

Mitigation of Harmonics in Multilevel Inverter using Bee Algorithm

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Abstract—This paper presents an optimization technique for Cascaded H-Bridge inverter to eliminate the predominant harmonics. Cascaded H-Bridge Inverter (CHB) is suitable for renewable energy sources as it contains separate DC sources. The output voltage of the CHB inverter consists of predominant lower order harmonics. The objective is to eliminate the selected predominant harmonics and to minimize the Total Harmonic Distortion (THD) using the Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM) technique, by solving the nonlinear equations. The nonlinear equations are solved by using the Bee Algorithm (BA). The BA is a metaheuristic nature inspired algorithm, depending on the foraging behavior of honey bees. It has high accuracy than the all other algorithms. To authenticate the proposed work, several simulation studies have been carried out in MATLAB/SIMULINK.

Key words—Bee Algorithm (BA), Cascaded H-Bridge Inverter (CHB), Selective Harmonic Elimination PWM (SHE-PWM), Total Harmonic Distortion (THD).

I. INTRODUCTION

In present scenario the demand of high power electronic equipment is increased due to increased population and development of technology. The fossil fuels like coal, petroleum are decaying day by day so the power generation using fossil fuels is reducing consequently. And burning of these fuels causes the environmental effects such as emission of green house gases which leads to depletion of ozone layer, global warming and acid rains [1].

By considering these factors, it is important to generate the power using Renewable energy sources namely, solar, wind and tidal. Among these renewable energy sources *solar* energy is abandoned in nature, force of cost and pollution free and has become a demanding energy source. The solar energy is metamorphosing to electrical energy by employing photo voltaic modules. This is in the form of DC (Direct Current) it has to be converted into AC (Alternating Current), since most appliances in India are of AC. For this purpose the multilevel inverters are preferable. There are many applications [2] for multilevel inverters more specifically in High Voltage DC lines (HVDC) [4], Flexible AC Transmission System (FACTS)[3], Hybrid Electrical Vehicles (HEV) [9] and in Electrical Drives[5].

The major drawbacks of two level inverter is, unable to produce output waveform as nearer to sinusoidal wave thus it

contains harmonics in voltage and current. It leads to increase in filter size for high power applications. Hence cost will increase, this is not beneficiary. By considering this problem multilevel inverter (MLI) concept is introduced [2]. The output voltage of the MLI is stepped waveform thus it is closer to the sinusoidal waveform and harmonic content is less. The performance of MLI is improved by employing the switching control strategies [6], they are categorized as fundamental-frequency switching and High-frequency switching. The high frequency techniques are conventional PWM, carrier based SPWM and SVM (Space Vector Modulation). Due to high frequency the inverter size is less and transient response is faster. The fundamental- frequency switching techniques are Space Vector Control, Selective Harmonic Elimination PWM (SHE-PWM) and Optimal Minimization of THD (OMTHD). The major benefits of these methods are higher efficiency, lesser power loss and low cost of inverter.

To mitigate the selected harmonics SHE-PWM technique is used at fundamental frequency, the non-linear equations of this method specify the harmonics are to be solved to evaluate these switching angles, but it is difficult to solve the non linear equations. Since these equations may provide multiple solutions or no solution at specific modulation index (M) value. Newton-Raphson (N-R) method is one to solve these equations, it is an iterative method it requires a suitable initial guess and modulation index value at beginning for which solutions are occur [10]. All above mentioned methods do not convey optimum solutions for unachievable M's.

To overcome these difficulties evolutionary algorithms are introduced. These algorithms exhibits the capability to solve issues which doesn't have solution, simplicity, pliability and capable of self optimization [8]. The extensively used evolutionary algorithm is Genetic Algorithm (GA) and it is a simpler. From the literature survey it is observed that, The BA gives better results than the genetic algorithm [7]. In this paper, 5th & 7th harmonics are omitted by using Bee Algorithm (BA) for 7-level CHB inverter.

II. MULTILEVEL INVERTER

A. Multilevel Inverters

There are three configurations of multilevel inverters; they are:

1. Diode Clamped or Neutral Point multilevel inverter

2. Flying Capacitor multilevel inverter
3. Cascaded H-Bridge multilevel inverter

Among these multilevel inverters cascaded H-bridge inverter is used, hereunder the advantages of cascaded inverter: Modularity, flexibility, simplicity and less number of electronic components required. The 7-level cascaded multilevel inverter with exemplified output voltage waveform is depicted below in fig. 1(a) and (b). Cascaded multilevel inverter (CMLI) is the series connection of simple single phase inverters. A quasi square wave is produced by each H-Bridge of CMLI by phase shifting the switching time.

