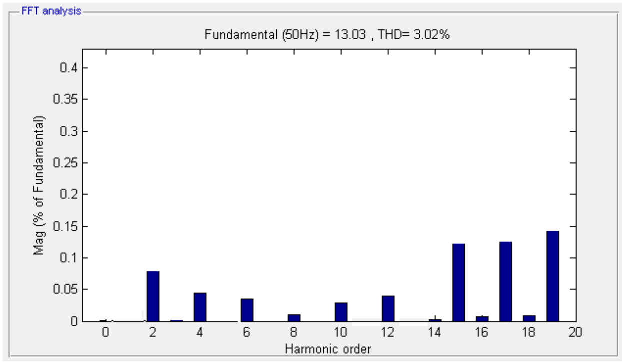

Fig.6. FFT analysis at the MI =0.8

5.2 Elitist Teaching Learning based Optimization Technique

The Proposed ETLBO algorithm is developed with MATLAB code and the program is run at different modulation index from 0.5 to 1.0 in steps of 0.5. The obtained switching angles of SHE equation set and THD values are tabulated in Table 2. The values of %THD obtained at different steps of modulation indices are decreased gradually as the modulation index is increased. The value of %THD obtained at the modulation index of value 0.95 is 6.95% and completely complies with

FFT analysis at 0.95 modulation index is shown in Fig. 7. It is observed that all targeted order of harmonics are minimized and below 5% in magnitude only. It is further observed that the average computational time required for running the TLBO code is 16.6 sec. The potential of TLBO algorithm is, it has successfully solved SHE equation set at the modulation indices of value 0.85, 0.9, 0.95 and 1.0.

M	α1	α2	α3	α4	α5	α6	α7	α8	α9	α10	α11	α12	α13	α14	α15	%THD
1.0																
0.95								**No feasible solution**								
0.9																
0.85																
0.80	17.01	25.95	32.30	47.25	52.17	59.04	61.23	77.97	78.31	81.31	78.31	82.60	83.60	84.05	85.95	3.02
0.75	16.28	25.11	33.29	48.11	53.32	60.55	62.99	76.31	77.21	78.21	79.21	81.00	83.00	81.97	82.97	4.56
0.70	15.83	24.47	34.06	48.45	53.95	61.04	63.92	75.21	76.21	77.21	78.21	80.95	82.95	82.65	82.65	5.67
0.65	15.41	23.76	34.86	48.64	54.41	61.13	64.47	74.21	76.09	78.09	79.09	80.97	82.97	83.80	87.80	7.65
0.60	14.84	22.61	36.06	48.92	54.83	60.99	64.73	73.09	80.87	81.87	81.87	81.65	82.65	86.13	88.13	8.67
0.55	10.11	17.69	39.9	54.58	59.95	66.80	78.43	80.87	81.54	82.54	84.54	82.80	87.80	87.56	88.67	9.56
0.5	10.08	17.89	39.93	54.17	59.95	66.16	80.17	87.54	79.97	86.97	87.97	85.13	88.13	88.78	89.78	10.67

Comparative analysis of %THD at different values of modulation indices are shown in Table3. It is observed that though the %THDs obtained by NR method is minimum but it could not provide the feasible solutions at the modulation index of values 0.85 and above. The ETLBO algorithm has successfully solved the SHE equation set where NR method could not solve it. The ETLBO algorithm has solved the SHE equation set at highest magnitude of the fundamental voltage with minimum %THD of value 2.30%. The computational time required for both the algorithms are less but NR method is very less with the value of 07 sec.
The flow chart or finding switching by NR method is shown below in fig.8.

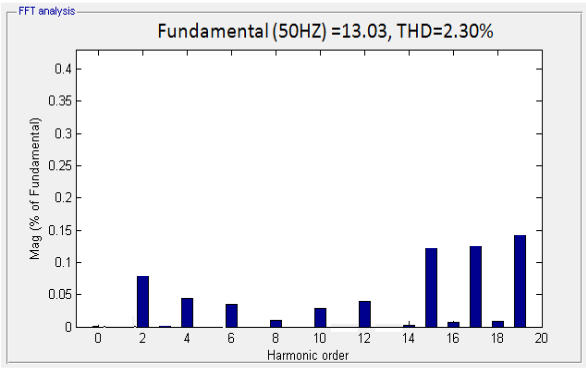

Fig.7. FFT analysis at MI=0.95.

