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Selective Harmonics Elimination Of Cascaded Multilevel Inverter Using Genetic Algorithm

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***Abstract*— In this paper, a genetic algorithm (GA) optimization technique is applied to cascaded multilevel inverter to determine optimum switching angles for eliminating some lower order harmonics also minimize the total harmonics distortion while maintaining the required fundamental voltage. This technique can he applied to multilevel inverters with any number of levels; as an example in this paper, a 15-level inverter is considered, and the optimum switching angles are calculated offline to eliminate 5th, 7th and 11th harmonics. Then, these angles are used in MATLAB similink to validate the results.**

***Index Terms*— Genetic Algorithm, Multilevel Inverter, Selective Harmonics Elimination (SHE), Total Harmonic Distortion (%THD).**

I. Introduction

Several topologies for Selective harmonics elimination of multilevel inverts have been proposed over the year. One important application of multilevel converters is focused on medium and high-power conversion[1][2]. Now a days, there exist three commercial topologies of multilevel voltage-source inverters: neutral point clamped (NPC), cascaded H-bridge (CHB), and flying capacitors (FCs)[3][4]. Among these inverter topologies, cascaded multilevel inverter reaches the higher output voltage and power levels and the higher reliability due to its modular topology. Battery and renewable energy like fuel cell, solar cell etc also can be used as a DC unequal voltage sources[5].

To eliminate harmonics, improve performance and output quality, several methods are suggest. Those are[6], sinusoidal pulse width modulation[7], selective harmonic elimination PWM[8], space-vector modulation[9][10], and optimal minimization of Total Harmonic Distortion.

It is possible to eliminate selective harmonics and minimization of total harmonics distortion by solving the non linear equation of multilevel inverter. Several iterative numerical techniques have been suggested like Newton-Raphson method, Bisection method, Polynomial theory, Resultant theory, Particle swarm optimization etc are implemented to solving the non linear equations[11]. The Newton–Raphson (N–R) method is commonly used to solve the non linear SHE equation [12]. The disadvantage of this methods is, it depend on that initial guess and divergence problems are likely to occur for large numbers of inverter levels.

In this paper Selective Harmonics Elimination technique is used to eliminate the lower order harmonics like fifth, seventh, eleventh, thirteenth etc. and minimize the THD, while maintaining the required fundamental voltage. The transcendental non-linear equations are solved using Genetic Algorithm[13]. The calculated switching angles are used to trigger switching devices of fifteen level cascaded multilevel inverter which is modeled in MATLAB and harmonic analysis is carried out.

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II. Cascaded Multilevel Inverter

In this paper a three phase fifteen level cascaded multilevel inverter is considered. Fig. 1 shows the structure of a single phase of this inverter.

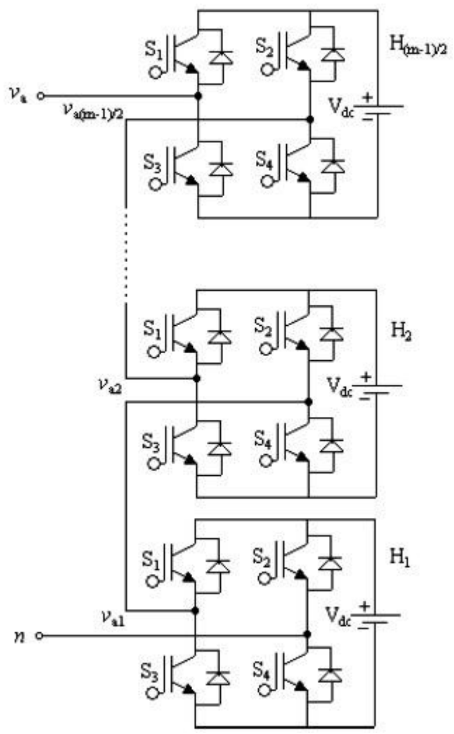

Fig. 1. Single-phase configuration of a n level multilevel inverter.

It consists of seven simple H-bridge inverters, each can produce three output voltages +Vdc, 0 or –Vdc by connecting the dc source, to the ac output side by different combinations of the four switches, S1, S2, S3 and S4. The total ac output voltage waveform is the sum of all the individual inverter outputs[17]. Thus the whole inverter can produce fifteen voltage levels. Fig.2 shows an odd-symmetric output waveform of each phase of an fifteen level cascaded multilevel inverter .

