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Efficiency determination of in-service induction machines using gravitational search optimization

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ABSTRACT

Diverse techniques have been put forth having different levels of accuracy and intrusion for evaluating the efficiency of in-service induction machines. An accurate, least intrusive method for assessing the efficiency with restricted measurements and unbalanced working supplies is needed for in-service induction motors without interrupting the electric drive process in the field. This research paper presents gravitational search optimization (GSO) to determine the induction machine efficiency in balanced/unbalanced power supply conditions. The proposed technique does not need intrusive no-load test. Proposed GSO technique utilizes the theory of Newtonian physics where masses act as agents to attain best values. The performance of proposed GSO technique for estimating the efficiency of induction machine at different load points is verified through simulation and established experimentally. Results indicate that the proposed computational intelligence technique performs better as compared to other computational based techniques like genetic algorithm and cuckoo search algorithm, with greater accuracy.

1. Introduction

Induction machines (IMs) are the workhorses in industrialized sectors. They constitute a bulk of industrial load. So, energy management of IMs is of utmost importance. Most often, IMs are working at lower loads in industry resulting in the lower IM efficiency. This reduces the production activities. So, energy management of IMs to utilize hidden potentials is the need of hour and condition monitoring plays an imperative role in estimating the efficiency of IMs in presence of asymmetric voltages. It has been observed that load variations and consequences of three-phase asymmetric voltages are overlooked for sake of convenience. Energy consumption of IMs for better energy conservation can be optimized for achieving power savings by replacing IMs of lower efficiency with energy efficient IMs of suitable ratings.

Various techniques have been employed using numerous Standards in efficiency evaluation of in-service IMs. The evaluation of output power and losses in IM is done differently for various methods resulting in different accuracies [1–3]. A novel technique for efficiency estimation under partial load conditions for heating, ventilation and air-conditioning (HVAC) applications is investigated using mechanical output quantities [4]. Application of support vector machines is presented for the identification of IM parameters with good accuracy [5]. It has been investigated that asymmetric IM is advantageous over conventional three-phase IM for driving high power loads where availability of three phase supply is not feasible [6]. Equivalent circuit method has its basis on nameplate of IM and some data assumptions results in loss of accuracy. Also, the impact of unbalancing power supply is neglected in calculations. In air gap torque method, empirical data is assumed based on mechanical output for avoiding no-load test. This reduces the accuracy in efficiency estimation. Most of these techniques work on assumptions or have a limitation of computational complexity and search space. Identification of IM parameters working in steady state using adaptive GA for reducing computational time has been used for predicting the performance of IM by solving non-linear curve fitting problem [7]. Statistical tools are used to study the fault signatures for diagnosing rotor faults in IM fed by different supplies under steady state [8]. Efficiency evaluation of in-service IM is done by measuring the vibration signature of IM by accelerometer and using Fast Fourier Transform to extricate rotor speed and supply frequency [9]. Torque and efficiency of IM is obtained by using modified stator resistance estimation using PSO for in-service applications [10]. A new adaptive observer which is implementing modified indirect field oriented control approach estimates IM fluxes and extracts IM parameters and shaft speed [11]. A least mean square method and PSO is used to identify IM parameters in steady state operation in low voltage no load starting test [12].

In evaluation of IM efficiency in industrial environmental conditions, IEEE Standard 112 is not acclaimed because this method

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considers stray load loss to be a fixed portion of mechanical output power. Still the continued efforts are devised for techniques to evaluate IM efficiency when IM operates at unbalanced power supply with varying load conditions keeping good accuracy and least intrusion levels [13]. A critical analysis for obtaining stray load loss in various international standards for efficiency estimation is demonstrated [14].

The conventional control strategies utilize mathematical model based calculations to observe speed, torque and the rotor position of IM [15]. But this approach seems not to fit due to change in values of parameters. The non-intrusive techniques may require an optimization algorithm for the assessing the IM efficiency. Various optimization techniques till now have captured much attention and have been applied to solve the associated problems. A recent method to attain rotor speed from harmonic analysis of supply current utilizing Chirp-Z Transform is demonstrated for obtaining more accuracy in efficiency evaluation procedure [16]. It has been observed that in many of the soft computing techniques, the solution search equation compromises either exploration or exploitation.

Nature based optimization algorithms are presented to select the best parameters of equivalent circuit of IM to evaluate the performance of algorithms and to determine the efficiency [17]. Unification of GA and IEEE Form-2 method F1 has been investigated for full load efficiency evaluation for IM in unbalanced scenario. It incorporates online speed detection capability on one line for acquisition of current signal [18].

Comparison of particle swarm optimization, differential evolution and their variants have been demonstrated for determining efficiency of IM using parameter identification [19]. Input electrical quantities and output mechanical wattage are the parameters in various algorithms.

In this research work, IM efficiency is estimated using GSO for balanced/unbalanced power supply. It has been found that the proposed computational intelligence technique performs better with greater accuracy as compared to other computational based techniques like GA and cuckoo search algorithm (CSA).

