Controlling of Induction Motor Using Grey Wolf Optimization Algorithm

Ghaith M. Fadhil¹, Issa A. Abed¹ and Rasheed S. Jasim¹
Engineering Technical College Basrah, Southern Technical University, Iraq
kaithbabil889@gmail.com, issaahmedabed@stu.edu.iq, r.s.almansory@stu.edu.iq

Abstract. This paper introduces the improved Direct Torque Control (DTC) of the Induction Motor (IM) to enhance its performance. The DTC method is generally used to control electrical machinery. The traditional Proportional Integral (PI) speed controller parameters are manually adjusted to match the speed with the given reference. However, traditional PI has a drawback such that it does not fit all error limits. Thus, the intelligent DTC has been discussed with the proposed Grey Wolf (GWO). The grey wolf algorithm is used to adjust PI speed controller parameters as well the results are compared with those of genetic algorithm. Simulation results show that the GWO algorithm is exceptionally successful for improving induction motor with a fast-tracking response.

1. Introduction
The induction machine from particular attention mainly because of its reliability, robustness, relatively low cost, simplicity of construction as well as the maintenance [1, 2]. These advantages are supplanted by control issues when utilizing the Induction Motor (IM) in industrial drives with high-performance requests. The variation of speed and torque control of electric machines drives have huge methodological and technological advances in the most recent years. Indeed, the replacement of digital electronics projects and the development of power electronics components by implementing the control algorithms which envisaged in the last ten years ago.

It is important to control IM due to expanding the demand for this part. In that case, the fundamental factor that assists with picking Direct Torque Control(DTC) is the simplicity of structure just as high performance and efficiency [3]. In DTC the measured error which belongs to the flux and torque is controlled and reduces as minimum as possible. This control method is also used with field-oriented control to get better performance [4]. In addition to that, it is fast [5], a low-cost method, and it is broadly used in industrial applications.

The arrangement control of IM is detailed in [6]. The mathematical model of IM will perform on the flux and torque equation of stator. Where the classical DTC of IM has high ripple and its response is low. The classic DTC is controlling by the utilization of PI, which associates with the speed to get the reference torque. After obtaining the reference torque it is comparing with estimation torque to reduce the percentage of error. The control is finished by changing the parameters of PI when connected with speed to get the best results. The switching table is operating after getting the errors of flux and torque after included to hysteresis band then give pulses that are feed to an inverter. While the inverter is utilizing to convert DC power into AC power.

The primary goals of this paper are a technical study of speed and torque control of IM based on the DTC technique which is in this paper is improved technique. However, a genetic algorithm [7] and grey
wolf were introduced that give the best value to solve problems that occur while operating. Also, an analysis of these algorithms has been discussed as these algorithms are used to improve the control process when applied to adjust the PI torque parameters.

2. Classical DTC Model

The direct torque control of IM is used to predict the required voltage to achieve the required output torque. Utilizing the DTC to control torque required also to reduce torque and stator current ripple. There are two factors of control are stator transition and torque which are limited by hysteresis control units. Direct self-control is preferred in wide applications with a high-power range when the low frequency of inverter conversion can be justified for a higher current bending.

Currently, the speed controller parameters are adjusted manually. The hysteresis band was used to avoid errors but not responding to big errors. This switching table (ST) works with eight states where six of them work while the rest are out of work. Flux errors, torque, and position are obtained to the switch table. Therefore, with this switching technique depending on the hysteresis band, the error of torque is large and the flux error is small and does not constitute discrimination. Various errors caused ripples if the induction motor was running stably [8]. The switching table is used to obtain pulses obtained from flux error and torque after being included in the hysteresis band. Diagram of the classic DTC as shown in Figure 1.

![Figure 1. The Classical Direct Torque Control Model](image)

Induction Motor model utilizes stator flux with a stationary reference system is denote to $\alpha$ refer to stator reference as in equation (1) [9],

$$\Psi_s^\alpha = \int (V_s^\alpha - R_s I_s^\alpha)dt$$  \hspace{1cm} (1)

|\Psi_s^\alpha|: The term is referring to flux of stator with stationary reference

$V_s^\alpha$: The term is referring to the voltage of $\alpha$ with stationary reference

$V_s^\beta$: The term is referring to the voltage of $\beta$ with stationary reference

$R_s$: The term is referring to stator resistance

$I_s^\alpha$: The term is referring to the stator current of $\alpha$

$I_s^\beta$: The term is referring to the stator current of $\beta$

The stator fluxes of $\alpha-\beta$ with stationary references are in equations (2) and (3).

$$\Psi_{s\alpha} = \int (v_\alpha - I_s^\alpha R_s)dt$$  \hspace{1cm} (2)

$$\Psi_{s\beta} = \int (v_\beta - I_s^\beta R_s)dt$$  \hspace{1cm} (3)

While the stator flux vector is given in equation (4),

$$|\Psi_s^-| = \sqrt{(\Psi_s^\alpha)^2 + (\Psi_s^\beta)^2}$$  \hspace{1cm} (4)

$\Psi_s^-$: The term is referring to stator flux vector.

