

PARAMETER ESTIMATION OF INDUCTION MOTOR USING MUSIC INSPIRED ALGORITHM

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of

MASTER OF ENGINEERING *in* POWER SYSTEMS

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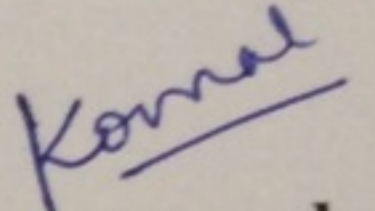
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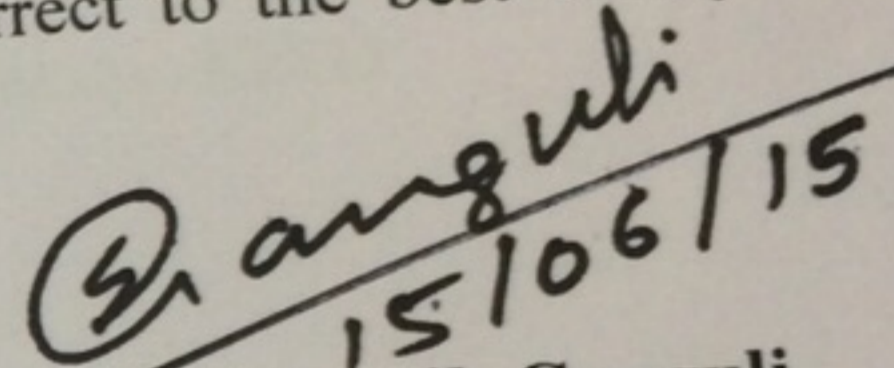
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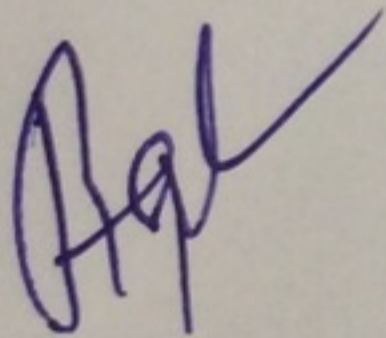

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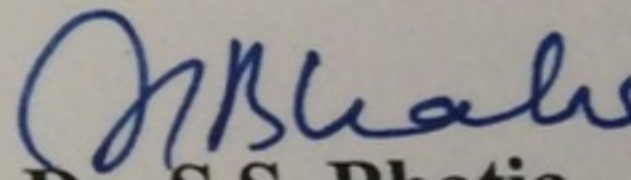


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LIST OF ABBREVIATIONS

Genetic Algorithm - GA
Bacterial Foraging – BF
Neural Network - NN
Artificial Neural Network - ANN
Particle Swarm Optimization - PSO
Harmony Memory Considering Rate- HMCR
Pitch Adjusting Rate - PAR
Electromagnetic Transients Program - EMTP
Torque Gauge Method - TGM
Equivalent Circuit Method - ECM
Slip Method - SM
Current Method- CM
Segregated Loss Method - SLM
Immune Algorithm- IA
Bacterial Foraging Optimization Algorithm- BFOA
Simulated Annealing-SA
Harmony Search Algorithm - HSA
Least Square- LS
Harmony memory size - HMS

SYNOPSIS

In this dissertation work, parameter estimation of induction motor is being carried out using harmony search algorithm. The parameters are estimated based on maximizing the starting torque and efficiency respectively. Both the classical as well as intelligent methods are being reviewed for parameter estimation of induction motor. The efficacy of harmony search algorithm is being test using some standard non linear functions. Later on this rotor side parameters are obtained by maximizing the torque where as rotor and stator copper losses are reduced by considering maximizing efficiency as objective function.

CHAPTER 1

INTRODUCTION

1.1 Background of Work

An induction motor is an AC motor in which the principle of electromagnetic induction is used to produce electric current in the rotor by which torque is produced from the magnetic field of stator winding. This AC motor is widely used in variable frequency drive and fixed speed applications. The main feature of induction motor is that this motor does not require mechanical commutation, separate or self excitation as it is required in DC motor [1]. The construction of three phase induction motors is simple. Moreover it requires little maintenance and is economical. Owing to these inherent characteristics it is widely used in industries. Some of the most important industrial application of induction motor are in drilling machines, agricultural and industrial pumps, lathes and industrial drives. One of the most important and difficult step is to do mathematical modeling of induction motor. In modeling, the aim is to identify the induction motor parameters and to estimate the value of those parameters.

