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Fuzzy Logic and Firefly Algorithm based Hybrid System for Energy Efficient Operation of Three Phase Induction Motor Drives

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Abstract

Background/Objectives: Three phase induction motors have been the workforce for several industrial, manufacturing, propulsion and transportation applications for the past several years. Energy efficient operation of induction motors is the important task in industries.The objective of the present paper is to provide energy efficient operation of induction motors using soft computing techniques. **Methods/Statistical analysis:** A fuzzy logic and firefly algorithm based hybrid technique is used for performance improvement of a.c.voltage controller fed three phase induction motor drives. Simulation is done by using matlab software. **Findings:** It is shown that the conventional search method for reaching the best efficiency point has got many drawbacks. These demerits are overcomed using the proposed softcomputing techniques. **Application/ Improvements:** Improvement in motor efficiency and power factor is achieved and the motor always operates in the energy efficient region.

Keywords:A. C. Voltage Controller, Firefly Algorithm, Fuzzy Logic

1. Introduction

Energy crisis in the world plays a vital factor to reduce the economic growth of both developing and developed countries. By the survey done by WEC[1], in industrialized countries the following are the main sectors that are responsible for consumption of electricity: electric motors(particularly AC Motors) around 45%, lighting, about 15%, and home appliances and consumer electronics consumes around 15%. In order to compensate the consequences due to reduction of the availabilty source of non-renewable energy, several researcher are mainly concentrating on energy efficient motors. Three phase induction motors are the most sought after machines in industry as they are relatively less costly and rugged due to the absence of commutators. About 90% of the electrical energy consumed by industries is due to the operation of induction motors

On account of this, enhancement in the energy efficient operation of three phase induction motors will lead to save in energy. It has been proved that the efficiency improvement with reduced voltage operation of the lightly loaded induction motor drive is an attractive scheme for energy conservation. The concept is simple and many researchers have focused on it. In their study they brought out the fact that three-phase induction motors appear as the largest consumer of electricity as they are accountable for the major percentage of about 30% of the energy consumption in the world. Performance optimization of induction motor during soft starting[2] by removing supply frequency torque pulsation while the line current making as constant was presented[3].

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In 2009 presented a review of the developments in the field of efficiency optimization of three-phase induction motor through optimal control and design techniques is presented in Artificial Neural Network (ANN) was used for induction motor control[4]. In 2009 suggested the need of providing energy awareness for saving energy[5]. Even though elaborate studies have been carried out in the performance improvement of voltage controlled induction motor drives a few major drawbacks are noticed and are listed below:

1. The best efficiency point is obtained by gradually changing the SCR firing angle α. This search algorithm is similar to trial and error based one and hence in the previous works provides no clear cut in the design procedure of the controller.
2. The search technique consumes extra time for reaching the best point than can be convincingly be allowed. More the time spent, less will be the energy saved.
3. The stepwise change in stator voltage leads to reduced dynamic response of the drive system. This is more predominant in motors with low moment of inertia.
4. In search technique, the accurate point of minimum current may be missed if the change in voltage is large since the voltage-current characteristics curve is more flat in optimum efficiency region. Further by the search technique based method, the minimum current point is never attained and only persistent oscillations about this point are observed which requires an further controller.

In this paper a hybrid fuzzy logic along with firefly algorithm based approach is applied for performance enhancement of induction motor drive. It is shown that the conventional search method for reaching the best efficiency point has got many drawbacks. These demerits are overcomed using the proposed fuzzy-fire fly algorithm technique. Recently firefly algorithm has been applied to many applications[6-9].

2. Problem Formulation

The proper identification of suitable firing angle of SCR to obtain increased efficiency, particularly when there is change in load occurs is the main problem considered in this proposed work. The matrix equation of motor in stator d-q axis frame is given by

$$\begin{bmatrix} \frac{di_{ds}}{dt} \\ \frac{di_{qs}}{dt} \\ \frac{di_{dr}}{dt} \\ \frac{di_{qr}}{dt} \end{bmatrix} = \frac{1}{\sigma}\begin{bmatrix} \frac{-r_S}{L_s} & \frac{\omega_r L^2{}_m}{L_s L_s} & \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} \\ \frac{\omega_r L^2{}_m}{L_s L_s} & \frac{-r}{L_s} & \frac{\omega_r L_m}{L_s} & \frac{r_r L_m}{L_s L_r} \\ \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} & \frac{r_r}{L_r} & \frac{\omega_r L_m}{L_s} \\ \frac{\omega_r L_m}{L_s} & \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} & \frac{r_r}{L_r} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} + \frac{1}{\sigma}\begin{bmatrix} \frac{1}{L_s} & 0 & 0 & 0 \\ 0 & \frac{1}{L_s} & 0 & 0 \\ 0 & 0 & \frac{1}{L_r} & 0 \\ 0 & 0 & 0 & \frac{1}{L_r} \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qs} \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

where $\sigma = \frac{L^2{}_m}{L_s L_m}$, V_{ds} and V_{qs} are functions of α.

