HILL CLIMBING BASED LOCAL SEARCH OPTIMIZATION TECHNIQUE FOR EFFICIENT INDUCTION MACHINE OPERATION

P Ponmurugan[1], Dr.R.Maheswari[2], Dr.N.Rengarajan[3], Dr.V.Kamatchi Kannan[4], Dr.V.Akila[6]

Article History: Received: 12.12.2022 **Revised:** 29.01.2023 **Accepted:** 15.03.2023

Abstract

Search Optimization technique designed with multi-objective functions is used to improve the efficiency of the design of the induction machine termed as Random restart local search optimization technique or Hill Climbing based Local search optimization technique (HC –LSO). In order to design an induction machine with high operation efficiency, the above algorithm uses the repeated explorations of the problem space to provide the induction machine data. This proposed technique selects the objective functions from the discrete and continuous hill climbing process to design the induction motor. The proposed HC-LSO technique for multi-objective design optimization of induction motors is compared with two existing algorithms namely Non-dominated Sorting Genetic Algorithm (NSGA-II) and Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO). From the simulation carried out in the MATLAB, results of the proposed HC – LSO and other existing techniques are compared. As a result the performance of the proposed technique influences on the factors such as rotor current, power factor and efficiency of the induction machine.

Keywords: Induction machine, Hill Climbing Based Local Search Optimization, HC-LSO, NSGA-II, Threshold condition, Rotor Current, Power factor, Efficiency, Objective function.

[1]Professor, Meenakshi Academy of Higher Education and Research, Chennai
[2]Assistant Professor, Department of Management Studies, Kongu Engineering College, Perundurai, Erode
[3]Principal, Nandha Engineering College, Perundurai, Erode
[4]Professor, Department of EEE, Knowledge Institute of Technology, Kakapalayam, Salem
[5]Research Associate, Department of Research, Meenakshi Academy of Higher Education & Research, Chennai
[6]Managing Director, ARAA Techno-Research Services, Erode

DOI: 10.31838/ecb/2023.12.s2.199

1. Introduction

In the fast moving world, the need for electrical power requirements is increasing day by day due to the enormous increase in electrical equipment. The power generation and management are the two major areas of focus to provide uninterrupted supply. Effective energy utilization leads to the improvement in energy conservation. Many applications are using the induction motors for its operations due to its simple construction and flexible operations. Nearly 60 % of the generated powers are used for the induction motor running purposes. In every application, the efficiency of the electrical drives and the consumption of the electrical power are the most important targets in considering their improvements. Hence, the design of the induction motor includes producing high energy efficiency with less power consumption is the major issue to be addressed.

The design of an induction motor is created and finalized by well experienced designers and manufacturers based on their experience and innovations before half a century. Due to the advancement in the modern electronic world, the induction machine has undergone noticeable improvements in the materials and the manufacturing capabilities. There are many developments in the design of the induction machine over the past periods. The performance of the induction machines are improved by considering the various design parameters such as geometrical values, type of winding used in the machine, type of reaction rail and thrust value as a function of input frequency. There are many other parameters that are taken into consideration are linear velocity, input voltage and primary connection used in the induction machine.

The proposed multi objective optimization technique helps to provide an optimum result by having more objective functions called as objective programming, multi criterion optimization or multi attribute optimization. This technique helps to achieve the optimal solution for the design of machine induction in an efficient manner using the optimization technique. Many research works have been carried out in order to develop an optimized approach for the design of induction motors by considering numerous parameters. In this proposed work, a three phase squirrel cage induction motor has been designed and developed by considering a multi objective problem. The article outline comprises the following sections. Section 2 reveals the review of the related work involved in the operation of the induction motor. Section 3 describes the proposed Hill climbing based local search optimization technique and its description. Section 4 simulates the implementation environment of the proposed work carried out along with the necessary parameters. Section 5 depicts the results received from the implementation. Section 6 gives the summary and conclusion of the paper.

