Modelling and Simulation for Used Genetic Algorithm Method to Speed Control of Three-phase Induction Motor

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Abstract Optimization techniques are very well-known to improve the performance of Three-phase induction motor (TIM). Inverter and SVPWM method can be used for setting voltage and frequency appropriating with loads requirements. This study deals with the tuning of PID controller parameters to be used TIM. Genetic algorithm is used to tune each parameters of PID speed controller to improve the speed response performance of the TIM. PID-GA aims to minimize the error signal speed of TIM, reduce overshoot, and tune parameters of PID controller. The error signal speed of TIM has objective function from integrated error signal (ISE). Parameters of PID controller from optimization are used to the model of the closed-loop speed control of three-phase induction motor using PID. PID-GA has the best speed response. On the model of the closed-loop speed control of three-phase induction motor using PID, various load torque can result in decreasing flux stator and rotor, increasing current stator and rotor, and decreasing speed of the induction motor.

Keywords Three-phase Induction Motor, Inverter, SVPWM, Genetic Algorithm, PID

1. Introduction

Electricity demand has increased everytime and the growth in the industrial sector leads to modernization. Most electricity in the industrial sector is consumed by electric motors. Over 90 % industrial sector uses three-phase induction motors because the price is relatively cheap, robust construction, and easy maintenance.

Source of electrical energy from the power network is limited to a certain voltage and frequency making it difficult to control the speed of induction motor. Inverter and space vector pulse width modulation (SVPWM) can be used for setting voltage and certain frequency corresponding load requirements. SVPWM has the advantage to reduce total harmonic distortion (THD)[8][12].

The rapid development of power electronic devices and converter technologies in the past few decades, however, has made possible efficient speed control by varying the supply frequency, giving rise to various forms of adjustable-speed induction motor drives. Researchers soon realized that the performance of induction motor drives can be enhanced by adopting artificial intelligence based methods. Artificial intelligent techniques mean use of expert system, fuzzy logic, neural networks and genetic algorithm. Artificial Intelligent Controller (AIC) could be the best controller for induction motor control. Researchers has developed hybrid controller for speed control induction motor [1][5][10][12][17][19]. A hybrid controller is that with a combination of fuzzy logic and neural network, such as uncertainty or unknown variations in plant parameters and structure can be dealt more effectively.

This paper purposes to develop PID-GA controller for controlling speed of three-phase induction motor. PID controller can solve many problem such as high overshoot, high steady state error, and oscillation speed response system. Genetic algorithm can produce the best solution global [3][7][18]. Genetic algorithm can prevent local optimum condition because it uses several point as initialize value.

Metaheuristic optimization techniques of genetic algorithm can be used to optimize error signal using intergated square error (ISE). Genetic algorithm will tune parameters PID controller such as K_p , K_i , and K_d so that it can work. PID-GA controller be hoped control speed of TIM.

2. Dynamic Model of Three-phase Induction Motor

Dynamic model of three-phase induction motor can utilise mathematical model to some stationary equation. Variable equation stator and rotor such as voltage, current, and flux linkage can be converted to dq-axis reference frame. The flux linkage can be found the equation following [2][10][14]:

$$\frac{1}{\omega_b} \frac{d\psi_{qs}}{dt} = v_{qs} - R_s i_{qs} - \frac{\omega_e}{\omega_b} \psi_{ds} \quad (1)$$

$$\frac{1}{\omega_b} \frac{d\psi_{ds}}{dt} = v_{ds} - R_s i_{ds} + \frac{\omega_e}{\omega_b} \psi_{qs} \quad (2)$$

$$\frac{1}{\omega_b} \frac{d\psi_{qr}}{dt} = v_{qr} - R_r i_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b} \psi_{dr} \quad (3)$$

$$\frac{1}{\omega_b} \frac{d\psi_{dr}}{dt} = v_{dr} - R_r i_{dr} + \frac{(\omega_e - \omega_r)}{\omega_b} \psi_{qr} \quad (4)$$

