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Grey Wolf Optimization Algorithm Based Speed Control of Three Phase Induction Motor

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ABSTRACT

Three phases Induction motor is a universal motor used in industrial applications exhibits nonlinear property and the incorporation of SCR voltage Controller with an induction motor makes the system more complex and difficult to analyze. Hence the design and development of a feedback controller to maintain speed regulation of induction motor is a major challenge. The dynamic characteristics obtained by traditional Proportional Integral controller are very poor at various working points of the drive. Considering the above fact, this article presents a novel Grey Wolf Optimizer Algorithm for controller design and utilized for regulating the speed of induction motor drive and also the proposed system nullifies the parameter variation and disturbance rejection which is validated through simulation and experimental results.

Keywords: Induction motor, SCR, PI controller, Grey Wolf Optimizer Algorithm

1. INTRODUCTION

The squirrel cage three phase induction motor is trouble free, cost effective and used as driving mechanism for majority of operations in industries such as pulp, paper industries, cement industries, refineries, agriculture, commercial complexes etc. The stator voltage control approach is economical and convenient way of regulating the speed of induction motor and is employed for fans and pump drives. [1-3]. The controller design part has to be consider little attention for closed loop speed control systems using stator voltage controlled system. Even though AC voltage controlled system is simple, the study of system is complicated owing to nonlinear and complicated dynamic motor equations. The closed loop variable speed operation along with experimental setup is described in [3]. The drawback of the above system is that an analytical connection was not set up between motor torque and supply voltage. Ac voltage controllers are also acts as soft starters as well as energy savers [4-6]. SCR voltage controller fed induction motor system is defined by a fifth order differential equation and provides large variation of motor speed. Most of the earlier works linearized the motor models for the controller design. In this paper, a new small signal model of Induction motor is first derived and Grey wolf Algorithm (ACO) is used for the tuning of an optimal controller.

2. MATERIALS AND METHODS

2.1. Modeling of Induction motor

Electromagnetic torque of induction motor in general is given by.

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

V-phase voltage of motor

ω_r-Rotor speed

The phase voltage of the motor is changed by SCR firing angle α. Therefore, equation (1) can be written as

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

Considering small perturbations on variables in equation (2) and by applying Taylor Series, the transient process can be written as

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

Where

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

Equation (3) corresponds to linearized model of SCR fed induction motor at specific working point of the drive system.

Equating electromagnetic torque and mechanical torque, the equation is given by

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

K_a, K_w values are obtained from the speed-torque characteristics curve of the induction motor under steady state conditions. Table 1 represents the values of firing angle, rotor speed, K_a and K_w at various operating points.

Table 1
Motor Parameters at various 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

2.2. Proportional Integral-controller as Feedback controller

A PI Controller is designed as feedback controller and shown in Fig 1. Considering the speed change reference $\Delta\omega_r^*$ as 0, the transfer function is given by

$$\frac{\Delta\omega_r(s)}{\Delta T_L(s)} = \frac{-s}{Js^2 + (F + K_a K_P - K_w)s + K_a K_I} \tag{5}$$

The controller constants are calculated at specific operating points and the response of motor is simulated with MATLAB with unit step input applied at time t = 0 sec and with load applied at t = 10sec. Figure 2 shows the transient Characteristics of motor. The observation from the figure2 shows that the design of controller at particular operating point will not give suitable output at all other operating points.

