SAKARYA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ

Sakarya University Journal of Science
SAUJS

ISSN 1301-4048 e-ISSN 2147-835X Period Bimonthly Founded 1997 Publisher Sakarya University
http://www.saujs.sakarya.edu.tr/

Title: Parameter Estimation of Induction Motors using Hybrid GWO-CS Algorithm

Authors: Selcuk EMİROGLU

Recieved: 2022-09-15 00:00:00

Accepted: 2023-01-30 00:00:00

Article Type: Research Article

Volume: 27
Issue: 2
Month: April
Year: 2023
Pages: 361-369

How to cite
Selcuk EMİROGLU; (2023), Parameter Estimation of Induction Motors using Hybrid GWO-CS Algorithm . Sakarya University Journal of Science, 27(2), 361-369, DOI: 10.16984/saufenbilder.1175899
Access link
https://dergipark.org.tr/en/pub/saufenbilder/issue/76551/1175899

Sakarya University Journal of Science 27(2), 361-369, 2023

SAKARYA ÜNİVERSİTESİ

Parameter Estimation of Induction Motors using Hybrid GWO-CS Algorithm

Selçuk EMİROĞLU *[1]

Abstract

This study investigates a hybrid algorithm between Grey Wolf Optimization (GWO) and Cuckoo Search (CS) algorithms to find the parameters of induction motors. The parameters of the induction motor have been estimated by using the data supplied by the manufacturer. The problem for parameter estimation of the induction motor is formulated as an optimization problem. Then, the optimization problem is solved by using GWO and hybrid algorithm based on GWO and CS algorithms for the estimation of induction motor parameters. Numerical results show that both algorithms are capable of solving the optimization problem for finding the parameters of induction motor. Also, two algorithms and other algorithms such as Differential Evolution (DE), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Shuffled Frog-Leaping Algorithm (SFLA), and Modified Shuffled Frog-Leaping Algorithm (MSFLA) are compared for the problem. The results show that the hybrid GWO-CS algorithm gives a smaller objective value and closer torque value to the manufacturer's data than the GWO algorithm and several algorithms for motor 1. Hybrid GWO-CS algorithm gives nearly the same results with GWO algorithm for motor 2.

Keywords: Parameter estimation, induction motors, grey wolf optimization, cuckoo search optimization, hybrid algorithm

1. INTRODUCTION

Induction motors are widely used in many applications due to their simple construction, ease of use, low cost of maintenance, and durability [1].

Equivalent circuit parameters for induction machines are necessary for control, design of the controller, dynamic simulations, etc. [2]. The circuit parameters for a motor, however, are typically not provided by the manufacturer [3].

The typical values obtained in the literature are frequently not exact enough because the parameters are motor-specific. Therefore, it is preferable to estimate motor equivalent circuit parameters using the information provided by manufacturers in their catalogs, such as full load torque, full load power factor, breakdown torque, etc. It is important to find the parameters correctly for simulations, design, or control, etc. [4]. So, accurate modeling is viewed as a significant issue for induction machines in order to

* Corresponding author: selcukemiroglu@sakarya.edu.tr
[1] Sakarya University, Faculty of Engineering, Department of Electrical and Electronics Engineering
ORCID: https://orcid.org/0000-0001-7319-8861

attain the target performance of induction machines. The accurate modeling of induction machines is a significant issue, especially in terms of drives and control of them which affect the efficiency.

Also, various research studies in the literature have made significant efforts to determine the parameters of induction machines. For decades, meta-heuristic algorithms have been used to solve the parameter estimation problems of induction machines, such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), etc. GA is employed the offline parameter estimation of the induction motors considering magnetic saturation and iron losses in [5]. Also, Grey Wolf Optimization (GWO), Jaya Algorithm, and Cuckoo Search (CS) have been used for the parameter identification of DC motors with dynamic response relations [6]. A global optimum solution can be obtained in less time with these methods, which are easy to implement in the problem of parameter estimation. But hybrid algorithms have been studied in solving the parameter estimation problem in few works. They have been developed for effectively solving optimization problem recently. It has been shown in many studies that hybrid algorithms give good results. In [7], the parameters of poly-phase induction motors are estimated by a hybrid optimization algorithm between PSO and Jaya algorithms. The parameters of double-cage induction motors are also estimated by using a hybrid metaheuristic algorithm with the help of Phasor Particle Swarm Optimization (PPSO) and Gravitational Search Algorithm (GS) [8]. The performance of the hybrid algorithm has been tested on different motors [8].

