Harmonic Minimization in Solar Fed Hybrid Cascaded Multilevel Inverter by Implementing NR & Biogeography Optimization Algorithm

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Abstract: Selective harmonic elimination method is one of the most extensively used methods in medium and high voltage application. The nonlinear transcendental trigonometric Selective harmonic elimination equations are very highly nonlinear character in multilevel inverter, so it is very difficult to solve and find the switching angles at exact value of modulation indices with less THD. This paper presents the performance and comparative study of Newton Raphson optimization technique with new optimization technique such as Bio geographical based optimization (BBO) method to solve the Selective harmonic elimination equation with different modulation indices. The proposed method is applied to a single phase 31 level Cascaded Multilevel Inverter and tested with different modulation index to find the switching angles. SIMULINK model has been developed to analyze the both optimization methods. A 5kW solar photo voltaic power plant has been designed and implemented with 31 levels Cascaded Multilevel Inverter with the SHEPWM algorithm. From the analysis the proposed optimization method produces only THD level at 2.30%.

Keywords: PV system, 31 level hybrid multilevel inverter, NR method, Bio geographical based optimization (BBO), SHEPWM Equations, THD analysis.

1. Introduction

The multilevel inverters are most suitable application in the areas of medium and high power rating applications of photo voltaic power system. The multilevel inverters are considered to beat the margins of square wave two level voltage converters. The main important benefits of the cascaded multilevel inverters are very less electromagnetic interfering, superior power quality, lesser switching losses and superior voltage capacity. The multilevel inverter survey and control of all topologies are discussed with applications in [1].The non-equal dc link voltage performance of Selective Harmonic elimination Technique in cascaded multilevel inverter in [2].The complete results for the harmonic elimination in multilevel inverter in [3]. The initial values are used to eliminate the Selective harmonic nonlinear equations in [4].The resultant theory using Eliminating harmonics in cascaded multilevel converter in [5]. Genetic Algorithm used for Elimination of harmonics for cascaded multilevel converter in [6-7]. Particle Swarm Optimization method is used to eliminate Harmonics in Modified Multilevel Inverters in [8].To find the compound controlled optimization TLBO algorithm IS used in [9]. Analytical control based selective harmonic elimination method is applied in multilevel converters [10]. Harmonic elimination in thyristor inverters by voltage control in [11].The lower order harmonics will be eliminated by Selective harmonic elimination method for cascaded multilevel inverter [12].The elitist TLBO algorithm method applied to solve the complex nonlinear selective harmonic equations[13]. The Harmonic minimization in cascaded multilevel converters was reduced using genetic algorithms in [14]. The design of Implementation small cost Multilevel with for novel DC link voltage inverter with enhancement harmonic profile and reducing harmonics in [15]. The Harmonic reduction in cascaded multilevel converters was reduced using particle swarm optimization (PSO) in [16]. Harmonic reduction in cascaded multilevel converters using BBO method is discussed in [17]. Biogeography based optimization (BBO) with antenna for Harmonic reduction in cascaded multilevel converters in [18].the reduction in cascaded multilevel converters based on BBO optimization for dissimilar economic load dispatch troubles in [19]. Biogeography Based (BBO) Algorithm implemented for Economic Analysis with Power organization in a very Small independent mixture Power System in [20].

From the analysis of literature review the optimization methods such as Newton Raphson(NR) technique WALSH, resulting theory of regular polynomials methods facing problems of extended computational moment, deadly iterative calculations and very difficult to give possible result for the modulation index range from 0 to 1.The other new optimization methods like fire fly algorithms and genetic algorithm methods need initialization of values such as social parameter, perceiving parameter, variation rate, restriction issue etc. From the analysis this paper represents the performance and comparison of the BBO algorithm with Newton Raphson technique in solving selective harmonic Elimination equations in single phase hybrid cascaded 31level inverter.

2. Problem Formation and SHE Equations in 31 level cascaded MLI

The block diagram of the proposed cascaded multilevel inverter is shown in fig.1. The proposed BBO optimization techniques is applied to solve the set of non-linear transcendental trigonometrically SHE equations of inverter. Adaptive MPPT is used to give maximum output from bidirectional DC-DC converter. The bidirectional DC-DC converter operates in buck and boost mode. The output power of DC-DC converter has been given to 31 Level cascaded MLI. Selective Harmonic Elimination method (SHEPWM) with is BBO optimization is applied to cascaded multilevel inverter to reduce THD of output voltage. The circuit diagram of the proposed 31 level inverter is shown in fig. 2.

