Research Journal of Applied Sciences, Engineering and Technology 7(24): 5119-5128, 2014
DOI:10.19026/rjaset.7.907
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 13, 2014 Accepted: February 15, 2014 Published: June 25, 2014

Research Article

Improving the Efficiency and Power Factor of Induction Motor using Enhanced ABC with Aid of GA

[1]N. Anbalagan and [2]S. Chenthur Pandian
[1]TANGEDCO, Erode, India
[2]Mahalingam College of Engineering and Technology, Coimbatore, Tamil Nadu, India

Abstract: This study presents a technique for improving the efficiency and power factor of induction motor. In the proposed method, enhanced Artificial Bee Colony (ABC) with the aid of Genetic Algorithm (GA) algorithm is used to optimize the induction motor's parameters at various loading points. In the proposed algorithm, employed bees are generated the new solution for the input parameters by using GA. In the proposed method, GA is used for controlling the frequency of perturbation and improving the searching performance of ABC. The proposed method is used to provide the exact parameters from the optimized parameter values for all type of loading conditions. The parameters of induction motors are determined from the current, voltage, power loss, stray load losses and etc. The proposed technique is implemented in MATLAB platform and performance is evaluated. The performance of the proposed method is compared with ABC, FLC and integrated technique.

Keywords: Efficiency, enhanced ABC, frequency of perturbation, GA, power factor

INTRODUCTION

The three-phase induction motors are the most commonly employed electric motors in industry (Soltani *et al*., 2002). They run at principally regular speed from no-load to full-load. Alternatively, the speed is occurring reliant and hence these motors are not merely adjusted to speed control (Vries *et al*., 1997). We commonly select D.C. motors when vast speed variations are required. To go with most industrial requirements, however, the 3-phase induction motors are simple, rugged, low-priced, easy to continue and can be factory-made with physiognomies. We shall focus our alertness on the general principles of 3-phase induction motors (Bhalerao and Hanwate, 2012). For drives required variable speeds owing to alleviate of their speed control techniques (Bose, 1998). Only DC motors were employed before. The traditional techniques of speed control of an induction motor were either too expensive or too ineffectual as a result limiting their application to only firm speed drives (Carlin *et al*., 2003). On the contrary, recent improvements and development of speed control techniques of an induction motor have enhanced the exploit of induction motors in electrical drives commonly.

The preparatory tool requires more space and besides adds to the price of the motor. A 1-phase motor is about 30% larger than a comparable 3-phase motor (Singh, 2005) for the related output. The characteristics of single phase induction motors are similar to 3-phase induction motors separately from that single phase induction motor has no inherent starting torque and a few specified stipulations have to be prepared for making itself starting (Undrajavarapu *et al*., 2012). It chases that during starting time the single phase induction motor should be altered to a kind which is not a single phase induction motor in the logic in which the phrase is usually applied and it turns into a proper single phase induction motor when it is running and following the speed and torque have been raised to a point outside which the additional tool may be allocated (Sen, 1990).

The induction motor has comprised two important performance characteristics such as, efficiency and power factor. Several motors are oversized and under loaded, resulting in reduced efficiency and power factor (Slocombe *et al*., 1990). Unfortunately, efficiency and power factor have not gained enough attention in traditional, while low efficiency leads to more energy consumption and low power factor causes more occupation of transmission line capacity and non optimal use of inverter (Campos-Delgado *et al*., 2008; Bose, 2009). Usually, improvement in one feature might have an adverse effect on the other one. Therefore, a compromise is needed between the efficiency and the power factor (Bose, 1993; Gustafsson and Gyllenswärd, 2005). It is important to identify that when the efficiency of the motor is increased its power factor tends to decrease parallelly and vice versa. To comprehend power factor, it is cooperative to apprehend three different types of power

Corresponding Author: N. Anbalagan, TANGEDCO, Erode, India

in electrical classifications (Eltawil and Zhao, 2010; Browne and Feringa, 2006). Power factor can be improved by connecting capacitors either on an individual motor basis or, by preference, on a common bus covering several motors (Ayres *et al*., 2003). Here, an enhanced technique is used for improving the efficiency and power factor of the induction motor. By applying an enhanced ABC with aid of GA technique, the precise parameters can be forecasted while the parameter deviation at different loading conditions.

LITERATURE REVIEW

In literature, numerous related works are formerly available which stands to develop the proficiency and power factor of induction motor. Some of them reviewed here. Chandrasekaran and Manigandan (2011) have suggested three phase induction motors that are applied in more or less all the industries for its uncomplicated construction and simple function. More than 60% of the electrical energy generated was being consumed by the induction motors was anticipated. Whichever attempt to build up the proficiency and power factor will cost competent. For the induction motor which capable operation with power factor improvement is possible by replacing a Double Winding Induction Motor (DWIM). A three phase EMF was made bigger in the other winding due to mutual induction that works as an Induction Alternator (IA). For its utmost proficiency and power balancing modes of operation both mechanical and electrical load can be powered by a PIC Microcontroller. The improvement in proficiency and power factor is confirmed by a capacitor bank with incoherent steps included in the planned model. In addition, energy conservation was possible due to loading the second set of winding for which separate supply is not required.