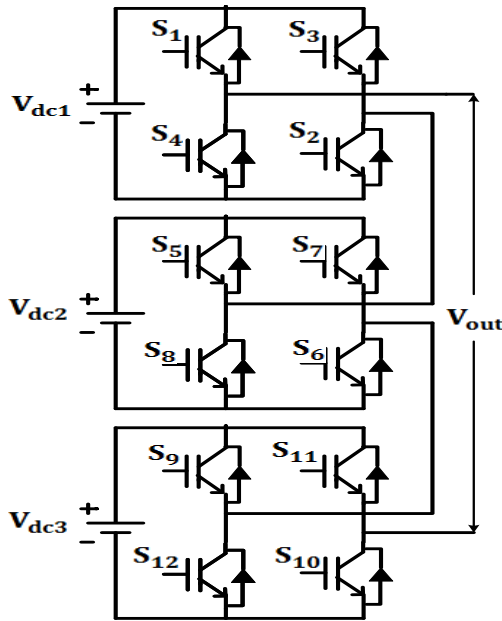


Fig. 1(a). 7-level Cascaded H-Bridge Inverter

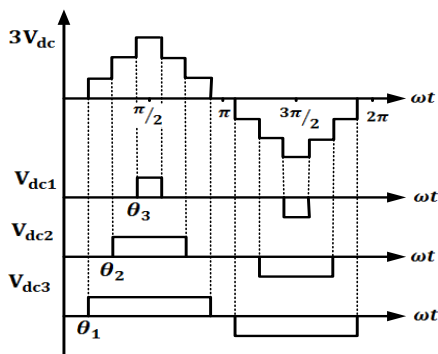


Fig. 1(b). 7-level Cascaded H-Bridge Inverter's output voltage

B. Selective Harmonic Elimination - Pulse Width Modulation Technique

Fig. 1(b) shows a 7-level inverter output voltage profile, consist of θ_1 , θ_2 , and θ_3 as variables. All dc sources are considered with equal amplitude, the output voltage in Fourier analysis is

$$V(\omega t) = \sum_{n=1}^{\infty} V_n \sin(n\omega t) \quad (1)$$

Where, V_n is n th harmonic magnitude. The limits for switching angles should be in between 0 and $\pi/2$. Due to quarter wave symmetry, even order harmonics are going to be zero. As a result, V_n becomes

$$V_n = \begin{cases} \frac{4V_{dc}}{n\pi} \sum_{i=1}^S \cos(n\theta_i) & \text{for odd} \\ 0 & \text{for even} \end{cases} \quad (2)$$

This SHE-PWM technique is one of the fundamental frequency pulse width modulation technique. The objective of this technique is to suppress predominant harmonics by satisfying the fundamental voltage. The 7-level CMLI is taken to suppress 5th and 7th harmonics. Triplen harmonics are not considered because they will become invisible in three phase loads. Below non linear equations are supplied to be solved to suppress the lower order harmonics.

$$V_1 = \frac{4V_{dc}}{\pi} [\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3)]$$

$$V_5 = \frac{4V_{dc}}{5\pi} [\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3)]$$

$$V_7 = \frac{4V_{dc}}{7\pi} [\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3)] \quad (3)$$

In eqn (3); V_5 and V_7 are made zero, to suppress 5th and 7th harmonics. Modulation index is needed to obtain dissimilar switching angles which is described as

$$M \triangleq \frac{V_1}{12V_{dc}/\pi} \quad (0 \leq M \leq 1) \quad (4)$$

To cover various values of V_1 , the M should be in the range of 0 & 1. Therefore by substituting eqn (4) in eqn (3), eqn (5) is derived. The following equations to be solved for the proposed inverter:

$$\begin{aligned} M &= \frac{1}{3} [\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3)] \\ 0 &= [\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3)] \\ 0 &= [\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3)] \end{aligned} \quad (5)$$

By solving these equations three switching angles are known and modulation index is calculated. Solving the above equations is difficult so Bee Algorithm is introduced and is explained briefly in the third section.