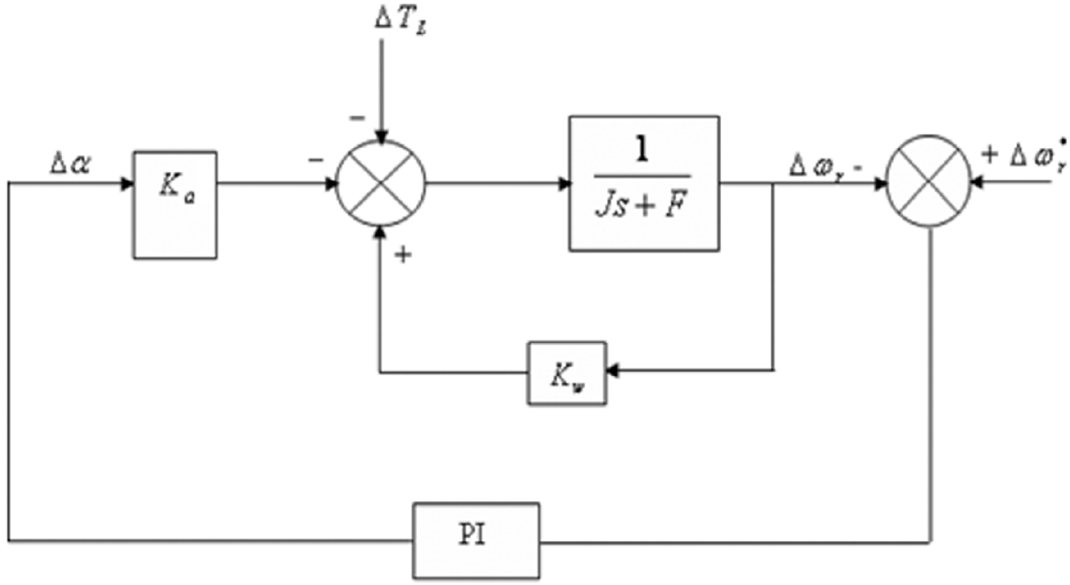

Figure 1: Simulink model of Induction motor with Proportional Integral-controller

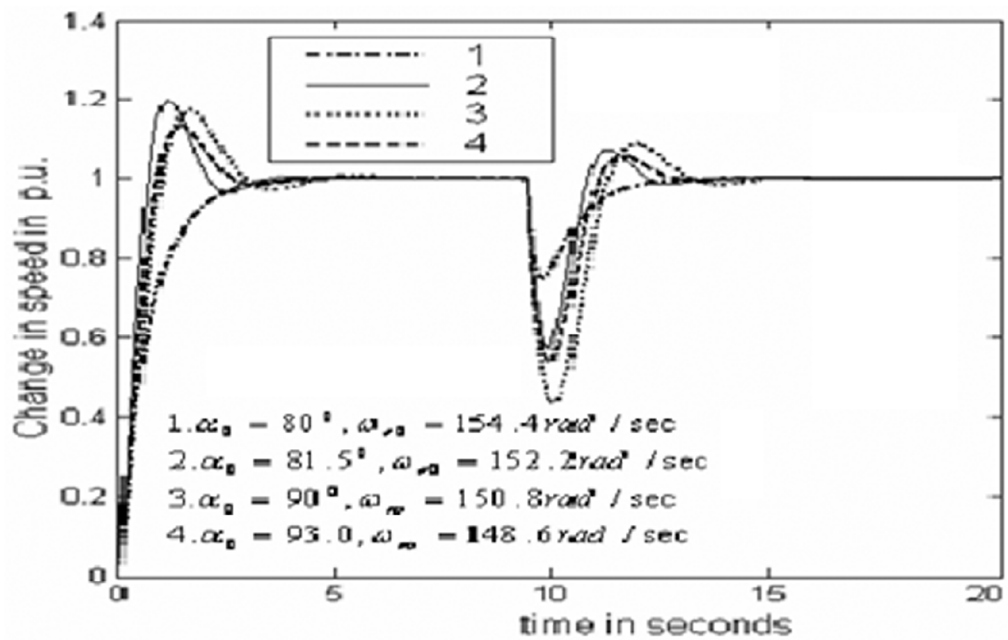

Figure 2: Speed output with Proportional Integral-controller for various operating points and.

