Applied Soft Computing 12 (2012) 2132–2136

Contents lists available at SciVerse ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Feedback controller design for variable voltage variable speed induction motor drive via Ant Colony Optimization

N. Rajasekar [a,*], K. Mohana Sundaram [b]

[a] School of Electrical Engineering, VIT University, Vellore 632 014, India
[b] Department of Electrical and Electronics Engineering, RMK Engineering College, Kavaraipettai, Chennai 601 206, India

ARTICLE INFO

Article history:
Received 6 May 2010
Received in revised form
22 December 2011
Accepted 4 March 2012
Available online 21 March 2012

Keywords:
PI-controller
Ant Colony
Optimization algorithm

ABSTRACT

This paper deals with the development of feed back controller design for a voltage controlled induction motor drive employing an enhanced optimization algorithm derived from the principles of foraging of natural ants. A linearized incremental model of a voltage controlled induction motor drive is shown to exhibit parameter variation at different operating points of the drive system. A PI-controller derived at a typical operating point using traditional methods does not give satisfactory performance for a wide bandwidth of load and reference speed changes. The newly developed Ant Colony Optimization technique enforces continuous exploration of the solution space and identifies optimal controller structure. The development of optimization algorithm and its application to feed back controller design for a variable voltage induction motor drive is well documented in this paper. Experimental and simulation results are presented to validate the efficacy of the optimized controller.

1. Introduction

The squirrel cage induction motor is basically a simple, less costly and reliable drive and can provide excellent characteristics at a constant shaft speed. Probably the cheapest and most reliable scheme of speed control of induction motor is stator voltage control using back-to-back connected SCRs. This scheme is widely used for certain types of loads such as fan and pump drives. It was shown that speed ranges of 5 to 1 can be easily obtained using this method [1–3]. It may be noted that Induction motors are largely employed for Fan and pump drives in various industries as outlined in [4–11]. As a real data example, one may find the applications in Pulp and Paper industries [4], Cement industries [5–7], Refineries [8], etc. to name a few. AC voltage controller fed induction motors is also used for energy efficient operation [9–11]. However, little attention is paid to the design of controller for closed loop operation using the above scheme. An experimental closed loop variable speed operation is described in [3]. The drawback of [3] is that an analytical relationship could not be established between induction motor torque and applied voltage with thyristor excitation and only an empirical approach was used. Further, motor parameter variation with different operating points is not considered. In the recent days, ac voltage controllers are used for soft starting of induction motors and as energy savers [12–14].

In this paper, an attempt has been made to develop an improved optimization technique based on Ant Colony Systems (ACS) [15,16] and is used for feedback controller design of stator voltage controlled induction motor drive. Each artificial ant is a complete solution to the problem at hand and is made to move towards increased pheromone traces. The movement of ant is probabilistically decided so as to simulate real ant movements. The optimization algorithm thus developed is employed for the feedback controller design of variable voltage induction motor drive system. The fifth order induction motor model is reduced to a first order linear incremental model and the effect of motor parameter variation on the speed response is analyzed. It is observed that, induction motor being a non-linear device, exhibits large parameter variation which requires online tuning of the controller parameters to achieve the best dynamic response at each operating point of the drive system. It is found from extensive simulation results that the proposed algorithm based on ant foraging identifies optimal controller parameters to achieve excellent dynamic response at all operating points.

2. Induction motor model

The electromagnetic torque developed by a voltage controlled induction motor can be written as given in [17]

$$T_e = f(V, \omega_r) \tag{1}$$

where V is motor phase voltage in volts and ω_r is the rotor speed in rad/s.

* Corresponding author.
E-mail address: nrajasekar@vit.ac.in (N. Rajasekar).

1568-4946/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.asoc.2012.03.012

Table 1
Induction motor parameters at different operating points.

α_0	ω_{ro}	K_a	K_w
80.0	154.4	0.666	−2.500
81.5	152.0	0.667	−0.667
90.0	150.80	0.372	−0.633
93.0	148.6	0.500	−0.800

With thyristorised voltage control, the motor voltage is varied using SCR firing angle, α. Hence, the torque equation of such a drive can be re-written as

$$T_e = f(\alpha, \omega_r) \tag{2}$$

Assuming small perturbations on each variable in (2) and using Taylor Series, the transient process can be described by the following equation [18]:

$$\Delta T_e = K_a * \Delta\alpha + K_w * \Delta\omega_r \tag{3}$$

where

$$K_a = \left.\frac{\Delta T_e}{\Delta\alpha}\right|_{\omega_r=\text{constant}}$$

is expressed in N-m/degrees and

$$K_w = \left.\frac{\Delta T_e}{\Delta\omega_r}\right|_{\alpha=\text{constant}}$$

is expressed in N-m/rad/s.

Eq. (3) represents the linearized model of a.c. voltage controller fed induction motor at a particular operating point.