Isfahani *et al*. (2008) have suggested Linear electrical Motors (LMs) linear motion. They go through from two main drawbacks: low competence and low power factor. Raised energy use and a raise in input current and dwell in transmission line capacity are caused by these drawbacks. Along with, to develop both competence and power factor, they present a multi-objective optimization method. These methods employ a systematic model of the machine to solve the competence and power factor. It allows us to inspect the results of dissimilar motor conditions on the proficiency and the power factor. Motor parameters and dimensions can be optimized next by using a genetic algorithm in an appropriate objective function. The effects express a development in motor concert.

Ferreira and Almeida (2008) have suggested the low-load operating periods, motor concert in terms of competence and power factor. In this presented technique, as a function of load, a multi flux level, three-phase, squirrel-cage induction motor was existing, in which the proficiency and power factor can be both used. Due to its flexibility, this novel motor can be an extra value in industry primarily, for variable load applications in which major energy savings can be achieved and can also be used as new or re-wound common purpose spare motor. The proposed motor has a stator winding with two sets of turns, distributing the related positions in the stator slots. Six modes were selected and inspected among all the possible stator winding connections. The basic principles for appropriate connection mode change were disputed. An electronic tool and a contactor thought for automatic connection mode change were proposed.

The power of the derange factors in scheming total copper losses, competence, power factor, input power, output torque, peak currents and de rating factor of the motor operating under uneven voltage system has been reviewed by Anwari and Hiendro (2010). The whole definition for the voltage unhinge is employing complex voltage-unbalance factor that encloses its magnitude and angle. A coefficient to choose either under-or over unhinge conditions was launched. The study of the motor was implemented by using the technique of symmetrical component and MATLAB software was employed to scrutinize the performance of the induction motor. To review total copper losses, input power, power factor and total output torque precisely, the reproduction effects express that the International Electro technical Commission definition of the voltage unbalance united with the coefficient of unhinge condition could be applied. On the other hand, the phase angle of the unbalance factor should be squeezed for correct computation of peak current and peak copper losses of the phase windings and de rating feature of the motor.

Bazghaleh *et al*. (2010) have suggested Linear Induction Motors (LIMs) linear motion directly, but the low proficiency, low power factor and Longitudinal End Effect (LEE) are their prime problems. Initially, they present a precise Equivalent Circuit Model (ECM) in this proposed technique. Next, they place in a factor, which can demonstrate the end result intensity in the LIM. We inspect the authority of motor design parameters on the proficiency, power factor and end result intensity at the following stage. We cultivate a number of dissimilar multi-objective functions, which will be used to improve proficiency, power factor, end effect intensity and motor weight later. Results will reveal the accuracy of the equivalent circuit model and the improvement of objective functions at the final part of the optimization procedure. Two-dimensional finite-element study reviews the effects from the ECM.

Looking upon the proficiency developments to electrical machines that could have an awfully large bang on energy use has been conversed by Mecrow and Jack (2008). The main arguments to enhanced proficiency in systems strengthen by electrical machines lounged in three regions: to lengthen the application of variable-speed electric drives into new regions by reduction of power electronic and control costs; to integrate the drive and the driven load to use system proficiency; and to increase the proficiency of the electrical drive itself. In the little to medium period, proficiency gains within electrical machines would affect from the growth of novel materials and construction methods is prepared. More or less a quarter of new electrical machines were driven by variable-speed drives. Over the following 50 years, these were a smaller amount mature product than electrical machines and must see superior proficiency gains. Progress would occur with new kinds of power electronic tools that reduce switching and conduction loss. There was a whole freedom to diverge the speed of the driven load with variable-speed drives. Replacing fixed-speed machines with variable-speed drives for a raised ratio of industrial loads could indicate 15-30% energy save. This could set away the UK 15 billion kWh of electricity per year which, when linked with motor and drive competence gains, would amount to a total annual saving of 24 billion kWh.

Cunkas and Sag (2010) have offered a method based on multi-objective evolutionary algorithms for the purpose of in-service induction motor efficiency (2008). In general, the proficiency was detected by gathering multiple objectives into one objective by a linear amalgamation and optimizing the resulting single-objective problem. The strategy has some drawbacks such that exact data about solution alternates would not be freely obvious. They made clear the multi-objective evolutionary optimization algorithms, the Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and Strength Pareto Evolutionary Algorithm-2 (SPEA2), were successfully applied to the proficiency purpose problem in induction motor.

Three-phase Induction (asynchronous) Motors (IM) are industrial work-horses, formulating the security of IM a very significant topic. To offer the motor protection functionalities like current overload, over/under voltage, etc, IM protection tools classically observe the motor current and/or voltage. One of the fascinating parameters to watch is the operating Power Factor (PF) of the IM, which offers improved under-load protection compared to the motor current-based strategies. Usually, in order to pertain the displacement technique, PF estimation would need both the voltage and the current measurements. A technique of determining the operating PF of the IM has been offered by Ukil *et al*. (2010) using only the measured current and the manufacturer data that was classically obtainable from the nameplate and/or datasheet. Experimental effects were offered to validate the possibility of their suggested technique, authenticated beside the state of the art PF assessment methods. For under load detection, Operational PF can be successfully employed, like in a pump application, or PF compensation for developing the power quality.