However, the angle of stator flux is presented in equation (5).
\[ \theta_{es} = \tan^{-1} \left[ \frac{\Psi_{e}^{f}}{\Psi_{s}^{f}} \right] \]  

(5)

The estimated torque of the induction motor is determined according to:

\[ T_e = \frac{3}{4} p (\Psi_s^\alpha I_s^\beta - \Psi_s^\beta I_s^\alpha) \]  

(6)

\( T_e \): The term is referring to estimation torque

\( P \): Number of poles

By using the stator flux, the voltage of the stator is as follows [10],

\[ V_s = \frac{d\psi_s}{dt} + R_s I_s \]  

(7)

The error of the flux is determined using equation (8) by comparing the reference and estimated values then the error is fetching to the hysteresis band to reduce the error as shown in Figure (2)

\[ e_\Psi = \Psi_s^* - \Psi_s \]  

(8)

\[ e_\Psi : \text{The term is referring to the reference flux.} \]

\[ \Psi_s^* : \text{The term refers to estimation flux} \]

Also, the error of the torque is obtained as in equation (9), where two hysteresis bands are used to eliminate the negative value as shown in Figure 3.

\[ e_T = T_e^* - T_e \]  

(9)

\[ T_e^* : \text{The term is referring to the reference torque.} \]

\[ e_T : \text{The term referring to the error of torque} \]

This indicates that the change in the flux of the stator vectors is due to the influence of the voltage carriers. Therefore, the voltage vector is the supply that variants in the flux of stator to increase the angle between the flux of stator and the rotor carriers also produces an increased torque. The switching table operates with eight states, six of which are not equal to zero while two equals zero. The flow error operates with two states and two levels of hysteresis band as in equation (10) [11].

\[ e_\Psi = 1 \text{if } \Psi_s < \Psi_s^* - \text{band}_\Psi \text{ and } e_\Psi = 0 \text{ if } \Psi_s > \Psi_s^* + \text{band}_\Psi \]  

(10)

Also, the error of the torque works with three states and three levels of hysteresis band as in equation (11) [11].

\[ e_T = 1 \text{if } T_e < T_e^* - \text{band}_T \text{ and } e_T = 0 \text{ if } T_e = T_e^* \text{ and } e_T = -1 \text{if } T_e > T_e^* + \text{band}_T \]  

(11)

\[ e_\Psi : \text{The term is referring to the error of flux.} \]

\[ e_T : \text{The term referring to the error of torque} \]

Then the inverter is utilized to convert DC power into an AC power where it is consisting of a power bridge each contains two power switch and two anti-parallel diodes that supply the induction motor [12].
3. Grey Wolf Optimization Algorithm
This method is used to improve the controller where it is used to tune the parameter of PI. The Grey Wolf Optimization (GWO) will be a meta calculation suggestive by Mirjalili et al [13], which representable the social men of a grey wolf and the grey wolf candidate of the family. The structure of this group will be relying on those social hierarchies as shown in Figure 4.

![Figure 4. Grey Wolf in Hierarchy](image)

The leaders are a male and a female, known as alphas (α). That alpha wolf is also called the prevailing wolf since his requests if make trailed eventually should be followed the pack [14]. The other level in the progressive structure of grey wolves is beta (β) those wolves continuously must submit to every one of alpha wolves. Delta wolves must obey (δ) the will α and, according to rule. Scouts, rangers, elders, hunters and caregivers have a place in the omega category. The mainly phase on hunting the grey wolf as following:

- Tracking prey
- encircling, when the prey is stopped to moves
- Attack the prey

The mechanism operation of the social hierarchy, tracking, encircling, also attacking prey would have furnished. That point the GWO algorithm may be delineated.

