GSJ: Volume 9, Issue 1, January 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

An overview of Induction Motor Design Optimization using Artificial Intelligence Techniques

Abdulraheem T. & Ike S.A.

[1]*Department of Electrical and Electronic Department, University of Benin, Edo State Nigeria.*

[2]*Power Equipment and Electrical Machinery Development Institute, Okene, Kogi State, Nigeria.*

ABSTRACT

This paper presents an overview on the optimization of induction motor design using artificial intelligence techniques. Artificial intelligence techniques are increasingly used in the optimization of induction motor as alternative to the classical approach. Numerous related works have been reviewed and their findings also presented. A lot of researchers have used different artificial intelligence optimization algorithms to optimize induction motor, with many authors claiming the superiority of the techniques used in their respective works. However, authors have only compared not more than four techniques in a study, which does not provide opportunity for a broader comparison of the many notable available techniques. In order to fill this research gap, numerous optimization techniques of not fewer than seven that have been established by researchers to be efficient need to be compared in a study, with all techniques subjected to the same conditions. Hence, providing an opportunity for a broader comparison and extensive analysis leading to a conclusive assertion of which techniques optimizes induction motor the best.

Keywords

Artificial intelligence, algorithm, optimization, induction motor.

1.0 INTRODUCTION

The induction motor (IM) is without doubt the most used electric motor and a great energy consumer. Three-phase induction motors consume 60% of industrial electricity and it takes considerable efforts to improve their efficiency. The vast majority of induction motor drives are used for heating, ventilation and air conditioning [1]. Squirrel Cage type of Induction Motor (SCIM) is the most widely used in industrial sector due to its low cost, simplicity and robustness [2]. Their development started in 1885 with Galileo Ferraris who first realized the fundamental induction motor. After that, Nikola Tesla exposed the theoretical foundations for understanding the principle of operation. In all the years since the first induction motor was produced, induction motors have been developed and modified for several reasons. In the last decade according to modern energy efficient society, the development has been oriented into the improvement of induction motor energy efficiency [3]. Improving efficiency in electric drives is important, mainly for economic saving and reduction of environmental pollution [2]. Therefore, the study of optimization of induction motor design by increasing energy saving and performance is very important as a small percentage increase in efficiency will save huge amount of energy [4].

Optimization is the process of finding a set of machine dimensions, materials, methods of assembly and so forth that constitute the best machine. In principle, it should be possible to figure out which machine is best and perhaps even to teach the computer program to seek out the optimal machine [4]. The objective of the optimization process is usually to minimize either the initial cost of the machine or its lifetime cost including the cost of lost energy. Other objectives such as mass minimization or efficiency maximization may be also appropriate in some situations. Very often, design engineers primarily rely on their experience to obtain a machine design suited for some particular purpose. This classical approach guarantees only that a fully functional design will be accomplished, but it does not ensure that this design will be accomplished with minimum amount of material used or that it will consume a minimum amount of energy in its exploitation or that its initial cost will be the smallest possible. At the same time, these are very important factors that need to be considered to make a machine more competitive in the market. If properly utilized, the optimization will lead to the design that relatively satisfies all imposed requirements, [5]. Design variables are automatically varied with computer to find the optimal solution. This computer based optimization involves the use of Artificial intelligence (AI).

In recent decades, several classical techniques such as nonlinear programming, direct and indirect search methods have been used in Induction motor design optimization. Many of these methods are most cumbersome and time consuming and pose difficulty in handling non-linear and discontinuous objectives and constraints. Besides, a few of them require derivatives and exhibits poor convergence properties due to approximations in derivative calculations, and may converge to local solution instead of global ones when the initial guess is in the neighborhood of a local solution [6]. The optimal design of electrical motors is a difficult problem because it involves many variables, which nonlinearly affect all the features and the behavior of the machine [7] .The optimization techniques which do not require a specific starting point represent a more flexible and attractive approach. Therefore, mostly metaheuristic techniques capable of solving global optimization problems subject to non-linear constraint are used [5]. Recently nature inspired metaheuristic optimization algorithms have been widely applied in solving the IM design problems with a view to overcoming the drawbacks of classical methods. These algorithms have yielded satisfactory results across a great variety of design optimization problems [6].