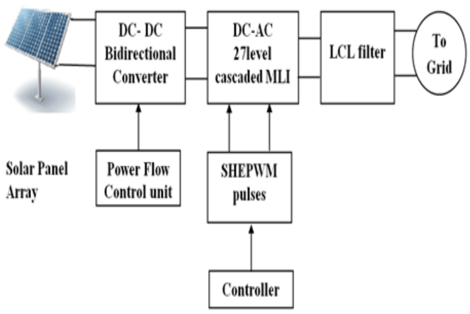


Figure 1 Block Diagram of Proposed 31 level Multilevel Inverter

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

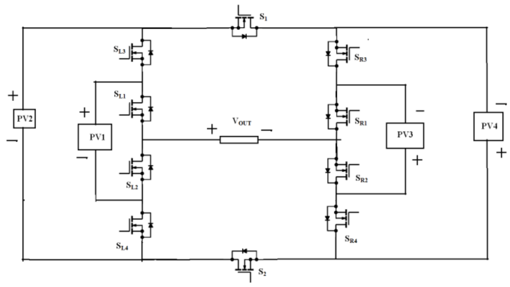


Figure2. Circuit diagram of Proposed Cascaded 31 level Inverter

Table1. 31 Level Inverter Output Voltages with switching states

S. No	SL1	SL2	SL3	SL4	SR1	SR2	SR3	SR4	S1	S2	VOUT
1	1	0	1	0	1	0	1	0	0	1	1V
2	1	0	1	0	0	1	1	0	0	1	2V
3	0	1	1	0	1	0	1	0	0	1	3V
4	0	1	1	0	0	1	1	0	0	1	4V
5	1	0	1	0	1	0	0	1	0	1	5V
6	1	0	1	0	0	1	0	1	0	1	6V
7	0	1	1	0	1	0	0	1	0	1	7V
8	0	1	1	0	0	1	0	1	0	1	8V
9	1	0	0	1	1	0	1	0	0	1	9V
10	1	0	0	1	0	1	1	0	0	1	10V
11	0	1	0	1	1	0	1	0	0	1	11V
12	0	1	0	1	0	1	1	0	0	1	12V
13	1	0	0	1	1	0	0	1	0	1	13V
14	1	0	0	1	0	1	0	1	0	1	14V
15	0	1	0	1	1	0	0	1	0	1	15V
16	1	0	1	0	1	0	1	0	1	0	0V
	0	1	0	1	0	1	0	1	0	1	0V
17	1	0	1	0	0	1	1	0	1	0	-15V
18	0	1	1	0	1	0	1	0	1	0	-14V
19	0	1	1	0	0	1	1	0	1	0	-13V
20	1	0	1	0	1	0	0	1	1	0	-12V
21	1	0	1	0	0	1	1	0	1	0	-11V
22	0	1	1	0	1	0	0	1	1	0	-10V
23	0	1	1	0	0	1	0	1	1	0	-9V
24	1	0	0	1	1	0	1	0	1	0	-8V
25	1	0	0	1	0	1	1	0	1	0	-7V
26	0	1	0	1	1	0	1	0	1	0	-6V
27	0	1	0	1	0	1	1	0	1	0	-5V
28	1	0	0	1	1	0	0	1	1	0	-4V
29	1	0	0	1	0	1	0	1	1	0	-3V
30	0	1	0	1	1	0	0	1	1	0	-2V
31	0	1	0	1	0	1	0	1	1	0	-1V

The proposed hybrid 31level inverter is exposed in Fig.2. This arrangement has 10 unidirectional power MOSFET and four dc voltage sources from solar panel. The power MOSFET switches of (SL1, SL2), (SL3, SL4), (SR1, SR2), and (SR3, SR4) turn on concurrently. The dc voltage of solar panel Vpv1, Vpv2, Vpv3, and vpv4 will be short-circuited if all switches turn on simultaneously. So

S1 and S2 should not turn on simultaneously. The hybrid 31 level topology with different potential voltage will be shown in fig.2.
The designed values of solar panel dc voltages of the proposed hybrid 31 level inverter as follows:
Vpv1 =Vdc
Vpv2 =5Vdc
Vpv3 =2Vdc
Vpv4 =10Vdc.
The proposed hybrid cascaded 31 level inverter can create all the positive and negative voltage levels from 0 to 15Vdc with each steps voltage Vdc is shown in table1.

As given in Fig.2, the staircase output voltage waveform will be induced by summing up of the generated output voltage of each solar cell, i.e.

$$\text{Vout} = V_{PV1} + V_{PV2} + V_{PV3} + V_{PV4} \quad (1)$$

The Fourier series of the symmetric quarter wave form of hybrid multilevel is given 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 output voltage of the first height equals to V1; the second height voltage equals to V2 and so on. By taking into consideration the waveform of Fig. 3, there are three feasible optimization methods to decrease the voltage THD: 1) step heights are optimized with equally spaced steps; 2) considering step spaces are equal to height; and 3) considering both heights and spaces.