3. CONTROLLER DESIGN USING GWO

In this case, the dynamic characteristics of the motor are considered as an optimization problem. Let $\delta\omega_{rp}$ and t_s are the peak overshoot and settling time. The objective function can be written as

Minimize $$F(\phi) = (1+\Delta\omega_{rp})\ (1+t_s) \tag{6}$$

Subject to $\phi_{\min} \le \phi \le \phi_{\max}$

Where ϕ is a set containing controller elements namely K_p and K_i.

Grey wolf optimizer (GWO) is used for tuning the PI controller parameters thereby controlling the speed of the induction motor. Grey wolf (Canis lupus) is a novel population based algorithm introduced in 2014. GWO algorithm is actually inspired by grey wolves. Steps involved in grey wolf hunting are:

1) Tracking, chasing, and approaching the victim.
2) Pursuing, encircling, and niggling the victim until it stops moving.
3) Attacking towards the victim.

3.1. Algorithm

Initialize the grey wolf population X_i (i = 1, 2, ..., n)
Initialize a, A, and C
Calculate the fitness of each search agent
X_α=the best search agent
X_β=the second best search agent
X_δ=the third best search agent
***while** (t < Max number of iterations)*
    ***for** each search agent*
        Update the position of the current search agent by equation (3.7)
    end for
    Update a, A, and C
    Calculate the fitness of all search agents
    Update X_α, X_β, and X_δ
    t=t+1
end while
return X_α

4. RESULTS AND DISCUSSION

Induction motor model is simulated along with GWO controller as Feedback controller. The figure 3 shows the results of simulation and from the results, it is proved that the peak overshoot, peak under shoot and

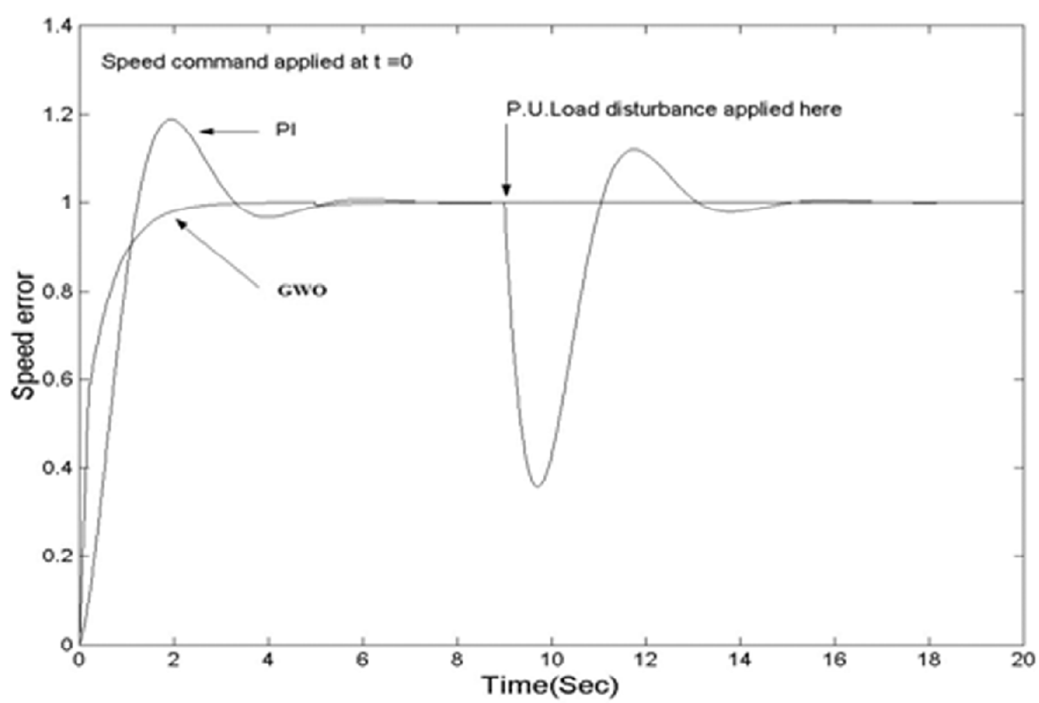

Figure 3: Dynamic response of GWO and PI controller

settling time (i.e objective function) are reduced thereby providing good response at all working points with GWO based controller compared to Proportional Integral controller. The table 2 and 3 gives the comparison of time domain specifications between conventional PI controller and GWO controller at time t = 0 seconds and t = 9 seconds respectively.