METHODOLOGY

Problem formulation: The development of induction motor competence and power factor are important not only from the concerns of energy savings and cooler system operation, however in addition from environmental pollution avoidance feasible. The vantage points of energy savings and associated air pollution abatement, it is obvious that higher induction motor operating competence is a subject. The competence of an induction motor system is a composite function of the motor, converter and control system. As a result, that in literature, dissimilar kinds of control method is applied for enhancing the competence and power factor of induction motor. Due to strong nonlinear magnetic saturation results and temperature dependence of the motors electrical parameters, the conventional control of an induction motor is made difficult. In common, the conventional control strategies require a compound mathematical model of the motor to enlarge controllers for measures such as speed, torque and position. This mathematical model based calculations have to be accomplished mainly for each motor and the resulting model based controllers may not implement well if temperature change causes parameter values to change. In order that, the difficulty of the online search strategies comprises their difficulty with their potential propensity to display slow convergence. ABC has captured much attention and has been applied to solve the above optimization problems since its invention. The solution search equation of ABC is good at exploration but poor at exploitation which results in the poor convergence. In the study, an enhanced ABC with aid of GA algorithm is proposed to maximize the efficiency and power factor of induction motor. Using the proposed technique, the efficiency and power factor parameter of the induction motor is optimized.

Evaluation of induction motor parameters: The efficiency and power factor of the induction motor mainly depends on the voltage magnitude, stator and rotor resistance, stator and rotor leakage reactance, magnetizing resistance, leakage reactance, stator and rotor current, stray resistance and etc. So, efficiency of the induction motor is maintained by controlling the above mentioned parameters. It can be formulated as a multi-objective problem with the following objectives and constraints:

$$\text{Min } y = f(x) \tag{1}$$

$$\text{Subject to } h(x, u) = 0 \tag{2}$$

$$p(x, u) \le 0 \tag{3}$$

where, y is the objective function, h is the equality constraints and p is the inequality constraints which depends on the control variables x and u. The voltage magnitude is having its own lower and upper bound. The input power and output power of the induction motor can be estimated by the following Eq. (4) and (5):

$$P_e^{in} = 3[I_s^{2E} R_s + I_r^{2E}(R_r/S + R_{sy}) + I_m^{2E} R_m] \quad (4)$$

$$P_e^{out} = (3I_r^{2E} R_r)\left(\frac{1-S}{S}\right) \quad (5)$$

where,

$I_s^E = \left|\frac{V_s^E Y_s Y_r}{Y_s + Y_r + Y_m}\right|$ = The estimated stator current

$I_r^E = \left|\frac{V_s^E Y_r}{Y_s + Y_r + Y_m}\right|$ = The estimated rotor current

$I_m^E = \left|\frac{V_s^E Y_r}{R_m(Y_s + Y_r + Y_m)}\right|$ = The estimated magnetizing current

Then the voltage can be expressed as:

$$V_s^E = V_s/\left(\sqrt{3}\right) \quad (6)$$

where,

V_s^E = The stator per phase voltage

$Y_s = \frac{1}{R_s + jX_s}$ = The stator admittance

$Y_r = \frac{1}{(R_r/S) + R_{sy} + jX_s}$ = The rotor admittance

$Y_m = -\frac{1}{X_m} + \frac{1}{R_m}$ = The equivalent admittance of the parallel branch

The three phase induction motor power factor can be calculated by the following Eq. (7):

$$Cos\phi^E = \frac{\mathrm{Re}al(I_s^E)}{I_s^E} \quad (7)$$

The efficiency of the three phase induction motor can be estimated by the following equation:

$$\eta_e = \left(\frac{P_e^{out}}{P_e^{in}}\right) \quad (8)$$

where, η_e is the estimated efficiency and P_e^{out} and P_e^{in} is the estimated output and input power. From the above mentioned parameter evaluations are utilized to discover the induction motor operation efficiency and power factor at various loading points. It should be estimated from half loading to over loading conditions. The actual efficiency and power factor of the induction motor at various loading points are determined by the different techniques. It is important to note that these measured parameters are used to compare and verify the estimated efficiencies. Then the determined parameters are compared with the estimated efficiency and power factor. Minimization of error between them is considered as the fitness function of the proposed method. The minimized error between the measured and estimated parameters provides the increased efficiency and the power factor.

Using enhanced ABC with aid of GA for optimizing parameters of induction motor: ABC algorithm is a swarm based meta-heuristic algorithm which was stimulated by the sharp foraging behavior of the honey bees. Employed bees, onlooker bees and scout bees are the three components of ABC algorithm. The employed bees are combined with the food sources in the area of the hive and they transmit the information to the onlookers about the nectar quality of the food sources they are using. Onlooker bees are gazing the dance of the employed bees within the hive to choose one food source to use according to the information presented by the employed bees. The employed bees whose food source is discarded turn out to be Scout and looking for novel food source randomly. The number of food sources indicates the position of possible solutions of optimization problem and the nectar amount of a food source indicates the excellence of the solution (Ouadfel and Meshoul, 2012).