1.1 Induction motor

Induction motor is an electric machine that covert electrical energy to mechanical energy. It is made up of the stator, or stationary windings, and the rotor. The stator consists of a series of wire windings of very low resistance permanently attached to the motor frame. As a voltage and a current are applied to the stator winding terminals, a magnetic field is developed in the windings. By the way the stator windings are arranged, the magnetic field appears to synchronously rotate electrically around the inside of the motor housing. The rotor is comprised of a number of thin bars, usually aluminum, mounted in a laminated cylinder. The bars are arranged horizontally and almost parallel to the rotor shaft. At the ends of the rotor, the bars are connected together with a “shorting ring.” The rotor and stator are separated by an air gap which allows free rotation of the rotor. The magnetic field generated in the stator induces an EMF in the rotor bars. In turn, a current is produced in the rotor bars and shorting ring which creates another magnetic field induced in the rotor with an opposite polarity of that in the stator. The magnetic field revolving in the stator will then produce the torque which will pull on the field in the rotor and establish rotor rotation. As the rotor is free to rotate, the torque will cause it to move round in the direction of the stator field. In the design of the induction motor, operational characteristics can be determined through a series of calculations. Performing these calculations can help the engineer provide a motor that is best suited to a particular application [8].

1.2 Artificial intelligence techniques

Artificial intelligence is a branch of science which deals with helping machines find solutions to complex problem in a more human-like fashion. This is accomplished by studying how human brains think, learn, decide and work while trying to solve a problem and using the outcomes of this study as a basis of developing intelligent software and system [9]. It involves borrowing characteristics from human intelligence and applying them as an algorithm in a computer friendly way. The application of AI is endless. The technology can be applied to many different sectors and industries. AI is used in healthcare industry for dosing drug and different treatment in patient. AI also finds its application in areas like robotics, predictive search engines, e-mail spam filtering , self driving cars, optimization of processes and machines.

Genetic Algorithm, Artificial Bee Colony, Ant Colony Optimization, Cuckoo Search Optimization, Firefly Optimization, Invasive Weed Optimization, Grey Wolf Optimization, Whale Optimization, Chicken Swarm Optimization, Bat Optimization, Fuzzy Logic, Artificial Neural Network are all examples of artificial intelligence techniques. Some of these techniques are being inspired by the behaviour of social animals like ants, bee, firefly etc.

2.0 REVIEW OF RELATED WORKS

The Design of induction using different artificial intelligence techniques have been carried out by different researchers. Some of these authors along with the concept and theory of their works have been highlighted.

György et al [10] optimized a three-phase induction motor using genetic algorithm. The GA-based design approach was successfully applied to an induction motor in order to improve its efficiency, weight and power factor. The results demonstrated that the proposed method can lead to a significant improvement in the efficiency and power factor of an induction motor. It was observed that GA locates the global optimum region faster than the conventional direct search optimization techniques.

Raghuram and Shashikala [11] designed an induction motor using simplified method of genetic algorithm with the objective of maximizing efficiency. The work was implemented using MATLAB. A program was developed for the design and was tested on typical 3-ph, (1kw, 2.2kw, 5kw, 6kw, 8kw, 10kw) 400v, 3-phase, 50 Hz, 1500 synchronous r.p.m. squirrel cage induction motor. The results of the investigation clearly demonstrated that the constraints can easily be incorporated in the design optimization of the induction motor.

Abdulraheem T. et al [12] in their paper optimized the copper and iron losses of a 20kVA, 4 Pole, 3- phase, 50Hz squirrel cage inductor motor using genetic algorithm. Ten design variables were used in the optimization process. The optimization was implemented using MATLAB software. The result showed that using the analytical method (without optimization), the losses were 710 W. But with the use of genetic algorithm to optimize the design, the losses were reduced to 642W. A comparison of these two methods shows a 9.6% decrease in losses with the use of optimization, resulting into an increase in efficiency.

Ramdan et al [4] focused on the method on improving squirrel cage induction motor efficiency. The paper discussed main importance of efficient motors and its drive systems. They presented optimization of squirrel cage induction motor efficiency using intelligent techniques which are of particular interest. The study proposed to the motor manufacturers to consider the V/I maximum efficiency software control to be embedded in their motor controller to increase the motor efficiency, thus increase the energy saving.

Ranjith et al [13] presented a new approach that minimized copper & iron losses and optimized efficiency of a variable speed induction motor drive. The method was based on a simple induction motor field oriented control model. Fuzzy model identification and Particle Swarm (PSO) Optimization Algorithm were integrated for loss minimization. An improvement of efficiency was obtained by adjusting the magnetizing current component with respect to the torque current .component to give the minimum total copper and iron losses. The whole circuit was simulated using MATLAB. The proposed method was compared with other soft computing techniques. The results obtained by Fuzzy PSO showed better results compared with other approaches.

Satyajit et al [14] worked on comparison of performance of GA based design with regular design. The result showed that normal design has high air-gap length, losses and low efficiency. This is because in regular design procedure, the design parameters are selected manually whereas, in GA method the design parameters are automatically varied to find the optimal solution. So, the optimally designed motor has lower air-gap length which in turn improved power factor to a great extent. Also, there was significant increase in the efficiency due to the reduction in losses.