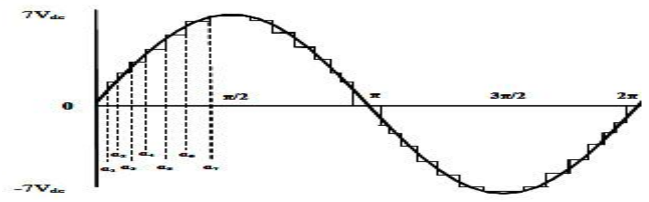

Fig. 2. Output voltage waveform of a 15-level multilevel inverter.

The output voltage waveform V(t) of multilevel inverter, shown in Fig. 2 can be expressed in Fourier series as,

$$V(t) = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \qquad (1)$$

Due odd quarter wave symmetry of the output voltage waveform the even harmonics are absent ($a_n = 0$) and only odd harmonics are present [18]. The amplitude of the n^{th} harmonic can be expressed with the first quadrant switching angles i.e. α_1, α_2, ... , α_m as follows:

$$b_n = (4V_{dc}/n\pi) \sum_{n=1}^{\infty} \sin \omega t \qquad (2)$$

and,

$$0 < \alpha_1 < \alpha_2 < \cdots \alpha_m < \frac{\pi}{2} \qquad (3)$$

III. Selective Harmonics Elimination for Cascade Multilevel Inverter

As a fifteen level cascade multilevel inverter there are seven dc sources per phase and seven angles as degrees of freedom. Hence, it is possible to satisfy fundamental component and to eliminate four lower order of harmonics i.e 5^{th}, 7^{th}, 11^{th} and 13^{th} respectively. It is not required to eliminate triplen harmonics because they will be eliminated automatically in the line to line output voltage in the Y connection.

For an fifteen-level inverter, the SHE equations are,

$\cos(a_1) + \cos(a_2) + \ldots\ldots + \cos(a_7) = 7M$
$\cos(5a_1) + \cos(5a_2) + \ldots\ldots + \cos(5a_7) = 0$
$\cos(7a_1) + \cos(7a_2) + \ldots\ldots + \cos(7a_7) = 0$
$\cos(11a_1) + \cos(11a_2) + \ldots\ldots + \cos(11a_7) = 0$
$\cos(13a_1) + \cos(13a_2) + \ldots\ldots + \cos(13a_7) = 0$
.
.
.
$\cos(na_1) + \cos(na_2) + \ldots\ldots + \cos(na_7) =$ □ (4)

where M is modulation index and defined as,

$$M = \pi V_1 / 4V_{dc} \qquad (0 \le M \le 1) \qquad (5)$$

Equations set (4) are called non linear transcendental trigonometric equations. The main challenge associated with SHE technique is to obtain the analytical solutions of non linear transcendental trigonometric equations which naturally exhibit multiple solutions and during some range of M (5) does not have any feasible solution. However, in some drive application it is required to operate during whole range of M. Hence it is necessary to calculate α_1, α_2, α_3, α_4, α_5, α_6 and α_7 such that equation (4) is satisfied. This paper deals with the problem of finding solution during whole range of M from 0 to 1. Genetic algorithm (GA) is applied to the given problem to find solution. These optimum switching angles are used to trigger semiconductor switches for a particular modulation index.

IV. Genetic Algorithm

As mentioned in Section III, SHE equations are non linear transcendental in nature. In order to solve these equations modern stochastic technique like Genetic Algorithm (GA) is used to calculate switching angles during whole range of Modulation Index (M) from 0.1 to 1. Genetic Algorithm (GA) replaces the difficulty associated in numerical algorithms, because of its intrinsic ability to begin searching randomly, handle large amount data simultaneously and "jump" out of local optimum automatically.

This GA has advantage of less storage requirement, inherently faster than binary GA. In GA all decision variables are expressed as real numbers. The complete discussion of GA is found in [13]-[16]. The flow chart in Fig. 3 represents overview of process of GA and it is briefly explained in this section.

A. Chromosome Representation

In this study, each chromosome is taken as a possible solution for the problem, then each chromosome is developed based on single dimensional arrays with a length of S, where S is the number of angles.