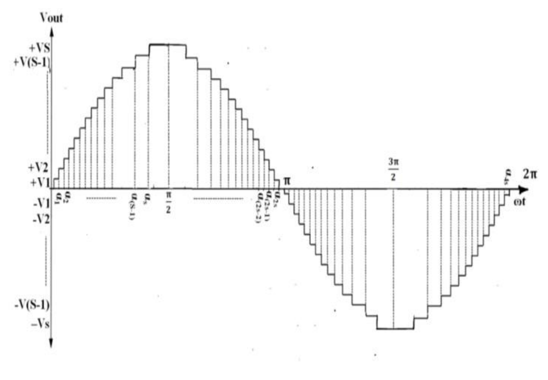


Figure 3. 31level multilevel inverter Output voltage waveform

The modulation indices of Selective harmonic elimination PWM is the ratio between modulating signal voltage Vout to the carrier signal voltage Vdc.

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

Where
Vout is the output voltage of 41level inverter and *Vdc* is the input dc sources of solar panel.

The unknown values from α1, α2, α3... and α15 from a single-phase system should be found by eliminating the lower order odd harmonics.
The four nonlinear equations to remove the lower order harmonics are as follows

$$[\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) + \cos(\alpha_4) + \cdots + \cos(\alpha_{15})] = M\frac{3\pi}{4} \quad (4a)$$

$$[\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3) + \cos(3\alpha_4) + \cdots + \cos(\alpha_{15})] = 0 \quad (4b)$$

$$[\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) + \cos(5\alpha_4) + \cdots + \cos(\alpha_{15})] = 0 \quad (4c)$$

$$[\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) + \cos(7\alpha_4) + \cdots + \cos(\alpha_{15})] = 0 \quad (4d)$$

3. Newton-Raphson Method

The Newton Raphson (NR) optimization technique is applied to calculate the roots of equations by applying successive approximation process by using MATLAB programming. Nonlinear set of equations are solved by using linearization procedure. Multivariable nonlinear systems having set of independent values arranged in matrix arrangement and the Newton's Raphson optimization method procedure is shown below:

1. Assume the set of first value for α with *j* =0

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

2. compute the value of

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

3. Linearize the equation 7 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

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

1. Find the $d\,\alpha^{j}$ *value* from 7 by

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

2. As updated the initial values

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

3. Repeat the iterative process, from equations 6 to 9 until $d\ \alpha^{j}$ is fulfilled to the preferred degree of accuracy and the obtained results must satisfy the following switching angle condition:

$$(\alpha_1, \alpha_{2,}\alpha_{3,}\alpha_4, \alpha_5, \alpha_{6,}\alpha_{7,}\alpha_{8,}\alpha_{9,}\alpha_{10,}\alpha_{11,}\alpha_{12,}\alpha_{13}, \alpha_{14}, \alpha_{15} < \frac{\pi}{2}) \qquad (10)$$

The obtained switching angles of the NR optimization algorithm are used to trigger the MOSFET device in cascaded multilevel inverter.NR optimization algorithm implemented in MATLAB.

4. Biogeography based optimization

Biogeography Based Optimization analyses the learning and sharing of animals and plants in iteration process. Mathematical models of biogeography Optimization mainly discuss with the kind of migration from one island to another, begin of species, and the annihilation of species .The Word Island is referred as habitat. HSI represents the greatest region for the biological species to endure. The next generation is formed in Biogeography Based Optimization based on the HSI rate, immigration and emigration rate that starts between neighbour habitats. The emigration rate and immigration rate are used to find out the best region for immigration and emigration. In addition a very new quality to low HSI results in raising the quality of solutions. During this complete process the outcome of poor results use the lot of good ones from the neighbour results.

4.1. BBO Algorithm

The algorithm has following steps as shown below

Step1. Initialize the switching angle values SIV = 15 for a 31 level inverter with BBO parameters of probability of habitat modification, probability of habitat mutation, mutation rate maximum value, immigration rate maximum value, emigration rate maximum value, every gene lower bound immigration probability, immigration probability per upper bound gene, numerical integration step size , maximum value of iteration for elitism parameter.

Step2. The habitat value given by

$$[\alpha_1, \alpha_{2,}\alpha_{3,}\alpha_4, \alpha_5, \alpha_6, \alpha_7, \alpha_8, \alpha_9, \alpha_{10}, \alpha_{11}\alpha_{12}, \alpha_{13,}\alpha_{14}, \alpha_{15}]$$

each habitat value satisfy the condition of switching angle <90. Each habitat value decides the problem for given variable.

