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Gravitational search algorithm based tuning of a PI speed controller for an induction motor drive

Jamal Abd Ali[1,2], M A Hannan[1] and Azah Mohamed[1]
[1]Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Malaysia.
[2]General company of electricity production middle region, Ministry of electricity, Iraq.

E-mail: eng_jhy@yahoo.com, hannan@eng.ukm.my, azah@eng.ukm.my.

Abstract. Proportional-integral (PI)-controller is very useful for controlling speed and mechanical load variables for the three-phase induction motor (TIM) operation. However, the conventional PI-controller has a very exhaustive trial and error procedure for obtaining it is parameters. In this paper, PI speed controller has been improved in it is design technique to suite TIM by utilizing a gravitational search algorithm (GSA) optimization technique. The mean absolute error (MAE) of the speed response has been used as an objective function. An optimal GSA based PI speed controller (GSA-PI) objective function is also employed to tune and minimize the MAE for developing the performance of the TIM in terms of changes speed and mechanical load. This experiment use space vector pulse width modulation (SVPWM) technique to create pulse width modulation for switching devices for three phase bridge inverter. Results obtained from the GSA-PI speed controller are compared with those obtained through particle swarm optimization (PSO) to validate the developed controller. Then it has been proved that the robustness of the GSA-PI speed controller is far better than that of the PSO controller in all tested cases in terms of damping capability and transient response under different mechanical loads and speeds.

Introduction

Three-phase induction motors (TIMs) are used widely in the industrial applications because of their simple structure, easy maintenance, low cost, robustness, and ruggedness [1]. Scalar controller is one of the controller methods used for induction motor, it is used in the most of controller design of induction motor because of easy design, simple structure and low cost [2]. Three phase bridge inverter is also plays an important role to control the variable speed of the induction motor such as fans and pumps, and controlling on three phase bridge inverter via pulse width modulation (PWM) techniques. There are many PWM techniques are used to control inverters SVPWM method is one of the best methods this is because has a great capability to minimize harmonic distortion [3].
PI-controller is one of these speed control schemes. It is considered very good controller technique that uses a numerous applications. These applications including scalar and vector techniques due to it is easy design, low cost, and simple structure [1],[4]. Moreover, PI-controller used to regulate for the main variables as voltages, currents, speed, torque, and rotor flux in the induction motors. Therefore, the disadvantages is difficulty to get on suitable coefficients for PI-controller (Proportional gain (kp), integral gain (ki)). These parameters are plays a role in sensitivity and stability to model control [1],[4],[5]. There are many methods to search for coefficient PI controller as Ziegler-Nichols method, Cohen-Coon method, and Lambda tuning method, etc. These methods have some problems as process upset, some trial-and-error, needed for some calculation operation, and needed for the mathematical

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model [6],[7]. There are number of researchers has used different way of optimization to solve these problems involved with PI-controller such as [6] use genetic algorithm (GA), [7] use PSO algorithm to find the best values for PI-controller parameters and etc. In this paper, the GSA optimization is developed to improve the performance of the TIM speed controller by tuning the free parameters and selecting the best parameters for PI speed controller. The results obtained from the developed speed controller and the PSO optimization algorithm has been compared in terms of the control process and robustness under specific condition such as sudden change in the speed and the mechanical load. On the other hand, the high-performance membership functions are also obtained by minimizing the error function using MAE of the system. In addition, employing the SVPWM switching algorithm to develop the GSA optimization-based PI speed controller is useful for TIM drives.

Design of tuning GSA based PI speed controller

Primary GSA is an evolutionary computation technique developed by E. Rashediet et al. at 2009, inspired by the law of gravity and mass interactions introduced in [8]. The numerical values of the parameters are difficult to calculate in PI speed controller design. Therefore, in this study, the PI speed controller was fixed with the parameters tuned by GSA to obtain the optimal numerical values of the parameters limits. The objective function is used to minimize the speed error (i.e., reduce overshoot, steady-state error, and settling time) while enhancing or maintaining the driving performance characteristics of TIM. The developed GSA-PI speed controller simulation model for the TIM drive model is shown in Figure 1. SVPWM switching technique was utilized to control the TIM drive with the V/f control PI-speed controller. The induction motor model is a stationary reference frame in which rotor speed is measured depending on the feedback signal. Therefore, the sensor speed needs to be measured. The developed PI speed controller was also utilized to tune the parameters and determine the best values for the parameters of PI speed controller through GSA optimization. The GSA-PI speed controller was used for the speed controller system for simplicity. The task of this controller is to allow the actual speed to track the reference speed. The speed controller provides the required slip speed to reach the reference speed (synchronous speed). The slip speed is then added to the feedback signal is the rotor speed to produce the required frequency to the inverter then to TIM. A V/f relationship is required to fix the machine at its rated flux linkage.