III. BEE ALGORITHM

Bee Algorithm is a metaheuristic algorithm, depending on food foraging behavior of honey bees. Which is a nature inspired algorithm. This algorithm can be modified and hybridized with other algorithms easily. The main advantages of BA are

- Flexibility, robustness and simple.
- Control parameters used in this are less compare to other algorithms.
- Implementation is easy by employing basic mathematical and logical operations.

A bee colony comprise three types of bees, they are

- Employed bees
- Onlooker bees and
- Scout bees

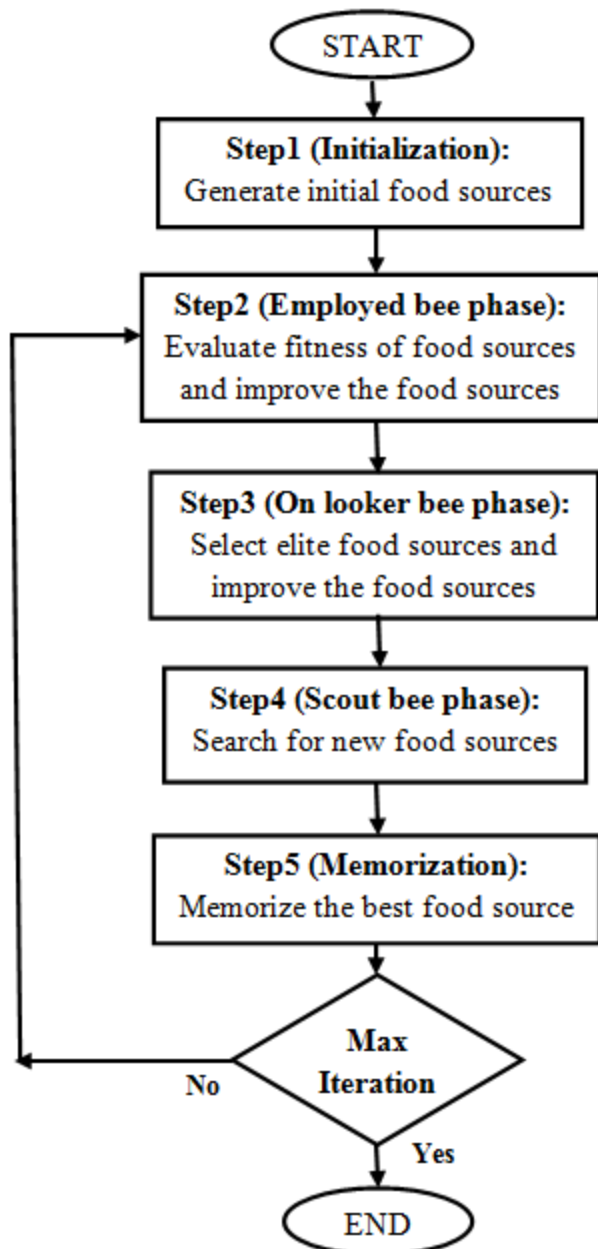


Fig.2. Flowchart of Bee algorithm

Employed bees, which will carry the information about amount of nectar and place, presented in a specific food sources. They share the information with onlooker bees by performing a waggle dance in hive, nectar quantity is decided by dance time of bee. Based on the nectar amount onlooker bees selected the food source. The more onlooker bees attracted to the food source which have additional nectar. Scout bee look for new food sources in search area.

In this evolutionary algorithm, feasible solutions are nothing but food sources. Food source is a D -dimensional vector, here D = optimization variable number. The nectar quantity in a food source will decide the fitness value. The flowchart of BA is shown in Fig.2.

Step1: Initial food sources are generated randomly. These are half of the Bee colony.

Step2: Only one employed bee is sent to each food source so number of employed bees is equal to number of food sources. Employed bees are sent to find out fitness value and determine the nectar amount. The employed bee saved solution in her memory and modifies the solution by searching in their vicinity food sources if its fitness value is better than the prior one.

Step3: Another half of the bee colony is called onlooker bees which select the best food source depending on probability. The food sources having more nectar amount will attract the more onlooker bees. The onlooker bees will upgrade the solution resemble to employed bee and computes fitness value and saves the new solution if its fitness is improved than the prior one.