I. Related Works

The Three Phase induction motor is designed by using the non dominated sorting genetic algorithm (NSGA – II) and the multi objective design optimization is embedded in order to achieve maximum efficiency [1]. The ranking method is introduced to attain the parent optimal solutions. But the efficiency of the induction machine is reduced due to the introduction of the optimal solution. Using the Hybrid genetic algorithm and particle swarm optimization, the parameters of the induction motor are evaluated by creating a commercial offline method. Genetic algorithms and particle swarm optimization are combined together into a hybrid model called HGAPSO model [2]. The developed model characteristics help to determine the steady state equivalent circuit parameters for machine design. Torque and power factor is estimated with the help of the existing machine data. This model helps to increase the efficiency of the induction machine. But the torque factor of the induction machine was not improved.

To increase the efficiency of the induction machine, external rotors were used in the industrial fans with fixed load in order to achieve the objective function by redesigning the machine structure. Using the Genetic algorithm, the design of an induction motor with an external rotor is introduced [3]. But the losses in the machine were not controlled. Genetic algorithm is used to optimize the direct torque control and back stepping of one of the induction motors [4]. Non linear hysteresis is used to manage the torque and stator flux at steady state operation. Hence the torque level is increased. But the efficiency of the induction machine is not discussed.

Energy efficiency of the three phase induction motors were enhanced by using the control plan depending on the indirect field oriented approach [5]. Minimization of various losses caused by the copper and iron are achieved by designing a loss model based controller with different load values. Quadrature current based non linear equation helps in attaining the steady state conditions. As a result, the copper and iron losses are reduced. But the power factor remains unimproved. Optimization of the inverter driven induction motor by particle swarm optimization is introduced in [6]. By identifying the optimal output frequency and voltage of drive, the maximum efficiency of the motor is attained. Modified PSO algorithm is used to identify the optimal amplitude and frequency of excitation voltage. As a result, the efficiency of the motor is not increased beyond the threshold level.

Induction motors with semi closed slots and the usage of magnetic wedges were discussed in [7].

This technique improves the motor efficiency and reduces the losses due to the core and copper components. This study focuses on the improvement of motor efficiency by reducing the core and copper losses. But there is no improvement in the rotor current. In order to address this issue, a combined star delta winding is introduced in order to carry out the analytical calculation of the induction motor efficiency [8]. Optimization of the Induction Motor Drives (IMD) is carried out by using the new hybrid model proposed in [9]. In the steady condition of the drive and loss model, the search control technique is applied. Direct vector controlled induction motor drives efficiency is optimized by a new hybrid model proposed in [10].The total losses in the induction machine is reduced by replacing the rotor flux with load torque. But the total losses in the motor are not reduced after a certain point with respect to the increase in the efficiency.

To increase the efficiency, the Genetic Algorithm is used to design the induction motor as discussed in [11]. Even if the efficiency of the motor is increased, the value of the computational cost remains unchanged. The speed of the induction motor drive is controlled by a genetic algorithm based self tuned neuro fuzzy controller given in the [12]. Hence the speed of the induction motor is controlled by the neuro fuzzy controller. But the efficiency of the motor remains constant. To estimate the efficiency of the induction motor, an improved big bang big crunch (I-BB-BC) is introduced [13]. Objective function is used to measure the current value, power factor and input factor in order to calculate the induction motor efficiency. But the torque value of the induction motor is not improved by using the improved big bang big crunch (I-BB-BC) algorithm.

In harmonic equivalent circuits, the quantification of the additional losses is calculated for the non intrusive efficiency evaluation of the induction motors. Efficiency estimation of the induction motor is carried out by using the recommended methods designed in [14]. Dynamometer is used to calculate the full load and partial load efficiency [15]. But recommended methods failed to improve the rotor current. For calculating the induction motor's full load and partial load efficiency, a new technique is designed. To Estimate the efficiency of the induction motors, an Air Gap Torque (AGT) based method is introduced [16].