The torque is given by,

$$T_e = \sqrt{\frac{3}{2}}\frac{P_0}{2} L_r \left(i_{dr} i_{qs} - i_{qr} i_{ds}\right) \quad (2)$$

The electrical torque is equated to the mechanical torque and the following equation is obtained.

$$J\frac{d(\Delta\omega_r)}{dt} + F\Delta\omega_r = \Delta T_e - \Delta T_L \quad (3)$$

Based on the dynamic equations, the three phase induction motor model integrated with SCR voltage controller is developed in matlab. In the developed model, firing angle α and load torque T_L are considered as independent variables. The AC voltage controller fed Induction motor model is made to operate at specific working point with maximum efficiency using trial and error approach.

The motor current corresponding to optimum efficiency, I_{opt} is noted. Similalrly load torque disturbance is applied to the induction motor model and the motor current(new), correspond to this operating point is noted as I_{new}.

The SCR angle is slowly altered to attain minimum motor current that corresponds to maximum efficiency point. Once maximum efficiency point is attained, the SCR firing angle, α_{opt}, is measured. The proposal is to build a non-linear relational mapping between I_{opt}, I_{new} and α_{opt}. The relationship can be written as

$$\alpha_{opt} = f(I_{opt}, I_{new}) \quad (4)$$

3. Development of Fuzzy and Firefly based Algorithm for Problem

To obtain input and output fuzzy sets, simulation of SCR controller fed induction

motor drive is carried out for broad range of operating points[10,11] .

The relationship in Equation 4 is obtained through fuzzy variablesand an proper decision table is formed. Membership functions and rule base are shown in Figure 1(a),(b),(c) and 2. The membership functions are selected as triangular in shape.

The universe of discourse of I_o is characterized by 11 subsets and are grouped between I_{o1} (Optimum 1) to I_{oB} (Optimum B).

- The universe of discourse of I_{new} is described by 8 fuzzy subsets and are labeled as IN1 (New current 1) to IN8 (New current 8).

The membership functions of $\alpha_{opt(new)}$ are depicted by 7 subsets with names α_1 to α_7.

Once defining all subsets, the rule base is developed shown in Figure 2.

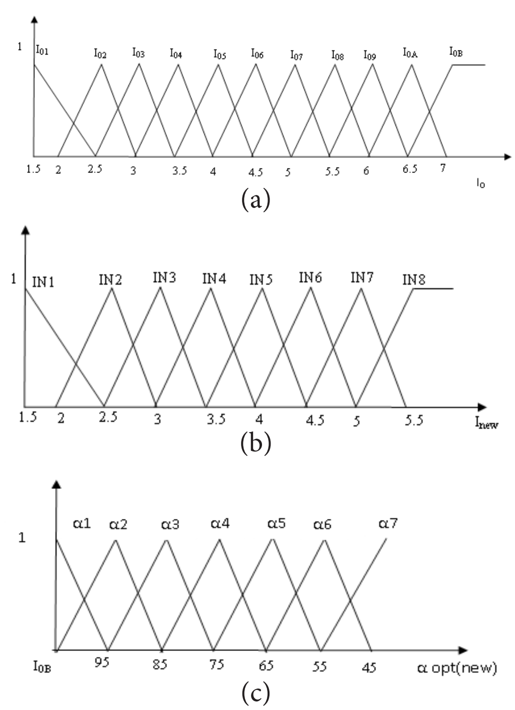

Figure 1. **(a)** Membership function of optimum current. **(b)** Membership function of new load current. **(c)** Membership function of new optimum firing angle.

I_o \ In	IN1	IN2	IN3	IN4	IN5	IN6	IN7	IN8
I_{01}	α1	α1	α3	α3	α3	α3	_	_
I_{02}	α1	α1	α2	α3	α3	α3	_	_
I_{03}	_	α2	α2	α3	α4	α4	_	_
I_{04}	_	_	α2	α3	α4	α5	α5	α6
I_{05}	_	_	α3	α3	α4	α5	α6	α6
I_{06}	_	_	_	α4	α4	α5	α6	α7
I_{07}	_	_	_	α4	α5	α6	α7	α7
I_{08}	_	α1	α1	α4	α5	α6	α7	α7
I_{09}	_	_	α2	α3	α4	α5	α7	α7
I_{0A}	_	_	α1	α1	α4	α6	α7	α7
I_{0B}	_	_	α1	α1	α5	α6	α7	α7

Figure 2. Rule base of fuzzy estimator.