Due to substituting the values of flux linkages as (1) to (4), generated the following current equation are obtained as :

$$i_{qs} = \frac{(\psi_{qs} - \psi_{mq})}{X_{ls}} \quad (5)$$

$$i_{ds} = \frac{(\psi_{ds} - \psi_{md})}{X_{ls}} \quad (6)$$

$$i_{qr} = \frac{(\psi_{qr} - \psi_{mq})}{X_{lr}} \quad (7)$$

$$i_{dr} = \frac{(\psi_{dr} - \psi_{md})}{X_{lr}} \quad (8)$$

Where ψ_{mq} and ψ_{md} are the mutual flux linkages in the (d-q) axis. The mutual flux equations are written as follows:

$$\psi_{md} = X_{ml} \left(\frac{\psi_{ds}}{X_{ls}} + \frac{\psi_{dr}}{X_{lr}} \right) \quad (9)$$

$$\psi_{mq} = X_{ml} \left(\frac{\psi_{qs}}{X_{ls}} + \frac{\psi_{qr}}{X_{lr}} \right) \quad (10)$$

$$X_{ml} = \frac{1}{\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}} \quad (11)$$

Electromagnetic torque can be determined as follow:

$$T_e = \left(\frac{3}{2} \right) \left(\frac{P}{2} \right) \left(\frac{1}{\omega_b} \right) (\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad (12)$$

Relation speed induction motor and electromagnetic torque can be found following equation:

$$T_e = T_{Load} + J \frac{d\omega_m}{dt} = T_{Load} + \frac{2J}{P} \frac{d\omega_r}{dt} \quad (13)$$

Rotor speed can be expressed as follow:

$$\omega_r = \int \frac{P}{2J} (T_e - T_{Load}) dt \quad (14)$$

The design and implement depended on the above equations and of build by using MATLAB/SIMULINK and

execution by using parameters in the Table 1.

Table 1. three-phase induction motor parameters

Parameter	Definition	Values
HP	Power rated	3 hp
ω	Rated speed	1710 rpm
V	Voltage	220 V
f	Frequency	60 Hz
P	Number of poles	4
R_s	Stator resistance	0.435 ohm
R_r	Rotor resistance	0.816 ohm
X_m	Mutual reactance	26.13 ohm
X_{ls}	Stator reactance	0.754 ohm
X_{lr}	Rotor reactance	0.754 ohm
J	Inertia of motor	0.089 kg.m ²
B_m	Friction coefficient	0,05 kg.m ²
ω_e	Electrical Speed	377 rad/s
ω_b	Based speed	377 rad/s
$\omega_{referensi}$	Reference speed	1800 rpm

3. Svpwm Technique

SVPWM technique is special switching scheme of six power IGBTs of a 3-phase inverter. It is one best way the Pulse Width Modulation (PWM) due to reduce minimum Total Harmonics Distortion (THD)[8][12]. Operation principle is rotation of this space vector can be executed by variable frequency device to generate three phase sine waves to go TIM. The three-phase voltage source can be changed to a space vector using following equation [12]:

$$V = v_a e^{j0} + v_b e^{j2\pi/3} + v_c e^{4\pi/3} \quad (15)$$

Control signal of SVPWM technique based on using following equation[12]:

$$\begin{aligned} \frac{V_{control-a}}{V_{tri}} &= \frac{\left(v_a - \left(\frac{\max(v_a) + \min(v_a)}{2} \right) \right)}{V_d} \\ \frac{V_{control-b}}{V_{tri}} &= \frac{\left(v_b - \left(\frac{\max(v_b) + \min(v_b)}{2} \right) \right)}{V_d} \\ \frac{V_{control-c}}{V_{tri}} &= \frac{\left(v_c - \left(\frac{\max(v_c) + \min(v_c)}{2} \right) \right)}{V_d} \end{aligned} \quad (16)$$

Trigger signal is applied a triangle wave using switching frequency f_s . SVPWM is taken from comparison control signal SVPWM and trigger signal.