The term estimation means process of finding an approximation of a value even if the data is incomplete and the term identification means mathematical model of the system from observed data of input and output. Many methods have been developed for parameter estimation like test when rotor is at blocked condition, when rotor at no load and the frequency response test at standstill condition. But these tests cannot be implemented easily. This tests measures incorrect frequency of rotor and give many errors in results. The IEEE standard 112 –F method used for parameter estimation is the standard equivalent circuit method [7]. The main advantage of this test is that there is no need of measurement of torque. A classical approach with linear least square [2] and non linear least square [3] were also implemented to identify the machine parameter. These techniques have been used to estimate the parameters like rotor resistance, self inductance of rotor and stator separately. Toliyat *et al.* [17] has surveyed various efficiency estimation methods. Different mathematical techniques for estimating the parameters of an induction motor were shown in [8]. These are the different classical approaches that have been previously used to identify the parameters but these approaches have some limitations and in order to overcome these limitations different intelligent approaches are used.

The intelligent approaches seem to be more promising as compared to the classical approaches. The Genetic Algorithm (GA) [10-13], Adaptive GA [14], Bacterial Foraging (BF) technique [19-

21] , Neural Network (NN) [9] , Artificial Neural Network (ANN) [4], and Particle Swarm Optimization (PSO) [22,23] has been used for estimating the induction motor parameters .

In modern meta –heuristic algorithms there are two major components that are: exploration and intensification. For the working of any algorithm in a powerful and effective way, it must be able to produce optimal solution so as to explore its work effectively. These algorithms are used in every field to solve optimization problems because it can deal with large complicated problem and can deal with both continuous and time varying variables.

Recently, a new algorithm called harmony search algorithm i.e. meta heuristic algorithm has been developed and was first developed by Zong Woo Geem in 2001[29]. This technique takes ideas from the music improvisation process, where a ideal state of harmony is improvised by the pitches of the musicians instruments. The calculation of a harmony is subjective and on the other side aesthetic, there are many scientists who have given the perfection of harmony estimation and determination: Greek philosopher and mathematician Pythagoras studied the ratios of frequency (or ratios of string length with proportionate tension) and seen that they had a selective mathematical relationship, after seeing that what beats sounded nice together [25]. This technique does not need any starting values for the decision variables and employ a random search that is based on the Harmony Memory Considering Rate (HMCR) and Pitch Adjusting Rate (PAR) so that the derivative information is not required. It needs very less mathematical calculations in comparison to other meta-heuristic algorithms and can be efficiently used for different types of optimization problems. To improvise one pitch by the musician, three different rules are applied and he (or she) has to use any one of them: firstly playing any popular notes from his (or her) memory; second playing an similar note of one pitch by adjusting the pitch from his (or her) memory; and thirdly compose a totally different value from the different range of values with in limit, which is called as randomization.

Thus, we have applied this meta –heuristic algorithm to optimize the parameters and specifications of the induction motor. The next step is to estimate the parameters of the motor for desired purpose. The fact of the squirrel-cage motor is that it has fixed value of resistance and also has small value as compared to its reactance that is of very large value especially at the time of starting, the frequency of the rotor currents equal to the frequency supplied and the magnitude of starting current of the rotor is very large and lags by a large angle, this results in a poor

starting torque per ampere i.e. nearly 1.5 times the value of torque at full load, also the initial current is 5 to 7 times the value of current at full load. Hence, such type of motors have poor starting torque are not useful where the motor has to start against heavy loads like electric traction and therefore it becomes necessary that the best architecture have to be made in way to maximize the value of starting torque besides improving the efficiency of motor with respect to several applications requiring high value of starting torque such as in electric traction systems. Thus the aim is to develop a design methodology using this algorithm for maximizing the efficiency and to maximize the starting torque of induction motor with a view to obtaining the global best solution.

1.2 Objective of Work

The dissertation fulfills the following type of objectives:

- i.** A review of different classical approaches and intelligent algorithm for parameter estimation of induction motor.
- ii.** Study of harmony search algorithm has been done to test the different non-linear benchmark functions like Sphere, Rastrigin and Ackley function.
- iii.** Parameter estimation of induction motor is been carried out using Harmony Search Algorithm to achieve maximum starting and maximum efficiency.

