Introduction of Intelligence Water Drop Algorithm for Minimization of Harmonics in Multi-Level Inverters: A Survey

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***Abstract*- The requisite for the multilevel inverters has achieved great heights in the recent years. The need of achieving the power demand, a lot of power circuitry is being employed in a system. These devices give rise to harmonics and in return the functioning gets distorted. The minimization of harmonics is an important aspect to increase the lifetime of the system. This paper presents an overview for minimization of harmonics using SHE-PWM and Intelligence Water Drop Technique in Multilevel Inverters.**

Keywords*- *Multilevel inverters (MLI), Selective Harmonic Elimination-Pulse Width Modulation (SHE-PWM), Harmonics, Particle Swarm Optimization (PSO), Intelligence Water Drop algorithm (IWD)

I. INTRODUCTION

Multilevel inverters have drawn increasing attention in recent years, especially in the field of distributed energy resource area because several batteries, fuel cells, solar cells and microturbines through MLI without voltage balancing problems [1]. The ability to reduce the harmonics of AC output voltage waveform and also for its high voltage capability and high efficiency operation, hence are accepted worldwide. These inverters are more advanced and latest type of power electronics converters which synthesize a desired output voltage waveform from several levels of DC voltage as input. By taking the sufficient number of DC sources, a nearly sinusoidal output voltage waveform can be obtained.

Compared to traditional two level inverters, the stepwise output of MLI is a major advantage and this result in better electromagnetic compatibility, higher power quality, lower switching losses, higher voltage capability and Needlessness of the transformer at distribution voltage level, thereby reducing the cost.

MLI are generally divided into three categories: Diode-clamped, flying capacitor, cascade H-Bridge multilevel inverters. Among these categories cascade MLI has the highest power and voltage levels and high reliability due to its modular structure [2]. Cascade MLI is based on series connected single phase H-bridge inverter, each with their own isolated bus to get a sinusoidal voltage output [3]. These MLI are very popular in high power ac supplies and adjustable speed drive applications.

As the output voltage of MLI is in a stepped form resulting in reduced harmonics as compared to square wave inverter [1]. To further reduce the harmonics in MLI, there are several well-known topologies as follows:

1) Sinusoidal Pulse Width Modulation (SPWM)

2) Selective Harmonic Eliminated Pulse Width Modulation (SHE-PWM)

3) Optimized Harmonic Stepped-Waveform Technique (OHSW)

From the above techniques, Optimized harmonic stepped-waveform is best suited for MLI topologies. Implementation of this technique along with the multilevel topology, a low THD output waveform can be obtained without using any filter circuit, and switching devices switch only one time per each cycle. This will improve the switching loss problem, as well as EMI problem. Harmonics are used to describe the distortion in the electrical power system. The MLI have harmonic current and reactive power from the AC source and affect the quality of power. Harmonics are caused by the non-linear loads that draw the non-sinusoidal current from a sinusoidal voltage source. Some examples of the loads that produce harmonics are Static VAR, Compensators, Inverters, Switch-Mode power supply, and Electric Arc furnace. Non-linear loads produce harmonic currents which are injected back into the supply systems. These currents can interact adversely with power system equipments such as Capacitors, transformers, motors, energy and demand metering causing additional losses overheating and overloading. These harmonic currents can also cause interference with telecommunication lines also affect the normal working of computers, telephone systems, controllers, sophisticated electronic equipment such as relays resulting in false operation [4].
Harmonic content is one of the most important aspects of these inverters. The amount of harmonics, introduced to the system, is lesser as compared with those of common inverters because of the staircase waveform of MLI [2].

The THD output voltage of the inverter is a measurement of the harmonic distortion, which is expected to be as small as possible in many applications of MLI .THD is defined as

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the Summation of all harmonic component of the voltage or current waveform compared against the fundamental component of the voltage or current wave [5]:

$$THD = \frac{\sqrt{\sum_{n=3,5,7..}^{\infty} Vn^2}}{V1} \quad (1)$$

II. CASCADE MULTILEVEL INVERTER

The MLI start with the three level inverters. The MLI have drawn the tremendous interest in the power industry [6]. A cascade MLI can produce high power and high voltage as compared to simple inverters. The most important topology in the family of MLI is the cascade MLI. The number of components requires in cascade MLI is less as compared to diode-clamp and flying capacitors MLI. It has a modular structure and simple switching strategy, require less space [7].