Now, equating the electrical torque developed by the motor with the mechanical torque required to drive the rotor and load, the following equation is obtained.

$$J\frac{d(\Delta\omega_r)}{dt} + F\Delta\omega_r = \Delta T_e - \Delta T_L \tag{4}$$

2.1. Determination of K_a and K_w

The values of K_a and K_w are obtained from the steady state speed-torque characteristic curve of the motor and for details one may refer to [18]. The parameters of induction motor at different operating points are obtained and are given in Table 1.

2.2. Performance of the drive with a PI-controller

For closed loop speed regulation, a PI-controller is now introduced with the small signal model of induction motor. The block diagram of the system is shown in Fig. 1. Assuming the change

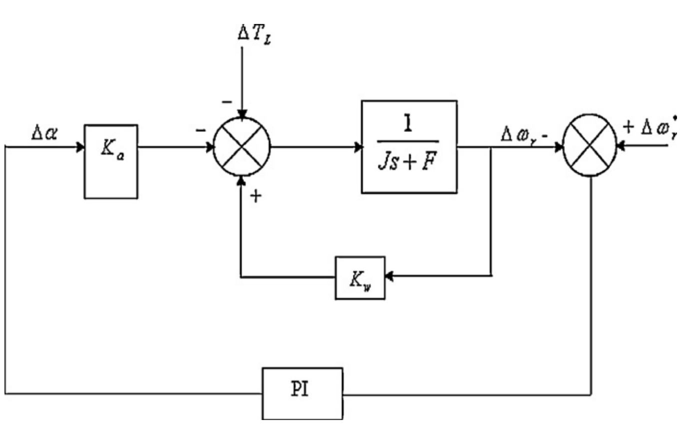

Fig. 1. Induction motor drive with PI-controller.

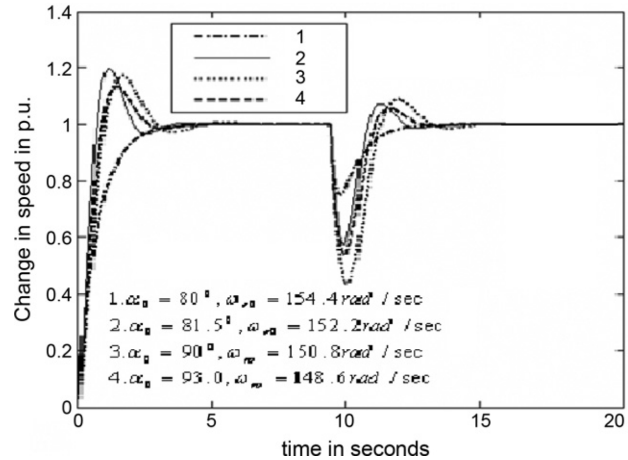

Fig. 2. Speed response with PI-controller for different operating points α_0 and ω_{ro}.

in speed reference $\Delta\omega_r^*$ is zero, the transfer function with load disturbance is obtained as

$$\frac{\Delta\omega_r(s)}{\Delta T_L(s)} = \frac{-s}{Js^2 + (F + K_aK_P - K_W)s + K_aK_I} \tag{5}$$

At a typical operating point, the controller constants are now calculated and the drive response is now simulated for unit step input at $t = 0$ and for load disturbance at $t = 10$ s. The transient response of the motor is depicted in Fig. 2. It is obvious that controller designed at one operating point does not guarantee satisfactory response at other operating points.

3. Controller design using ACS

The ACS was proposed in [15] by Marco Dorigo, Vittorio Maniezzo and Colorni and subsequently modified in [16]. The basic tenet of ACS is that real ants are capable of finding shortest paths from their nest to food sources and back. They can perform this behaviour due to a simple pheromone laying mechanism on the ground. When ants move from their nest to the food source they move randomly, but their random movements are biased by pheromone trails left on the ground by preceding ants. Because the ants that initially chose the shortest path arrive at the food first, this path will be seen as most desirable by the same ants during their journey back to the nest. This, in turn, will increase the amount of pheromone deposited on the shortest path. Eventually this auto-catalytic process causes all the ants to take the shortest path. Recently, Ant Colony Optimization is employed for a few engineering applications and are seen in [19,20].

In this paper, improved dynamic response of the drive is formulated as an optimization task and is stated below; let $\Delta\omega_{rp}$ and t_s represent the peak overshoot and settling time respectively. Then we can write,

$$\begin{aligned}&\text{Minimize } F(\phi) = (1 + \Delta\omega_{rp})(1 + t_s)\\ &\text{Subject to } \quad \phi_{\min} \le \phi \le \phi_{\max}\end{aligned} \tag{6}$$

where Φ is a set containing controller elements namely K_P, K_I and K_D.

The following steps describe how ACS is applied to the problem under consideration.

Step 1: Deploying ants initially

The initial step involved is deploying the ants in a feasible solution space randomly subject to the constraint $\phi_{\min} \le \phi \le \phi_{\max}$. Here, position of an ant refers to one complete solution set to the problem. In this work, there are three variables to be optimized namely K_P, K_I and K_D. Hence, the