Harmonic Analysis of Photovoltaic-Fed Symmetric Multilevel Inverter using Modified Artificial Neural Network

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Abstract: This paper presents a control scheme to eliminate the harmonics in a symmetric cascaded multilevel inverter- connected grid system. It is controlled by modified artificial neural networks and genetic algorithm. The solar photovoltaic acts as input source and the output power is synchronized with grid. The switching angles are acquired such that the fundamental component of output voltage is kept steady and lower- order harmonics are limited or removed. The equipped system is coordinated with sun-oriented photovoltaic framework to decrease the harmonics. Also, this work's target is to achieve the proposed idea using genetic algorithm strategies to get the ideal switching angles required for the inverter switches. The modelling of the solar panel contributes on the generation of energy. The proposed combination offers an important outcome to generate the minimal total harmonic distortion and furthermore empowers the inverter to work under unhinged photo photovoltaic conditions exhaustively.

Keywords: Power Generation, Multilevel Inverter(MLI), Symmetric MLI (SMLI), Modified Artificial Neural Networks (MANN), Genetic Algorithm(GA)

1 Introduction

The Photovoltaic (PV) power generation occupies an important role in the advancement of Distributed Generation Scheme Systems(DGSs), Micro grids (MGs) and Flexible AC Transmission system(FACTs). The advancement in the field of power electronics with high power ratings has introduced revolutionized growth in the above areas. The concept of the transformerless PV grid-connected inverter has been proposed to obtain cost effective, reduced size with increased reliability. The idea of Multilevel Inverter (MLI) is to use the available direct current (dc) sources to generate stepped output voltage clean sinusoidal waveform [1]. This reduces the lower order harmonics and hence the reduction in Total Harmonic Distortion (THD) [2][3]. The input sources used are generally battery, PV system, rectified output from wind generation or a capacitor. The disadvantage of conventional MLI topologies is due to the presence of large number of switching devices, since each device requires a separate driver circuit[4]. The conventional cascaded Asymmetric MLI(AMLI) or Symmetric

MLI(SMLI) topology requires separate dc sources for every stepped output[6].The number of semiconductor switches required for m level is 2(m-1) and the number of dc sources are (m -1)/2. As per IEEE 519-1992 standards the permissible harmonics limits should be within 5% in case of THD and within 3% in individual harmonics.

This paper proposes a topology of MLI with equal dc sources. The Genetic Algorithm (GA) based switching scheme imitates the predefined parameter of a sinewave (i.e amplitude and frequency) or grid voltage Vg. Using this technique of switching the harmonics factor is reduced when compared with classical methods. The power output from MLI is filtered using reduced size of inductor if further reduction in harmonics is required. This output is fed into the grid power system after synchronization. The simulation results are compared with previous results. The proposed technique of grid interfacing uses MANN and GA to find the suitable switching angles to maintain the voltage of inverter and grid.

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A number of studies were carried out to prove the ability to optimize solar-based multilevel inverter configurations of renewable energy systems in order to maximize performance while minimizing cost.

The over modulation schemes [6, 8, 10, 11] uses the fundamental geometrical understanding which is stated in [3]. However, these methods change from each other in the way they actualize the over modulation switching strategy. The method presented in [6] is the quickest one which depends on the processing time. It leads to distorted current and flux waveforms due to the significant harmonic content in the voltage waveform. The technique depicted in [10] utilizes computationally intensive algorithms to accomplish over modulation. As an alternate to pre-process the voltage vector, approximated piecewise linearized equations have been used in [8, 11], to achieve over modulation switching. All these methods have been extended for the dc bus utilization of the inverter until the six-stage mode and all the strategies are tested for the open loop v/f drives. Throughout over modulation, less-order harmonics contributed to improve the fundamental voltage gain of the modulator. These harmonics interfere with the current linear controllers, when it is used as a part of a closed loop torque and flux vector control scheme [9]. A compensation method [9] is suggested. It uses a different model to evaluate the harmonic component of the current vector in case of over modulation. The harmonic substance is then removed from the inputs to the linear controllers. During dynamics at higher angular velocities, the strategy proposed in [2], is to choose the voltage vector that is nearest to the reference. This is attained by designing the reference voltage vector tip point on the closest inverter hexagon side. An additional strategy carried out in [4] utilizes neural networks for implementation [2]. This methodology fails to use the voltage capability and requires a computationally intensive control algorithm. The concept in the reference [5] an endeavor is prepared to conquer the adverse impact of the nonlinear gain on the current linear controllers by using the non-linear inverter gain-capacity model. This technique seems to give an execution that is similar and much simpler approach using LUT that is proposed as a part of [3].

