

THD Analysis in Multilevel Inverter Fed Induction Motors Using Particle Swarm Optimization

Heena Manhas¹, Baljit Singh², Gagandeep Sharma³

M tech Student¹, DAV Institute of engineering and technology, Jalandhar

Assistant professor², DAV Institute of engineering and technology, Jalandhar

Assistant professor³, DAV Institute of engineering and technology, Jalandhar

ABSTRACT

Harmonics measurement of an industrial unit is done to aid the power quality aspects in a typical factory. The real issues are the harmonics generated by the inverters which affects the induction machine performance. Several inverters like Voltage Series Inverters, PWM fed Inverters, Multilevel inverters etc. exist in literature. Amongst all these, multilevel inverters have been very popular due to its several advantages. But there is a challenge of optimal design of the inverter and optimal selection of pulse width of each level so as to get minimal Total Harmonic Distortion. For these reasons a novel multilevel inverter design based on Particle Swarm Optimization is proposed in this paper for obtaining the optimal width of the pulse of each level so as to get minimal Total Harmonic distortion. The results has been compared to that of the existing techniques and found to be quite better than the existing ones.

Index Terms— Particle Swarm Optimization, cascaded Multilevel Inverter (CMLI), Induction Motor, Multi-level Inverter (MLI)

I. INTRODUCTION

In various industrial applications, usually, DC motors were the work horses for the adjustable Speed Drives (ASDs) due to their excellent speed and torque response. But, they have the intrinsic disadvantage of commutator and mechanical brushes, which endure wear and tear with the passage of time. Mostly AC motors are preferred to DC motors, mostly, an induction motor due to its low cost, low maintenance, lower weight, higher efficiency, improved ruggedness and reliability. All these features make the use of induction motors necessary in many areas of industrial applications. The advancement in Power electronics and semiconductor technology has encouraged the development of high power and high speed semiconductor devices in order to attain a smooth, continuous and step less variation in motor speed. Applications of solid state converters/inverters for adjustable speed induction motor drive are wide spread in electromechanical systems for a large spectrum of industrial systems. Modified CSI based induction motor drive is given by Gopukumar [1]. Multilevel inverter modulation schemes to eliminate common mode voltage is given by Zhang, 2000. Modulation schemes for six phase induction motor are given by Mohapatra [2]. Active harmonic elimination for multilevel inverters is given by Tolbert [3]. The inverters are either Current Source Inverter (CSIs) or Voltage Source Inverters (VSIs). Current source inverters are widely used for the application of fully generative induction machine

variable speed drives. An important and attractive feature of CSI is its good fault protection capability and the inherent regeneration capability. But, CSI-fed induction motor suffers from severe torque pulsations, especially at low speeds, which manifest themselves in cogging of the shaft. The usual technique of overcoming such problems in Voltage Source Inverters (VSIs) is to pulse width modulate the input voltage waveforms. Pulse width modulated voltage source inverters are invariably used for AC/DC/AC conversion to provide a variable ac voltages to the induction motor. However, inverter fed induction motor suffers from the presence of significant amount of harmonics which causes undesired motor heating, torque pulsation and EMI [4]. The reduction in harmonics calls for large sized filters, resulting in increased size and cost of the system. However, the advancements in the field of power electronics and microelectronics made it possible to reduce the magnitude of harmonics with multilevel inverters, in which the number of levels of the inverters are increased rather than increasing the size of the filters [5]. The performance of multilevel inverters will be better than a classical inverter. The THD for multilevel inverters will be lower than that of a classical inverter [6].

This paper aims at designing of a multilevel inverter based on an Improved Particle Swarm Optimization technique [10] for reduction of harmonics in induction motor control.

Section 2 describes theory of cascaded multilevel inverter. Section 3 describes harmonic elimination in

multi-level inverters. Section 4 introduces our methodology and discusses the implementation of our proposed algorithm. Section 5 shows the results of our approach and finally Section 6 concludes the paper with a discussion on the future scopes of this method.

II. POWER TOPOLOGY OF CASCADE MULTILEVEL INVERTERS

Cascaded Multilevel Inverter (CMLI) topology is the most advantageous topology in the family of multilevel inverters. It needs less number of components as compared to diode-clamped and flying capacitors type multilevel inverters. It has modular structure with easier switching Strategy and occupies less space [7] - [8]. Fig. 1(a) shows the structure of a single-phase H-bridge cascaded multilevel converter topology that is used to synthesize a $2s + 1$ staircase output waveform. Fig. 1(b) also shows the staircase voltage waveform produced by multilevel converters.