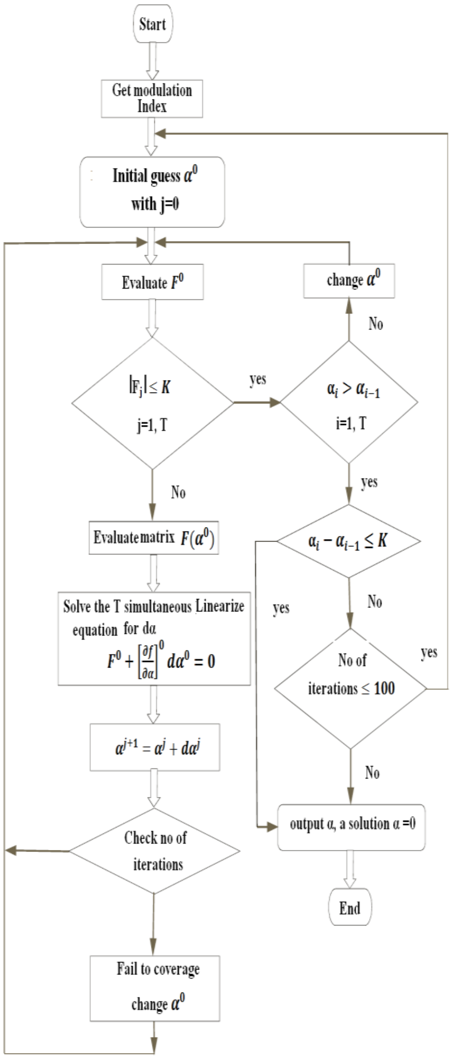

Fig.8. Flowchart for calculating α

Table. 2 Switching angles in degrees and %THD

M	α1	α2	α3	α4	α5	α6	α7	α8	α9	α10	α11	α12	α13	α14	α15	%THD
1.0	13.85	15.75	20.99	42.89	46.30	53.51	56.31	61.23	62.99	75.21	77.97	83.45	84.76	85.45	87.76	2.20
0.95	17.03	19.22	21.36	44.44	48.90	55.21	57.97	81.88	79.97	80.97	79.97	82.64	83.64	84.64	87.64	2.30
0.9	17.01	25.95	32.30	47.25	52.17	59.04	61.23	77.97	78.31	81.31	78.31	82.60	81.60	82.60	83.60	3.46
0.85	16.28	25.11	33.29	48.11	53.32	60.55	62.99	76.31	77.21	78.21	79.21	81.00	83.00	81.00	83.00	3.95
0.80	15.83	24.47	34.06	48.45	53.95	61.04	63.92	75.21	76.21	77.21	78.21	80.95	81.95	81.95	82.95	4.08
0.75	15.41	23.76	34.86	48.64	54.41	61.13	64.47	74.21	76.09	78.09	79.09	80.97	81.97	81.97	82.97	5.56
0.70	14.84	22.61	36.06	48.92	54.83	60.99	64.73	73.09	80.87	81.87	81.87	81.65	81.65	82.65	82.65	6.67
0.65	10.11	17.69	39.9	54.58	59.65	66.80	78.43	80.87	81.54	82.54	84.54	82.80	86.80	83.80	87.80	8.65
0.60	10.08	17.89	39.93	54.17	59.95	66.16	80.17	87.54	79.97	86.97	87.97	85.13	87.13	86.13	88.13	9.67
0.55	9.79	16.46	41.04	55.65	60.45	65.67	82.54	88.78	78.89	87.45	88.56	86.56	87.67	87.56	88.67	10.56
0.5	9.08	15.67	42.45	56.56	62.56	65.78	84.56	89.56	77.98	88.67	89.67	89.77	88.78	88.78	89.78	15.67

Table. 3. Comparative analysis of THD

MI	%THD ETBLO	%THD NR
1.0	2.20	
0.95	2.30	
0.9	3.46	
0.85	3.95	
0.8	4.0	3.02
0.75	5.56	4.56
0.7	6.67	5.67
0.65	8.65	7.65
0.6	9.67	8.67
0.55	10.56	9.56
0.5	15.67	10.67

The flow chart or finding switching by ETBLO method is shown below in fig.9.

