Optimized Design for Improving the Performance of Stator
Three-Phase Induction Motor for Industrial Applications
Using HHO Algorithm

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Abstract. In the present study, an optimal design method of industrial induction motor is developed. All design equations are formulated, all constraints and limitations requirement are assigned. Harris Hauk Optimization (HHO) is a robust heuristic optimization technique; it is considered fairly new. It is adopted to find optimal values of parameters to achieve the best efficient design. An industrial practical sample is suggested to validate the proposed performance improvement method. For comparison, Particle Swarm Optimization (PSO) is used as another robust optimization widely used. Some of important performance parameters of induction motor design system were compared with the performance of convergent systems in size available in literatures.

Keywords. PSO, HHO, Design, Induction Motor.

1. Introduction
The great scientist Einstein says that the greatest discoveries can be simply represented. In the year 1820, the scientist Ohrsted accidentally made a practical discovery of the relationship between the current passing through a wire and the movement of the magnetic compass [1]. It was this great simple discovery that opened uncle an introduction to electrical science. In the year 1822, Faraday found the relationship between changing magnetic flux and the number of turns with the induced voltages paving the way for the invention of DC machines [2, 3]. The most important development in electrical machinery is the invention of induction motors by scientist Nikola Tesla in 1889, which laid the foundation stone for the development of alternating generation machines. From the beginning of the twentieth century to the present day, the three-phase and single-phase inductive motors became the backbone of the global industry and household uses according to scientific statistics, as they consume 67 percent of the energy generated in America and developed countries [4,5]. And with the tremendous development in the design and manufacture of electric induction motors specifically in metallurgy and economic light weight and increase the power density per kilogram in addition to the development of winding methods in the stators and rotors to improve the behavior of motors in obtaining the greatest torque when starting with the lowest possible current. However, the amount of waste energy in small engines less than one kilowatt is still within the range of 20 to 30 percent, depending on the design and manufacturing efficiency. In most of the practical tests conducted in the electrical engineering laboratories at the University of Diyala for the past ten years on small three-phase induction motors, losses were monitored,
ranging from 20 to 30 percent. For example, in an Arab country such as Libya, the dependency ratio forms small and medium drawing pumps from groundwater wells for drinking and watering purposes by almost a full percentage, not less than using several million whose losses exceed several hundreds of megawatts, according to official statistics in the Libyan and Iraqi Ministry of Electricity also for the same reason. Therefore the solution to be followed to reduce losses and waste energy in motors includes several directions: design, modern manufacturing methods, winding methods that reduce magnetic losses, reduce thermal losses. These trends have been found by researchers since the 1992 Brazil Conference on Global Warming and the Kyoto Conference in Japan in 1998 that the solution can be reached using optimized machine design methods [6, 7].

2. An Overview of HHO and PSO

During the last thirty years, many mathematical algorithms, engineering methods, and software have emerged, which have contributed significantly to speeding up mathematical calculations to reach the design goal. For example, the following algorithms have emerged: Tabu Search (TS) [6], Socio Evolution Learning Optimization (SELO) [8]. Teaching Learning Based Optimization (TLBO) [9]. Harris hawks optimization: Algorithm and application. Colony Optimization (ACO) [10]. Artificial Bee Colony (ABC). Global optimum. [7]. Simulated Annealing (SA) [5]. Genetic Algorithm (GA) [10].

The HHO optimization method used for binary variables. The BHHO transition function converts the binary variable into a continuous variable. Another method, QBHHQ (Quadratic Binary Harries), improves BHHO performance. In this study, (19) data sets and conditions were collected from the design of the Stetter three-phase synchronous machine. A comparison was made with the results of the first code model for the mathematical design of the same machine specifications, as it turned out that the synchronous generator efficiency has already improved from 78% to 89% with an improved power factor. The efficiency of the design code and program results from calculations of 4,500 consecutive approximations over a very short time, which shows us how much the program is very fast in obtaining the best values and results.

This paper introduces a method for optimization of continuous nonlinear functions. Particle swarm optimization has roots in two main component methodologies. Perhaps more obvious are its ties to artificial life (A-life) in general, and to bird flocking, fish schooling, and swarming theory in particular. It is also related, however, to evolutionary computation, and has ties to both genetic algorithms and evolutionary programming. These relationships are briefly reviewed in the paper.