Step3. Find the HSI for each habitat set for the values of given emigration rate μ, immigration rate λ. The values HSI shows the minimum value of THD level of the 31 level inverter given by

$$THD = \frac{\sqrt{\sum_{n=2}^{63}\left[\frac{1}{n}(\cos(n\alpha_1)+\cos(n\alpha_2)+\cdots+\cos(n\alpha_{15}))\right]^2}}{[\cos(\alpha_1)+\cos(\alpha_2)+\cos(\alpha_4)+\cdots+\cos(n\alpha_{15}))]} \qquad (11)$$

The generated switching angle given to multilevel inverter must generate the output waveform with lowest amount value of THD. The SIV HSI

$$SIV = [\alpha_1, \alpha_2, \alpha_{3,}\alpha_4, \alpha_5, \alpha_6, \alpha_7, \alpha_8, \alpha_9, \alpha_{10}, \alpha_{11}\alpha_{12}, \alpha_{13,}\alpha_{14}, \alpha_{15}] \qquad (12)$$

Step4. The elite habitats are recognized Based on the obtained THD value. Elite habitats of inverter output produce lesser THD value.

Step5. Probabilistically acts as migration process on the *SIVs* of each non elite habitat. The process to choose any *SIV* for migration process is specified in the next step.

Step6. Select the lower and upper value of immigration Rate. Estimate the value of λ and μ for each habitat set. Calculate the habitat and SIV to be selected for recently developed habitat after migration process.

Step7. Regulate the immigration rate value using the equation

$$\lambda_{scale} = \lambda_{lower} + (\lambda_{upper} - \lambda_{lower}) * \frac{\lambda(K) - \lambda_{minimum}}{\lambda_{maximum} - \lambda_{mimimum}} \qquad (13)$$

Step8. Mutation process is applied on the non-elite habitat. In mutation process change the chosen habitat by arbitrary habitat set.

Step9. Go to the step (3) for the next iteration to find the THD value. This loop can be completed after a predefined number of iterations.

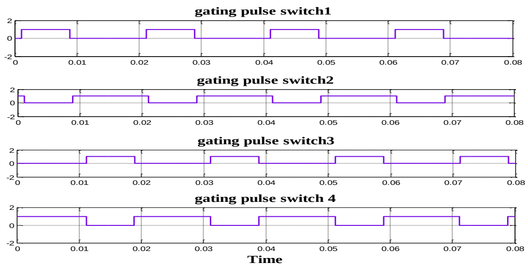
5. Simulation Result

The nonlinear transcendental SHE equations of single phase 31level inverter are solved by using planned techniques like NR method and BBO algorithm. The MATLAB code has been developed for the proposed two techniques and the THD & FFT are analysed using SIMULINK model.

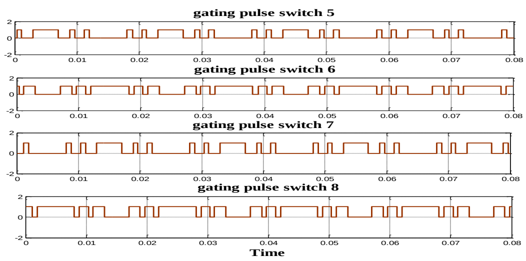
5.1 Newton Raphson Method

The planned NR method and BBO algorithm has been programmed and implemented in MATLAB algorithm for the modulation index value from 0.5 to 1 in each steps of 0.05.The switching angles from α1 to α15 with THD level for each value of modulation index are tabulated in Table1.

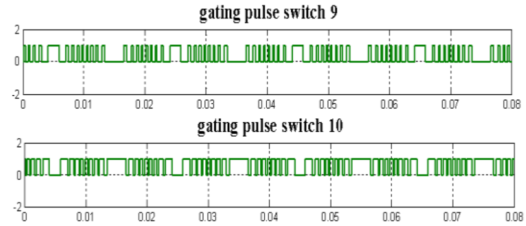
From the NR analysis no solution are obtained for the SHE equations set below the value 0.4 and above the value of 0.8. The gating pulses by SHEPWM technique is given to 10 switches as shown in fig.4 (a) to 4(c). Switching angle vs modulation index by NR method cascaded 31 level inerter is shown in fig.5. The 31 level output voltage by NR method is shown in fig 6.The average computational time required to run the NR algorithm for the used modulation index are 09.00 sec only. From the analysis NR method could not provide the best feasible solution for the modulation index values of 0.85, 0.9, 0.95 and 1.0.



(a)



(b)



(c)

Figure 4. (a) Gating pulses for switch SL1 to SL4 (b) gating pulses for switch SR1 to SR4 (c) gating pulses for switch S1 to S2