The parameter estimation of induction motors has been done using GWO and hybrid GWO-CS algorithms and compared with some heuristic-based techniques, including GA, Differential Evolution (DE), PSO, Shuffled Frog-Leaping Algorithm (SFLA) and Modified Shuffled Frog Leaping Algorithm (MSFLA).

2. PROBLEM DEFINITION

The model of the induction motor can be obtained by using an equivalent circuit under steady state [9]. The parameter of induction motor is estimated based on optimization using the equivalent circuit. So, the problem of parameter estimation for induction motors is formulated as an optimization problem. By minimizing the objective function which corresponds the square of the difference between manufacturer ‘data and estimated data, the parameters can be estimated. The optimization problem uses an objective function and some constraints to find the parameters of induction motor. The optimization problem is solved by using GWO and hybrid GWO-CSO algorithms. The motor data provided by manufacturer such as the maximum torque, starting torque, the full load torque and power factor under full load are used in optimization problem. As a result of optimization problem, the rotor and the stator resistances, the rotor, stator, and magnetizing reactance can be estimated.

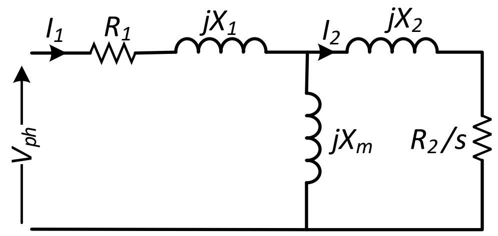

Figure 1 Single-phase steady-state equivalent circuit of a three-phase induction motor

The equivalent circuit model of an induction motor under a steady state is shown in Fig. 1. R_1, R_2, X_1, X_2, and X_m are the stator resistance, rotor resistance transferred to the stator side, stator leakage reactance, rotor leakage reactance transferred to the stator side, and magnetizing reactance, respectively. As can be seen in Fig. 1, the rotor parameters are referred to the stator and also the core losses are assumed to be negligible.

The aim of the optimization is to find the parameters of the induction motor. An optimization problem is solved by minimizing the objective function satisfying several constraints. Based on the manufacturer's data, the multi-objective function can be written as follows.

$$Objective = F_1^2 + F_2^2 + F_3^2 + F_4^2 \tag{1}$$

where,

$$F_1 = \frac{T_{st,est} - T_{st,md}}{T_{st,md}} \tag{2}$$

$$F_2 = \frac{T_{\max,est} - T_{\max,md}}{T_{\max,md}} \tag{3}$$

$$F_3 = \frac{T_{fl,est} - T_{fl,md}}{T_{fl,md}} \tag{4}$$

$$F_4 = \frac{p_{fl,est} - p_{fl,md}}{p_{fl,md}} \tag{5}$$

here, T_{st}, T_{max} T_{fl}, and p_{fl} are the starting torque, maximum torque, full load torque, and power factor at full load, respectively. Subscript *md* and *est* represent the manufacturer and estimated data, respectively. Also, the parameter limits need to be considered as inequality constraints. So, the optimization problem has to satisfy the constraints given below. Eq. 6 contains inequality constraints for the problem.

$$\begin{aligned} R_{1_{\min}} &\le R_1 \le R_{1_{\max}} \\ R_{2_{\min}} &\le R_2 \le R_{2_{\max}} \\ X_{1_{\min}} &\le X_1 \le X_{1_{\max}} \\ X_{2_{\min}} &\le X_2 \le X_{2_{\max}} \\ X_{m_{\min}} &\le X_m \le X_{m_{\max}} \end{aligned} \tag{6}$$

The upper bounds for the parameters of the motors are given as [0.6 0.6 0.5 0.5 11] for motor 1 and [100 100 100 100 100] for motor 2 and the lower bounds are given as [0.1 0.2 0.1 0.1 4] for motor 1 and [0.001 0.1 0.1 0.1 0.1] for motor 2 corresponding to [R_1 R_2 X_1 X_2 X_m]. The GWO and hybrid GWO-CS algorithms are applied for the estimation of induction motor parameters.