Aslani and Taghikhani [15] in their paper proposed parameters design and characteristics optimization of a split-phase single-phase induction motor using particle swarm optimization (PSO) algorithm. The PSO considered the motor efficiency as objective function and five performance related items as constraints. The PSO algorithm was implemented on a test motor and a code was provided under MATLAB software. The results showed that the PSO method gives more suitable design optimization against conventional methods.

Mahdavi and Monsef [16] worked on using advanced particle swarm optimization (APSO) algorithm in designing single-phase induction motor with permanent capacitor. Efficiency was taken as the objective function. The results evaluation revealed that the motor design by advanced particle swarm Optimization (APSO) algorithm made the efficiency to increase in comparison with classic methods and genetic algorithm. Also, the convergence speed of advanced PSO algorithm is more than GA method because it uses previous best position of each particle and the group to select the new velocity and position of particles.

Mohammad [17] proposed an effective method for estimating the parameters of double-cage induction motors by using Artificial Bee Colony (ABC) algorithm. The unknown parameters in the electrical model of asynchronous machine were calculated such that the sum of the square of differences between full load torques, starting torques, maximum torques, starting currents, full load currents, and nominal power factors obtained from model and provided by manufacturer were minimized. To confirm the efficiency of the proposed method, the results were also compared with those achieved by using GA, PSO, and PAMP. The simulations showed that in the problem under consideration ABC converged considerably faster than other algorithms and the results are as accurate as PAMP.

Prakash and Aravindhababu [6] presented a Harmony Search Optimization (HSO) based design methodology for maximizing both the starting torque and the efficiency of Induction Motor (IM). Among the number of design variables of the IM, seven variables were identified as primary design variables and the HSO based design methodology was tailored to optimize the chosen primary variables with a view to obtaining the global best design. It involved formulation of the problem, representation of harmonies through the chosen design variables and construction of a fitness function. The developed design methodology was applied in designing two IMs and the performances studied. The results on the two IMs clearly demonstrated the ability of the HSO to produce the global best design parameters that maximizes the efficiency and starting torque.

Radha et al [18] in their research work carried out design optimization of a squirrel-cage three-phase induction motor, selected as the driving power of spinning machine in textile industry using genetic algorithm (GA) and particle swarm optimization (PSO). Efficiency, which decides the operating or running cost of the motor (industry), was considered as objective function. First, the algorithms were applied to design a general purpose motor with seven variables and nine performance related parameters with their nominal values as constraints. To make the machine feasible, practically acceptable to serve in textile industries and less operating cost, certain constraints were modified in accordance with the demands in spinning application. Comparison of the optimum design with the industrial (existing) motor revealed that the motor designed for textile load diagram consumes less power input.

Vadugapalayam et al [19] designed three-phase induction motor based on Particle Swarm Optimization (PSO). The induction motor design was treated as a non-linear and multivariable constrained optimization problem. The annual material cost and the total annual cost of the motor were chosen as two different objective functions. The PSO was used to find a set of optimal design variables of the motor which were then used to predict performance indices. The proposed method was demonstrated with two sample motors and compared with both GA and the conventional design methods. The results showed that the PSO-based method effectively solved the induction motor design problems and outperformed the other methods in both the solution quality and computation efficiency.

Vahid and Bizhani [20] presented a new online loss minimization for an induction motor drive. In the development of the loss model, there is always a tradeoff between accuracy and complexity. The proposed online optimization determines an optimum flux level for the efficiency optimization of the vector-controlled induction motor drive. An induction motor (IM) model in d-q coordinates was referenced to the rotor magnetizing current, thus no leakage inductance was considered on the rotor side. The performance of the proposed optimization algorithm was tested by simulating different operation conditions. The result showed that the performance of the drive with PSO algorithm was improved in terms of power saving and fast response as compared to without optimization and other optimization algorithm such as LMA and GA.

Vincent and Mohammed [21] used genetic algorithm (GA), particle swarm optimization algorithm (PSO) and the simulated annealing (SA) to calculate the value of the magnetic flux in induction motor for optimal efficiency. The characteristics of the optimal magnetic flux were represented in the form of a multi-objective cost function that was developed. The results obtained showed that GA, PSO and SA can be used to calculate the value of the magnetic flux in induction motor for optimal efficiency.

Yasodha et al [7] in their paper modeled the optimal design of an induction motor as a nonlinear multi-objective optimization problem and described the different methods for its solution. The state of the art study of evolutionary multi-objective optimization was used in the induction motor design optimization. The algorithms used addressed the challenge connected with the choice of selection of the population and other factors.

Asghari et al [22] worked on a novel method in order to identify parameters of induction motors in an accurate manner. The proposed method was based on minimizing an objective function (the error between real and simulated values) by three algorithms and choosing the best method. The algorithms used were the imperialist competitive algorithm (ICA), Particle swarm optimization (PSO) and Bees algorithm (BA). Using these algorithms resulted in good parameter identification. The Results showed that the ICA has a good performance as an efficient optimization method which is used for parameter identification of motor and optimization purposes in contrast with some other identification methods like PSO, BA and traditional tests.