Even though scout bees are liable for the process of searching, the process of improvement is carried out by employed and onlooker bees in ABC algorithm. Now, a novel candidate solution is fabricated by moving the old solution and it is chosen arbitrarily from the population. Alternatively, there is no promise that the novel candidate solution is healthier than the previous one. Subsequently, the progress skills of the algorithm require adapting this process in a way to direct the search towards promising regions (Hardiansyah, 2013). In this part, we explain a few alterations to develop the ABC algorithm and it indicates how to attain the optimal effects. For optimizing the parameters of the induction motor, the suggested technique is employed. Now, improved ABC with help of GA is utilized for enhancing the competence and power factors of induction motor. The precise value can be forecasted by the suggested method during the parameters deviation time from the optimized parameters. It forecasts the precise parameters by the expert system. The suggested method is momentarily elucidated in the subsequent section.

Procedure of proposed algorithm:

Initial phase:

Step 1: First the population of input current, efficiency and power factor of the food sources X^j_i (i = 1, 2…N) are generated arbitrarily. Where, N denotes the size of the population. This food sources contains the input parameters of the induction motors, which are the stator resistances, rotor resistances, stator leakage, rotor leakage and magnetizing reactance values. This generation process is called as initialization process.

Step 2: To evaluate the best parameter of the induction motor, the fitness value of the input parameter is calculated using Eq. (9):

$$Fitness\ function\ \ F_i^j = \min\begin{pmatrix} f_1(x) \\ f_2(x) \\ f_3(x) \end{pmatrix} \tag{9}$$

After the calculation of fitness value, the iteration is set to 1. After that, the phase of employed bee is carried out. The absolute error function of the multi-objective formulation can be described in the following manner:

$$f_1(x) = \left| I_s^E - I_s^A \right| \tag{10}$$

$$f_2(x) = \left| P_{inp}^E - P_{inp}^A \right| \tag{11}$$

$$f_3(x) = \left| COS\phi^E - COS\phi^A \right| \tag{12}$$

Employed bee phase:

Step 3: Optimal controlling frequency of perturbation in ABC using GA:

Initialization: In the section, new population parameters are generated randomly using GA. In GA, the new population parameters are initiated randomly:

$$x_i^j = \left(x_i^1, x_i^2 \ldots\ldots\ldots\ \ldots\ldots\ldots\ x_n^d \right) \tag{13}$$

where, (i = 1, 2…n), (j = 1, 2…d) and V_i^j is the new parameter value of the jth position.

Fitness calculation: Then the fitness value is computed for every new generated population parameters of induction motor:

$$V_i^j = \begin{cases} x_i^j + \phi_i^j (x_i^j - x_k^j), if\ \ rand_i^j < M_r, \\ x_i^j, \qquad\qquad\qquad otherwise \end{cases} \tag{14}$$

where, k and j are the randomly chosen index. From the computed fitness value of the population, the frequency of perturbation parameter is controlled and the best population parameter is selected. Here, the frequency of perturbation is based on the modification rate M_r which controls the number of parameters to be modified. In the above equation, $rand_i^j$ is a uniformly distributed random real number within the range (0, 1). For each parameter x_i^j a uniformly distributed random real number ($0 \leq rans_i^j \leq 1$) if the real number is less than the modification rate, the parameter x_i^j is modified.

Crossover: Crossover is nothing but the creation of one or more offspring from the parents chosen in the pairing process. The crossover operation is based on the crossover rate. The crossover rate can be calculated by using the following equation:

$$crossover\quad rate = \left(\frac{number\ of\ genes\ crossovered}{chromosome\ length} \right) \tag{15}$$

There are different types of crossover operators, they are: one point crossover, two point, uniform, arithmetic, heuristic crossovers. After crossover operation, mutation operator takes place.

Mutation: Mutation adjusts one or more gene values in a chromosome from its initial state. It prevents the population from stagnating at any local optima. Mutation is mainly based on mutation rate. It is expressed as:

$$mutation\quad rate = \left(\frac{mutation\ \ point}{chromosome\ length} \right) \tag{16}$$

Some of the mutation operations are Flip bit, Boundary, uniform, non-uniform and Gaussian. After mutation, new offspring are produced and these are updated in the population to form the next generation of the population. After updating the population, save the optimal parameter solution and the above process is repeated until it reached the maximum iteration. From the output of the GA, the frequency of perturbation parameter is controlled based on their fitness function.

Step 4: After applying GA, the fitness value is computed for every new generated population parameters of induction motor using Eq. (9).

Step 5: The greedy selection is applied between X_i^j and V_i^j parameters. From the fitness value of the input parameter, calculate which one has the highest fitness value.

Onlooker bee phase:

Step 6: After selecting the best population parameter, probability of the selected parameter is computed using the Eq. (4):

$$P_i^j = \frac{F_i^j}{\sum_{j=1}^{d} F_j} \quad (17)$$

where, k and j is a random selected index, ϕ is randomly produced number in the range (-1, 1) and P_j is the probability of the j^{th} parameter. After computing the probability of the selected parameter, number of onlooker bee is estimated. Following, generate new solutions (V_i^j) for the onlooker bees from the solutions (x_i^j) based on the probability value (P_j). Then the fitness function is calculated for the new solution. Subsequently apply the greedy selection process in order to select the best parameter.

Step 6: Apply the selection process to find the better fitness of the new solutions. For each onlooker bee produce the new solutions using the equation. Neighbourhood of solution selected is depending on the probability and evaluate it.