A class of discontinuous PWM methods has been discussed along with the SVM-based modulation methods [7]. This extends to the linear range of working principle using the sine-triangle PWM method. Likewise, the more traditional technique is tested for v/f induction motor drives in [1]. The uses of these strategies have been presented by hybrid method that consolidates and is presented in [7]. The utilization of these methods in the over modulation range is appeared to be oscillatory in the steady state of FOC driving performance. The location of the reference vector and figures are described in the proposed scheme quickly on time [12]. Numerous multiphase MSVPWM algorithms have been developed in the recent couple of years [13, 14, 15, 16, 17, 18]. The MSVPWM issue for the multilevel converters is tended in [13] and [18] where two different algorithms for converters are presented. The algorithm presented in [13] and [18] can also work with the multi-frequency with the use of multidimensional approach in [17] The impact of modulation on total harmonic distortion (THD) in the line current has been scrutinized in [14] and [16, 17, 18, 19].

The optimization methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and bee algorithm for Selective Harmonic Elimination (SHE) are introduced [20, 21, 22]. These methods require maximum number of iterations to terminate the process. GA-based method is applied only to equal DC sources and needs considerable computational time. Artificial Neural Network (ANN)-based method for an eleven level-cascaded multilevel inverter is introduced in [20, 21] which uses Genetic Algorithm to obtain datasets. A nondeterministic method is used to solve the system of the angles in order to obtain dataset for ANN training. The coefficients of objective function are to be set based on trial and error basis, in this method. Also, GA requires fixed voltage in four of the five input voltages and the fifth one is to be varied of its range. But, in real time all the input DC voltages vary owing to temperature and irradiance of solar panels. Similarly in batteries voltage differ, due to charging cycle [23, 24, 25].Genetic algorithm is employed to represent the fitness function by finding the switching angles to eliminate the lower-order harmonics[30]

2 Proposed Solar Fed Multilevel Inverter Methodology

In this paper, a switch topology of MLI of equal dc sources is proposed, as appeared in Fig. 1. Its performance is based on GA Switching Scheme that attempts to mimic the predefined parameter of a reference sine wave (i.e., abundancy and recurrence) or the grid voltage (Vg). The proposed topology with optimizing the semiconductor switching, the harmonic component is reduced when compared with the established techniques. The power yield from MLI is then separated utilizing passive inductor filter and synchronized to encourage the grid-control framework. The proposed grid interfacing strategy utilizing GA-based MANN on discovering the recurrence of the framework and keeping up the brace voltage and inverter current stage point. Subsequently, it is not required to apply otherworldly or palindrome capacities for the computation to restrict the edges to interface the inverter to grid.
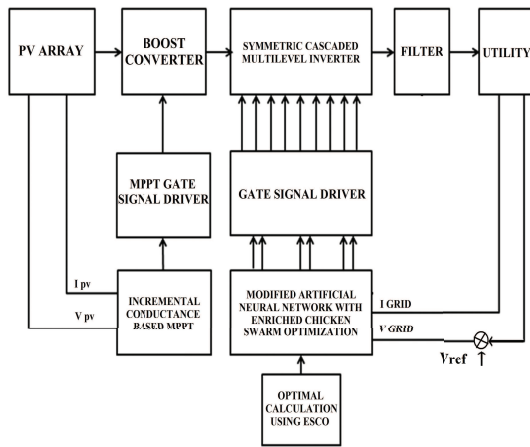
Fig. 1: Block diagram of proposed Solar-fed symmetric MLI