To address the issues like output power, losses and efficiency of the induction motors with unbalanced voltages, a bacterial foraging algorithm is proposed in [17]. This algorithm acts as an economic, exact and low invasive tool adopted to work in any kind of field conditions. In order to improve the efficiency and power factor of the induction motor, a genetic algorithm based multi objective optimization method [18] is proposed to reduce the motor weight. For optimal design of the induction motors, the multi objective fuzzy genetic algorithm is proposed in [19-21]. As a result of the above discussed methods, the computational complexity remains high. These methods failed to address this issue. Hill climbing based local search optimization is proposed to design the induction machines and to address this issue. With the help of the firefly behaviour, the multimodal optimization problem is identified and resolved for the induction motor design.

II. Proposed Hc - Lso Technique For Im Design

A series of hill climbing searches are made from the randomly created initial states by the random restart hill climbing algorithm and end when the stated objectives are satisfied. To address the optimization issue in discovering the local optimum, a mathematical optimization technique named hill climbing based local search optimization is used. The number of iterations for restarts is made based on the assured characteristics of the local optima. Once the process gets initiated with a sub optimal solution, it is further enhanced until the stated objective gets satisfied. The solution based on the design with optimal solution is compared with the design from the starting base of the hill in order to obtain the enhanced solution. The solution is calculated based on walking to the hill and reaching the top of the hill. The steps followed in the hill climbing techniques are as follows.

Step 1: Construction of the sub optimal solution by satisfying the problem constraints.

Step 2: Step by step solution increment.

Step 3: Increase the solution till no further possible enhancement.

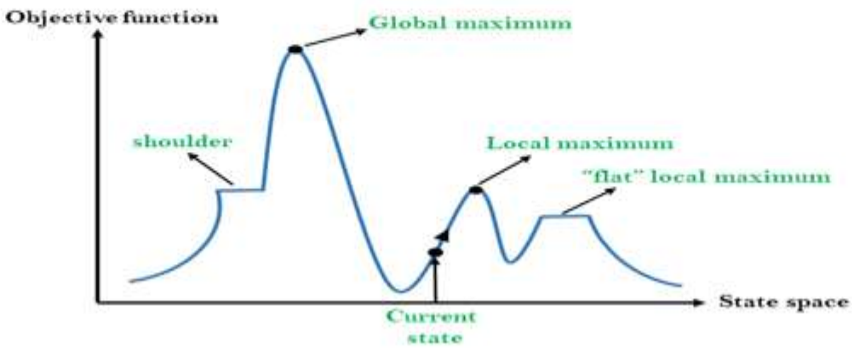

Figure 1: Representation of Hill Climbing Algorithm

In figure 1, the state space and the objective function of the hill climbing process is explained.

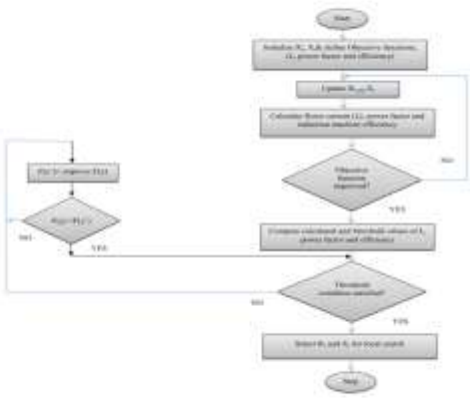

Figure 2: Flowchart of Discrete HC-LSO Algorithm

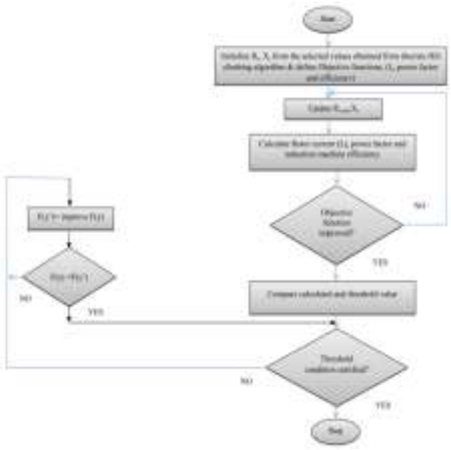

Figure 3: Flowchart of Continuous HC-LSO Algorithm

For every iteration, there must be a change in any of the parameters to be optimized and checks whether the change has any impact over the objective function of the process. If the changes in the optimization process have an improvement in the objective function, then the changes are accepted and proceed further until no improvements can be made in the optimal value of the objective function. The local search and global search has been combined and performed with the help of discrete hill climbing and continuous hill climbing algorithm resulting in the hill climbing based local search optimization. The following figure 2 and figure 3 shows the flow of the HC-LSO algorithm.