Mehmet and Ramazan [23] presented an optimal design method to optimize three-phase induction motor in manufacturing process. Genetic algorithm was used for optimization and three objective functions namely torque, efficiency and cost were considered. A package program that analyzes and optimizes induction motors and evaluates the cost and performance of the designs was developed. The optimally designed motor was compared with an existing motor having the same ratings. Computer simulation results showed the effectiveness of the proposed design process. Higher starting and pullout torques, larger efficiency and finally a reduced cost (by about 25%) designs were achieved.

Fazlipour et al [24] worked on an optimally designed six-phase induction motor in comparison with a non-optimally designed induction motor having the same ratings. The genetic algorithm method was used for optimization and multi objective function was considered. The results showed that the comparison of the final optimum with non optimum design indicates that the gain of the proposed performance was better , with a higher starting torques and a greater efficiency (with respect to the corresponding constraints) for a voltage at nominal load. Variations of performance characteristics (in %) of the optimum designs with phase voltage was rather low compared to the non-optimized design.

Malagoli et al [25] in their work carried out the formulation and resolution of a three phase induction motor with volume minimization and motor slip minimization as objective function. For this purpose, the Multi-objective Optimization Differential Evolution (MODE) algorithm was used, and the results were compared with those obtained with the NSGA II (Non-dominate

Sorting Genetic Algorithm). The results obtained showed that the methodology used is an interesting approach to the treatment of the formulated problem.

Neves [26] presented a multi-objective optimization design of an induction motor that operates at constant V/f, whose objective functions were active weight, power factor, efficiency, locked rotor current and locked rotor torque. The optimization was based on genetic algorithm. The result showed a variant solution in which the locked rotor current was reduced by 22.4% without affecting too much of the other goals, mainly locked rotor torque and power factor which decreased only by 9.25 % and 0.54 %, respectively. A decrease of 17.87% in copper weight with an increase of only 1.17% in iron weight was accomplished.

Sivaraju1 et al [27] proposed a design optimization method where the optimal design of multi flux stator winding was shown to improve motor efficiency and power factor in a wide load range using **p**article **s**warm **o**ptimization (PSO) algorithm. The technique was applied to the design of 7.5 kW three-phase induction motor. A package program that analyzes and optimizes induction motor in multi flux levels of stator windings was developed. Comparison of the final optimum designs was made with the existing design and it was found that optimal designs produce larger efficiency and power factor.

Thanga et al [28] presented an optimal design of poly-phase induction motor using Quadratic Interpolation based Particle Swarm Optimization (QI-PSO). The optimization algorithm considered efficiency, starting torque and temperature rise as objective function (which were considered separately) and ten performance related items including harmonic current as constraints. The QI-PSO algorithm was implemented on a test motor and the results were compared with the Simulated Annealing (SA) technique, Standard Particle Swarm Optimization (SPSO), and regular design. Some benchmark problems were used in validating QI-PSO. C++ code was used for implementing entire algorithms. QI-PSO gave better results and more suitable for the motor design optimization.

Yusuf et al [29] in their paper**,** designed parameter optimization of three-phase asynchronous motor using Artificial Bee Colony Algorithm. In the optimization process three different fitness functions were used. In the study, firstly initial parameters of the motor was determined and then these parameters compared with optimized values. Results show that all of fitness functions give better results than initial condition and improve the motor efficiency.

Chakroune et al[30] in their work titled "Design optimization of induction motor using hybrid genetic algorithm "a critical analyze"" described the procedure to determine the design of three phase electrical motors by combining a motor design program and employing a Hybrid Genetic

Algorithm (HAGs) technique to obtain the maximum of objective function such as the motor efficiency. The technique was tested and applied on 2.2 kW experimental machines. The optimal design was then analyzed by finite element method (FEM) and compared with results from genetic algorithms (GAs) optimization technique for validation.

3.0 CONCLUSION

An overview of optimization of induction motor design using artificial intelligence techniques has been carried out, with related works reviewed. Numerous techniques such as genetic algorithm, particle swarm optimization, ant colony optimization, harmony search optimization, artificial bee colony, imperialist competitive algorithm (ICA) have been employed by authors in the optimization of induction motor. While some authors considered single objective, other performed multi-objective optimization, with efficiency, losses, cost and torque as objective functions. However, comparative analysis of these techniques in the optimization of induction motor has not been broad enough (with a maximum comparison of just four techniques in a study). Therefore, more notable techniques (of at least seven) need to be compared in a study to provide an opportunity for wider comparison

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