Scout bee phase:
Step 7: Determine the Abandoned parameters for the scout bees. If any abandoned parameter is present, then replace that with the new parameters discovered by scouts using the following equation and evaluate the fitness value:

$$x_i^j = x_{\min}^j + rand\,[0,1](x_{\max}^j - x_{\min}^j) \quad (18)$$

Then memorize the best parameters achieved so far.

Step 8: Then the iteration is incremented and the process is continued until the stopping criterion is reached:

Cycle = cycle + 1

In addition, in the conventional ABC, a new solution is produced by changing only one parameter of

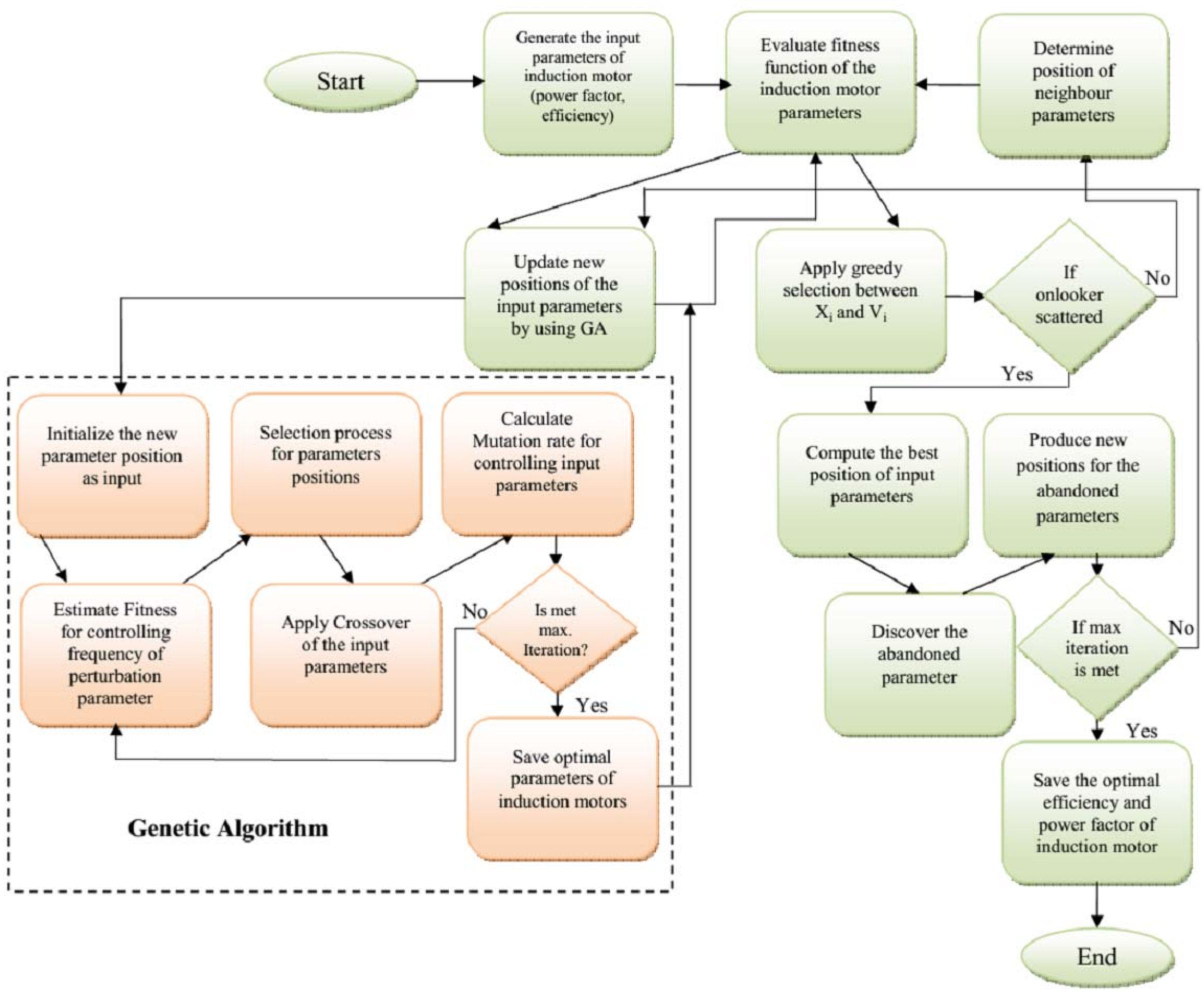

Fig. 1: Flow chart for enhanced ABC with aid of GA for optimizing induction motor parameters

the memorized solution, but the adaptive ABC is controlling the frequency of perturbation parameters and improving the efficiency and power factor of the induction motor. The flow chart of the proposed method diagram is illustrated in Fig. 1.

RESULTS AND DISCUSSION

The proposed method is used to improve the efficiency and power factor of the induction motor by optimizing their parameters. In this section, the implementation parameters of the induction motors are specified. The proposed method using the 5.4 HP, 380 V, 50 Hz, 4 pole induction motor and the parameters configurations of the motor can be specified. Here, the stator Resistance is (R_s) and the rotor resistance value is taken as 3.9 and 4.2 Ω, respectively. Then the stator reactance (X_s) and the rotor reactance (X_r) value is specified as 6.6 and 6.4 Ω, respectively. Then the mutual Resistance (R_m) and mutual reactance (X_m) are represented as 136.5 and 1382, respectively. The proposed method is implemented in MATLAB platform and analyzed their performances.