The following equation shows the mathematical expression of the multi objective function optimization.

$$F = min_{y \epsilon Y}\left(F_1(y), F_2(y), \ldots\ldots F_M(y)\right), max_{y \epsilon Y}\left(F_1(y), F_2(y), \ldots\ldots F_N(y)\right) \quad (1)$$

The multicriterion function is represented by '$F(y)$', where the value of 'y' lies as '$y = y_1 and\ y_2$'. The boundary value of multicriterion function is given by '$y_i^{min} \leq y_i \leq y_i^{max}$' where, i=1and 2.

The multicriterion function described above is considered as follows.

$y_1 = rotor\ resistance$ $y_2 = rotor\ reactance.$

The upper and lower limit values for rotor resistance represented by (R_r) is$0.05 \leq y_1 \leq 0.2\Omega$ and rotor reactance represented by (X_r) is $1.0 \leq y_2 \leq 2.2\Omega$ respectively. When the calculate values are within the range specified in the upper and lower limit values, the condition is satisfied.

From the given Equation (1), 'Y' indicates the feasible set of values used for decision. These decision values of feasible set are generated with the help of threshold values of each objective function. By comparing with these threshold values with objective function, vector-valued objective function is presented and described in the following equation given as.

$$F: X \rightarrow R^k,\ F(y) = (F_1(y), F_2(y), F_3(y), F_4(y), \dots F_N(y))^T \quad (2)$$

In the given Equation (2), number of objective functions in the system is denoted as 'K' and T represents the threshold values of those objective functions. The three objective functions Rotor current (I_r), power factor and induction machine efficiency in the HC-LSO technique are described in the following Equation 3.

$$F(y) = min\ (F_1(y)), max(F_2(y)), max(F_3(y)) \quad (3)$$

Where $F_1(y)$ in the equation indicates the rotor current, $F_2(y)$ indicates power factor and $F_3(y)$ indicates the induction motor efficiency. The threshold values of the objective functions for designing the IM using HC-LSO technique is given by,

$$F_{1T}(y) < 20A \ \text{(7.5kW)}$$
$$F_{1T}(y) < 40A \ \text{(30kW)} \quad (4)$$

$$F_{2T}(y) > 0.7 \quad (5)$$

$$F_{3T}(y) > 70\% \quad (6)$$

The upper and lower limit values for three objective functions are given in Equations (4), (5) and (6). When the selected value of the objective function satisfies above the threshold conditions, then that value is selected for designing the efficient induction motor using HC-LSO technique.

In the earlier stages, the induction machine values like Rotor Resistance (R_r) and Rotor Reactance (X_r) are selected randomly in the search space. While selecting the data using the initial version of discrete hill climbing algorithm in the search space, during each iteration the value of R_r and X_r are adjusted. For each value of R_r and X_r, the corresponding objective function is calculated and the algorithm helps to find out the improvement of the objective function caused due to the change in the values. If there is any improvement in the objective function caused by the change in the R_r and X_r values, then the modified values are accepted for the objective function. The adjustment process is carried out until there is no change or modification in the objective function caused by the change. Once the objective function is calculated, then it is compared with the upper and lower limit values defined already. A point in which the upper and lower limit values are satisfied, then the values used for the improvements are selected for searching in local with the help of the continuous hill climbing algorithm.

The value of R_r and X_r are selected randomly to provide data for designing of the objective function and the same procedure cn be followed for all the other selected values. During each iteration, the algorithm modifies the R_r and X_r values. Subsequently, the calculation of the objective function is started for the R_r and X_r values and checks whether there is any improvement. If the modified values have impact with the values of the objective function, then that modified value is considered for further processing. This process is iterated until no further improvement is seen in the objective function. The induction motor design is finalized with the values R_r and $X_{r,}$ which have the most impact over the objective function.