The procedure for implementing the GSA-PI speed controller is given by the following pseudo-codes:

```
Initialize the population size (N), the positions and the dimensions of the population (D):
For t = 1 to Maximum Iteration T
    Run the simulation with PI speed controller for each position
    Calculate objective function (MAE = Σ_{i=1}^{n} |error| /n) for each population (Xij)
    Update forces, velocity, and position using GSA equations
end
Output the PI speed controller with optimal parameters Xij
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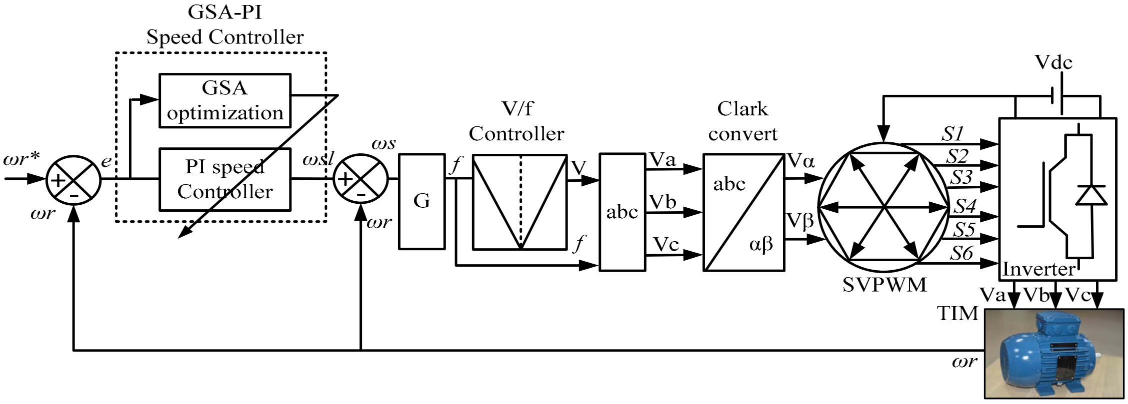

Figure 1. Block diagram of the proposed GSA-based PI speed controller for TIM.

Results and discussion

The results were obtained by execution the control scheme to validate the proposed GSA-PI speed controller and the performance of the overall system. The switching frequency used was 20 kHz in the SVPWM technique. The PI speed controller parameters were tuned by GSA methods in order to search for the optimal parameters. Using GSA-PI speed controller and PSO-PI for optimal parameter speed controller for the purpose of comparison and to evaluate the GSA optimization robustness. Figure 2 shows the relationship between the objective function curve and the number of iterations performed by the two optimization methods (GSA and PSO). For fair comparison, the optimization methods take the same number of population and iteration. The simulation results are presented in two test cases to determine the effectiveness and robustness of the proposed PI speed controller. In this work, the two tests carried out in the system were variation of speed and mechanical load.