Cascade MLI consist of a series of single phase full bride (H-Bridge) inverter units as shown in fig.1. The basic function of the MLI is to produce the desired voltage from separate DC's sources (SDCS) connected to each single phase full bridge inverter and can generate three different outputs, +Vdc, 0, - Vdc. This can be realized by connecting the dc sources to the AC output side by using different combinations of the four switches. The AC output voltage of each single phase full bridge is connected in series such that output voltage waveform is the sum of all the individual H-Bridge Output [8].

By connecting the required number of H-Bridge in cascade and using proper modulation technique, closely sinusoidal output voltage waveform can be synthesized. The number of levels in the output voltage waveform is 2S+1, where'S' is the number of H-bridges. For e.g.- the AC output phase voltage waveform of a seven level MLI using two H-Bridges is shown in fig-2. In a seven level multi inverter there are three switching angles and three non-linear transcendental equations. From 'S' number of switching angles only one switching angle is used to calculate the fundamental voltage and the remaining (S-1) switching angles are used to eliminate most noticeable lower order harmonics. The magnitude of the output phase voltage is:

$$V_n = V1+V2+V3 \quad (2)$$

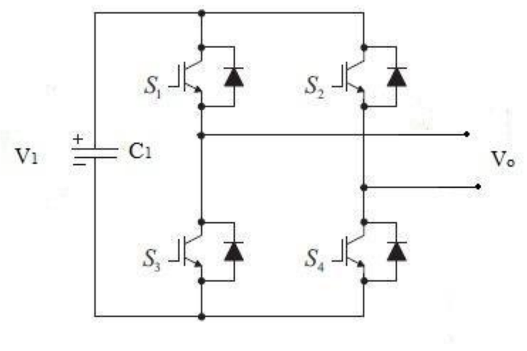

Fig.1 H-Bridge

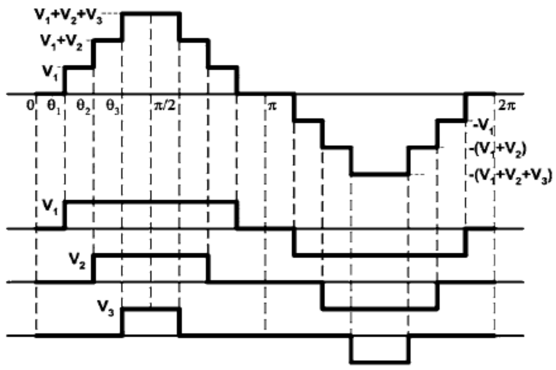

Fig-2 Output Voltage of 7-Level Cascade Inverter

By applying the Fourier series analysis for a cascade MLI with 'S' switching angles, the amplitude of any odd nth harmonic can be expressed as:

$$Van(wt) = \sum_{n=1,3,5}^{\infty} \frac{4Vdc}{n\pi}[cos(n\alpha_1)+..+\cos(n\alpha_{k)})][\sin(n\omega t)] \quad (3)$$

Where 'n' is an odd harmonic order, and switching angles are considered equal to the number of dc sources and α_k is the kth switching angle. The amplitude of the entire even harmonic is zero. The switching angles should be in the range of 0 to 90 considering 5^{th} and 7^{th} order output phase voltage to zero. For a seven-level cascade MLI, the fundamental voltage in terms of switching angles is given:

$$V1 = \frac{4Vdc}{n\pi}[\cos(n\alpha 1) + \cos(n\alpha 2) + \cos(n\alpha 3)] \quad (4)$$