1.3 Organization of the Dissertation

Chapter 2 Discusses the fundamental principle associated with induction motor

Chapter 3 Review of parameter estimation technique, literature review and discuss the different types of classical approaches and intelligent algorithms that are used for estimation of induction motor parameters.

Chapter 4 Dicusses the Harmony Search Algorithm and its implementation on various different non-linear functions like Sphere function, Rastrigin function and Ackley function.

Chapter5 Covers the results and discussions using harmony search algorithm and also concludes the dissertation work and also discusses its future perspectives.

CHAPTER 2

BASICS OF INDUCTION MOTOR

2.1 Introduction

Three-phase induction motors [34] are commonly used and often encountered machines in industries due to preceding advantages:

- Simple design, bristly in construction, cheap
- Little maintenance
- Broad range of power ratings: fractional horsepower to hundreds of hp.

In despite of these advantages, the induction motor has essential two inherent limitations:

- The induction motor is not a real constant-speed machine, its full-load slip is existing 1-5% and
- Frequency of power source check its speed
- Difficult to have adjustable speed control
- For best speed control
- For optimal speed control, a adjustable-frequency power-electronic drive is needed.

In spite of these limitations around 80% motors in industries are induction motors. Consequently, there is great significance to improve the reliability of induction motors below different working conditions. For this aim induction motor parameters play a vital role. The three phase induction motor schematic drawing is shown in Fig. 2.1.



Fig. 2.1 Induction motor

2.2 Constructional Features of Induction Motor

An induction motor has basically the following parts

i. A stationary stator

It is according of a steel frame, stator core, stator windings and a connection box as shown in Fig. 2.2 The steel frame of stator that mounts a hollow, cylindrical core known as yoke. The stator core manufactured from stacked laminations and allowing a number of evenly distributed slots which handed the area for the stator winding.



Fig. 2.2 Stator of Induction Motor

ii. A revolving rotor

The induction motor rotor is harmonizing of laminated core, rotor windings, shaft, slip rings in case of wound rotor induction motors as shown in Fig. 2.3. The rotor core is self possessed of punched laminations which are joined to bring about rotor slots held in series and provide way for the winding of rotor.

There are two types of windings used in rotor, to wit:

a. Conventional 3-phase windings invented of insulated wire (wound-rotor) similar to the stator winding. In general, Y-connected, the termination point of the three rotor wires are linked to 3 slip rings on the shaft of rotor. Hence, the circuit of rotor is attainable.

b. Aluminum rotor bars low lying together at the ends toward two aluminum end rings, forming a squirrel-cage shaped rotor (squirrel-cage)

(a) Squirrel cage rotor



(b) Slip ring induction motor



Fig. 2.3 Different types of rotor of induction motor.

iii. Bearings- A bearing is a mechanical constituent that authorizes relative motion between the parts, like as the shaft and the housing having lower friction.

iv. Cooling Fan- All circulating electrical machines procreate heat due to which the electrical and mechanical losses hushed the machine. Losses are maximum through launching, overload or dynamic braking. Cooling is required to constantly transfer the heat to a cold area, such as the air. For AC induction motors, natural or forced air is normally internally rotated and externally circulated by one or more fans accumulated on the shaft of rotor. The most general type of AC motor is the entirely placed within fan cooled motor that is supported with a mandatory external

cooling fan placed on the non-drive end (NDE) of the shaft with cooling ribs which run equatorial along the outer skin of the frame of the motor. The fans are constructed that sustain the air flow near to the surface of the motor for its entire length and improve self-cleaning and cooling of the ribs. A gap is left between the fan cap and the ribs conventionally.

2.3 Principle of operation of Induction Motor

The induction motor works upon the principle of induction. When three phase supply is supplied to a equalize three phase stator windings, which is steady distributed in space or mechanically transposed by 120 degree, make a constant amplitude revolving magnetic field called as stator rotating MMF (F_s) as drawn in Fig. 2.4. This revolving magnetic field rotates at which speed known as synchronous speed (N_s), precisely written in term of frequency, and number of a stator poles as:

$$n_s = \frac{120f}{p} \text{ rpm} \quad \dots (2.1)$$

This revolving magnetic field cutting the rotor windings and generate an induced voltage in the windings of rotor. As the windings of rotor are short circuited, for wound-rotor as well as squirrel cage, and current flows in the rotor windings. one more magnetic field is generated by the rotor current called rotor MMF (F_r). A torque is generated due to the intercourse of those two magnetic fields that is stator MMF and Rotor MMF :

$$T_m = K F_s \times F_r \quad \dots (2.2)$$

Where T_m is motor torque and

F_r and F_s are the MMFs of rotor and stator separately.