In this research paper, problem formulation for estimating efficiency of IM has been presented. The proposed work structure has been implemented on MATLAB platform supported by results obtained in laboratory. The findings of the proposed research are compared with other computational intelligence based techniques like GA and CSA to demonstrate the effectiveness of proposed GSO over them. It has been found that the proposed computational intelligence technique performs better with greater accuracy as compared to other computational based techniques like GA and CSA. The mathematical modeling for determining efficiency of in-service IM is presented in the following section.

2. Problem formulation for efficiency estimation

Performance of IM working under different voltages with some unbalance in voltage can be analyzed by implementing the schematic of the proposed technique presented in Fig. 1.

The negative and positive sequence fluxes are created when IM is subjected to asymmetric power supply. The positive and negative sequence equivalent circuits of IM are modeled using Ref. [23] where R_a is the stator resistance, X_a is the stator reactance, R_b is the rotor resistance of positive sequence, X_b is the rotor reactance of positive sequence, r_d is the rotor resistance of negative sequence, x_d is rotor reactance of negative sequence, R_m is the core loss component and X_m is the mutual reactance of IM.

The positive and negative sequence voltages can be utilized while analyzing IM behavior under unbalanced conditions. The positive and negative sequence components can be obtained by splitting three-phase unbalanced line voltages V_{ab}, V_{bc} and V_{ca} into two symmetrical components V_p and V_n.

With the help of model equations from Ref. [23], at each loading level, two quantities namely output power of the negative sequence and the rotor parameters based on the measured values of the negative sequence voltage, current and input real power can be obtained. An effort has been put forth to estimate the positive sequence parameters by gravitational search optimization (GSO) technique. By the utilization of parameters of IM and the unascertained coefficients, in-service IM's efficiency can be computed for any loading point. The speed estimation is achieved using model reference adaptive system employing rotor flux error vector as feedback signal from adaptive mechanism. The output signal is tuned by employing a particular integral controller to attain rotor speed. The procedure of applying the proposed computational technique is explained elaborately in the following section.

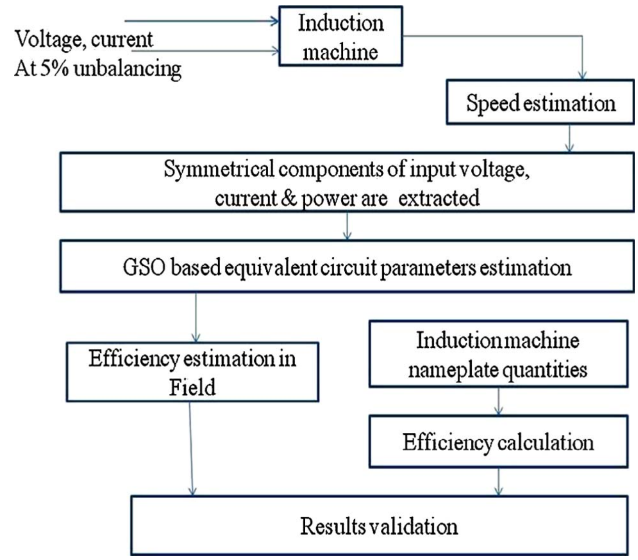

Fig. 1. Flowchart of the proposed GSO technique for estimating the IM.

3. Application of GSO technique for IM efficiency estimation

GSO technique is the newest of its kind in population based stochastic search algorithm. This technique works in accordance with Newtonian physics where its agents are masses. It was developed by Rashedi, Nezamabadi-pour and Saryazdi in 2009 [20]. This technique finds favors in optimization of non-linear problems in various disciplines. This technique employs exploration capability at the beginning to circumvent local optimum problem and then performs utilization later. The working of gravitational search optimization technique is improvised by governing exploration & exploitation. The proposed technique differs from the Ref. [20] in terms of utilization of capability of exploration and the power of exploitation. In the proposed technique, it is considered that inertial mass of agents is bigger than gravitational mass whereas in Ref. [20] it has been assumed that inertial mass and gravitational mass of agents are the same. In the proposed technique, the assumption of higher inertial mass will result in the slow motion of heavier agents in the search space. Heavier agents will experience greater force of attraction among themselves. Therefore, more precise search is performed by *Kbest* agents. Also, the merit of using higher inertial mass as compared to gravitational mass is that agents don't get trapped locally at the start of exploration process. Due to this feature, accuracy of the results is more. This added feature makes the proposed computational intelligence technique novel in nature.

In this research paper, GSO is presented for determining the efficiency of in-service IM. GSO is utilized for depreciating the error among measured efficiency and estimated efficiency. Application of GSO for the efficiency evaluation of in-service IM can be done by initializing the GSO parameters and measured values of input electrical quantities to IM, per phase resistance of stator and rotational speed of rotor of IM. Boundary conditions for equivalent circuit parameters of IM can be