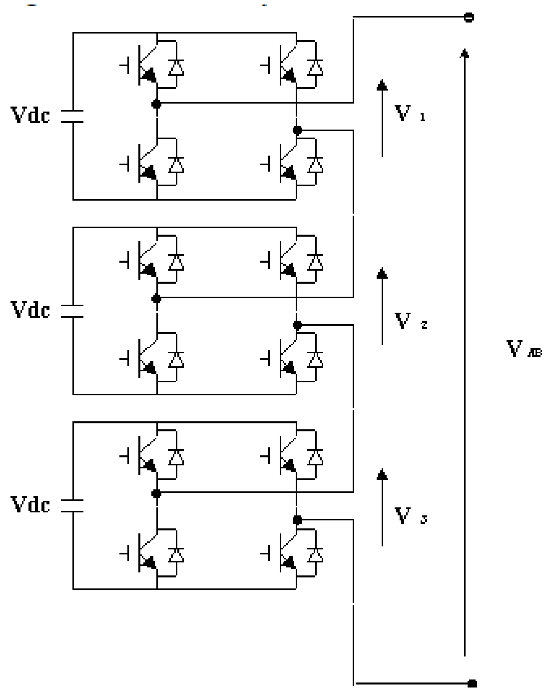

Fig-3 Seven Level Cascade Inverter

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The modulation index 'M' is defined as the ratio of the fundamental voltage (V1) to the maximum obtainable fundamental voltage (V1max) [12]. The maximum fundamental voltage is obtained when all the switching angles are zero and V1max is given as:

$$V1max = 3*\left(\frac{4Vdc}{\pi}\right) \qquad (5)$$

Then the modulation index is given as:

$$M=\frac{V1}{\left(3*\left(\frac{4Vdc}{\pi}\right)\right)} \qquad (6)$$

The seven level cascades MLI require two H-bridge. To obtain the required switching angles and the desired fundamental voltage nonlinear switching equations are used as given below:

$$\text{Cos}\ (\alpha 1) + \text{Cos}\ (\alpha 2)\cos\ (\alpha 3) = 3M$$

$$\text{Cos}\ (5\alpha 1) + \text{Cos}\ (5\alpha 2) + \cos(5\alpha 3) = 0$$

$$\text{Cos}\ (7\alpha 1) + \text{Cos}\ (7\alpha 2) + \cos(7\alpha 3) = 0 \qquad (7)$$

These are the non-linear transcendental equations for elimination the 5^{th} and the 7^{th} order harmonics and get the desired fundamental voltage. For the given values of m (from 0 to 1), it is required to get complete and all possible solutions of these equations for determining the switching angles and lower THD.

III. CLASSIFICATION OF MULTILEVEL INVERTER CONTROL STRATEGIES

The main purpose of the modulation strategy of MLI is to synthesize the output voltage as closed as possible to sinusoidal waveform. To symphonize this sinusoidal waveform using several level of dc inputs, semiconductor devices must be switched on and off in a manner that a stepped output voltage waveform is obtained with fewer harmonics and losses. Numerous modulation techniques have been developed for harmonic reduction and switching loss minimization. The modulation method used in multilevel inverters can be classified according to switching frequency, as shown in fig 4

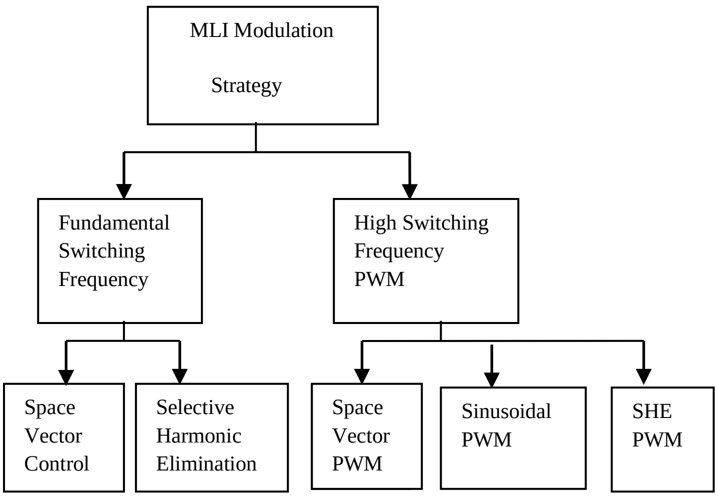

Fig-4 Classification of Modulation Techniques

Low switching modulation techniques are used in high power applications to keep the losses below the acceptable values. These methods generally perform one or two commutations of the semiconductors devices during one cycle of the output voltage, generating the staircase waveform. Representatives of this family are the selective harmonic elimination and space vector control strategies, which results in less complexity and better output waveform have been reported in literature [9]. In these strategies, firing angles are selected in such a way that the THD is minimum in the output voltage waveform.