B. Initialization of the Population

For any GA it is necessary to initialize the population. The most common method is to randomly generate solutions for the entire population. All of the experiments discussed in this paper employ a completely random seeding of the initial population. Population size depends only on the nature of the problem and it must achieve a balance between the time complexity (consume for computing the fitness function and the genetic operators) and the search space measure. In this paper, the population size is set at 200.

C. Reproduction

The degree of conformity of each object is calculated and an individual is reproduced under a fixed rule depending on the degree of conformity. Here, some individuals with a low degree of conformity will be screened, while individuals with a high degree of conformity will increase.

D. Cross Over

New individuals are generated by the method of intersection that has been set up.

E. Mutation

This is performed by an operation determined by the installed mutation probability or mutation, and then a new individual is generated.

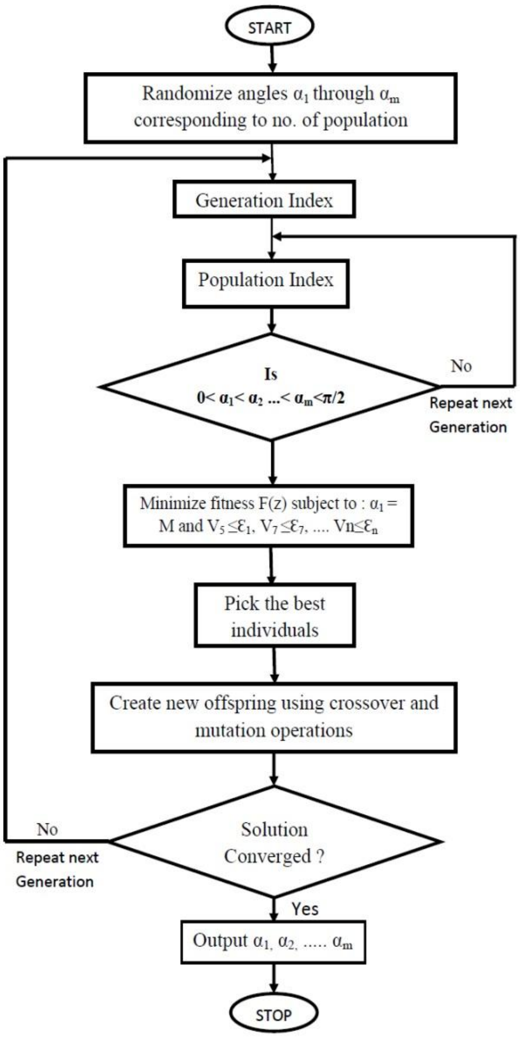

Fig. 3. Flow chart of Genetic Algorithm

F. Evaluation Fitness

The most important part of the GA to evaluate the fitness function. Minimization of specified harmonics and THD is the main objective of this study. The fitness function is related to the harmonics. In this paper, the lower order harmonics like 5^{th}, 7^{th}, 11^{th}, 13^{th} and THD at the output voltage has to be minimize. The fitness function is formulated as:

$$f(z)= k_1|h_1- M|^2 + k_2|h_5-\square_1|^2 +k_3 |h_7-\square_2|^2 +k_4 |h_{11}-\square_3|^2 +k_5 |h_{13}-\square_4|^2 + THD_1 \quad (6)$$

where are z is the set of the seven switching angles i.e. $[\alpha_1\ \alpha_2\ \alpha_3\ \alpha_4\ \alpha_5\ \alpha_6\ \alpha_7]$, h_1 is fundamental component, h_5, h_7, h_{11}, and h_{13} are the 5^{th}, 7^{th}, 11^{th}, 13^{th} order voltage harmonics respectively and M is themodulation index and THD_1 is the rest of component up to h_{31}, k_1, k_2, k_3, k_4 and k_5 are the co-efficient of GA. Using this formulation (6), the fitness value is calculated for each chromosome

V. Simulation Result and Harmonics Analysis

The offline computed switching angles using GA are shown in Table. I. It is observed that the developed genetic algorithm runs for all of the range of modulation index (M) that is 0.1 to 1 for minimizing harmonics and least %THD.