To calculate the torque value of the motor for the solution of the problem in terms of slip, firstly, the stator current needs to be calculated with the following equation [9].

$$\bar{I}_1(s) = \frac{\bar{V}_{ph}}{R_1 + jX_1 + \bar{Z}_p(s)} \tag{7}$$

where

$$\bar{Z}_p(s) = \frac{1}{\dfrac{1}{jX_m} + \dfrac{1}{\dfrac{R_2}{s} + jX_2}} \tag{8}$$

Then, the rotor current can be expressed as below.

$$I_2(s) = \frac{\bar{Z}_p(s) \cdot \bar{I}_1(s)}{\dfrac{R_2}{s} + jX_2} \tag{9}$$

Finally, torque is calculated as

$$T(s) = \frac{3p}{\omega_s}\left[I_2(s)\right]^2 \frac{R_2}{s}. \tag{10}$$

Therefore, the torque at full load and starting is calculated as $T(s_{fl})$ and $T(1)$, respectively. Also, maximum torque $T(s_{max})$ can be obtained using

$$s_{\max} = \frac{R_2}{\sqrt{R_{th}^2 + \left(X_{th} + X_2\right)^2}} \tag{11}$$

where

$$Z_{th} = R_{th} + jX_{th} = \frac{1}{\dfrac{1}{R_1 + jX_1} + \dfrac{1}{jX_m}} \tag{12}$$

Then, the power factor can be calculated as follows [10].

$$pf = \cos\varphi = \cos(\arg(Z_{in})) \tag{13}$$

where

$$Z_{in} = R_1 + jX_1 + \frac{jX_m\left(\frac{R_2}{s} + jX_2\right)}{\frac{R_2}{s} + j\left(X_m + X_2\right)} \tag{14}$$

3. HYBRID GWO-CS ALGORITHM

Recently, two or more algorithms have been used together, called a hybrid to find a better solution for the optimization problems [11]. The GWO technique is proposed by Seyedali Mirjalili and Andrew Lewis to solve numerous optimization problems in many disciplines [12]. This algorithm emulates the typical hunting cooperative behavior of grey wolves [13]. The social leadership structure and the hunting behavior of grey wolves in nature serve as the primary driving forces behind this algorithm [12, 14].

Due to its varied lives and aggressive reproduction, the cuckoo bird serves as an inspiration for the CS [11, 15-17].

The traditional GWO has a strong ability to exploit local solutions, while the traditional CS has a strong ability to explore global solutions in the space [18]. Due to a weak ability of global search, GWO can fall into local minimum easier.

So, it is useful to combine GWO and CS algorithms to get the advantages of these two algorithms [19]. CS can update the next positions independently of the search path [17]. Therefore, moving from current place to another is considerably easier in CS algorithm. So, CS is utilized to update the positions of search agents and get new ones for GWO [20]. The flowchart of the hybrid GWO-CS algorithm is depicted in Fig. 2.