Proposed HC-LSO technique's efficiency is compared with the two existing algorithms, HGAPSO and NSGA-II algorithms by simulating the objective function parameters rotor current, power factor and induction motor efficiency.

The flux 'φ' produced by stator is directly proportional to stator emf 'E_s' as in equation (7).

$$\varphi \propto E_s \quad (7)$$

The given equation (7) depicts the relationship among the stator emf. Similarly, rotor voltage is estimated by using the expression as given in equation (8).

$$K = \frac{E_r}{E_s} \quad or \quad E_r \propto \varphi \quad (8)$$

From equation (8), 'K' is the constant parameter and it is expressed as the ratio of rotor voltage 'E_r' to the stator voltage 'E_s'. As a result, the rotor voltage 'E_r' is directly proportional to the magnetic flux 'φ'. After measuring stator and rotor voltage, rotor current of induction motor is given by equation (9).

$$I_r = \frac{sE_r}{Z_r} \text{ Amps} \quad I_r = \frac{sE_r}{\sqrt{R_r^2+(sX_r)^2}} \text{ Amps} \tag{9}$$

Using equation (9), the estimation of rotor current is carried out. It is defined as the ratio of product of slip and emf induced in rotor during running condition 'sE_r' to the rotor impedance 'Z_r'. Here's' denoted the slip of induction motor. The slip is defined as the difference between synchronous speed (N_s) and the rotor speed (N_r) of the induction machine. From the given equation (9), the resistance of the rotor is represented as 'R_r' and the reactance of rotor is denoted as 'X_r'. With the help of resistance and impedance, power factor is expressed as in equation (10) and it is given as the ratio of rotor resistance to the impedance.

$$cos\ cos\ \theta_r = \frac{R_r}{\sqrt{R_r^2+(sX_r)^2}} \tag{10}$$

Induction Machine Efficiency is defined as the ratio of output power to the input power. The induction machine efficiency is determined using Equation (3.11)

$$Induction\ Machine\ Efficiency = \frac{Output\ power}{Input\ power} * 100 \tag{11}$$

Simulation Settings

The proposed Hill Climbing Based Local Search Optimization (HC-LSO) technique is implemented and tested using MATLAB. The simulation strategy for the proposed HC-LSO algorithm and the two existing methods namely HGAPSO and NSGA-II are carried out for two different motors 7.5kW and 30kW respectively. The specifications of the 7.5kW and 30kW motors are listed in Table 1. Based on the discussions made in previous research analysis specified in various books and with reference to IEC Standards, the upper and lower limits values for Rotor Resistance (R_r) and Rotor Reactance (X_r) are listed in Table 2.

Table 1: Specification Details of Induction Motor 1 and Induction Motor 2

Parameter	**Parameter Values**	
	Induction Motor 1	**Induction Motor 2**
Number of Poles	4	6
Supply Voltage	400 V	400 V
Power	7.5 kW	30 kW
Frequency	50 Hz	50 Hz
Synchronous Speed	1500 rpm	1000 rpm

Table 2 Lower and upper limits of variables

Parameter	**Lower Limit**	**Upper Limit**
Rotor Resistance (R_r)	0.05	0.2
Rotor Reactance (X_r)	1.0	2.2

2. Results & Discussion

The proposed Hill Climbing Based Local Search Optimization (HC-LSO) technique is developed and compared with two existing methods namely Non-dominated Sorting Genetic Algorithm (NSGA-II) [1] and Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO) model [2]. The effectiveness of the proposed method is validated using simulation for the objective functions' rotor current, power factor and induction motor efficiency. The analysis is carried out for the slip range varies from 2.75% - 5%. The optimized Rotor Resistance (R_r) and Rotor Reactance (X_r) values using the proposed HC-LSO algorithm and the two existing methods NSGA-II and HGAPSO are represented in Table 3.