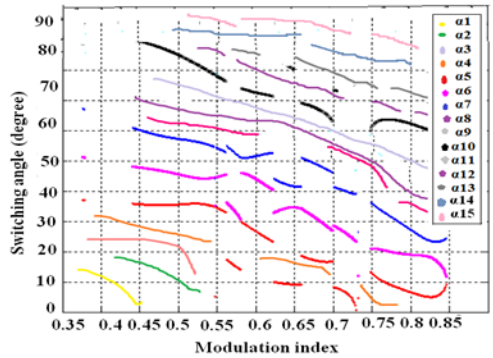


Figure5.switching angle vs modulation index by NR method

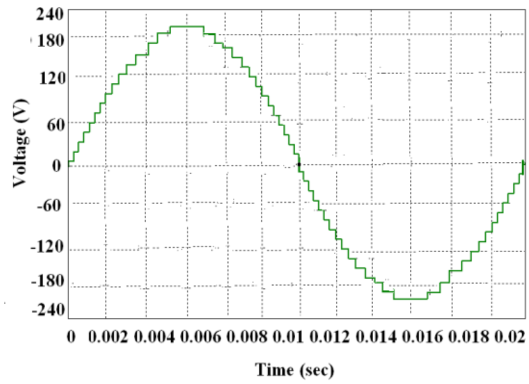


Figure 6 .31 level output voltage by NR method

Table 2. Switching angles in degrees & %THD

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

From the test result of Table 2, it is found that THD value by NR method gradually decreases as the modulation index increases and lower value of THD is 3.02% obtained at a modulation index of 0.8. FFT analysis modulation index value of 0.8 is shown in Fig. 7. From the test result the targeted order lower order harmonics says 3rd, 5th and 7th are reduce with greater value.

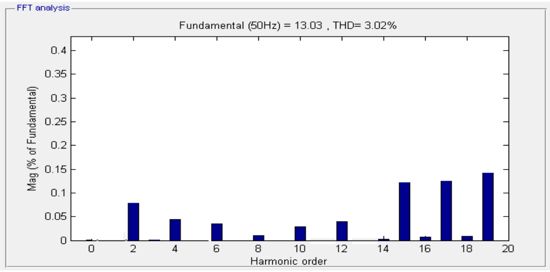


Figure 7. FFT analysis at MI 0.8

5.2 BBO Optimization Method

The new BBO algorithm is designed and implemented run in MATLAB programming with different modulation index of values from 0.5 to 1.0 in steps of 0.5. The obtained switching angles by solving the SHE equation set and the THD values are listed in Table 3. From the obtained results THD value decreases gradually as the modulation index is increased. The switching angle found in this proposed BBO algorithm with different modulation indices is given in fig.8. The THD value at the modulation indices at 0.95 is 6.95% shown in THD analysis Fig. 9. From the result obtained it is found all lower order of harmonics 3rd, 5th and 7th are reduced with THD value below 5% only. It is also further found that that the average time required for running the BBO code in MATLAB is 16.6 sec, but this BBO algorithm solved the SHE equation set for the modulation index of values 0.85, 0.9, 0.95 and 1.0.

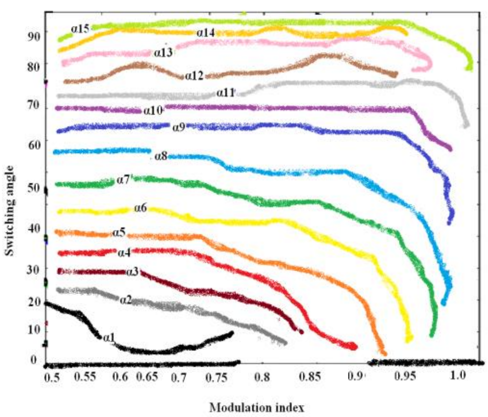


Figure8.switching angle vs modulation indices by BBO method

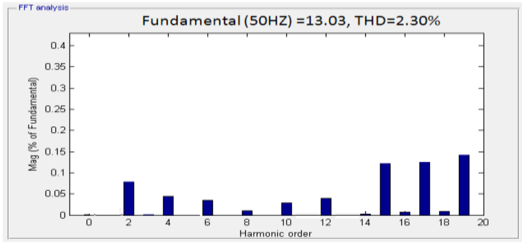


Figure9. FFT analysis at MI 0.95

6. Comparative analysis

The performance and Comparative analysis of %THD with different values of modulation index of both methods are shown in Table3. From the analysis it is concluded that the obtained %THD by Newton Raphson optimization method is very minimum but it does not give the greatest feasible solutions at the modulation indices of values above 0.85. The BBO algorithm has been effectively implemented to solve the Selective harmonic elimination equation set above modulation index of values 0.85 but Newton Raphson method could not solve above it. From the analysis it is observed that the implemented BBO algorithm in MATLAB solved the Selective harmonic elimination equation set at largest value of fundamental voltage with lower value of %THD at modulation indices 1.0 at 2.30%. It is also found that the time required for finding the THD for both optimization algorithms are less but Newton Raphson optimization method is very lower with the value of 07 sec. The flow chart for finding switching angle by NR method is shown below in fig.10. The flow chart for finding switching angle BBO method is shown below in fig.11.