In order to validate the simulation results an experimental setup is developed. The hardware results are shown in the figure 4 and 5. The experimental results clearly indicate that the GWO controller is capable of maintaining the reference speed at different operating points successfully.

Table 2
Comparison between conventional controller and GWO controller in the simulation study at t = 0 sec

Time domain specifications	*Conventional PI controller*	*GWO controller*
Rise time	0.88 secs	1sec
Settling time	4.6 secs	1.95secs
Overshoot	20%	0%
Undershoot	3%	0%

Table 3: Comparison between conventional controller and GWO controller in the simulation study at t = 9 sec

Time domain specifications	*Conventional PI controller*	*GWO controller*
Rise time	0.57 secs	0 secs
Settling time	3.98 secs	0 secs
Overshoot	12.73%	0%
Undershoot	64%	0%

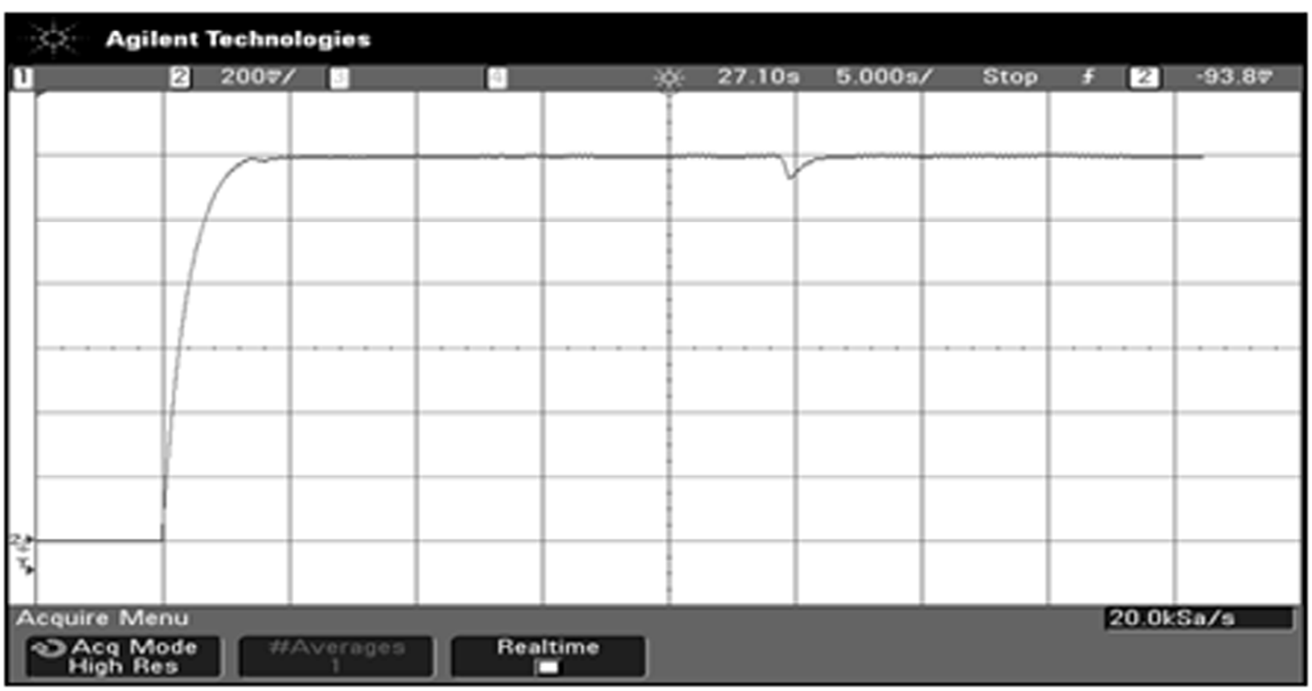

Figure 4: Response of PI controller

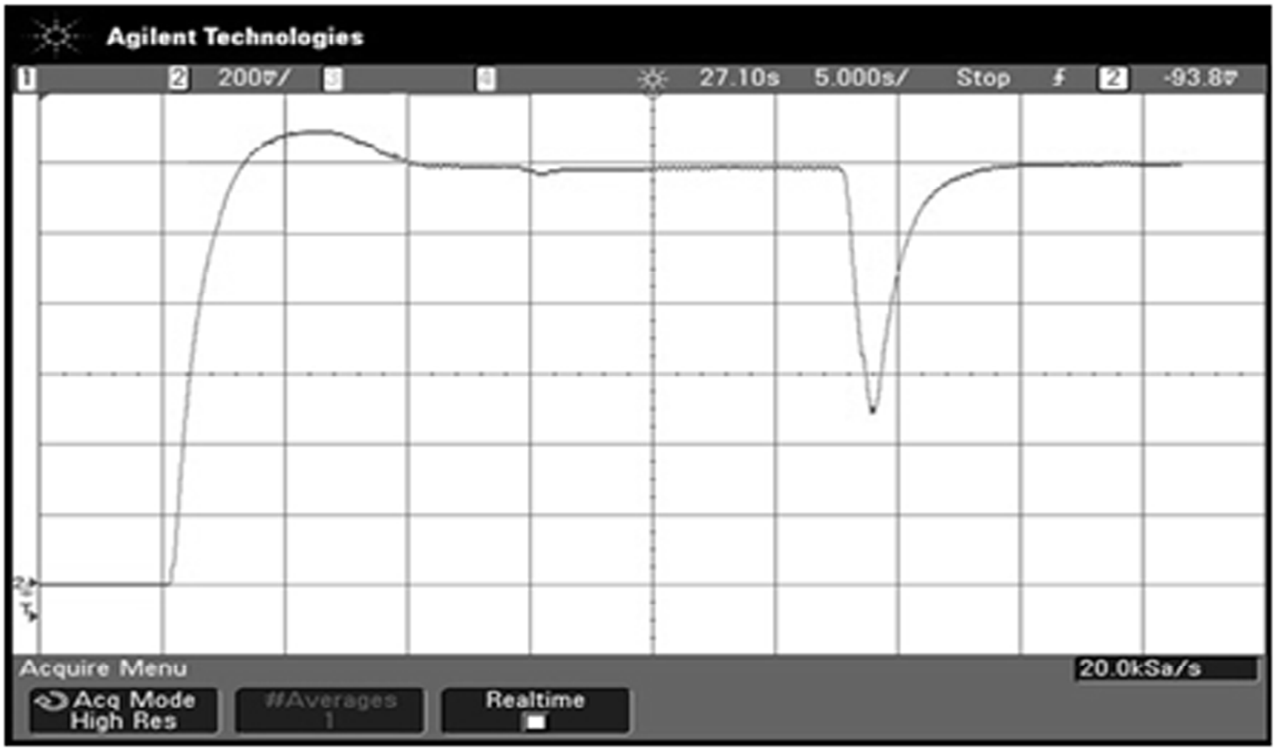

Figure 5: Response of GWO controller

5. CONCLUSION

An optimization approach for robust controller is next carried out using Grey Wolf Optimizer Algorithm (GWO).While small signal model is used for optimization process; the estimated controller structure is shown immune to external disturbances and parameter variations. Thus the dynamic response of the motor obtained with GWO based tuned controller is more efficient than with the traditional PI controller.

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