In this paper, a solar-fed to the five level cascaded multilevel inverter with a novel, creative techniques such as modified Artificial Neural Network (MANN) optimized with GA Optimization is formulated to reduce the harmonic distortions. The datasets required for the ANN is obtained by solving the harmonic equations by considering various modulation indices. The output voltage is generated based on the switching angles. Hence, the Total Harmonic Distortion is evaluated. The output voltage is compared with the reference voltage and error is generated. Now the aim is to generate the output voltage same as that of grid voltage also with the harmonic content within the specific limits. As per the IEEE 512 the individual voltage harmonics as well as the current must be within 3%, whereas the total harmonic distortion within 5%. Based on these criteria a data set is created listing the error voltage and the respective switching angles. The objective function and its related constraints are developed for GA with detailed procedures which are also given.

2.1 Photovoltaic System Model with MPPT For Input Voltage Control

To ensure the MPPT from the PV panels, the Incremental Conductance (IC) method is used to control the boost converter. A novel controller is then used to monitor the MLI inverters input voltage and the grid voltage as references magnitude to be employed by the MANN with GA algorithm. The phase angle (θ_{grid}) of the reference voltage is obtained from a conventional phase-locked loop (PLL) to ensure the grid synchronization. Solar-based radiation information is gathered on a level surface. The created control from PV framework could be expanded significantly if the PV cluster is introduced confronting the sun. Numerous designs can be utilized as a part of this respect. The least difficult and least expensive route is to pick the yearly best tilt angle. The

best angle edge is the scope points of the site; the PV exhibits tilted best-case scenario tilt edge, some different setups utilized one pivot or two hub sun trackers to expand the created control from PV framework yet it builds the cost and structure complexities. Most extreme power point tracker ought to be utilized to track the greatest power generated from PV. The global solar radiation on the best tilt angle can be obtained from the following equation:

$$G_{G,titled} = G_{dir\,titled} + G_{diff\,titled} + G_{ref\,titled} \quad (1)$$

where $G_{dirtilted}, G_{difftilted}$, and $G_{reftilted}$ are the hourly direct, diffused, and reflected radiations on the tilted surface. Values of these variables can be calculated from hourly solar radiation on a horizontal surface. The modified radiation data on a tilted surface and the hourly output power from PV array is given by the following equation:

$$P_{pv} = P_R f_{pv} \left(\frac{\bar{G}_T}{G_{T,STC}} \right) \left[1 + \alpha_P \left(T_C - T_{C,STC} \right) \right] \quad (2)$$

Where f_{pv} is the PV module derating factor, P_R is the PV module capacity, G_T is the incident irradiance on the tilted PV module, $G_{T,STC}$ is the incident irradiance at standard conditions, α_P is the temperature coefficient of power, Tc is the PV temperature, and $T_{C,STC}$ is the PV temperature under standard conditions.

2.2 Symmetrical configuration of H-Bridge MLI Topology

The dc voltages of the H-bridge power cells are the same. Similarly different dc voltages may be selected for the unequal dc voltages due to the variations in temperature, irradiation shadow, weather conditions etc. Fig. 2 is constructed with equal dc voltages. A switching scheme is implemented that renders an equal voltage-stepped waveform. With $\frac{(m-1)}{2}$ number of dc sources, m levels are obtained and $\frac{(m-1)}{2}$ numbers of odd harmonics are to be eliminated. Conversely, Fourier expansion of equal voltage steps is given by the following:

$$V(t) = \frac{4V_{dc}}{\pi} \sum_{n=odd}^{\infty} \cos n\alpha_n \frac{\sin n\omega t}{n} \quad (3)$$