Table 3: Optimal design values for the existing NSGA-II and HGAPSO and the proposed HC-LSO techniques

Parameter	**Induction Motor 1**			**Induction Motor 2**		
	NSGA-II	**HGAPSO**	**HC-LSO**	**NSGA-II**	**HGAPSO**	**HC-LSO**
Rotor Resistance (R_r)	0.114	0.093	0.089	0.058	0.051	0.049

Rotor Reactance (X_r)	2.103	1.932	1.964	1.124	1.156	1.167

The rotor current values of Induction Motor 1 and Induction Motor 2for the optimized Rotor Resistance (R_r) and Rotor Reactance (X_r) for various slip values (2.75% – 5%) are presented in Table 4, Table 5 and Figure 2, Figure 3.

TABLE 4: Rotor current values of Induction Motor 1for the existing NSGA-II and HGAPSO and the proposed HC-LSO techniques

Slip	**Induction Motor 1**			**Induction Motor 2**		
	Rotor current (in Amps)			**Rotor current (in Amps)**		
	NSGA-II	**HGAPSO**	**HC-LSO**	**NSGA-II**	**HGAPSO**	**HC-LSO**
0.0275	12.42	14.82	15.25	24.16	26.42	27.11
0.03	13.29	15.81	16.23	25.82	28.08	28.76
0.0325	14.12	16.72	17.13	27.38	29.62	30.28
0.035	14.89	17.57	17.97	28.83	31.04	31.68
0.0375	15.62	18.37	18.74	30.20	32.35	32.96
0.04	16.30	19.10	19.45	31.47	33.55	34.13
0.0425	16.94	19.78	20.11	32.66	34.65	35.20
0.045	17.54	20.41	20.71	33.76	35.66	36.17
0.0475	18.09	20.99	21.27	34.79	36.60	37.07
0.05	18.61	21.53	21.78	35.75	37.45	37.89

TABLE 5: Power factor of Induction Motor 1for the existing NSGA-II and HGAPSO and the proposed HC-LSO techniques

Slip	**Induction Motor 1**			**Induction Motor 2**		
	Power Factor			**Power Factor**		
	NSGA-II	**HGAPSO**	**HC-LSO**	**NSGA-II**	**HGAPSO**	**HC-LSO**
0.0275	0.892	0.868	0.855	0.883	0.849	0.837
0.03	0.875	0.849	0.834	0.865	0.827	0.814
0.0325	0.858	0.829	0.813	0.846	0.805	0.791
0.035	0.840	0.809	0.791	0.828	0.783	0.768
0.0375	0.822	0.789	0.770	0.809	0.762	0.746
0.04	0.805	0.769	0.750	0.790	0.741	0.724
0.0425	0.787	0.750	0.729	0.772	0.720	0.703
0.045	0.769	0.731	0.710	0.754	0.700	0.682
0.0475	0.752	0.712	0.690	0.736	0.681	0.662
0.05	0.735	0.694	0.672	0.718	0.662	0.643

TABLE 6: Induction Motor Efficiency of Induction Motor 1for the existing NSGA-II and HGAPSO and the proposed HC-LSO techniques

Slip	**Induction Motor 1**			**Induction Motor 2**		
	Efficiency (%)			**Efficiency (%)**		
	NSGA-II	**HGAPSO**	**HC-LSO**	**NSGA-II**	**HGAPSO**	**HC-LSO**
0.0275	89.51	85.81	84.08	87.23	84.01	83.56
0.03	89.12	85.54	83.89	86.94	83.71	83.13
0.0325	88.95	84.98	82.68	84.55	80.48	78.92
0.035	84.57	80.17	79.46	82.18	78.12	75.65
0.0375	82.25	78.81	77.12	80.86	76.81	74.21
0.04	81.04	76.65	75.90	79.54	74.65	71.92
0.0425	78.87	74.25	72.57	77.17	72.25	70.45

0.045	77.65	73.98	71.17	75.85	70.98	68.17
0.0475	77.38	71.65	69.85	74.48	68.65	66.82
0.05	77.04	70.45	68.38	72.04	67.35	65.38