Table. I.
Switching angles at Various modulation Index (M)

M	α_1	α_2	α_3	α_4	α_5	α_6	α_7
0.1	0.612	0.789	0.977	1.137	1.355	1.562	1.563
0.2	0.617	0.785	0.974	1.132	1.35	1.458	1.564
0.3	0.609	0.781	0.971	1.123	1.342	1.459	1.562
0.4	0.318	0.592	0.893	1.025	1.17	1.457	1.562
0.5	0.35	0.577	0.849	0.962	1.079	1.214	1.554
0.6	0.103	0.528	0.675	0.808	1.033	1.208	1.476
0.7	0.093	0.314	0.483	0.65	0.856	1.029	1.222
0;8	0.079	0.295	0.462	0.626	0.851	1.002	1.184
0.9	0.04	0.125	0.179	0.314	0.436	0.566	0.736
1.0	0.02	0.125	0.177	0.3	0.427	0.555	0.716

The simulation result of the switching patterns with varying modulation index (M) considering seven dc sources is shown in Fig. 4, so as to produce minimum voltage THD. In this case, the lower order harmonics, i.e. 5th, 7th, 11th and 13th harmonics are eliminated, where as higher order harmonics are optimized to contribute minimum voltage THD. THD (%) up to 31st order of output voltage between varying modulation index is shown in Fig. 5.

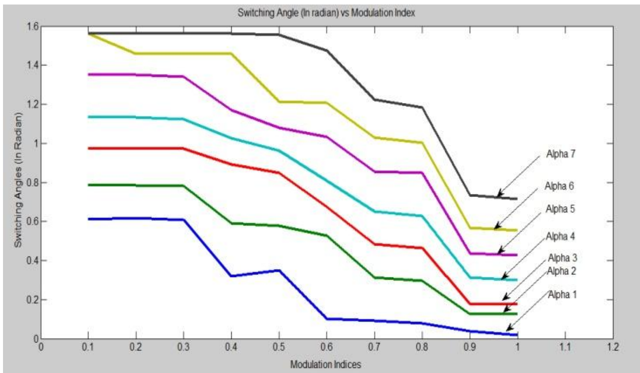

Fig. 4. Modulation Index vs. Calculated switching using GA

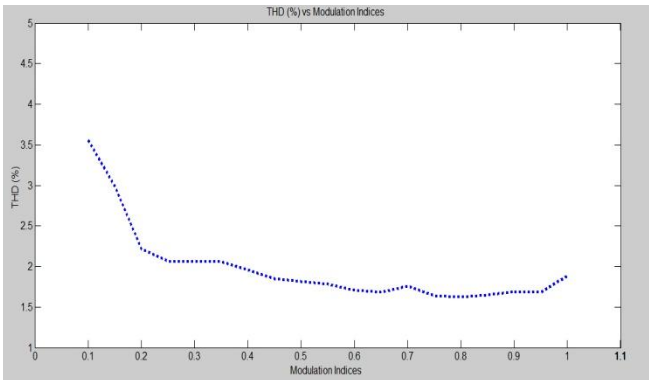

Fig. 5. THD vs. Modulation Index

To validate the proposed topology and theory, MATLAB model of the 3-ph, 15 level cascaded H-bridge multilevel inverter has been built using the GTO as the switching devices shown in Fig. 6. Subsystem for switching is shown in fig 7. Seven DC source voltages are applied per phase which is equal to 25 volts. Hence finally the output AC voltage for each phase is equal to 175 volts.