3.1 Pursing Prey
Likewise mentioned, grey wolves encircle prey throughout this hunting. In a place for modeling behavior surrounded by mathematics following the equations they propose [15].

\[
D^r = |C^r(Xp^r) - X^r| \quad (12)
\]

\[
X_{t+1} = Xp^r - (A^-). (D^-) \quad (13)
\]

The (t) refers to the iteration, the coefficient vectors are defined \(A^-\) and \(C^-\), the position of prey \(X_p^r\), position the grey wolf \(X_t^r\) and the coefficients vector can be calculated as:

\[
A^- = (2(a^-)(r^r_1) - a^-) \quad (14)
\]

\[
c^- = 2r_2^t \quad (15)
\]

\[
a^- = 2 - 2\frac{t}{\text{max}_{\text{iter}}} \quad (16)
\]

3.2 The Hunts
The hunting will be normally guided by that alpha. Those taking after formulas are representable toward those comparisons in the equation (17), (18) and (19) [15].

\[
D_{\alpha}^- = |C_{\alpha}^r(X_{\alpha}^r) - X^-| \quad (17)
\]

\[
D_{\beta}^- = |C_{\beta}^r(X_{\beta}^r) - X^-| \quad (18)
\]

\[
D_{\delta}^- = |C_{\delta}^r(X_{\delta}^r) - X^-| \quad (18)
\]

\[
X_1^- = X_{\alpha}^- - (A_{\alpha}^r). (D_{\alpha}^-)
\]

\[
X_1^- = X_{\beta}^- - (A_{\beta}^r). (D_{\beta}^-)
\]

\[
X_1^- = X_{\delta}^- - (A_{\delta}^r). (D_{\delta}^-)
\]
The GWO technique can be represented by a flowchart diagram of detection and updating of the parameters as in figure (5).

![Flowchart for GWO Algorithm](image)

**Figure 5.** Flowchart for GWO Algorithm

4. Proposed Classical DTC of IM with GA and BOA
Here, the classical DTC with GA and GWO techniques to improve the system parameter shown in Figure 6. Additionally, the system uses PI with speed to produce torque for control and to obtain the optimum value in the non-linear system. Through the operation of optimization, the work of the system becomes better when it operates with them. For these technologies, ripple and overflow are reduced and the system runs at high speed with a fixed reference. The PI controller parameter adjusts by optimization. Therefore, the system is a stable and ideal parameter when using GA and GWO and becomes more stable when operating with grey wolf optimization.
The error can be calculated from a difference of speed according to equation (20).

\[ u = w_r^* - w_r \]  

(20)

The objective function of the system can be calculated using equation (21). The PI controller is used to minimize the error signals and to find out the best possible solution that will be used with all optimizations algorithms to get the smaller error and suggestion the magnitude of PI controller as shown in Figure 6.

\[ \text{Objective function} = \frac{1}{\text{Performance index}} \]  

(21)

Performance index = ITAE

\[ \text{ITAE} = \int |u| \, dt = \int_0^T t |e_t| \, dt \]  

(23)

ITAE: integral of time multiply by absolute error

e_t : the error signal of time

To obtain that the fitness value is determined from the error of the system that PI supply to control on the system.

\[ f_i = k_p e_{(w)} + k_i \int e_{(w)} \, dt \]  

(24)

**Table 1. Specifications Parameter of IM [16]**

| Parameters                  | Value         |
|-----------------------------|---------------|
| Power of Motor              | 1.1 kw        |
| Resistance of Rotor         | 6.085 Ω       |
| Resistance of Stator        | 6.03 Ω        |
| Inductance of Rotor         | 0.5192H       |
| Inductance of Stator        | 0.5192H       |
| Mutual Inductance           | 0.4893H       |
| Number of Per Poles         | 2             |
| Moment of Inertia           | 0.01179       |

5. Simulation Result and Discussion

These results were extracted under a sudden change in speed and torque load. The initial value of the torque of the load is 3 Nm and varies in 0.3 seconds to 7 Nm. Also, the speed ranges from 130 rad to 148 rad at 0.5 seconds for three-phase IM. The speed curves \( \omega_r^* \) and torque \( T_l^* \) representing the reference values are compared with the estimated during system operation \( \omega_m, T_e \). This system is a Simulink / MATLAB injection process of the process to give an IM response according to the parameters.
in Table (1). Figures (7), and (8) and table (2) show the results of DTC with GA, while figures (9) and (10) and table (3) show GWO results. For this system that shows boarding and shooting response time, the PI controller and the best fitness function are shown in the tables (1,2). The system which incorporated GWO has a high response, best optimal value, and low ripple compared to the system with GA. Comparison between GA and GWO are given in Figures 11,12 and 13.