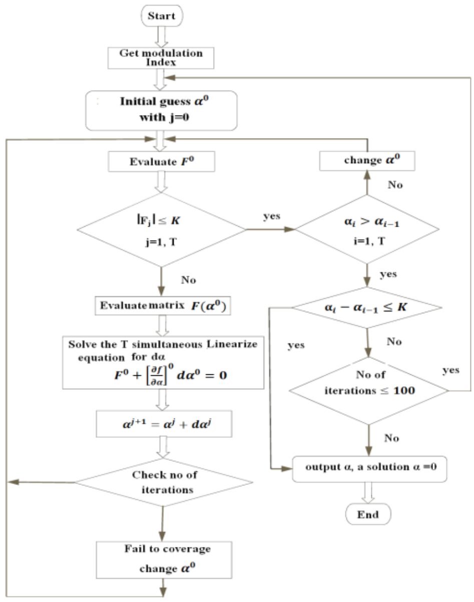


Figure 10. Flowchart for calculating α by NR

Table.3 Switching angles in degrees with %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

The figure 14 shows the comparison of THD level of both optimization methods, from this obtained result NR method could not give feasible solution above 0.85. But BBO method provides best solution above 0.85 modulation index. Fig. 15 presents the cost value of objective function with respect to the modulation index. It is observes that the BBO technique is used to find the optimum switching angles to eliminate the unwanted lower order odd harmonics.

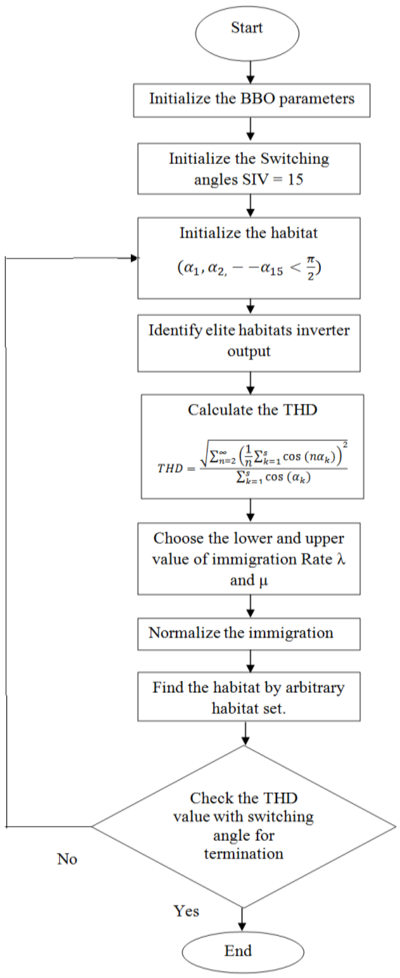
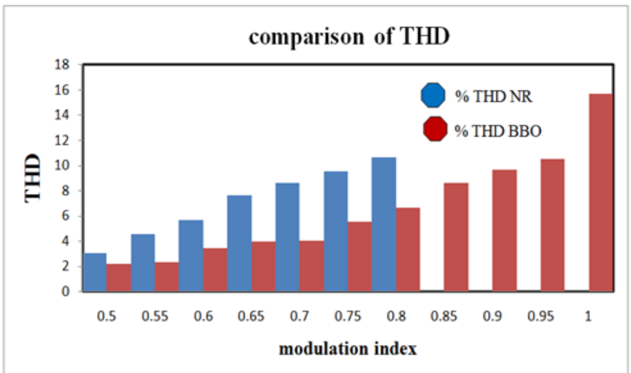


Figure 11. Flowchart for calculating α by BBO

Table.4. Comparative analysis of THD

MI	%THD NR	%THD BBO
1.0	No solutions	2.20
0.95		2.30
0.9		3.46
0.85		3.95
0.8	3.02	4.0
0.75	4.56	5.56
0.7	5.67	6.67
0.65	7.65	8.65
0.6	8.67	9.67
0.55	9.56	10.56
0.5	10.67	15.67



(a)

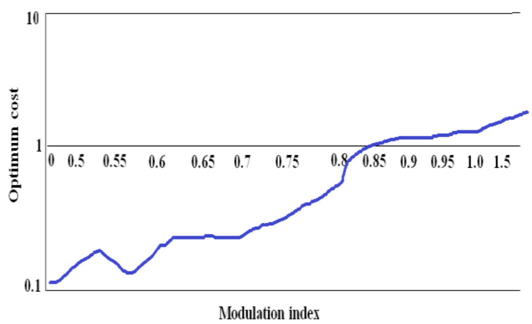
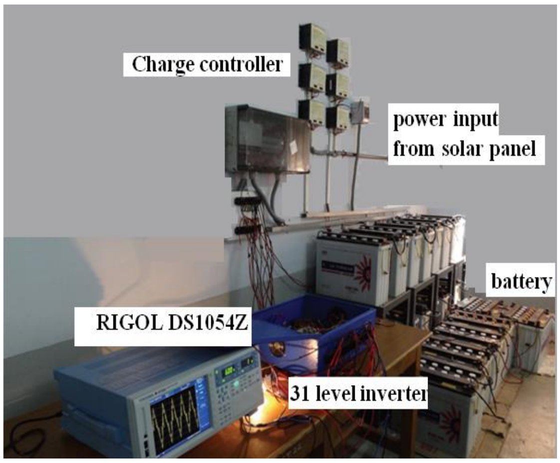