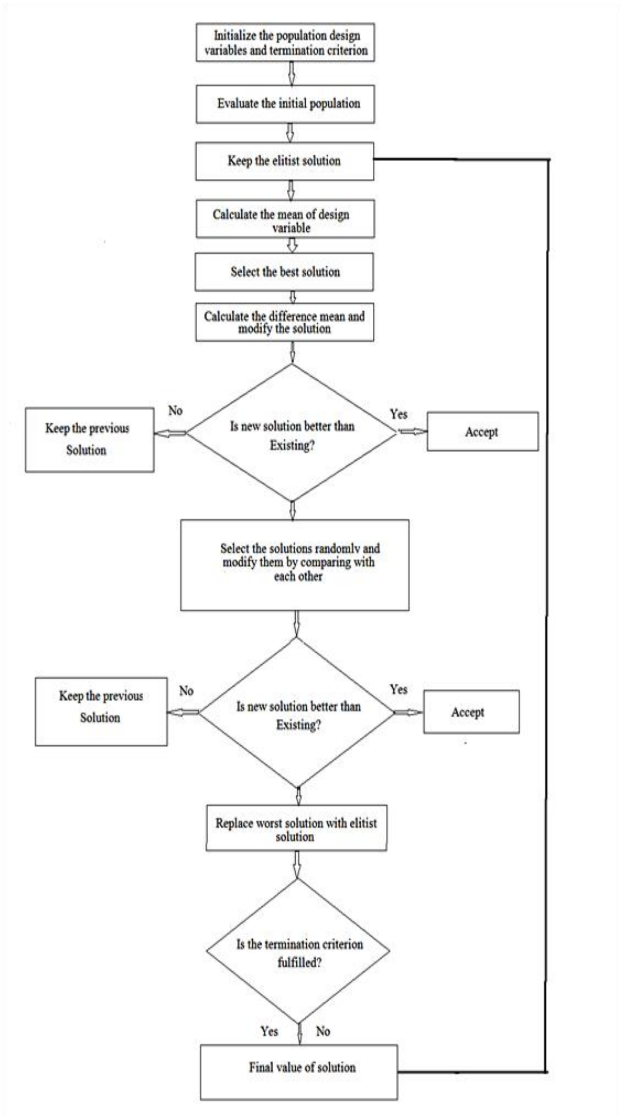

Fig.9. Flowchart for calculating α

6 Experimental Results.

5kWp solar PV power supply unit is designed and implemented for the 13 stage 27 level solar fed CMLI with the SHEPWM algorithm. The output voltage of the system is designed for the 230V AC supply for single phase. In order to achieve this, each photovoltaic panel has a rated power of 250W with voltage variation of 25 to 30 volts depending on the operating conditions such as light intensity and so on. Five numbers of 100, 100Ah Exide battery packs are connected in series to get a nominal DC bus of 100 volts. These batteries are charged from the photovoltaic unit through a controlled charging circuit. There are 5 sets of individual PV supply source used for the hardware implementation as they Produce 100 x 5=500Vp. This output is given as input for bidirectional converter. This converter has 2 MOSFET with two set of coupled inductor gate drive board with DSP processor. This DC-DC converter output is given to Cascaded multilevel inverter. Gating pulses are given by the FPGA processor Xilinx Spartan 6 FPGA. Based on the SHEPWM algorithm incorporated in the TIs DSP (TMS320F28335) processor, it generates the switching angles to the inverter switches MOSFET IRF840 through a driver circuit considering the sequences at each four quarters in the complete cycle. The complete hardware setup comprising of charge controllers, battery and the proposed inverter is given. The variation of input PV voltage is measured at every instant which is used for solving SHEPWM equations.fig.10.shows the hardware output setup of the PV plant.

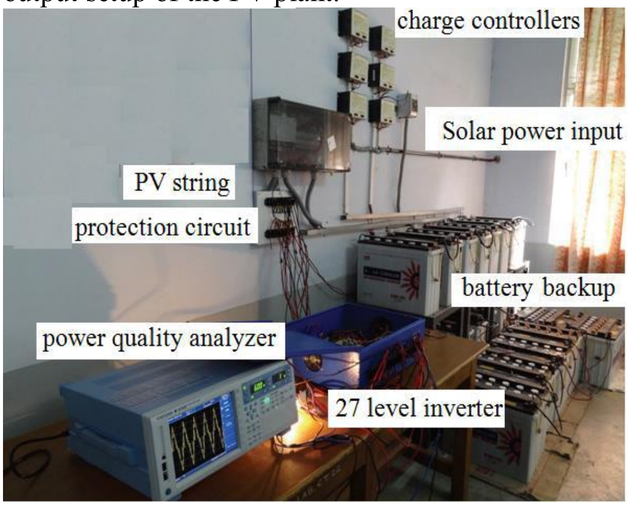

Fig.10.Experimental setup for 27 level inverter

The fig.11.shows the solar plant installed capacity of 5KW

Fig.11. Installed Solar plant rating 5Kw

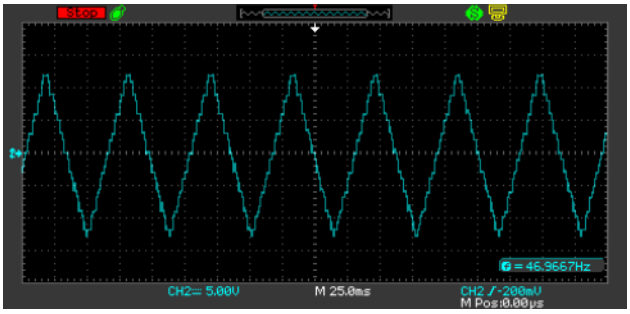

Fig.12. 27 level output voltage waveform

7 Conclusions

This research paper mainly focused on design of 27 level cascaded MLI and comparative analysis of various algorithms to solve nonlinear transcendental SHE equations. It is found that ETLBO algorithm is rugged, efficient and solved the SHE equation set form 0.5 to 1.0 values of modulation index where NR method could not provide the feasible solution at the values of modulation indices 0.85, 0.9, 0.95 and 1.0. Even though, the THD obtained by ETLBO algorithm is high at different values of MI but at 1.0 MI the THD is less in value at 2.20%. The computational time for NR method is very less say 07 sec but it has a problem of struck at global minima. The ETLBO algorithm takes somewhat more computational time say 17 sec but it can find feasible solutions at different values of MI where NR method could not find these values.

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