Figure 1. Space vector limited amplitude

4. Genetic Algorithm

Genetic algorithm [20] is stochastic techniques to optimize based on the natural selection mechanism and genetic, which work with a population of solution. A fitness value derived from the problem's objective function is assigned to each member of the population. Individuals that represent better solutions are awarded higher fitness value, thus enabling them to survive more generation. Commencing with an initial random population, successive generations of population are created by the operators reproduction, crossover and mutation to yield better solutions, which approach the optimal solution to the problem.

The Genetic Algorithm (GA) offers an effective way for automatically searching or tuning of PID parameter [21] according to the dynamic behavior and signals of the measured system. It performs especially well when solving complex problems because it does not impose many limitations of traditional techniques. The better performance is obtained because of global and robust nature of GA, its ability of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optimization, and its computational efficiency. The technique has the capability to solve nonlinear and complex optimization problems. PID controller has good performance and have been applied in practice.

5. Design Tuning Pid-Ga

PID control system consists of three ways such as P (proportional), D (Derivative), and I (Integral), which each parameter has advantages and disadvantages. In the implementation of each way can work alone or combined. In the design of PID control system needs to be done is to set the parameters P, I, and D in order to the response of the output signal of system against certain entries as desired. PID control will correct error between the output with the input or setting point by calculating and give correction output [14]. In general, the PID controller has form of equation (17)[13].

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt} \quad (17)$$

If equation (17) is converted to be PID controller transfer function, so that it will become equation (18)

$$G(s) = K_p + \frac{K_i}{s} + sK_d \quad (18)$$

Where K_p is the proportional gain, K_i is the integral gain, and K_d is the derivative gain.

Performance criteria is intergated of square error (ISE) that can be evaluated analytical in the frequency domain. ISE performance criterion formula is as follow:

$$ISE = \int_0^\infty e^2(t) dt \quad (18)$$

where $e(t) = \omega_{reference} - \omega_{rotor}$. Figure.2 show that flowchart of PID-GA speed controller.

Figure 2. Flowchart PID-GA

Performance is measured by combination overshoot and ISE. It is entried to equation of time domain response. The objective function, f is applied to evaluate the performance given by,

$$f = \alpha \times OS + \beta \times ISE \quad (19)$$

where α and β as weight constant each element of objective function, OS shown overshoot of speed response and ISE refers to integrated square.

Plant in model PID-AG apply a simple equation. It consists of an actuator and transfer function. Relation mechanic speed and torque of induction motor without load can be used a transfer function passing Laplace transform. It is noticed by equation (20). Mechanism of PID-GA is shown by Figure.3.

Figure 3. Block mechanism of PID-GA

$$G(s) = \frac{\omega_m(s)}{T_e(s)} = \frac{1}{Js + B_m} \quad (20)$$

Parameters of genetic algorithm is shown on the Table.2, whereas constraint parameter PID is noticed by Table 3.

Table 2. Parameter Genetic Algorithm

Parameters	Values
Population size	30
Maximum generation	50
Selection method	Roulette wheel
Crossover percentage	0,8
Extra range factor for crossover	0,4
Mutation percentage	0,3
Mutation rate	0,1

Table 3. Constraint of Parameter Pid

Parameter PID	Kp	Ki	Kd
Minimum	0	0	0
Maximum	5	5	5

6. Block MATLAB/SIMULINK

This section, mechanism of PID-GA is separated by closed-loop speed control of three-phase induction motor using PID. Genetic algorithm is used to tuning parameter K_p , K_i , dan K_d . Optimization error signal is shown by equation (18). Whereas objective function refer to equation (19). Plant of induction motor only apply an simple equation which noticed by equation (20). Block mechanism PID-GA in MATLAB/SIMULINK is shown by Figure.4

Figure 4. Block mechanism design tuning PID-GA in MATLAB/SIMULINK

Block closed-loop speed control of three-phase induction motor using PID is shown by Figure.5. It consists of block reference speed, block PID, block sinusoidal wave voltages controller, block SVPWM, block inverter, block filter, and block of dynamic induction motor. Block of dynamic induction motor uses DQ model. It is taken from equation (1)-(13). Block SVPWM is made from comparison signal voltages abc controller with signal trigger wave uses switching frequency f_s .

7. Simulation Result

In the first case, simulation PID-GA is worked. Tuning of PID controller parameters is gained in simulation and shown on Table 4.