Figure 12. (a) Comparative analysis of THD (b) The optimum value of cost function versus Modulation index

7. Experimental Results

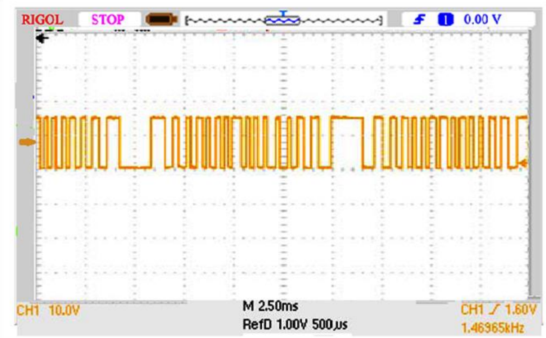
A grid connected 5kWp solar power plant is designed and developed for 15 stage 31 level CMLI with the SHEPWM algorithm. The solar power plant is designed to develop 230V AC supply for single phase supply. Each photovoltaic panel having the power rating of 250W with output voltage deviation of 25 to 30 volts depends on the light intensity and temperature variations. Five numbers of 100, 100Ah Exide battery backup was connected in series to get a nominal DC bus voltage of 100 volts. The implemented batteries are charged from the output voltage of PV panel unit using charging controlled circuit. Totally there are 4 sets of panel is used in hardware implementation to develop a voltage of 120 x 5=500Vp. This output power is given as input for bidirectional converter. DSP processor is used in this converter with two set of coupled inductor to drive 3 MOSFET (IRF840). Output of this DC-DC converter is given to input for Cascaded multilevel inverter. Gating pulses are generated using FPGA processor (Xilinx Spartan 6). Based on design the implemented SHEPWM algorithm in DSP (TMS320F28335) processor induces the switching angles to the cascaded hybrid multilevel inverter switches MOSFET (IRF840) through opto coupler driver circuit. The implemented complete hardware setup consists of charge controllers, battery backup and the proposed cascaded hybrid multilevel inverter. The variation of developed PV voltage in panel is measured each and every instant for getting maximum power. The comparison of THD is shown in fig.12 (a) and the optimum value of cost function versus Modulation index fig 12(b).Fig.13 (a) shows the PV plant installed and fig.13 (b) shows the control circuit of the proposed PV plant. Fig. 14 shows the Experimental results of output voltage of (a) SL1; (b) SL2; (c) SL3 (d) SL4 and (f) S1.Fig.15 (a) shows the output voltage of inverter. Fig.15 (b) shows power quality analyzer result of BBO optimization method.

(a)

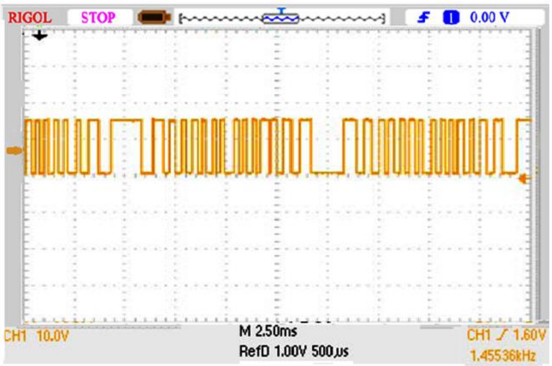


(b)

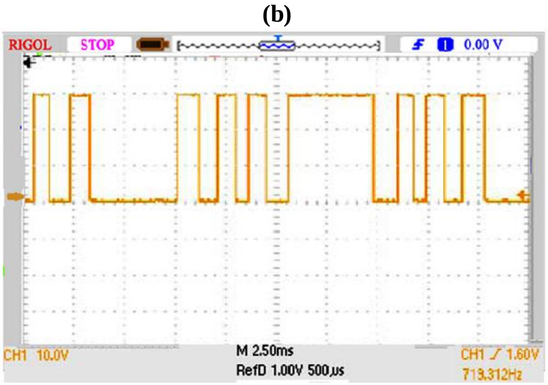
Figure13. (a) 5KW plant for 31 level inverter (b) control setup for 31 level inverter



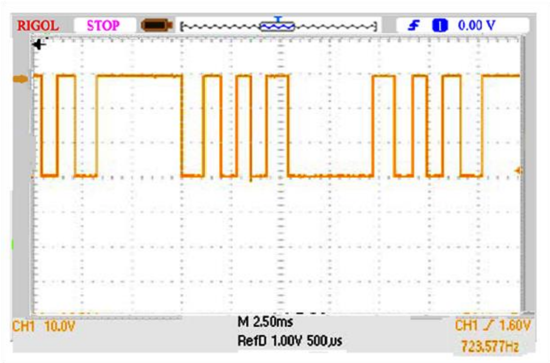
(a)