However, if voltage steps are unequal then,

$$V(t) = \frac{4}{\pi} \sum_{n=odd}^{\infty} \sum_{j-1}^{m-1} V_j \cos n\alpha_n \frac{\sin n\omega t}{n} \quad (4)$$

where Vj is the least common factor of voltages. On the other hand, if the voltages are integer multiples, then

the above equation can be written as

$$V(t) = \frac{4V_{dc}}{\pi} \sum_{n=odd}^{\infty} \sum_{j-1}^{m-1} j \cos n\alpha_n \frac{\sin n\omega t}{n} \qquad (5)$$

Equation is solved for the values of α_n. Thus, with the
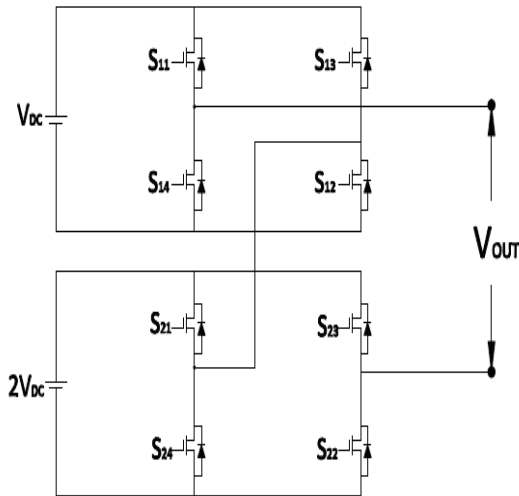

Fig. 2: Proposed AMLI topology

help of switching scheme, a number of voltage levels can be increased by increasing the number of H-bridge cells in the cascade. This permits increased voltage steps in the inverter and hence yields improved voltage waveform for the same number of power cells. In the present structure, the dc voltages for H-bridges are chosen as V_{dc}, and $2V_{dc}$, respectively. The three-cell inverter leg is able to produce 5-level voltage waveform; that is, voltage waveform constitutes $2V_{dc}, V_{dc}, 0V, -1V_{dc}, -2V_{dc}$. Simulation Circuit is shown in Fig. 2.

Fig. 2 shows the power circuit of cascaded SMLI five level inverter, consists of 3 independent input sources of equal values from PV modules. i.e., $V_{dc} = 2V_{dc}$. For three phase system, the similar circuit is repeated with a phase shift of $120°$.

2.3 Selective harmonic elimination technique

Generally, to analyze the SMLIs output waveform, Fourier series expansion is applied. According to Fig. 2, the phase voltage of SMLI output is stated by Fourier expansion as in(6a) and (6b)

$$V(t) = \begin{cases} \frac{4V_{dc}}{\pi}[\cos(n\alpha_1) + \cos(n\alpha_2)] \; for \; odd \\ 0 \qquad\qquad\qquad\qquad for \; even \end{cases} \qquad (6a)$$

where the input sources V_{dc}, of equal amplitude, are reflected. For the unequal input voltages,

$$V(t) = \begin{cases} \frac{4}{\pi}[V_1\cos(n\alpha_1) + V_2\cos(n\alpha_2)] \; for \; odd \\ 0 \qquad\qquad\qquad\qquad\qquad for \; even \end{cases} \qquad (6b)$$

The limitation can be stated that the switching angles lie between $0°$ to $90°$.

$$0 < \alpha_1 \leq \alpha_2 < \frac{\pi}{2} \qquad (7)$$

Where, α_1 and α_2 are the switching angles. The above equations are condensed using selective harmonic elimination method. While reducing, the main aim is to fulfil requirement fundamental component and to lessen the lower order harmonics of the voltage waveform. The fifth order harmonic of the output voltage is the prime intention of elimination. The third order harmonics are automatically removed while considering the balanced three phase system. The set of equations are reduced as follows:

$$\frac{1}{2}[\cos(\alpha_1) + \cos(\alpha_2)] = M$$
$$[\cos(5\alpha_1) + \cos(5\alpha_2)] = 0$$