Performance analysis: In the study, the enhanced ABC with aid of GA is used and their performance has been evaluated. In the proposed method, ABC algorithm is used to optimize the induction motor parameters. Here, the employed bees are generated by using GA, which is controlling the frequency of perturbation. Also, GA is used for improving the searching performance of ABC algorithm. The control parameter of the proposed algorithm is denoted as modification rate, limit and frequency of perturbation. Then, the proposed method minimizes the error between estimated induction motor parameters and actual parameters under various load conditions. From the performance evaluation, the optimal efficiency and power factor of the various load condition is calculated. The implementation parameter of the proposed algorithm is tabulated in Table 1.

Table 1: Implementation parameters of the proposed algorithm

Parameters	Range
Number of colony size (NP)	20
MCN of ABC	50
Number of food source	20
Chromosome of GA	(10*20)
Minimum and maximum iteration of GA (x_{min}, x_{max})	(50, infinity)

The three phase induction motor parameters are estimated with the suitable equations and specified values. This can be established for various loading conditions i.e., half loading to over loading conditions. The various techniques are used to determine the actual parameters of the induction motor such as ABC, FLC, ABC-FLC and proposed technique; it is also evaluated for half loading to over loading conditions. From the optimized parameters, the exact value can be predicted during the parameters variation time. From the actual and estimated values, calculates efficiency and power factor of the induction motors in the proposed method and other methods. After that, these values are compared with the proposed method. Then the effectiveness of the proposed method has been analyzed. The estimated values and actual parameter values of the various methods are illustrated in Table 2 and 3. The performance of efficiency and power factors of the proposed method is analyzed and their values are tabulated in Table 4. The performance comparison of the efficiency in various methods method is illustrated in Fig. 2.

From the below table, current, power factor, input power, load percentage, rotor speed and efficiency are

Table 2: Estimated data of three phase induction motor

Load (%)	Voltage (V)	Rotor speed (rpm)	Input current (A)	Power factor	Input power (KW)	Efficiency (%)
120	380	1410	3.4621	0.9102	2.07424	83.4797
100	380	1420	3.1881	0.8905	1.86860	83.9177
90	380	1430	2.9189	0.8644	1.66070	84.1800
70	380	1440	2.6572	0.8293	1.45031	84.1806
50	380	1450	2.4069	0.7811	1.23740	83.7720

Table 3: The efficiency and power factor using ABC

Load (%)	Voltage (V)	Rotor speed (rpm)	Input current (A)	Power factor	Input power (KW)	Efficiency (%)
120	380	1410	3.48	0.91	2.152	80.20
100	380	1420	3.19	0.90	1.790	84.26
90	380	1430	2.97	0.86	1.655	84.62
70	380	1440	2.59	0.81	1.453	84.58
50	380	1450	2.48	0.79	1.251	84.26

Table 4: Actual data of three phase induction motor at 380 V, 50 Hz in proposed method

Load (%)	Voltage (V)	Rotor speed (rpm)	Input current (A)	Power factor	Input power (KW)	Efficiency (%)
120	380	1410	2.9617	0.89164	1.732	83.0791
100	380	1420	2.6479	0.96000	1.568	83.9994
90	380	1430	2.3305	0.85425	1.398	83.6761
70	380	1440	2.0093	0.85347	1.221	84.2567
50	380	1450	1.6843	0.81250	1.037	83.9363

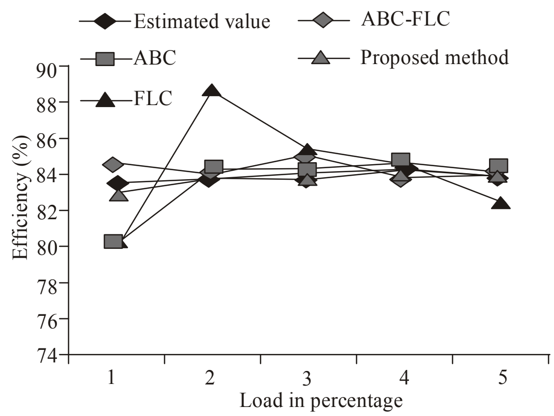

Fig. 2: Performance comparison of efficiency in various methods

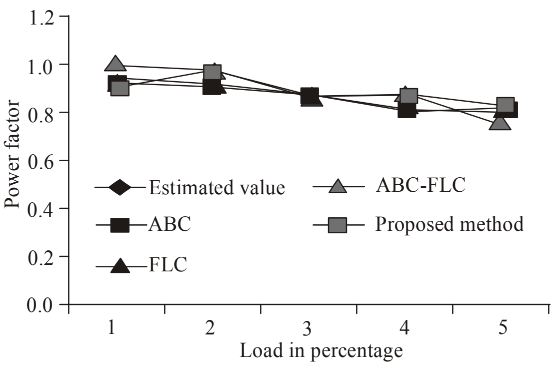

Fig. 3: Performance comparison of power factor in various methods

illustrated in various methods. Then the effectiveness of the proposed technique has been illustrated in the graphical representation. Comparing to the other techniques parameters, proposed technique parameters are much closer to the estimated parameters. The analysis used to calculate the percentage error in efficiencies and the percentage error in power factor, which describes the proposed method, has the minimized errors compared to the other techniques. Also, evaluates their percentage error in the ABC, FLC and ABC-FLC methods. The estimated power factor and power factor for various techniques in different loading points are described in the Fig. 3. The power