TABLE 7: Deviation in Percentage of Rotor Current, Power Factor and Efficiency of Induction Motor 1 and Induction Motor 2 for the proposed and existing techniques

	Induction Motor 1		**Induction Motor 2**	
	HC-LSO Vs NSGA-II	**HC-LSO Vs HGAPSO**	**HC-LSO Vs NSGA-II**	**HC-LSO Vs HGAPSO**
Rotor Current	- 16.48%	- 14.83%	- 8.15%	- 6.47%
Power Factor	+ 6.98%	+ 4.40%	+ 8.72%	+ 6.36%
Efficiency	+ 8.14%	+ 5.73%	+ 8.68%	+ 5.89%

Table 7 shows the deviation Percentage of Rotor Current, Power Factor and Efficiency of Induction Motor 1 and Induction Motor 2 for the proposed and existing techniques for the slip values ranging from 0.0275 to 0.05. It is evident from the above table that the rotor current is reduced and also the power factor and efficiency gets improved in the proposed method when compared to the existing algorithms.

3. Conclusion

Energy efficiency plays a vital factor in designing industrial applications. Design optimization of induction motor enhances the efficiency in electrical drives. Recently, many research works have been proposed and designed for improving the efficiency of induction motor using optimization techniques. An effective Hill Climbing Based Local Search Optimization (HC-LSO) technique is introduced to improve the efficiency of induction machine. The HC-LSO algorithm uses discrete and continuous hill climbing process for designing the induction motor. The simulation is carried out to optimize the parameters, Rotor Resistance (R_r) and Rotor Reactance (X_r) for two different motors 7.5kW and 30kW respectively. Based on the optimized values, the HC-LSO algorithm attains the optimal design of induction motor satisfying the objective functions Rotor Current (I_r), Power Factor and Efficiency and the results are analyzed for the slip range of 2.75% - 5%.

4. References

Soumya Ranjan and Sudhansu Kumar Mishra, “Multi-objective Design Optimization of Three-Phase Induction Motor Using NSGA-II Algorithm,” *Computational Intelligence in Data Mining*, *Springer*, vol. 2, pp.1-8, Dec. 2015.

Hamid Reza Mohammadi and Ali Akhavan, “Parameter Estimation of Three-Phase Induction Motor Using Hybrid of Genetic Algorithm and Particle Swarm Optimization”, *Journal of Engineering, Hindawi Publishing Corporation*, vol. 2014, pp. 1-6, 2014.

Gyorgy T and Biro K.A, “Genetic Algorithm based design optimization of a three-phase induction machine with external rotor”, *Intl Aegean Conference on Electrical Machines & Power Electronics (ACEMP)*, pp. 462-467, 2015.

SouadChaouch, Latifa Abdou, Said Drid and Larbi Chrifi-Alaoui, “Optimized Torque Control via Backstepping using Genetic Algorithm of Induction Motor,” *Automatika – Journal for Control, Measurement, Electronics, Computing and Communications*, vol. 57, no.2, pp. 379–386, 2016.

Jessé de Pelegrin, César Rafael ClaureTorrico and Emerson Giovani Carati, “A Model-Based Suboptimal Control to Improve Induction Motor Efficiency,” *Journal of Control, Automation and Electrical Systems, Springer*, vol. 27, no.1, pp. 69-81, Feb.2016.

Vahid Rashtchi and Amir Ghasemian, “Efficiency Optimization of Induction Motor Drive using Modified Particle Swarm Optimization”, *International Conference on Electrical, Electronics and Instrumentation Engineering (EEIE'2013)*, pp. 14-18, Nov.2013.

Carlos Verucchi, Cristian Ruschetti, Esteban Giraldo, Guillermo Bossio and José Bossio, “Efficiency optimization in small induction motors using magnetic slot wedges,” *Electric Power Systems Research, Elsevier*, vol. 152, pp. 1-8, 2017.