The switching constant, the modulation index M is distinctly as stated below: $M = \frac{V_{required}}{4S(V_{dc}/\pi)} \; 0 < M < 1$

Where, $V_{required}$ is the required fundamental quantity ofoutput voltage and S is the individual dc sources. The switching angles α_1 and α_2 are determined using the equation of selective harmonic elimination. The switching angles should be within thelimits of $0°$ to $90°$. Solving these non-linear transcendental equations is a challenging problem noticing that for a certain values M there is no solution. The proposed methods are explained below.

3 Proposed MANN With GA Controller Strategy

While interfacing the SMLI to the renewable energy sources, for example, PV panel or battery cells, the yield voltage would differ because of temperature, light and different elements. In SMLI based photovoltaic frameworks, the working DC voltages of standard PV modules go from 12 to 48V. Hence, the different voltages arrive at the inverter stages would cause unregulated fundamental with a higher magnitude of low order harmonics. To avoid this, a DC-DC converter is required at each stage to regulate the voltage which increases the complexity when a separate duty-ratio control algorithm is incorporated at each stage. A constant output voltage from the PV system is to be fed to the inverter.Using MathCAD Prime 2.0 software, the data set is obtained for firing angles of semi-conductor power switches of SMLI by solving the harmonic elimination equations. The

reference voltage is compared with the obtained system output and the error is calculated. A dataset is developed based on the error voltage against switching angles.
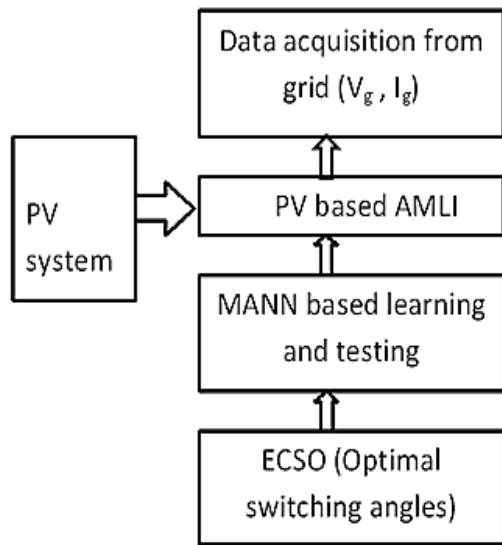

Fig. 3: Proposed controller

The neural system is trained from the acquired data sets consisting of error voltage and the switching angles. The trained system is used to find the firing angle of switches of inverter. The MANN control is gained from the acquired data set which decides the harmonic content of SMLI.The data set used by MANN is error voltage obtained from the inverter and the reference voltage and the switching angles. Harmonic elimination conditions are solved in the linear and non-linear arrangement of conditions in few seconds.

3.1 Tuning of weighting factor in harmonic reduction using MANN with GA

The control of switching angles of SMLI is based on GA and Modified Artificial Neural Network (MANN). The auto tune feature without any specific function control is the merit of MANN. The innovative MANN architecture consists of one input unit, n hidden units and two output units as shown in figure.4. It is trained based on the data set supplied to perform a particular function which is performed by adjusting the values of connection weights between the error voltage (V) and set of switching angle (radians) values are obtained using Back Propagation (BPN) algorithm. The neural network works by making of two phases, one is the learning phase and the other is the optimal tuning phase.

3.1.1 Learning/Training Phase

In the learning phase, nearly, 1500 datasets are collected in such a way that for the corresponding error voltage generated (difference between the reference output and the actual output defined for a specific modulation value) versus the respective set of switching angles (radians) values are obtained using Back Propagation (BPN) algorithm. Initially, the nodes are given random weights. As the output is already known in the training phase, the output obtained from the neural network is compared to the original and weights are varied so as to reduce the error. This process is carried for a large data so as to yield a stable system having weights assigned in the nodes. Modified Artificial Neural Network structure is delineated in Fig. 4. The input unit, the hidden unit and the yield unit has defined number of neurons. Back propagation calculation is utilized to prepare the neural system, which is portrayed beneath.