High switching frequency methods have many commutations for the power semiconductor devices during one cycle of fundamental output voltage. A very popular method in industrial application is the carrier-based sinusoidal pulse width modulation (SPWM) that uses phase-shifting technique to reduce the harmonics in the output voltage. Another method is space vector control strategy, which has been used in three-level inverters.

IV. OPTIMIZATION TECHNIQUE

For solving non-linear transcendental equations different optimization techniques have been suggested in literature.

A. Resultant Method

This method was based on the theory of resultant of polynomials. A nearly sinusoidal output voltage can be generated and also the higher order harmonics can be reduced to a great extent. Transcendental equations characterizing the harmonics content can be converted into polynomial equations by making some simple changes of variables and simplifying, which are then solved by using the method of resultant from elimination theory. In this method, all solutions to the non-linear equations can be found without the need for an initial guess. The degree of polynomials become quite large when several dc sources are connected, which results in high computational burden of resultant polynomials. Due to computational complexity associated with this method, it has been limited to 11-level inverter only. Limitation of resultant method appears when applied to multilevel inverters with unequal dc sources where transcendental equations are no longer symmetric and requires the solution of a set of higher degree equations [10].

B. Newton-Raphson Method

It is the most widely used method for root finding. It can be easily used to find solution of non-linear equations. This method has been applied to reduce the harmonic distortion. The switching angles have been calculated by implementation of this technique in a particular way producing complete solution for working range of modulation index without much computational complexity and reducing the certain number of harmonics component. This method only requires an initial guess, but if initial guess is not good enough, a solution will not be found. The main drawback with this method is divergence problem, and it will find only one solution if one exists [11].

C. Genetic Algorithm

Genetic Algorithm is a search method to find out the maximum of function by mimicking the biological evolutionary process and solves the non-linear equations with much simpler formulation and with any number of levels without extensive derivation of analytical expression. It is a technique used to eliminate some higher order harmonics while maintaining the required fundamental voltage. GA is a computational approach by which optimization problem can be solved using theory of evolution and genetic method. For the implementation of this method, proper selection of certain parameters such as initial size, cross-over and mutation operation are required, thereby implementing of this algorithm become tedious for higher multilevel inverters [12].

D. Artificial Neural Network

This technique helps in real time calculation of switching angles by transforming the non-linear transcendental harmonic elimination equations for all possible values of switching schemes into one input (modulation index) and multi-output (switching angles) three layer ANN. Then, the complete set of solutions of the equations is calculated using the back propagation of the errors between the desired harmonic elimination and non-linear equation system using the switching angles given by the ANN. The results in [13] show that the switching angles calculated through trained neural network and provided by look up table are almost equal. Hence, the look up table can be replaced by the trained neural network and reduce the computational effort and storing capacity. A trained neural network can also produce switching angles by interpolation/extrapolation even for those values of modulation index, where switching angles are not calculated.

E. Harmony Search Algorithm

This is the music-inspired harmony based optimization algorithm and it uses stochastic random search. This algorithm searches those values which optimize the objective function and at the same time satisfy the problem's constraints and improves iteration after iteration. This algorithm does not require initial value setting for decision variable and imposes fewer mathematical requirements. HAS generates a new vector, after considering all the existing vectors [14].

F. Bee Algorithm

This technique is also used for the minimization of harmonics in MLI. This algorithm is based on the natural foraging behavior of honey bees to find the optimal solution [15]. In this algorithm, food sources are considered as possible solution to the problem. The food sources are a D-dimensional vector, where 'D' is the number of optimization variables. This amount of nectar present in a food source calculates the value of fitness. This method has higher probability of convergence and high precision than Genetic Algorithm.

G. Particle Swarm Optimization

The PSO methodology is a very powerful approach for optimization of non-linear linear transcendental equations. It is an Artificial Intelligence technique to find the approximate solution to extremely difficult or impossible numerical minimization and maximization problems. The concept of PSO algorithm is simple, easy to implement, computational efficient, and fewer parameters to be adjusted mainly the velocity [16]. This method can easily find the optimum switching angles and has a fast convergence with better quality solutions than GA approach. PSO completely outperforms the GA and HAS.