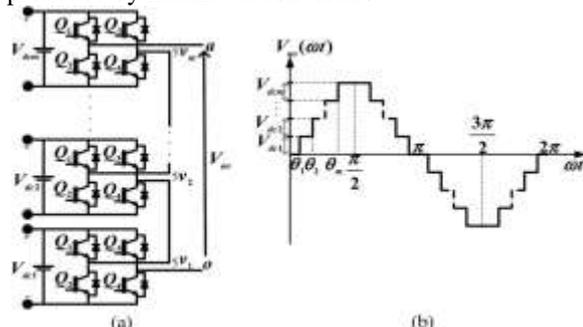


Fig.1. (a) Topology of a single-phase cascaded inverter (b) Staircase output phase voltage

A cascaded H-bridge multilevel converter comprises of some SDCS. The advantage of this topology is that the modulation, control, and protection requirements of each bridge are modular. It should be pointed out that, unlike the diode-clamped and flying-capacitor topologies, isolated dc sources are required for each cell in each phase. The number of output-phase-voltage levels in a cascade multilevel inverter is $2s + 1$, where s is the number of SDCSs. To obtain the three-phase configuration, the outputs of three single-phase cascaded inverters can be connected in Y or Δ .

III. HARMONIC ELIMINATION IN MULTILEVEL INVERTER

Harmonics are unwanted current or voltage [9]. They exist at some integer multiple or fraction of the fundamental frequency. The harmonics orders and magnitude depend on the inverter topology and the modulation technique, for example in single phase VSI, only odd harmonics are present in the output voltage waveform. The even harmonics are

absent due to the half wave symmetry of the output voltage harmonics. For three phase VSI, in addition to the even harmonics triplet (third and multiple of third harmonics) are also absent. The output voltage $V(t)$ as in eqn. 1 of the multi-level inverter can be expressed in Fourier series as:

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

Even harmonics are absent ($b_n = 0$) due to quarter wave symmetry of the output voltage and only odd harmonics are present. The amplitude of the n th harmonic a_n is expressed only with the first quadrant switching angle $\alpha_1, \alpha_2, \alpha_3 \dots \alpha_m$ as shown in eqn.(2) and (3).

$$a_n = \frac{4V_{dc}}{n\pi} \sum_{k=1}^m \cos n\alpha_k \dots (2)$$

$$0 < \alpha_1 < \alpha_2 < \alpha_3 < \dots < \alpha_m < \pi/2 \dots (3)$$

For any odd harmonics can be expressed up to k th term where m is the number of variable corresponding to switching angle α_1 through α_m of the first quadrant. THD expression is shown as in eqn. (4)

$$\text{THD} = \frac{1}{\text{fundamental}} \dots (4)$$

$$= \sqrt{\sum_{n=1}^{\infty} (nth \text{ harmonic component})^2}$$

IV. PROPOSED METHODOLOGY

Proposed methodology for the problem discussed in Section 3 is mentioned. The technique Particle Swarm Optimization for multilevel inverter has been applied on the induction motor model and then their performance was compared on the basis of Total Harmonic Distortion, machine performance etc.

4.1 Particle Swarm Optimization (PSO)

Kennedy and Eberhart [10] first introduced PSO in 1995 as a new heuristic method. Basically, the PSO was inspired by the sociological behaviour associated with swarms such as flocks of birds and schools of fish. The individuals in the population are called particles. Each particle is a potential solution for the optimization problem and tries to search the best position through flying in a multidimensional space. The sociological behaviour which is modelled in the PSO system is used to guide the swarm, hence probing the most promising areas of search space. The movement of each particle is governed by the efficiency of their own previous position and that of the neighbours. Each particle can be described by two parameters- position (x_i) and velocity (v_i), which is updated by the following rule:

$$v_i(t + dt) = w * v_i(t) + c_1 r_1 (pbest_i(t)) - x_i(t) +$$

$$c_2 r_2 (gbest_i(t)) - x_i(t)$$

$$x_i(t + dt) = x_i(t) + v_i(t) dt$$

Here, $pbest_i$ is the best position obtained by i_{th} particle and $gbest$ is the best position obtained by any particle till current iteration. c_1, c_2 are known as acceleration vectors whereas r_1, r_2 are two random vectors uniformly distributed between "0" and "1" and w denotes inertial weight.

4.2 Modification with PSO of Induction Motor

For better search, acceleration vectors $c1$ and $c2$ should be retained small, which however decreases the convergence rate and has to be selectively chosen varying from application to application. For a problem having large numbers of local extrema, the values of $c1$ and $c2$ should be kept low, so as to increase the chance of finding the global extrema at the cost of convergence time and vice-versa. Similarly, the inertial weight w is adjusted, depending on the amount of influence desired in a particles previous position on its current movement. This optimization algorithm is finally said to converge, when each particle reaches the global best or the preset extremum value of the cost function.

V. SIMULATION RESULTS AND DISCUSSION

All the simulations were prepared in MATLAB R2013, 2.7GHz processor with 4 GB RAM. The proposed model of Multilevel Inverter fed Induction Motor was designed in Simulink as shown in Fig 2.