3. Three-Phase Induction Motor

The Matlab program was used to create a multi-purpose code. After entering the main features of the asynchronous machine as shown in Table 1, which are related to the amount of voltages to be generated and the frequency of them. This means adding the number of poles that are mathematically and practically related to the required frequency. Some of the low-impact parameters were considered as constants such as copper wire resistance, insulation thickness inside slot, shaft diameter and iron density [6, 8]. The second part of the program includes the definition of nineteen parameters that are the backbone of the program and mathematical calculations. Certainly, all these basic parameters have values ranging from the lowest to the greatest, and for this reason the program has been provided with the boundary conditions for the basic parameters. All mathematical calculations ultimately aimed at achieving the best values that lead to the highest possible efficiency and the lowest economic cost. It is certain that the achievement of good design efficiency requires thousands of mathematical tests by selecting a matrix element that contains at least 4,500 elements formed by dividing the values of 19 parameters to at least 150 values per parameter [6, 9]. Below is part of the program that was used in programming the synchronous machine design in two methods (HHO and PSO). Figure 1 summarizes the optimization flowchart of design the presented Three-Phase Induction Motor.
Table 1. Main dimensions and specification of the motor under development.

| Parameter of the motor                    | Unit            |
|-------------------------------------------|-----------------|
| Input power to the motor (Pin)            | 0.9 kW          |
| Frequency of the applied voltage (f)      | 50 Hz           |
| Line to line voltage source              | 400 volts       |
| Nominal speed                             | 1490 rpm        |
| Number of stator poles (P)                | 4               |
| Number of stator slots                    | 36              |
| Number of rotor slots                     | 24              |
| Separation factor of insulators (SFP)     | 0.98            |
| Insolation thickness (h_ins) hr=0.005; ti=0.001; | 0.001mm         |
| Material yoke Density                     | 7600 Kg/m³      |
| Shaft diameter                            | 10 mm           |

Figure 1. Optimization Flowchart of Design Three-Phase Induction Motor.

4. Results and Discussion
Through the results in Table 1 where we show in the second column the minimum and maximum boundary conditions for each design parameter. All these parameters play a chain role in mathematical
calculations to reach the goal, which is the efficiency of the machine. According to the personal perspective of the researcher and the designer of the machine, it is certain that the choice of the value of each variable depends on its theoretical information and its practical experience, and for this reason you find it very rare for the designers in international companies to agree on the same design parameters for any machine. For example, the temperature in July and August in Iraq and inside the generator halls, the temperature may reach 45 degrees Celsius or more, and this requires forced cooling methods for generators, perhaps not needed in the American North, Russia or North Europe. Also, the tropical high humidity can reach 80 percent or more in Malaysia and Indonesia during the summer, requiring cooling methods that help dampen moisture and reduce its impact while the Iraqi air was dry and hot. These examples would like to clarify the reasons behind the differences in the designers’ opinions of synchronous electric machines, for example.

Table 2 shows the values of 19 design parameters for each improvement, the algorithm reached a convincing solution each time, and it is indicated by an excellent value for the target without any violations of the boundary conditions.

| S | Main Constraints (17 input variables) | Parameters values selected without optimization | selected values by HHO | selected values by PSO |
|---|--------------------------------------|-----------------------------------------------|------------------------|------------------------|
| 1 | Motor Efficiency (0.8< eta<0.9)       | 0.8                                           | 0.8                    | 0.89                   |
| 2 | Motor Power Factor(0.8< PF<0.95)      | 0.85                                          | 0.8                    | 0.94                   |
| 3 | Average Flux Density (0.52< Bavg<0.65) | 0.6                                           | 0.52                   | 0.64                   |
| 4 | elec. specific loading(8000<ac<25000) | 13000                                         | 8000                   | 14038                  |
| 5 | winding factor(0.94<Kw< 0.96)         | 0.95                                          | 0.94                   | 0.94                   |
| 6 | length over pole pitch(Ltau2 <0.6)   | 0.45                                          | 0.5                    | 0.56                   |
| 7 | Safety factor(0.9<SF<1)               | 0.95                                          | 0.9                    | 0.94                   |
| 8 | (q >2)                                | 3                                             | 2.00                   | 3.69                   |
| 9 | Space Slot factor --SSF=<0.5          | 0.45                                          | 0.45                   | 0.456                  |
| 10| 3 *10^6 < delta_s < 5*10^6            | 410^6                                         | 310^6                  | 4.9410^6              |
| 11| 1.1 < Fs < 1.35                       | 1.2                                           | 1.1                    | 1.31                   |
| 12| SCR < 1.5                             | 1.4                                           | 1.3                    | 1.44                   |
| 13| stator teeth flux density: Bts < 1.7  | 1.35                                          | 1.4                    | 1.50                   |
| 14| Bp < 1.7                              | 1.5                                           | 1.5                    | 1.63                   |
| 15| 2 *10^6 < delta_f < 4*10^6           | 2.510^6                                       | 210^6                  | 3.1410^6              |
| 16| 1.3< By < 1.7                         | 1.4                                           | 1.3                    | 1.1                    |
| 17| 0.9 < Bcs < 1.4                       | 1.1                                           | 0.9                    | 0.933                  |

The expected primary machine efficiency for synchronous generators within the limits of one kilowatt is usually between the efficiency limits of 80 and 90 percent, and therefore an average rate of 80% was chosen as a mathematical calculation by hand, while it is noted that the value of the initial by the optimal solution method PSO is greater than the average. The same is the case with the power factor, magnetic flux density rate, coil coefficient, safety coefficient and overflow density in the teeth. The deviation rate for the values chosen by the PSO method shows us the behavior that the algorithm follows in the selected values within the upper half of the mid value of the constraint boundaries. These deviations are shown in the values of the third column of Table 3, [1].