**Figure 7.** The response of Electromagnetic Torque with GA

**Figure 8.** The response of Rotor Speed with GA

**Table 2.** Response on Classical DTC of IM with GA

| Response         | Value     |
|------------------|-----------|
| Rise time        | 4.013ms   |
| I r m s          | 3.874     |
| I max            | 11.81     |
| I mean           | -0.0292   |
| Overshoot        | 33%       |
| Fitness function | 2.2       |
| K p              | 74.707    |
| Ki               | 0.2191    |
Figure 9. The response of Electromagnetic Torque with GWO

Figure 10. The response of Rotor Speed with GWO

Table 3. Response on Classical DTC of IM with GWO

| Response     | Value     |
|--------------|-----------|
| Rise time    | 4.656ms   |
| $I_{rms}$    | 3.932     |
| $I_{max}$    | 11.65     |
| $I_{mean}$   | 0.0767    |
| Overshoot    | 32%       |
| Fitness function | 2.1     |
| $K_p$        | 99.8739   |
| $K_i$        | 0.327     |

Figure 11. Compare Response of Torque
6. Conclusion
The optimization process DTC using GA and GWO algorithms has been presented to improve classic control versus differences in machine parameters and variable load. Simulation tests are conducted at MATLAB / Simulink to check the durability of this proposed control in different operating modes. The results show that the GWO is a very good choice to improve the overall performance of IM in terms of fast-tracking of signal with no effect for change of torque load.

7. References
[1] Bimal K. Bose, “Modern Power Electronic and AC Drives”, Pearson Education, 2003.
[2] Muhammed H. Rashid, “Power Electronics, Circuits, Derives and applications”, Pearson Education Inc. 2004.
[3] I. Takahashi and Y. Ohmori, “High-performance direct torque control of induction motor”, IEEE Trans. Ind. Appl., vol. 25, no. 2, pp. 257-264, 2009.
[4] Tao Zhao, Fenghong Xiang, Jianping Wang, Guo Zhang and Jianlin Mao, "Research on speed sensorless direct torque fuzzy control of induction motors," 2014 International Conference on Electronics and Communication Systems (ICECS), 2014.
[5] Parekh R., “AC Induction Motor Fundamentals", Microchip Technology Inc., AN887, U.S.A., 2003.
[6] Najib El Ouanjli1*, Aziz Derouchi1, Abdelaziz El Ghziza1, Saad Motahhir1, Ali Chebahbi2, Youness El Mourabit1 and Mohammed Taoussi3,” Modern improvement techniques of direct torque control for induction motor drives - a review” springer, 10.1186/s41601-019-0125-527 May 2019.
[7] Abed, I. A., Sahari, K. S. M., Koh, S. P., Tiong, S. K., and Jagadeesh, P. (2013). Using Electromagnetism-like algorithm and genetic algorithm to optimize time of task scheduling for dual manipulators.IEEE Region 10 Humanitarian Technology Conference, 2013.
[8] Domenico Casa dei, Francesco Profumo, Giovanni, Angelo Tani. "FOC and DTC: Two Viable Schemes for Induction Motors Torque Control", IEEE transaction on power electronics, vol.17, no. 5, september 2002.
[9] Giuseppe S. Buja, Marian P. Kazmierkowski. "Direct Torque Control of PWM Inverter-Fed AC Motor- A Survey", IEEE transaction on industrial electronics, vol. 51, no. 4, August 2004.
[10] Jawad Faiz, M.B.B Sharifian. "Comparison of different switching pattern in direct torque control technique of induction motors", Electric Power systems Research 60 (2001) 63-75.
[11] Farouk M. Abdel-kader, A. EL-Saadawi, A. E. KALAS, Osama M.EL-baksawi “Study In Direct Torque Control of Induction Motor By Using Space Vector Modulation” IEEE 978-1-4244-1933 (2008).
[12] Anhar.A, Sagger “Field Oriented Control of an Induction Motor Based on a Single –Phase to Three – Phase Indirect Matrix Converter” June 2016.
[13] Mirjalili, Seyed Ali, Seyed Mohammad Mirjalili, and Andrew Lewis. “Grey wolf optimizer.” Advances in Engineering Software 69. 46-61, 2014.
[14] L. D. Mech, "Alpha status, dominance, and division of labor in wolf packs," Canadian Journal of Zoology, vol. 77, pp. 1196-1203, 1999.
[15] Mohammed h. qais, hany m. hasanien, and saadalghuwainem “A Grey Wolf Optimizer for Optimum Parameters of Multiple PI Controllers of a Grid-Connected PMSG Driven by Variable Speed Wind Turbine” IEEE,2169-35362018.
[16] Md. Habibullah, Dylan Dah-Chuan Lu, Dan Xiao, and Muhammed Fazlur Rahman,” Finite-State Predictive Torque Control of Induction Motor Supplied from a Three-Level NPC Voltage Source Inverter” IEEE 2522977, Transactions on Power Electronics, 2016.