Step4: The food sources which are unimproved for the number of iterations considered as abandoned. Scout bee is sent to find out the new food sources and abandoned solution is replaced with it.

Step5: Based on maximum nectar, the best food source is memorized.

If best food source is not met, the algorithm continues from step2 for the second iteration.

IV. IMPLEMENTATION

Bee Algorithm program is written in MATLAB software to obtain the switching angles. The size of the bee colony is 100 and 200 cycles for each run. Using Fitness function quality of the solution is evaluated from all the proposed solutions to problem. And evaluate the good single solution in a current population.

a. Fitness function of BA

The formulated fitness function with its limitations is given below:

$$f = \min_{\theta_i} \left\{ \left(100 \frac{V_1^* - V_1}{V_1^*} \right)^4 + \sum_{s=2}^S \frac{1}{h_s} \left(50 \frac{V_{h_s}}{V_1} \right)^2 \right\} \quad i=1, 2, \dots, S \quad (6)$$

Subjected to

$$0 \leq \theta_i \leq \pi/2 \quad (7)$$

Where V_1^* is desired fundamental voltage, V_1 is calculated from eqn (3), S is the number of switching angles and h_s is feasible harmonic voltage. e.g. $h_2 = 5$ and $h_3 = 7$. According to IEEE 519 standard it needs to restrict magnitude of harmonic content to 3% of fundamental component. The first expression of eqn(6) is subjected to a penalty of power 4, if it break the limit beyond 1%. The second term of eqn(6) omit the harmonics under 2% of fundamental, if it exceeds this limit, second term subjected to a penalty factor of power 2. Every harmonic proportion is adjusted by its inverse of harmonic order. Thus the lower order harmonics are reduced efficiently.

b. Solving of Bee Algorithm

Step1: Initialize the parameters

$$\theta_i, \quad i = 1, 2, \dots, N$$

Step2: Compute the theta values.

Step3: Cycle = 1

Step4: Repeat

Step5: Generate new solution V_i using the equation below for the employed bees and evaluate them.

$$V_{ij} = \theta_{ij} + \phi_{ij}(\theta_{ij} - \theta_{kj}) \quad (8)$$

Here $k \in \{1, 2, \dots, N\}$,

$j \in \{1, 2, \dots, D\}$

Φ is a random number between $[-1, 1]$

D = Number of optimization parameters

Step6: Greedy selection process is applied.

Step7: Compute the probability (P_i) for θ_i solutions.

$$P_i = \frac{fit_i}{\sum_{i=1}^{100} fit_i} \quad (9)$$

Here,

$$fit_i = \begin{cases} \frac{1}{1+fit_i} & \text{if } fit_i \geq 0 \\ 1 + \text{abs}(fit_i) & \text{if } fit_i < 0 \end{cases} \quad (10)$$

Step 8: Generate the new solution (V_i) from θ_i for onlooker bees, which are selected based on P_i and estimate them.

Step 9: Greedy selection process applied for onlooker bees.

Step 10: The forsaken solution is determined for the scout bee.

If it exists, a new randomly generated solution is replaced by it.

$$\theta_i^j = \theta_{min}^j + \text{rand}[0,1](\theta_{max}^j - \theta_{min}^j) \quad (11)$$

Step 11: Best solution achieved up to now is memorized.

Step 12: Cycle = Cycle+1

Step 13: Until cycle = Maximum Cycle Number (MCN).

By utilizing the above steps bee algorithm program is written in MATLAB script, and run for several times. The best solution is selected based on the minimum fitness value.

V. SIMULATION RESULTS

The simulation of 7-level cascaded H-Bridge inverter carried out in MATLAB software. The input DC voltage for three bridges is considered equal in magnitude. The output voltage frequency is 50Hz. The optimizing switching angles obtained from the Bee algorithm at a Modulation index of 0.5 are shown in table with their harmonic content percentage and THD.

Table I. Switching angles with THD and Harmonic component

θ_1	θ_2	θ_3	Fitness Value	THD (%)	Harmonics (%)	
					5 th	7 th
38.0339	53.8891	73.2591	1.0000	14.08	9.05	1.78
17.5087	49.7422	86.2649	1.0000	18.03	9.69	1.52
35.1044	57.8861	71.3817	0.4201	13.69	7.89	2.54
22.1481	52.351	82.3206	0.4042	14.03	6.76	0.08
33.0218	55.65	75.3932	0.3698	12.72	3.86	0.39

From the above tabular it is noted that less THD is obtained at minimum fitness function and corresponding switching angles are taken into consideration since the lower order harmonics 5th and 7th are minimized.