It is observed from the curve of the behavior of the optimization codes in two Figures 1 and 2; that the efficiency optimization code used in the PSO method is faster in reaching the optimal value target through five iterations, while it is noticed that the HHO code needs up to ten iterations to reach the optimum efficiency value. But another thing is that the maximum value of design efficiency with the
HHO method is 87 percent, while the maximum design efficiency with the PSO method is 85 percent. The accuracy in choosing the values of the nineteen constraints parameters is more efficient as displayed in the fourth column, Table 1, where the values always chosen are differentials with a decimal or percentage value in addition to the theory chosen by the PSO method presented in the third column in Table 1.

**Table 3.** A comparison among manual calculated and that optimized parameters by HHO and PSO methods (900 Watt, 4P, 50Hz, synchronous machine).

| Design Variable (parameter) | Parameters values calculated without optimization | Parameter value by HHO | Parameter value by PSO |
|----------------------------|-----------------------------------------------|------------------------|------------------------|
| L                          | 0.0718                                        | 0.050709               | 0.048297               |
| D                          | 0.0914                                        | 0.12913                | 0.10395                |
| h                          | 0.0073                                        | 0.0080556              | 0.0059639              |
| Wts                        | 0.0035                                        | 0.0051703              | 0.0026013              |
| Lg                         | 0.000718                                      | 0.0008                 | 0.0008                 |
| dsc                        | 0.0163                                        | 0.029298               | 0.029481               |
| Po                         | 0.74                                          | 0.78325                | 0.76586                |
| Improved Efficiency        | 80.15                                         | 87.02795               | 85.09551               |

**Figure 2.** Efficiency of the designed Three-Phase Induction Motor by using HHO optimization method.
Figure 3. Efficiency of the designed Three-Phase Induction Motor by using PSO optimization method.

5. Conclusion
The methods of controlling the induction motor by means of the optimal solution proved good efficiency in reaching the optimal design of the parameters of the three-phase induction motor with a capacity of one and a half horsepower and a speed of 1490 revolutions per minute and 4 poles per stator, so the dimensions of the length and diameter of the stove in the engine were ideal.

Appendix
Implementation of the Matlab Optimal Design Code
%% Design of Synchronous Generator or Induction Motor by SAWHNEY
METHOD CODE
% CONSTANTS
Pin=0.9; % as output power on the shaft =900 Watt (required)
f=50; % frequency (constant value)
P=4; %Number of stator poles (constant value)
EL=415;
Wos=0.001; Kg=1.15;
Cl=1.2;
SFP=0.98; Ef_s=6; h_ins=0.001; hr=0.005; ti=0.001;
Rou=2.1*10^-8; tic=0.000038; shaft=0.010;
Density=7600; % (Kg/m^3)
Test case = inputdlg ({' Studded Cases IM or SynGen:', 'Max or Min:', 'Max Iteration', 'PSO (1) or ncase=css(1); % Assign Studied cases such as pjt-11- means problem 1 , R1 and so on
min_flag=css (2); % 1: minimization, 0: maximization
Meditation=css (3); % Optimization Max iteration number
Alga=css (4); % Algorithm GSA (1), PSO (2)
%% Call parameters
T=meditation;
Maxi=meditation;
N=30; % Number of particles
Dim=17; % dimension of input variables
% %CONSTRAINTS
down=[0.8;0.8;0.52;8000;0.94;0.5;0.9;2;0.45; 3*10^6;1.1;1.3;1.4;1.5;2*10^6;1.3;0.9];
% % start evaluation the base case without optimization
[X]=initialization (N, dim, up, down);
[eff1, rslt]=mch_design(X (: 5)); % Design equations file
Fitness=eff1;
%rslt= [L, D, hB, Wts, Lg, DSC, Po];
Po=rslt (7);
L=rslt (1);
D=rslt (2);
EFF_basic=eff1
Output_Power_shaft=Po
Length airgap=L
Diameter_Rotor_bar=D
% for j=1: length(X (: 5))
% return
%%% Call PSO or HHO program for feeder optimization

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