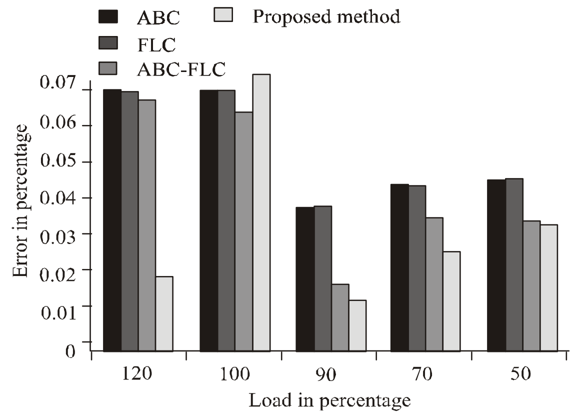

Fig. 4: Comparison of efficiency errors in percentage

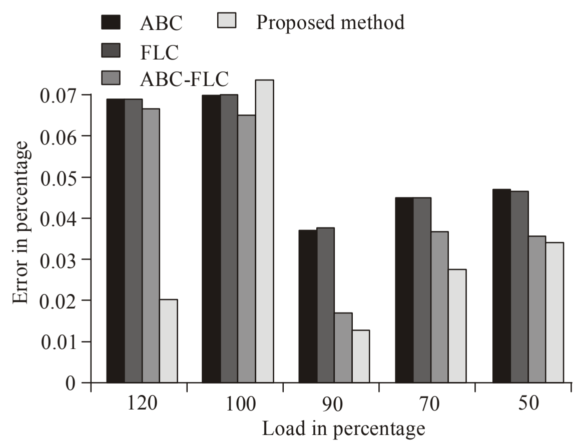

Fig. 5: Comparison of power factor errors in percentage

factor errors percentage can be calculated using the following equation:

$$Errors\left(Pf\right)=\left(\frac{COS\phi^{E}-COS\phi^{A}}{COS\phi^{A}}\right) \tag{19}$$

From the above equation, the percentage of power factor error values are determined and compared with the other methods. The percentage efficiency error in efficiency and power factor performance of the proposed method and other methods parameters values are tabulated in Table 5 and 6. Moreover, compares the performance of the percentage errors in efficiency and

Table 5: The efficiency and power factor using FLC

Load (%)	Voltage (V)	Rotor speed (rpm)	Input current (A)	Power factor	Input power (KW)	Efficiency (%)
120	380	1410	3.48	0.91	2.152	80.10
100	380	1420	3.19	0.90	1.790	88.86
90	380	1430	2.97	0.86	1.655	85.35
70	380	1440	2.59	0.81	1.453	84.65
50	380	1450	2.48	0.79	1.251	82.62

Table 6: The efficiency and power factor using ABC-FLC method

Load (%)	Voltage (V)	Rotor speed (rpm)	Input current (A)	Power factor	Input power (KW)	Efficiency (%)
120	380	1410	3.48	0.9751	2.152	84.02
100	380	1420	3.19	0.9509	1.790	84.04
90	380	1430	2.97	0.8499	1.655	85.00
70	380	1440	2.59	0.8624	1.453	83.90
50	380	1450	2.48	0.7485	1.251	84.01

Table 7: Comparison of percentage error in efficiency

Speed (RPM)	Load (%)	ABC	FLC	ABC-FLC	Proposed method
1410	120	3.27	3.37	0.55	0.4006
1420	100	0.35	4.95	0.13	0.0817
1430	90	0.44	1.17	0.82	0.5039
1440	70	0.40	0.47	0.28	0.0761
1450	50	0.49	1.15	0.24	0.1643

Table 8: Comparison of percentage error in power factor

Speed (RPM)	Load (%)	ABC	FLC	ABC-FLC	Proposed method
1410	120	0.0668	0.0668	0.0649	0.01856
1420	100	0.0665	0.0665	0.0604	0.06950
1430	90	0.0344	0.0344	0.0145	0.01015
1440	70	0.0417	0.0417	0.0331	0.02417
1450	50	0.0431	0.0431	0.0326	0.03140

power factor of these methods are illustrated in the Fig. 4 and 5. The efficiency and power factor error percentages are compared with various methods and these are tabulated in Table 7 and 8.

The efficiency and power factors are the important factors of the induction motors. These factors depend on the stator resistance, rotor resistance, stator reactance, rotor reactance, mutual resistance and mutual reactance, which are determined by using proposed method. The frequency of perturbation is controlled by using the proposed algorithm and the error percentage in efficiency and power factor are determined. From the performance analysis, the proposed method achieves better results compared with other methods.