Table 4. Parameters Pid-Ga

Methods	Kp	Ki	Kd
GA	3,4224	0,03291	4,4379

Whereas performance index consists of overshoot and ISE. It is looked at in Table.5

Table 5. Performance index of objective function pid-ga

Method	OS	ISE
GA	0,5%	2.919e+06

Graph optimal value of objective function genetic algorithm is noticed in Figure.6 and Graph response speed of induction motor using PID-GA is shown by Figure.7.

In other hand, simulation of the closed-loop speed control of three-phase induction motor using PID has resulted in form voltages abc controller, SVM, SVPWM, voltages of inverter, voltages inverter has been filtered, voltages dq, stator flux, rotor flux, mutual flux, stator current, rotor current, torque, and speed response of three-phase induction motor.

System response is applied variation load torque 20 Nm at 1 sec, 40 Nm at 1.25 sec, and 60 Nm at 1.5 sec. In the starting the operating full speed (1800 rpm) but no load until 1 sec. change the load torque will effect to decrease flux (Figure 14-16), and to derive speed response (Figure 19).

Table 6 summarizes the effect load torque to flux induction motor and Table 7 shows result in influence load torque to speed response.

Figure 8 explains signals of voltages control phase a, phase b, and phase c. Magnitude of Voltages controller is used 1 volt.

Figure 9 demonstrates output of voltages SVM. It is seem that has magnitude 0.98 because SVM uses value of modulation 0.98.

Figure 10 shows that It is output of SVPWM. It is used as power switching to impulse gate from inverter.

Figure 11 describes that It uses 240 volt for Inverter.

Figure 12 draws that It is output of signal exited filter. This voltages have 236 volt at simulation.

Figure 13 explains that It is output of voltages dq of three phase induction motor. It is seem that has about 354 volt.

Figure 5. Closed-loop speed control of three-phase induction motor using PID.

Figure 6. Optimal value of objective function PID-GA

Figure 7. Response speed of induction motor using PID-GA

Figure 8. Voltages abc controller

Figure 9. Voltage controller SVM

Figure 10. SVPWM

Figure 11. Voltages inverter

Figure 12. Voltages inverter have been filtered

Figure 13. Voltages V_{dq}

Figure 14. Stator flux

Figure 15. Rotor Flux

Figure 16. Mutual Flux

Figure 17. Stator current

Figure 18. Rotor current

Figure 19. Torque and speed induction motor

Table 6. Effect load torque to flux induction motor

Time (second)	Load Torque T_L (Nm)	Rotor Flux Φ_r (Wb)	Stator Flux Φ_s (Wb)	Mutual Flux Φ_m (Wb)
0-0.7	0	167	173	168
0.7-0.9	0	170	175	170
1-1.25	20	166	172	166
1.25-1.5	40	157	169	160
1.5-1.75	60	143	166	148
1.75-2	60	140	165	146

Table 7. Effect load torque to rotor speed induction motor

Time (second)	Load Torque (Nm)	Speed (rpm)
0-0.65	0	0-1710
0.65-0.93	0	1710-1800
1-1.25	20	1800-1734
1.25-1.5	40	1734-1655
1.5-1.75	60	1655-1543
1.75-2	60	1543-1523

8. Conclusions

This paper presents speed control of three-phase induction motor using PID and a simple model for mechanism PID-GA. Both of them are designed is separated. At the simulation of mechanism PID-GA has been done, it had a good response system. It has found very low overshoot 0.5% and ISE 2.919×10^6 , so the simulating shown effective performance. It also can find the tuning of the PID controller parameters for speed control of three-phase induction motor.

At the simulation experiment of closed-loop speed control of three-phase induction motor had been runned. The Rated speed 1710 rpm can be found at the time 0.65s. The average starting stator current is gained 111.58 A. The maximum starting torque is acquired 121,77 Nm. Breakdown torque or peak torque can be reach 68 Nm at the time 0.59s. When this simulation is added various load torque, it will gain and affect a decreasing stator flux and rotor flux, lifting stator current and rotor current, and speed of TIM will be decreased.

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