Step 1: Produce subjective weights inside the interim [0, 1] and rule out to the concealed unit neurons and the yield unit neurons. Keep up a solidarity esteem weight for all input neurons.
Step 2: The learning dataset is considered to find the BP_{err} as

$$BP_{err} = C_{tar} - C_{out} \tag{8}$$

In Eq. (8), C_{tar} is the required reference output and C_{out} is the system output, where $Y_2{}^1 Y_2{}^2\ Y_2{}^3$ represent system output and $Y_t{}^1 Y_t{}^2\ Y_t{}^3$ are the target output voltage (grid outputs). The network outputs can be determined as

$$Y_2{}^{(l)} = \sum_{r=1}^{N_H} w_{2r1} Y_1(r) \tag{9}$$

where,

$$Y_1(r) = \frac{1}{1 + \exp(-w_{11r} \cdot C_{in})} \tag{10}$$

Eq. (9) and Eq. (10) signifies the initiation function performed in the output unit and hidden unit respectively.

Step 3: Regulate the weights of all neurons as $w = w + \Delta w$, where, Δw is the change in weight which can be determined as

$$\Delta w = \gamma . Y_2 . BP_{err} \tag{11}$$

In Eq. (11), γ is the learning rate, usually it ranges from 0.12 to 0.7.

Step 4: Until the error of BP gets minimum $BP_{err} < 0.1$, the above procedure is repeated from Step 2. For a five level inverter, the above conditions are explained. In the above requirements, obviously by furnishing the necessary voltage with desired units

(amplitude and frequency) and other harmonic parts equivalent to zero, i.e., the lower arrange consonant substance, for example, fifth, seventh, eleventh, thirteenth etc. A portion of the datasets acquired is recorded in Table 1.

Table 1: Sample Dataset For Mann Training

S.No.	Error voltage	Switching angles(rad)
1	[2.034]	[0.111, 1.1]
2	[1.023]	[0.117, 1.526]
3	[3.457]	[0.136, 1.533]
4	[0.67]	[0.112, 1.53]

3.1.2 Optimal tuning phase of switching pulse

In the optimal tuning phase, the PV input voltage is fed to the trained neural network with particular weights in the nodes and the respective output is calculated based on the trained dataset. In any neural network the process is stopped after tuning. In this proposed modified neural network, testing process has been incorporated in the algorithm itself in order to optimize the weights used during training. In the proposed method the weights are optimized with the help of the Genetic Algorithm. By incorporating the optimization process the switching angles are fed to the MLI to provide better tuning. The structure of the artificial neural network is illustrated in Fig.4.
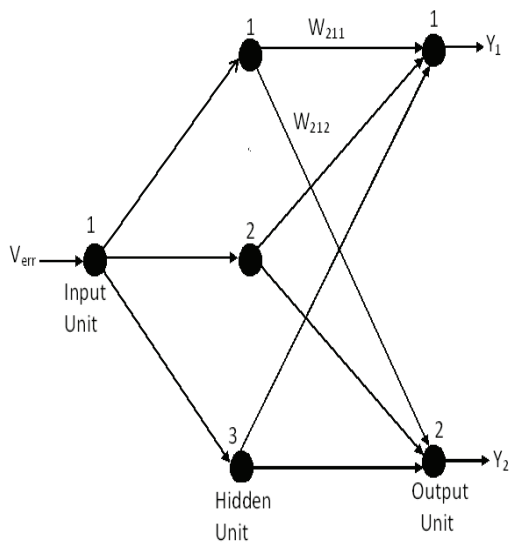
Fig. 4: Proposed Modified Artificial Neural Network