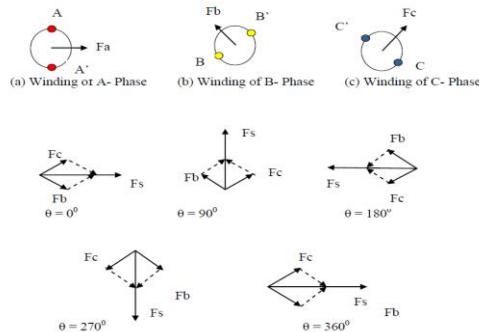


Fig. 2.4 Stator rotating MMF at different angles

2.4 Torque Production

In an induction motor usually 3-phase winding sets up the revolving magnetic field (F_s) and the rotor contain the current producing conductors. An EMF and thus current is produced in the rotor by the slip speed (i.e. distinction between the F_s and the rotor speed). This induced rotor current generated a torque. As a slip speed degrade the torque generated also degraded. However, this slip speed cannot come to zero because since would stop production of the torque generate current itself. Hence, induction motor can never be run at a synchronous speed and therefore, it is known asynchronous motor.

The parameter slip s is a measurement of this approximate speed difference (slip speed)

$$s = \frac{n_s - n}{n_s} = \frac{W_s - W}{W_s} \quad \dots\dots (2.3)$$

2.5 Determination of Induction-Motor Parameters

1. DC determination test of stator resistance

Connected any two stator terminal to a adjustable-voltage DC power supply. Power supply is well adjusted to supplied rated stator current. Then find out the resistance from the given voltage V_{DC} and stator induced current I_{DC} as follows.

a. For the Y-Connected Stator $R_{DC} = \frac{V_{DC}}{I_{DC}} \quad \dots\dots\dots (2.4)$

Stator resistance of every phase $R_{1y} = R_{DC} / 2 \quad \dots\dots\dots (2.5)$

b. For the Delta-Connected Stator $R_{DC} = \frac{V_{DC}}{I_{DC}} \quad \dots\dots\dots (2.6)$

$$R_{DC} = \frac{R_{1\Delta} \times 2R_{1\Delta}}{R_{1\Delta} + 2R_{1\Delta}} = \frac{2}{3} R_{1\Delta} \quad \dots\dots\dots (2.7)$$

2. Blocked rotor test

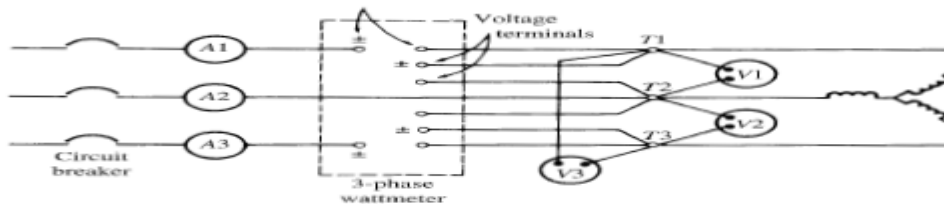


Fig 2.5 Blocked rotor test

From the DC test, decide R_2 when combined with data. The rotor is huddled so that it will not invert. An inconstant-voltage AC supply is jointed and adjust the supply voltage up to the rotor current at blocked condition is equal to the rated current. Neglect the rousing current beneath blocked-rotor conditions to eliminate the shunt parameters of equivalent circuit. Finally determine X_1 and X_2 .

3. No load test

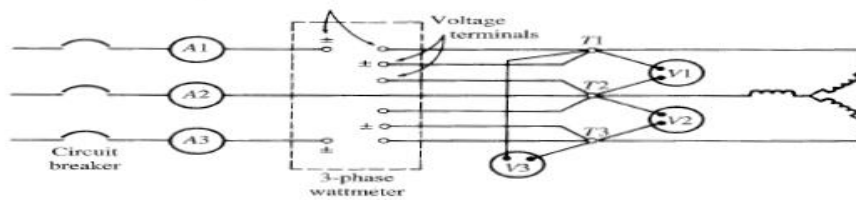


Fig 2.6 No load test

The rotor is allowed to flee freely under no-load condition at rated voltage and rated frequency. At no-load condition, the speed is very near to synchronous speed and the slip =0, reason the current in $R_{2/s}$ to be very less, and can be neglected in the calculations. Estimate the magnetizing reactance (X_M) and friction, linked core and windage losses.