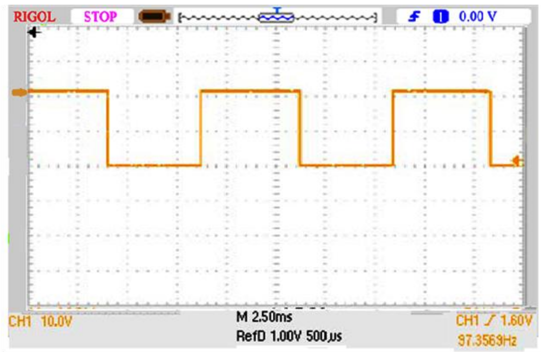
(b)



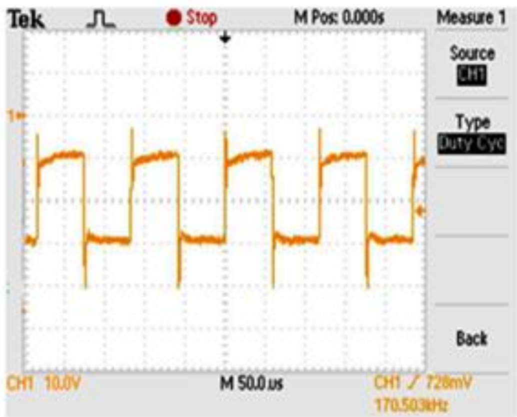
(c)



(d)

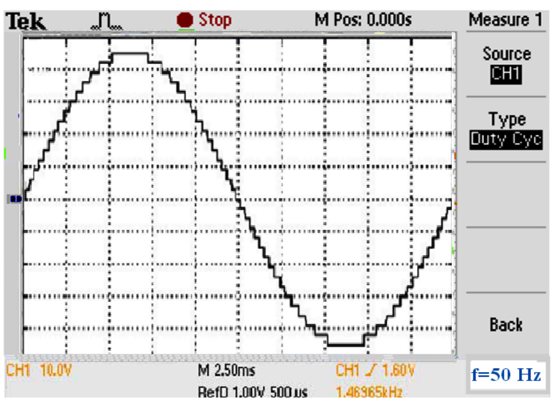


(e)

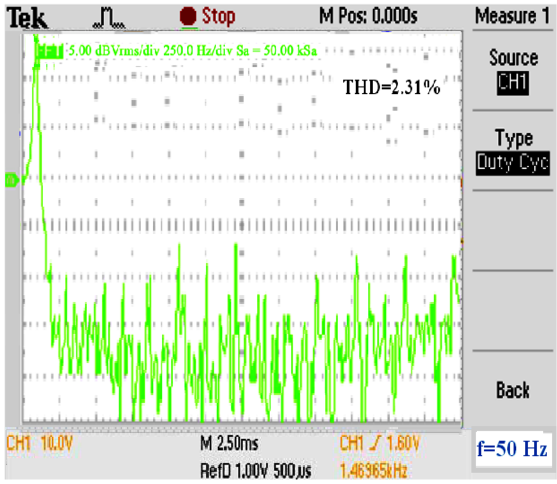


(f)

Figure 18. Experimental results: (a) Output voltage of (a) *SL*1; (b) *SL*2; (c) *SL*3 (d) *SL*4 ,(e) SL1 (and (f) *SL2*



(a)



(b)

Figure 15 (a). Hardware output voltage for 31 level inverter (b) FFT analyses at MI 0.95 for BBO method

Table 5.Analytical and Simulation values of THDs for MI= 0.95

Orders of THD	**Simulation results**	**Analytical results**
49th	4.04%	4.02%
63rd	2.30%	2.31%

The analytical and simulation values of THD have been computed up to 49th order and 63rd order is shown in Table 5. It can be seen that the analytical and simulation values of THD are very close agreement by validating the analytical results.

8. Conclusion

This research paper focused on the design and implementation of PV based 31 level cascaded MLI with performance and comparative analysis of Newton Raphson (NR) and BBO algorithms to solve the set of nonlinear transcendental SHE equations. From the analysis it is found that BBO algorithm is strong, efficient to solve the Selective Harmonic Elimination equations set for the modulation index value from 0.5 to 1.0. From the result Newton Raphson method could indices value of 0.85, 0.9, 0.95 and 1.0. The THD obtained by BBO algorithm is high at different values of not give the most excellent feasible solution at the values of modulation index but at the value of 1.0 the THD value is less at 2.20% only. The time required to find the switching angle with THD for NR method is very less say 07 sec but it has a big problem in solving modulation index higher value. But the BBO algorithm takes more computational time than NR method but it provides best feasible solutions above 0.85 Modulation index.

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