3.2 GA Algorithm For Optimizing Weights in ANN

Genetic Algorithm (GA) follows adaptive computational procedures simultaneously on a set of coded solutions.GA is derivative-free, stochastic, and considered as a optimization method based on the concepts of natural selection and evolution process. John Holland proposed and investigated the GA from the University of Michigen in the year 1975. GA is a powerful adaptive method to solve the search and optimization problems. The Fourier series transform the output voltage of MLI into non-linear transcendental equations. The solutions of the equations is not uniform for the entire region of the modulation index. There exists more then one solution in few regions, no solutions in some other regions and one solution in some other regions [28].Finding the solutions for the entire regions increases the computational burden. Hence to resolve this problem, an optimistic GA as a part of evolutionary programme is suggested.

In multilevel inverter, the switching angles required to trigger the semiconductor switches are selected.The objective function is to optimize the switching angles such that to reduce the Total Harmonic Distortion (THD) while preserving the desired fundamental component is preserved. In the five level MLI, the prominent fifth order harmonic is limited or reduced to obtain minimum THD.

Objective function is as follows,

$$THD = min. \left(\frac{V_5}{V_1} \right) \tag{12}$$

Constraint function is as follows,

$$0 < \theta_i < \frac{\pi}{2} \tag{13}$$

Where, θ_i is the switching angles of the semiconductor devices.

In case of the five level MLI, i.e.

$$0 < \theta_1 < \theta_2 < \frac{\pi}{2} \tag{14}$$

Step 1 Select the number of variables specific to the problem, where a variable specifies the genes in the chromosome. The problem specified in this is to reduce the Total Harmonic Distortion (THD). As per this, the variables are the switching angles which specify the exact instant at which the semiconductor switches need to be turned on and off. As a case study, the five level multilevel inverter is considered, which requires two angles θ_1 and θ_1.

Step 2 Select the representation of the population i.e., in binary strings, the population size and initialize the population. When the population size is increased, the rate to converge is increased hence the execution time is

also increased and vice-versa. The population is initialized with random selection of angles between 0° and 90° and considering the quarter wave symmetry of x-axis.

Randomly the individuals are selected, which are called parents that contribute to the population of the next generation.

Step 3 The objective of this problem is to reduce the lower-order harmonics. i.e., in case of the five level inverter, the dominant fifth order harmonics is to be reduced.

Objective function is to evaluate THD, which is given by
$THD = min.\left(\frac{V_5}{V_1}\right)$, which must be less than 5%. For each chromosome, i.e., the switching angles of the respective output voltage are generated. The Fast Fourier Transform (FFT) analysis is carried out to check the THD level.

Step 4 Apply crossover rules to the selected two numbers of chromosomes and obtain the output with required traits.

Step 5 Apply the mutation rules, i.e., the random changes to individual parents and it is to minimize the fifth order harmonics in case of the five level MLI.

Step 6 The most required function in GA is the fitness function which is as given below:

Fitness Function=

$$max.\left(\frac{1}{1+THD}\right) = max.\left(\frac{1}{1+\frac{V_5}{V_1}}\right) \qquad (15)$$

To find the fitness value, the maximum value of the above expression is considered as the best solution. The fitness value basically depends on the switching angles, which signifies the output voltage.

Step 7 Repeat the steps from step 2 to step 6, until the stopping criterion is met. Stopping criterion is given by two options. The two options are attainment of maximum fitness value or execution of certain number of iterations, whichever is earlier.

By using the GA calculation above, the weights are solved out and fed to the ANN to get the output voltage with less THD. The proposed system is then approved for its execution and thereafter Simulink model is created. To produce demonstration, the system gives the relating exchanging points on furnishing the voltage values. The exchanging edges produced by the neural system are then changed over to the comparing gating signals by

activating the circuit and after that are fed to the IGBT switches in the H Bridge inverter. This outcome is the base of Total Harmonic Distortion (THD).