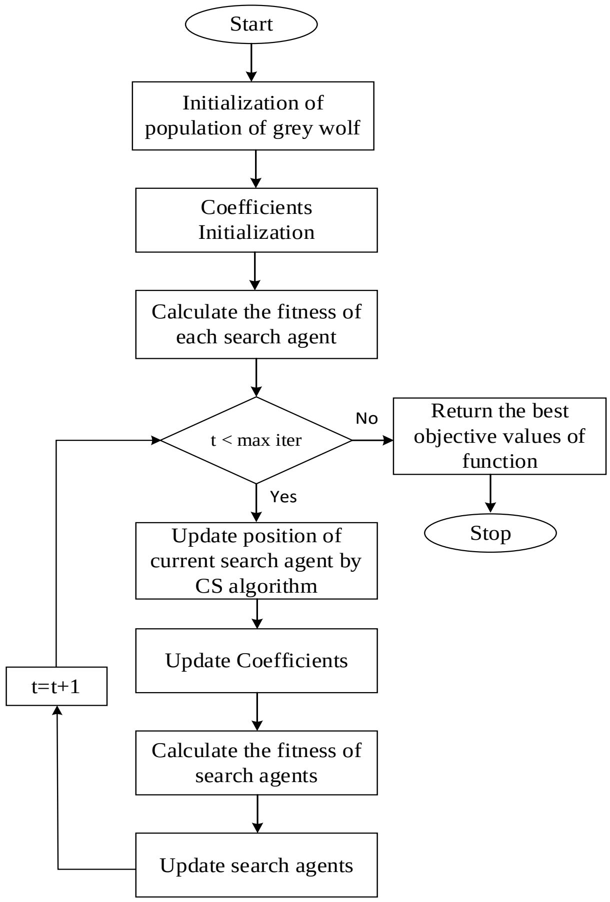

Figure 2 The flowchart of GWO-CS algorithm [11]

4. SIMULATION RESULTS

The hybrid GWO-CS and GWO algorithms have been tested on two motors with 40 HP and 5 HP. The manufacturer data of the two motors are given in Table 1.

Also, proposed hybrid GWO-CS and GWO algorithms are compared with several algorithms such as DE, GA, PSO, SFLA, and MSFLA algorithms.

To show the performance of the proposed approach, two different motors are considered. Tables 2 and 3 show the estimated parameters obtained with the proposed approach and several algorithms for motor 1 and motor 2, respectively. Also, objective function values for proposed approach and other algorithms are given in Tables 2 and 3. Objective values obtained with the proposed approaches for motor 1 are the smallest among all algorithms given in Table 2. In addition, the hybrid GWO-CS algorithm gives a smaller objective value than the GWO algorithm.

As seen in Table 3, the proposed approach has the smallest objective value, but it has an equal objective value with MSFLA algorithm for motor 2. Moreover, hybrid GWO-CS and GWO algorithms give the same objective value with the MSFLA. Besides, the parameters estimated hybrid GWO-CS, GWO and MSFLA are nearly same.

In Tables 4 and 5, starting torque, full load torque, maximum torque, and full load power factor values of the motors obtained from various algorithms and given by the manufacturer are given with the percent error.

Table 1 Manufacturer’s data of the induction motors [9]

Parameter	**Motor 1**	**Motor 2**
P_n	40 HP	5 HP
V	400 V	400 V
f	50 Hz	50 Hz
p	2	2
T_{st}	260 Nm	15 Nm
T_{fl}	190 Nm	25 Nm
T_{max}	370 Nm	42 Nm
pf_{fl}	0.8	0.8
s_{fl}	0.09	0.07

The errors of starting torque, full load torque, maximum torque, and full load power factor results for motor 1 obtained from the proposed approach GWO-CS and GWO are the smallest among the results of other algorithms in Table 4. Moreover, the results of the hybrid GWO-CS algorithm compared with the results of GWO are the closest to manufacturer data except for the maximum torque value of motor 1. However, the maximum torque values obtained with GWO-CS and GWO algorithms are very close to each other and manufacturer's data.

The proposed algorithms give the closest value to manufacturer data for motor 2 except maximum torque value as can be seen in Table 5. However, the results of proposed approach for the maximum torque value of motor 2 are close the results of other algorithms.

Fig. 3 and 4 show the curves of the torque versus rotor speed for motor 1 and motor 2, respectively. Both curves shown in Fig. 3 and 4 are obtained with GWO and hybrid GWO-CS algorithm. The red and blue dash line represent the curves obtained with GWO and GWO-CS, respectively.

As shown in Fig. 3, the results obtained with both the GWO-CS and GWO algorithms are close to the manufacturer's data, while the results of the starting and maximum torque values obtained with the GWO-CS appear to be closer to the manufacturer's data than those obtained with the GWO.

One can deduce from Fig. 4 that the results obtained with GWO-CS and GWO algorithms are very similar to each other. The parameters found by GWO-CS and GWO algorithm have already been estimated almost the same. The maximum torque value is estimated with more error regarding the starting torque and power factor for motor 2.