The first test involves increasing or decreasing the reference speed with the mechanical load constant. This case study aims to evaluate the performance of the proposed method of GSA-PI speed controller and estimate the reference speed variation with the mechanical load constant of TIM controlled by the V/f ratio. The reference speed variation was applied on induction motor in short times as shown in Figure 3 also shows the speed responses of GSA-PI and PSO-PI aped controller with speed change. The second test for induction motor involves constant speed and mechanical torque variations. This test aims to determine the system performance and robustness. The results were indicated by the speed response and its zoomed locations as in Figure 4, the estimated speed is consistent with the actual speed with good accuracy. GSA-PI speed controller achieved better results than PSO-PI controller by minimizing the overshoot, settling time, steady-state error, and damping ratio after change and exhibiting rapid stability after each speed change.

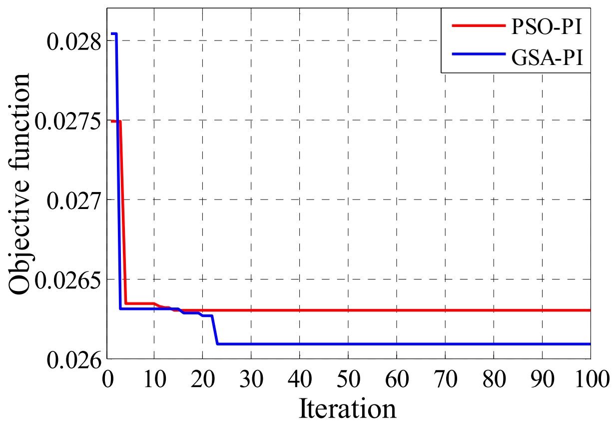

Figure 2. Objective function curve.

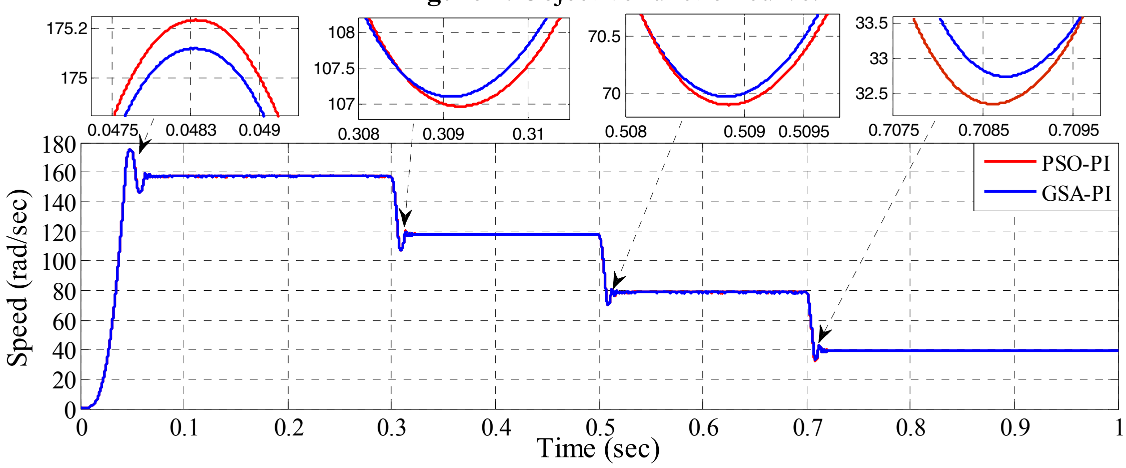

Figure 3. Mechanical load constant with speed variations.

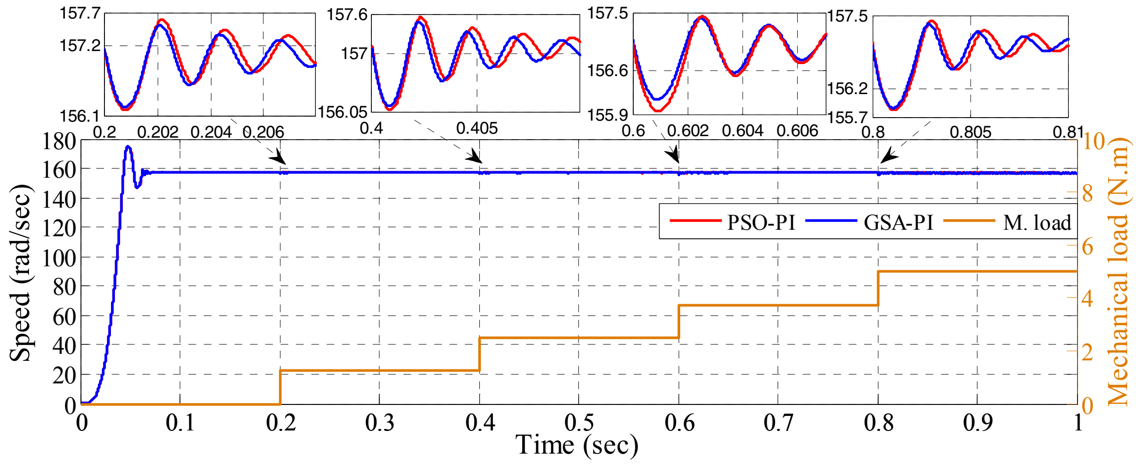

Figure 4. speed constant with mechanical load variations.

Conclusion

This paper presents PI speed controller-based optimization approach for induction motor using the GSA. The proposed method is formulated to automatically change the parameters of the PI speed controller. To effectively tune the parameters of the proposed PI speed controller used in the TIM applications, a suitable objective function was developed to minimize the MAE of the speed response. The developed GSA-PI optimization method helped to avoid traditional trial and error procedure for obtaining the best parameters. The performances of GSA-PI and PSO-PI were compared and the results show that the GSA-PI speed controller is far better than that of the PSO-PI speed controller in terms of robustness, damping capability, and improvement of the transient responses.

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