OnurMisir, SeyedMortezaRaziee, Nabil Hammouche, Christoph Klaus, Rainer Kluge and Bernd Ponick, “Prediction of Losses and Efficiency for Three-Phase Induction Machines Equipped with Combined Star-Delta Windings,” *IEEE Transactions on Industry Applications*, vol. 53, no.4, pp.3579- 3587, July-August.2017.

BrankoBlanuša and Bojan Knezevic, “Simple Hybrid Model for Efficiency Optimization of Induction Motor Drives with Its Experimental Validation," Hindawi Publishing Corporation, Advances in Power Electronics, vol. 2013, pp.1-8, Feb.2013.

FethiFarhani, AbderrahmenZaafouri and Abdelkader Chaari, "Real Time Induction Motor Efficiency Optimization," *Journal of the Franklin Institute*, *Springer*, vol.354, no. 8, pp. 3289-3304,May.2017.

Raghuram A and Shashikala V, "Design and Optimization of Three Phase Induction Motor using Genetic Algorithm," *International Journal of Advances in Computer Science and Technology*, vol. 2, no. 6, pp. 70-76, Jun. 2013.

Rushi Kumar K and Sridhar S, "A Genetic Algorithm Based Neuro Fuzzy Controller for the Speed Control of Induction Motor," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*", vol. 4, no. 9, pp. 7837-7846, Sep. 2015.

Mehdi Bigdeli, DavoodAzizian and Ebrahim Rahimpour, "An Improved Big Bang-Big Crunch Algorithm for Estimating Three-Phase Induction Motors Efficiency," *Journal of Operation and Automation in Power Engineering*, vol. 4, no. 1, pp. 83-92, 2016.

Chirindo M, Khan M.A and Barendse P.S., "Considerations for Nonintrusive Efficiency Estimation of Inverter-Fed Induction Motors," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 2, pp. 741 – 749, Feb. 2016.

Maher Al-Badri, Pragasen Pillay and Pierre Angers, "A Novel Algorithm for Estimating Refurbished Three-Phase Induction Motors Efficiency Using Only No-Load Tests", *IEEE Transactions on Energy Conversion*, vol. 30, no. 2, pp. 615 - 625, Jun.2015.

Camila P. S., Wilson C. S., Luiz E. Borges da Silva, Germano Lambert-Torres, Erik L. Bonaldi, Levy E. L. de Oliveira and Jonas G. Borges da Silva, "Induction Motor Efficiency Evaluation using a New Concept of Stator Resistance," *IEEE Transactions on Instrumentation and Measurement*, vol. 64, no. 11, pp. 2908 – 2917, Nov. 2015.

Vladimir Sousa Santosa, PercyViego Felipe and Julio Gómez Sarduy, "Bacterial foraging algorithm application for induction motor field efficiency estimation under unbalanced voltages," *Measurement, Elsevier*, vol. 46, no. 7, pp. 2232-2237, Aug. 2013.

Abbas Shiri and Abbas Shoulaie, "Multi-objective optimal design of low-speed linear induction motor using genetic algorithm", *Electrical Review, Iran University of Science and Technology*, pp. 185-191, 2012.

Mehmet Cunkas, "Intelligent design of induction motors by multiobjective fuzzy genetic algorithm", *Journal of Intelligent Manufacturing, Springer*, vol. 21, no. 4, pp. 393–402, Aug. 2010.

P.Ponmurugan, Dr.N.Rengarajan, "Random Restart Local Search Optimization Technique For Sustainable Energy Generating Induction Machine", Computers & Electrical Engineering-Elsevier, Vol.73, January 2019, pp. 268-278.

Dey, N., Kumar, G., Vickram, A. S., Mohan, M., Singhania, R. R., Patel, A. K., ... & Ponnusamy, V. K. (2022). Nanotechnology-assisted production of value-added biopotent energy-yielding products from lignocellulosic biomass refinery–a review. Bioresource Technology, 344, 126171.

P.Ponmurugan, Dr.N.Rengarajan, "Machine Learning Perspective Gene Optimization for Efficient Induction Machine Design", Journal of Electrical Engineering and Technology, Vol.13, No.3, May 2018, pp. 1202-1211.