3.1 Implementation of Fire Fly Algorithm

The firefly algorithm was invented by Dr. Xin she yang at Cambridge University in 2008 which was inspired by mating or flashing behavior of fireflies. This paper used to solve non-linear design problems. Here the objective function is to optimize the firing angle α_{opt} . The following shows the algorithm

Algorithm

Step 1: Start the program
Step 2: Enter the input values
Step 3: The generate initial population of firefliesxi (i = 1, 2, ..., n)
Step 4: To determine light intensity Ii at xi is determined by f(xi)
Step 5: Set the iteration count iter=1
Step 6: To calculate ith firefly for i = 1 : n all n fireflies
Step 7: To calculate jth firefly for j = 1 : n all n fireflies
Step 8: To check if (Ij> Ii), Migrate firefly i towards j in dimension;end if
Step 9: To calculate attractiveness, when Attractiveness Varies with distance r.
Step10: To Evaluate new solutions and update light intensity
Step11: end for j
Step12: end for i
Step13: Rank the fireflies and find the current best
Step14: To evaluate Iter = Iter+1
Step15: Check Iter >Iter max; the condition no means go to step 4.
Step16: Print the output
Step17: End the program.

4. Simulation Results

The following Figure 3 shows the simulation results obtained from the hybrid fuzzy based fire fly algorithm.

From the Figure 4, it is shown that at t = 0, the motor is driving a load torque of 5 N-m corresponding to optimum firing angle α = 63.2 degrees and corresponding to α = 63.2 degrees the rms value of optimum current obtained is I_{opt} = 1.3 amperes. Considering the next instance at t = 5 seconds, the load torque is decreased to 1.0 Nm and the corresponding new value of the motor current is 0.8 amperes. The firefly algorithm calculate approximately the value of the finest SCR firing angle to be 93.9 degrees and the ac voltage controller is now allowed to fired at this optimum angle. Thus value of voltage and current waveforms corresponding to optimum value before and after load change are shown in the Figure 5.

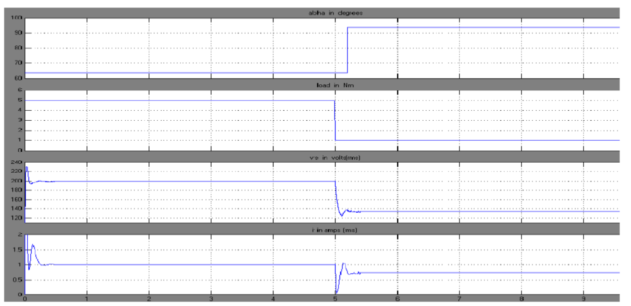

Figure 3. Dynamic response of the drive.

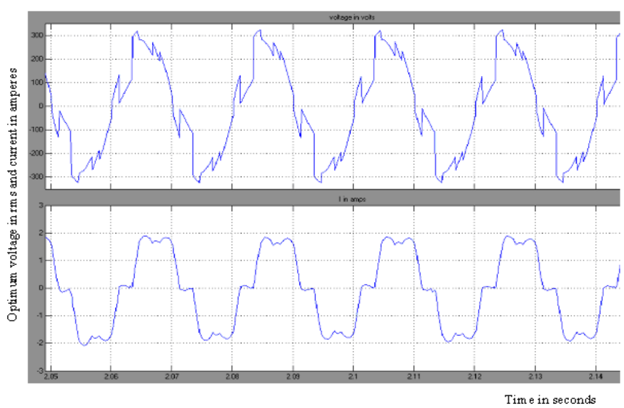

Figure 4. Voltage and current waveforms prior to load change (prior to optimization).

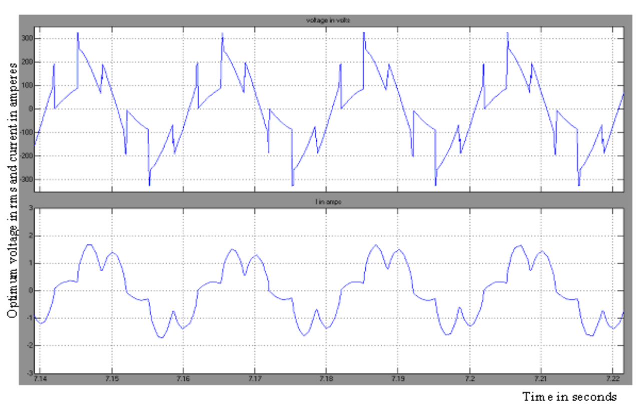

Figure 5. Voltage and current waveforms after optimization.

5. Conclusion

Thus the optimum firing angle is obtained for maximum efficiency of variable loaded three phase induction motor drive by fuzzy logic-fire fly based hybrid technique. The obtained simulation results proves that the proposed method works well and the induction motor always operates in the energy efficient region.

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