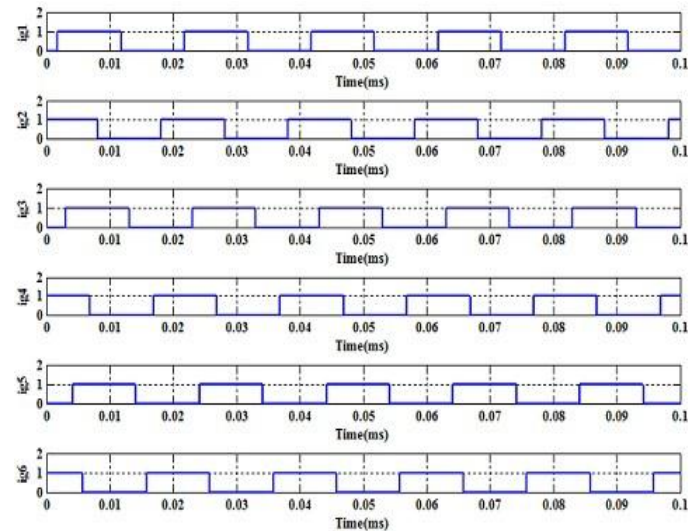


Fig.3. Gating pulses waveform of 7-level cascaded H-Bridge multilevel inverter

The above Fig.3 shows 7-level CHB inverter's gating pulses. The first two signals ig_1 & ig_2 are given to the first H-bridge's positive and negative legs. The gating signals ig_3 & ig_4 are given to the second H-bridge's positive and negative legs. The remaining signals ig_5 & ig_6 are given to the third H-bridge legs respectively. These gating pulses are for the better mentioned values at 0.5 modulation index.

The output phase voltage waveform is shown in figure.4

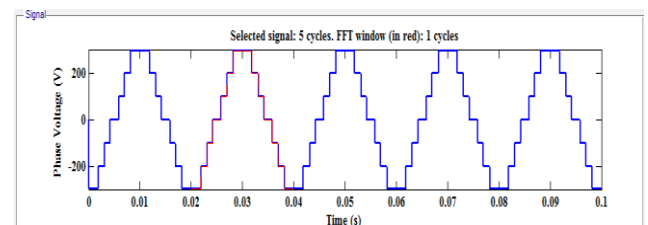


Fig.4. Output phase voltage waveform of 7-level cascaded inverter

The FFT analysis of cascaded inverter is shown in below figure.5 for which THD is minimum.

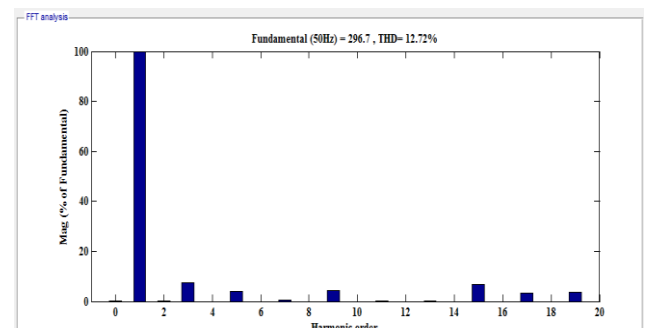


Fig.5. FFT analysis of 7-level cascaded inverter for THD calculation

VI. CONCLUSION

The selective harmonic elimination technique is applied to the CMLI to obtain the elimination of selected harmonics. Bee algorithm is applied to solve the non linear equations and to attain the switching angles. The simulation results show that 5th harmonic is reduced to 3.86% and 7th harmonic is eliminated, and also other lower order harmonics 11th & 13th are eliminated. The THD is around 12%, with RL load of $R=10\Omega$ and $L=10\text{mH}$. It can be concluded that the selected harmonics are mitigated and results obtained by BA are attained.

VII. FUTURE SCOPE

This work can be further extended to eliminate the predominant harmonics in cascaded H-bridge inverter at different Modulation indexes and performance will be verified.

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