Table 2 Estimated parameters of the induction motor 1 (40 HP) and objective value for several and proposed algorithms

Parameter (Ω)	**DE** [9]	**GA** [9]	**PSO** [9]	**SFLA** [9]	**MSFLA** [9]	**GWO**	**GWO-CS**
Objective Value	1.0e-04	5.0e-04	1.0e-04	1.0e-05	1.0e-06	**4.53e-08**	**1.196e-08**
R_1	0.4993	0.4875	0.3555	0.3437	0.2707	**0.2783**	**0.2779**
R_2	0.3264	0.3264	0.3455	0.3360	0.3573	**0.3609**	**0.3611**
X_1	0.3510	0.3556	0.4353	0.4345	0.4773	**0.4793**	**0.4796**
X_2	0.3510	0.3556	0.4353	0.4345	0.4773	**0.4793**	**0.4796**
X_m	5.6967	6.0718	6.4223	6.2629	7.5432	**7.5940**	**7.6014**

Table 3 Estimated parameters of the induction motor 2 (5 HP) and objective value for several and proposed algorithms

Parameter (Ω)	**DE** [9]	**GA** [9]	**PSO** [9]	**SFLA** [9]	**MSFLA** [9]	**GWO**	**GWO-CS**
Objective Value	0.0023	0.0045	0.0023	0.0023	0.00228	**0.00228**	**0.00228**
R_1	0.1838	1.1316	0.9872	0.0008	0.003681	**0.0001**	**0.0005**
R_2	2.1009	2.0330	2.0322	2.1330	2.181757	**2.2053**	**2.2058**
X_1	5.6197	5.3750	5.3785	5.5847	5.720209	**5.779**	**5.7794**
X_2	5.6197	5.3750	5.3785	5.5847	5.720209	**5.779**	**5.7794**
X_m	99.1792	87.1944	77.0420	77.9101	94.140145	**95.6469**	**95.5969**

Table 4 Torque – power factor values of the induction motor 1 (40 HP) and error for several and proposed algorithms

	T_{st} (Nm)		T_{fl} (Nm)		T_{max} (Nm)		p_{fl}	
Parameter	**Value**	**Error**	**Value**	**Error**	**Value**	**Error**	**Value**	**Error**
Nameplate	260	-	190	-	370	-	0.8	-
DE [9]	263.51	1.35 %	189.3514	-0.34 %	347.2340	-6.15 %	0.8065	0.82 %
GA [9]	265.8385	2.24 %	191.2220	0.64 %	351.2145	-5.08 %	0.8170	2.13 %
PSO [9]	261.1978	0.46 %	188.9053	-0.58 %	360.8307	-2.48 %	0.7883	-1.46 %
SFLA [9]	260.3347	0.13 %	193.5212	1.85 %	365.0454	-1.34 %	0.7860	-1.75 %
MSFLA [9]	259.5611	-0.17 %	190.6352	0.33 %	370.8140	0.22 %	0.7995	-0.06 %
GWO	**260.0361**	**0.0139%**	**190.018**	**0.0095%**	**370.0263**	**0.0071%**	**0.79991**	**-0.0109%**
GWO-CS	**260.0212**	**0.0082%**	**189.9856**	**-0.0076%**	**370.0405**	**0.0109%**	**0.79996**	**-0.0052%**

Table 5 Torque – power factor values of the induction motor 2 (5 HP) and error for several and proposed algorithms

Parameter	T_{st} (Nm)		T_{fl} (Nm)		T_{max} (Nm)		p_{fl}	
	Value	**Error**	**Value**	**Error**	**Value**	**Error**	**Value**	**Error**
Nameplate	15		25		42		0.8	
DE [9]	15.2351	1.57 %	26.3582	5.43 %	40.7443	-2.99 %	0.8110	1.38 %
GA [9]	15.3856	2.57 %	25.7210	2.88 %	38.9606	-7.24 %	0.8101	1.26 %
PSO [9]	15.3465	2.31 %	25.5692	2.28 %	39.0047	-7.13 %	0.7888	-1.40 %
SFLA [9]	15.4939	3.29 %	25.6484	2.59 %	40.7390	-3.00 %	0.7710	-3.63 %
MSFLA [9]	15.2725	1.82%	25.5541	2.22%	40.3870	-3.84%	0.7991	-0.11%
GWO	**15.2553**	**1.702%**	**25.5110**	**2.044%**	**40.3347**	**-3.965%**	**0.79997**	**-0.0038%**
GWO-CS	**15.2553**	**1.702%**	**25.504**	**2.016%**	**40.3281**	**-3.9807%**	**0.7999**	**-0.0125%**