CONCLUSION

In the study, an enhanced ABC with aid of GA is proposed to maximize the efficiency and the power factor of induction motor. Here, the induction motor parameters are optimized by the proposed algorithm at various loading conditions. From the optimized parameters the exact value has been predicted by the proposed algorithm. The proposed method has been implemented in the MATLAB platform. The proposed technique was tested with the 5.4 HP induction motor, which shows that the proposed method is effective for the efficiency determination with reduced estimation errors, i.e., less than 1% at nominal loads. The performance of the proposed method is compared with the ABC, FLC and ABC-FLC. The comparative results have proved that the proposed technique achieves optimal results for improving the efficiency and power factor of the induction motor compared to the other techniques.

REFERENCES

Anwari, M. and A. Hiendro, 2010. New unbalance factor for estimating performance of a three-phase induction motor with under-and overvoltage unbalance. IEEE T. Energy Conver., 25(3): 619-625.

Ayres, R.U., L.W. Ayres and B. Warr, 2003. Exergy, power and work in the US economy, 1900-1998. Energy, 28(3): 219-273.

Bazghaleh, A.Z., M.R. Naghashan and M.R. Meshkatoddini, 2010. Optimum design of single-sided linear induction motors for improved motor performance. IEEE T. Magn., 46(11): 3039-3047.

Bhalerao, R. and S. Hanwate, 2012. Study of designing regulator systems by using the different observer approach. IOSR J. Electr. Electron. Eng., 1(5): 1-5.

Bose, B.K., 1993. Power electronics and motion control-technology status and recent trends. IEEE T. Ind. Appl., 29(5): 902-909.

Bose, B.K., 1998. Technology trends in microcomputer control of electrical machine. IEEE T. Ind. Electron., 35(1): 160-177.

Bose, B.K., 2009. Power electronics and motor drives recent progress and perspective. IEEE T. Ind. Electron., 56(2): 581-588.

Browne, W.R. and B.L. Feringa, 2006. Making molecular machines work. Nat. Nanotechnol., 1: 25-35.

Campos-Delgado, D.U., D.R. Espinoza-Trejo and E. Palacios, 2008. Fault-tolerant control in variable speed drives: A survey. IET Electr. Power App., 2(2): 121-134.

Carlin, P.W., A.S. Laxson and E.B. Muljadi, 2003. The history and state of the art of variable-speed wind turbine technology. Wind Energy, 6(2): 129-159.

Chandrasekaran, V. and T. Manigandan, 2011. Double winding induction motor-an approach for improvement of power factor and efficiency. Eur. J. Sci. Res., 66(2): 262-273.

Cunkas, M. and T. Sag, 2010. Efficiency determination of induction motors using multi-objective evolutionary algorithms. Adv. Eng. Softw., 41(2): 255-261.

Eltawil, M.A. and Z. Zhao, 2010. Grid-connected photovoltaic power systems: Technical and potential problems-a review. Renew. Sust. Energ. Rev., 14(1): 112-129.

Ferreira, F.J.T.E. and A.T. Almeida, 2008. Novel multiflux level, three-phase, squirrel-cage induction motor for efficiency and power factor maximization. IEEE T. Energy Conver., 23(1): 101-109.

Gustafsson, A. and M. Gyllenswärd, 2005. The power-aware cord: Energy awareness through ambient information display. Proceeding of Extended Abstracts on Human Factors in Computing Systems (CHI EA '05). ACM, New York, USA, pp: 1423-1426.

Hardiansyah, H., 2013. Solving economic dispatch problem with valve-point effect using a modified ABC algorithm. Int. J. Elec. Comput. Eng. (IJECE), 3(3): 377-385.

Isfahani, A.H., B.M. Ebrahimi and H. Lesani, 2008. Design optimization of a low-speed single-sided linear induction motor for improved efficiency and power factor. IEEE T. Magn., 44(2): 266-272.

Mecrow, B.C. and A.G. Jack, 2008. Efficiency trends in electric machines and drives. Energ. Policy, 36(12): 4336-4341.

Ouadfel, S. and S. Meshoul, 2012. Handling fuzzy image clustering with a modified ABC algorithm. Int. J. Intell. Syst. Appl., 12: 65-74.

Sen, P.C., 1990. Electric motor drives and control-past, present and future. IEEE T. Ind. Electron., 37(6): 562-575.

Singh, G.K., 2005. A research survey of induction motor operation with non-sinusoidal supply wave forms. Electr. Pow. Syst. Res., 75(2-3): 200-213.

Slocombe, J.W., L.E. Wagner, A.J. Heber and J.P. Harner, 1990. Test equipment for determining performance of electric motors. Am. Soc. Agr. Eng., 6(1): 97-100.

Soltani, W., B. Szabados and G. Hoolboom, 2002. A new synthetic loading for large induction machines with no feedback into the power system. IEEE T. Energy Conver., 17(3):19-324.

Ukil, A., R. Bloch and A. Andenna, 2011. Estimation of induction motor operating power factor from measured current and manufacturer data. IEEE T. Energy Conver., 6(2).

Undrajavarapu, S., M.S. Rao and L.U. Kiran, 2012. PV fed boost SPWM inverter driven single-phase induction motor. Int. J. Eng. Res. Appl., 2(4): 2136-2141.

Vries, T.J.A., J.V. Amerongen, A.M. Rankers and E.W. Gaal, 1997. Linear motor motion control using a learning feedforward controller. IEEE-ASME T. Mech., 2(3): 179-187.