A new species based PSO (SPSO) method, which includes the suitable adjustment of the niche radius for calculation of the optimum firing angles of MLI's [17]. This method is able to find the optimum switching angles when their number is increased and their determination using conventional iterative methods in addition to GA and simple PSO technique is not possible. By modifying the original SPSO technique, it increases the robustness of the algorithm to find the global optimum of search space. Simulation and hardware results shows that all the lower order harmonics as well as higher order harmonics are effectively minimized in the output sinusoidal voltage waveform of MLI, and the switching frequency of MLI and the THD have decreased dramatically [17]. This method can also be applied to optimization problem of large dimension, often producing quality solutions more rapidly than alternative method.

V. TECHNIQUE TO BE IMPLEMENTED

Intelligent Water Drop Algorithm:

Overview

Intelligent water drop algorithm (IWD) is a swarm-based nature inspired optimization algorithm, which has been inspired from natural rivers and how they find the optimal path to their destination [18]. Among the lots of possible paths, natural rivers find a good path in its way from source to destination. These optimal paths follow from the actions and reactions occurring between the water drops and water drop within the river bed. This algorithm falls in the category of swarm-intelligence and metaheuristic and can be used for combitorial and continuous optimization. The IWD was first introduced for the travelling salesman problem in 2007[18]. In the IWD algorithm, several artificial water drops collaborate to change the optimal path in such a way that the optimal path is revealed with the lowest soil on its links. There are mainly two important properties of IWD that follows in its environment:

1. The amount of soil, soil (IWD)

2. The velocity that is posses, velocity (IWD)

For each IWD, value of the above properties, soil and velocity may change as it flows in its environment. Here, the environment can be considered as problem that is to be solved. A river of the IWDs tries to obtain an optimal path for the given problem.

Each IWD flow in the environment and possibly there are lots of paths in environment from a given source to destination, which the position of the destination may be known or unknown. If we know the destination position, then we can find the optimal or shortest path from source to the destination. But in many cases where destination is unknown, then our goal is to find the optimum destination in terms of costs or any other desired measure for the given problem.

An IWD is moving in discrete finite-length steps. When moving from one location to another location the velocity of the IWD increases by an amount, this is nonlinearly proportional to the inverse of the soil between the two locations. Also, the soil which the IWDs is carrying also increased by removing some soil of the path joining the two locations. The amount of soil added to the IWD is inversely (nonlinearly) proportional to the time needed for the IWD to pass from its current location to another location. By using simple laws of physics for nonlinear motion the time duration for the IWD can be calculated and is proportional to the velocity of the IWD and inversely proportional to the distance between the two locations.

Another mechanism of an IWD is that it prefer the paths with low soil on it beds as compared to the paths with higher soil on it beds. For realization of this mechanism, we use a random distribution of the available paths in such a way that the probability to choose the next path is inversely proportional to the soils of the available paths. The lower the soil of the path location, the more chance this path has for being selected by the IWD.

IWD Algorithm

The IWD algorithm takes on the number of the IWDs to find the optimal solution to a given problem. It can be represented in the form of graph (N, E) with node set N and edge set E. This graph is the environment for the IWDs and each IWDs flows on the edges of the graph. Each IWD begins constructing its solution gradually by travelling between the nodes of the graph along the edges until the IWD finally complete its solution denoted by IWD T. Each solution IWD T is represented by the edges that the IWD has visited. One iteration of the IWD algorithm is completed when all the IWDs complete their solutions. After each iteration, the iteration best solution is found and it is used to update the total best solution. On the edges of the iteration best solution the amount of soil is reduced based on the goodness of the solution. Then it begins iteration with new IWDs, but with the same soils on the paths of the graph and the whole process is repeated until it reaches the maximum number of iterations or total best solution reaches the expected quality and then the algorithm stops. The total best solution is the best solution of the IWD algorithm since beginning, which has been found in all iterations.

The IWD Algorithm has mainly two types of parameters: Static and Dynamic parameters. Static parameter always remains constant during the entire life of the algorithm and the Dynamic algorithm is reinitialized after each iteration of the algorithm.

CONCLUSION

In this paper it has been concluded that employing IWD for the minimization of harmonics can achieve great heights. As particle swarm optimization has given the best results as compared to other optimization techniques but by employing IWD all the aspects of PSO can be covered as well as harmonic calculation at location to location could be done at lower level. All feasible solutions are closed to average values and hence algorithm is robust and has fast convergence as compare to other methods.

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