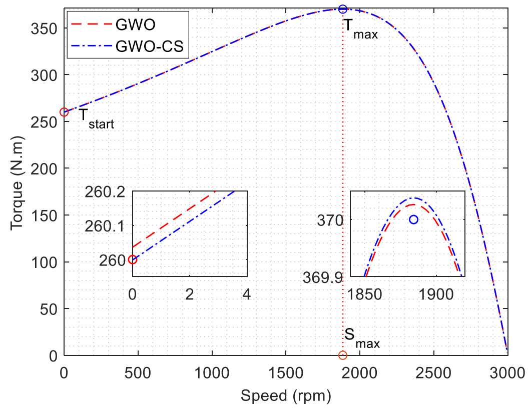

Figure 3 Torque–Speed curve of induction motor 1

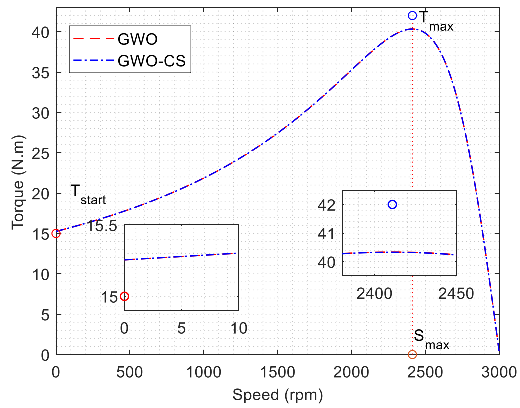

Figure 4 Torque–Speed curve of induction motor 2

5. CONCLUSION

In this paper, the parameter estimation of induction machines is made by using a hybrid algorithm based on GWO and CS algorithms. The hybrid GWO-CS algorithm are compared with GWO and other algorithms. The results show that GWO-CS is generally gives better results compared to conventional GWO algorithm. Also, the hybrid GWO-CS algorithm provides better results than several algorithms. Simulation results with the lowest values of the objective demonstrate the efficiency and robustness of the proposed GWO-CS and GWO algorithms.

Funding
The author (s) has no received any financial support for the research, authorship or publication of this study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] K. Chayakulkheeree, V. Hengsritawat, P. Nantivatana, “Particle swarm optimization based equivalent circuit estimation for on-service three-phase induction motor efficiency assessment,” Engineering Journal, vol. 21, no. 6 Special Issue, pp. 101–110, Oct. 2017.

[2] M O. Gülbahçe, M E. Karaaslan, “Estimation of Induction Motor Equivalent Circuit Parameters from Manufacturer’s Datasheet by Particle Swarm Optimization Algorithm for Variable Frequency Drives,” Electrica, vol. 22, no. 1, pp. 16–26, Jan. 2022.

[3] A I. Çanakoğlu, A G. Yetgin, H. Temurtaş, M. Turan, “Induction motor parameter estimation using metaheuristic methods,” Turkish Journal of Electrical Engineering and Computer Sciences, vol. 22, no. 5, pp. 1177–1192, 2014.

[4] H R. Mohammadi, A. Akhavan, “Parameter Estimation of Three-Phase Induction Motor Using Hybrid of Genetic Algorithm and Particle Swarm Optimization,” Journal of Engineering, vol. 2014, no. 148204, pp. 1–6, 2014.

[5] A. Accetta, F. Alonge, M. Cirrincione, F. D’Ippolito, M. Pucci, A. Sferlazza, “GA-Based Off-Line Parameter Estimation of the Induction Motor Model Including Magnetic Saturation and Iron Losses,” IEEE Open Journal of Industry Applications, vol. 1, no. July, pp. 135–147, 2020.