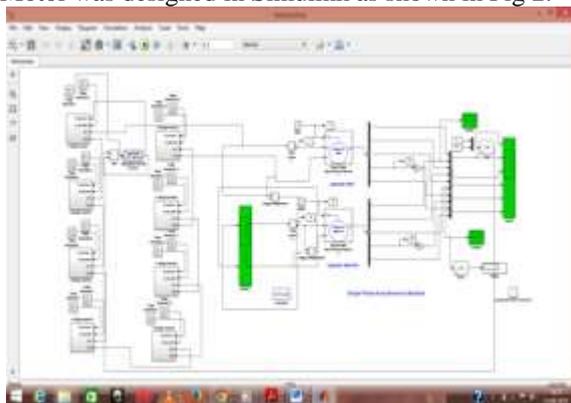


Figure 2: Complete Design of Multilevel Inverter fed Induction Motor model using PSO

Figure 2 shows the complete model of the multilevel inverter fed induction motor, tuned by Particle Swarm optimization. The PSO is employed using MATLAB s-function and is operated for the tuning of firing angles after taking feedback from the calculated THD.

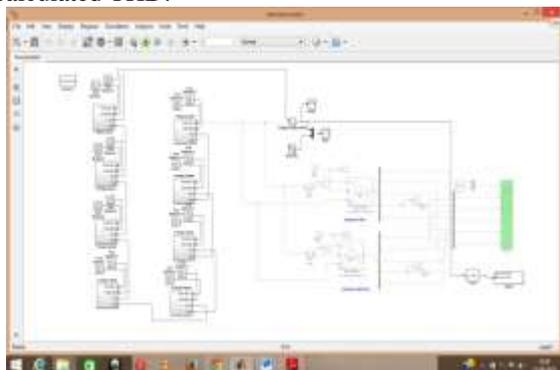


Fig. 3 Complete Design of Multilevel Inverter fed Induction Motor model without PSO

Fig. 3 shows the complete model of the multilevel inverter fed induction motor, without Particle Swarm optimization. THD analysis is done without using any algorithm.

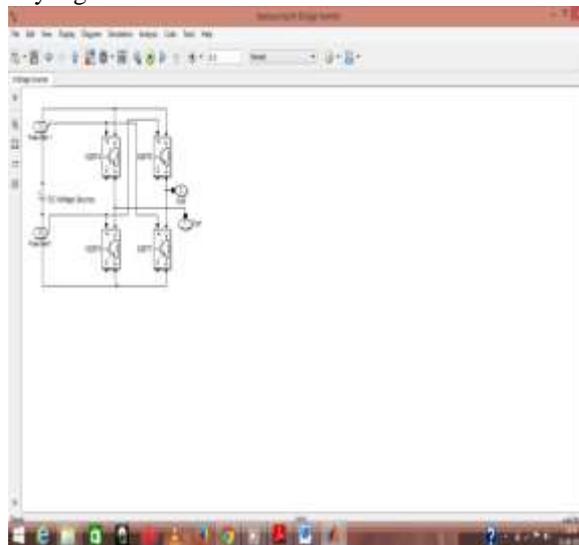


Figure 4: Individual components of H-Bridge Inverter

Figure 4 shows the individual H-bridge inverter which is implemented and cascaded using subsystem in the main model. The output of the individual inverters is kept around 8V.



Figure 5: Output of Multilevel inverter

Figure 5 shows the motor voltage when PSO algorithm is applied and is compared to the reference sine wave. The total Harmonic distortion is found to be 8.03% without using PSO while it comes down to 6.9% when PSO algorithm is applied.

Algorithm	Without PSO	With PSO
THD Value (%)	8.03%	6.9%

The THD has been taken as the optimization function for the Particle Swarm Optimization. The PSO is implemented by generating random particles in the given range and updating each particle using

the update rule of PSO. The best position of each particle is found out and called pbest and the best of all pbest is called as gbest.

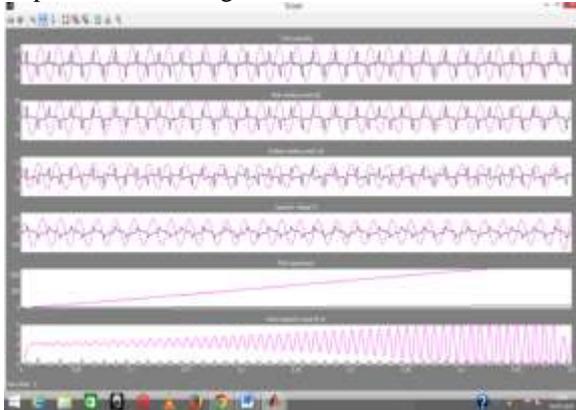


Fig 6: Simulation results of currents, capacitor voltage, electromagnetic torque, and rotor speed of Induction Motor using PSO.

VI. CONCLUSIONS AND FUTURE SCOPE

PSO (Particle swarm optimization) based harmonic elimination technique has been applied in this paper for control of induction motors and the various simulations has been performed on Simulink. The results have been shown and it is supposed that the use of PSO improves the performance and also the multilevel inverters have an edge over other designs due to their design simplicity and performance. In future, other algorithms can be implemented for the same problem and other configurations of inverters can be verified. Further, better objective functions can be considered and effect of other parameters can be considered in future.

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