4 Simulation Results and Discussion

The simulated results are shown in figures 6 using MATLAB Simulink. The specifications of simulation parameters are shown in Table 2.

Table 2: Parameters Used In Simulation

S.No.	Parameters	Function Values
1	No. of Neurons in Input Unit	Error Voltage: One
2	No. of Neurons in Hidden Unit	Twenty
3	No. of Neurons in Output Unit	Switching angles: Two
4	Network	Back propagation(BP)
5	Algorithm used	GA
6	Rate of learning	0.97
7	No. of Iteration	50
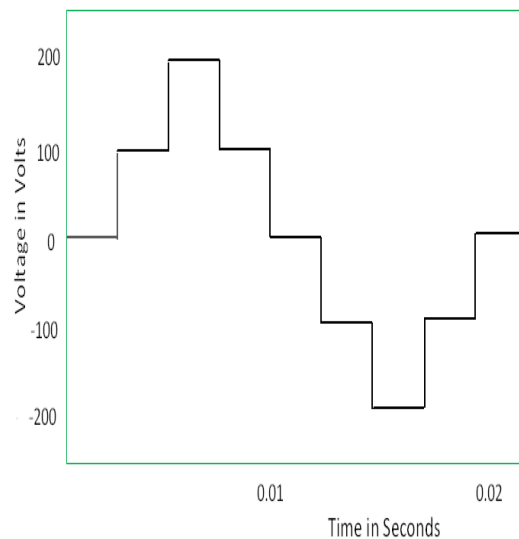
Fig. 5: Output Voltage of Five Level Inverter

4.1 Comparative Analysisof Various Controllers

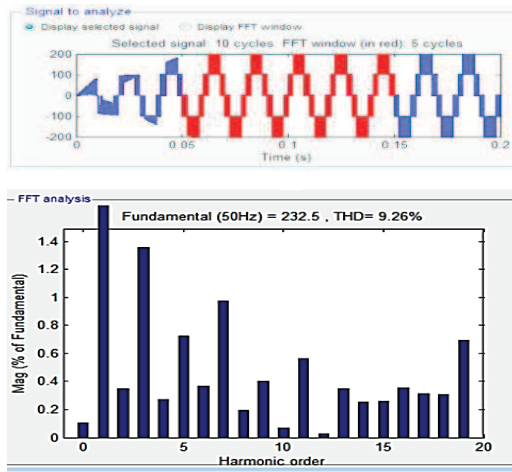Several controller schemes are simulated in various small MLI topology. The harmonic performance is compared

Fig. 6: FFT analysis of five-level inverter

based on the THD values. The comparative analysis is shown in Table III. On comparing the harmonic performance, proposed MANN with GA produces better results.

Table 3: Performance comparison of various controllers in five level inverter

S.No.	Controller used	THD (%)
1	PI	20.32
2	ANN	13.12
3	Proposed. MANN with GA	9.26

5 Conclusion

The five level solar-fed cascaded multilevel inverter to eliminate the fifth order is designed and implemented using intelligent techniques such as MANN with GA for the required power quality improvement. Based on the results, it is found that the MANN-based technique give better results when compared to other methods This system is well suitable for implementing the solar photovoltaic system. This method is compared with the conventional modulation controller approaches, which shows that MANN-based method which incorporates harmonic elimination is more suitable in Solar-fed SMLI systems. The advantages of this method include simple computational algorithm and no requirement of filters, detailed tables and output transformers. Moreover, this technique can be implemented in both standalone and the grid interacted PV systems. The dc voltage obtained from the nature is affected by irradiance, temperature, shadows etc., To maintain a constant dc voltage, any Maximum

Power Point Tracking (MPPT) algorithm like incremental conductance, Perturb and observe etc., is to be used. To implement the above MPPT, it requires additional circuitry. Power-quality analysis for the proposed control algorithm is also included to show the effectiveness of the proposed method.

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