[6] O. Rodríguez-Abreo, J. Rodríguez-Reséndiz, J. M. Álvarez-Alvarado, A. García-Cerezo, “Metaheuristic Parameter Identification of Motors Using Dynamic Response Relations,” Sensors, vol. 22, no. 11, pp. 1–22, 2022.

[7] M I. Abdelwanis, R. A. Sehiemy, M A. Hamida, "Hybrid optimization algorithm for parameter estimation of poly-phase induction motors with experimental verification," Energy and AI, vol. 5, p. 100083, 2021.

[8] J. Vukasinovic, M. Milovanovic, N. Arsic, J. Radosavljevic, S. Statkic, "Parameters estimation of double-cage induction motors using a hybrid metaheuristic algorithm," 2022 21st International Symposium INFOTEH-JAHORINA, 2022, pp. 16–18, 2022.

[9] I. Perez, M. Gomez-Gonzalez, F. Jurado, "Estimation of induction motor parameters using shuffled frog-leaping algorithm," Electrical Engineering, vol. 95, no. 3, pp. 267–275, Sep. 2013.

[10] M. Averbukh, Efim Lockshin, "Estimation of the Equivalent Circuit Parameters of Induction Motors by Laboratory Test," Machines, vol. 9, no. 340, pp. 1–12, 2021.

[11] H Y. Mahmoud, H M. Hasanien, A H. Besheer, A Y. Abdelaziz, "Hybrid cuckoo search algorithm and grey wolf optimiser-based optimal control strategy for performance enhancement of HVDC-based offshore wind farms," IET Generation, Transmission and Distribution, vol. 14, no. 10, pp. 1902–1911, May 2020.

[12] S. Mirjalili, S M. Mirjalili, A. Lewis, "Grey Wolf Optimizer," Advances in Engineering Software, vol. 69, pp. 46–61, Mar. 2014.

[13] W. Long, S. Cai, J. Jiao, M. Xu, T. Wu, "A new hybrid algorithm based on grey wolf optimizer and cuckoo search for parameter extraction of solar photovoltaic models," Energy Convers Manag, vol. 203, p. 112243, Jan. 2020.

.

[14] R K. Khadanga, A. Kumar, S. Panda, "A modified Grey Wolf Optimization with Cuckoo Search Algorithm for load frequency controller design of hybrid power system," Applied Soft Computing, vol. 124, Jul. 2022.

[15] R N. Kalaam, S. M. Muyeen, A. Al-Durra, H. M. Hasanien, K. Al-Wahedi, "Optimisation of controller parameters for grid-tied photovoltaic system at faulty network using artificial neural network-based cuckoo search algorithm," IET Renewable Power Generation, vol. 11, no. 12, pp. 1517–1526, Oct. 2017.

[16] M. Mareli, B. Twala, "An adaptive Cuckoo search algorithm for optimisation," Applied Computing and Informatics, vol. 14, no. 2. Elsevier B.V., pp. 107–115, Jul. 01, 2018.

[17] X. S. Yang, S. Deb, "Cuckoo search via Lévy flights," 2009 World Congress on Nature and Biologically Inspired Computing, NABIC, 2009, pp. 210–214.

[18] P H. Kumar, M. Rudramoorthy, "Distribution network reconfiguration considering DGs using a hybrid CS-GWO algorithm for power loss minimization and voltage profile enhancement," Indonesian Journal of Electrical Engineering and Informatics, vol. 9, no. 4, pp. 880–906, 2021.

[19] H. Xu, X. Liu, J. Su, "An improved grey Wolf optimizer algorithm integrated with Cuckoo Search," in Proceedings of the 2017 IEEE 9th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2017, Nov. 2017, vol. 1, pp. 490–493.

[20] A. Bouaddi, R. Rabeh, M. Ferfra, “Load Frequency Control of Autonomous Microgrid System Using Hybrid Fuzzy logic GWO-CS PI Controller,” in 2021 9th International Conference on Systems and Control, ICSC 2021, 2021, pp. 554–559.