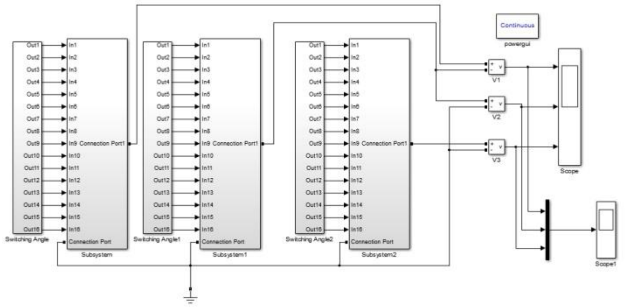

Fig. 6. MATLAB Modeling of 3ph 15 Level Cascade Multilevel Inverter

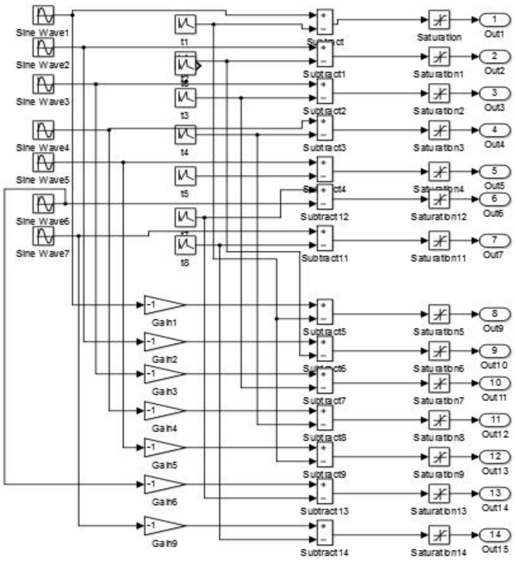

Fig. 7. Subsystem for switching

Simulink results for an fifteen-level inverter operating with equal DC sources are shown in fig. 8 with the voltage values indicated. Because of Modulation index 0.8 the output voltage is approximate (175*0.8)= 140V

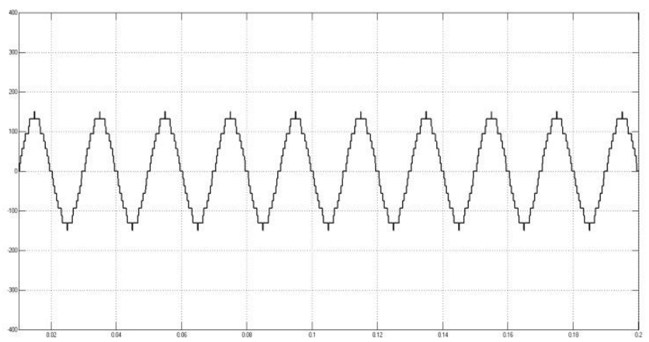

Fig.8. Per Phase Output Voltage waveform Of Inverter at M = 0.8

The frequency spectrum for the steady voltage waveform of the simulation result, is shown in Fig. 9, where it can be noticed that the target harmonics were minimized with a THD of 2.20%. 5th and 7th harmonic was minimize less than 0.8%, 11th and 13th harmonics was minimized less than 1%. Also it is noticeable that due to odd symmetric waveform the even harmonics are vanished and due to three phase star connection, the triplen harmonics was also vanished.

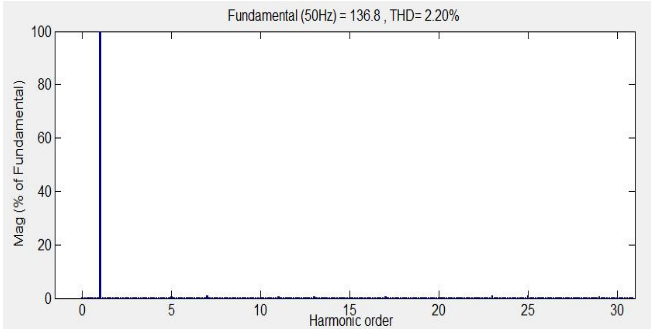

Fig. 9. FFT analysis of Output Line-Line Voltage of the Inverter

VI. CONCLUSION

A Genetic Algorithm based optimization technique is proposed to minimize the selective harmonics as well as overall THD of the output voltage of a multilevel inverter. With the help of the developed algorithm, the switching angles are calculated from the non-linear transcendental equations of selective harmonics elimination problem to minimize the THD from the output voltage waveform. The method is applied to the fifteen level multilevel inverter with seven equal dc sources. While minimizing the overall voltage THD, lower order harmonics like 5th, 7th, 11th and 13th are eliminated and higher-order harmonics are optimized in case of fundamental switching.

The advantage of this method is that, besides eliminating the targeted order of harmonics, it also optimize the other order of harmonics to minimize the objective function f(z). Moreover, the overall voltage THD is minimized without adding of additional switches. The proposed topology also can be applied to the multilevel inverter supplied from different dc sources. The proposed technique is simple and the cost of implementation will not differ much from that of a standard multilevel inverter. The simulated results also can be validate through suitable experiments.

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