All the overhead mentioned parameters of induction motor is determined under stationary conditions, but when motor runs these parameters transforms energetically predicting the motor conditions.

CHAPTER 3

REVIEW OF PARAMETER ESTIMATION TECHNIQUES

3.1 Introduction

The study of the parameters via electrical and mechanical is important for the determination and arrangement of both ac & dc drive systems. In an induction motor the drive electrical parameters are normally estimated by classical approaches (via blocked rotor test & no load tests) and by intelligent approaches (via Genetic Algorithm (GA), Particle swarm optimization (PSO), Bacterial Foraging Optimization Algorithm (BFOA), simulated annealing (SA), Artificial Neural Network (ANN).

Estimation and study of the performance of an induction machine is usually done by graphs plotting, the different slip curves. To produce the data for making the graph we must need the equivalent circuit relationships and the practically data obtained from the above defined tests. But due to some limitation in classical methods, the recent trend is to use intelligent meta-heuristic algorithm for AC motor identification.

3.2 Literature review

Ansuj *et al.* [1] presented a paper in which a method which uses mathematical model for calculating the equivalent circuit parameters of induction machines. This mathematical method utilized machine equations to calculate the specifications and then performed sensitivity analyses wrt the different parameters of the circuit to make similarity between the given data characteristics.

Filo *et al.* [2] discussed the latest identification methods to the problem of estimation of the steady state values of parameters of a three phase squirrel cage induction machine by non linear least square method .In this paper the algorithm used avoids the problem of handling with ill conditioned matrices.

Wang *et al.* [3] presented nonlinear least-square method for calculating the induction motor parameters. The problem was solved as a nonlinear identification problem and used elimination theory to calculate the different parameter vector that minimized the miscalculation.

Wishart *et al.* [4] discussed the usage of ANN to check and supervise the induction machine. In this paper a system was shown, a system to attentively supervise the stator currents and a system to attentively check the speed of rotor via estimation of the mechanical and current fed system.

Shaw *et al.* [5] in his paper proposed the identification of transient stator current measurements for parameter estimation. This paper described different tests for determining the lumped model specification of an induction motor. Calculations of the stator currents and voltages were needed for the identification and estimation procedure, but no calculations from the motor shaft were required.

Nangsue *et al.* [6] formulated the calculations of parameters in induction machine with genetic algorithm and genetic programming method.

Pedra *et al.* [7] determined the method in which measurement of torque is not required for parameter estimation of squirrel cage induction motors. The errors and problems comes in parameter calculation using the methods determined in IEEE Standard 112 had been shown. The induction motor parameters had been calculated from three different tests: test at no-load, blocked-rotor test and overload tests, and the system had the benefit of not requiring torque measurements.

Pedra *et al.* [8] presented a mathematical method for the estimation of double-cage model specifications of an induction motor from rated manufacturer data: mechanical power & reactive electrical power at full load, torque at breakdown condition, and current at starting. The method had been checked with 223 motors from dissimilar rating data, with an moderate value of the equalized residual error.

Bae *et al.* [9] introduced neural network for designing three phase induction motors using model-building among design variables and equivalent circuit parameters. This method was helpful for non linear problem such as parameter calculation.

Pillay *et al.* [10] developed the paper in which the genetic algorithm uses the calculation of torque transients and these calculations had been applied to the problem of motor specifications determination. Many various types of the genetic algorithm were studied by calculating the specifications for a small, medium, and a large size induction motor.

Alonge *et al.* [11] presented the paper that deals with genetic algorithms for identification of the specification of an induction motor model. Genetic algorithm was used with the target of calculating the parameters via mechanical and electrical, so as to reproduce the initial and final value of a real open-loop system.

Huang *et al.* [12] used genetic algorithm for field orientation control of induction motors. The direct on line start was used to estimate the parameters. Results were presented for both the general and mathematical system of the induction motor. Further the calculated data were correlated with simple random search method.

Kampisios *et al.* [13] introduced a new approach based on experimental transient measurements for checking induction motor equivalent circuit parameters from a vector controlled drive and with a linear machine model.

Abdelhadi *et al.* [14] presented an optimization technique based on steady state machine operation for parameters identification for the motor. This method used genetic algorithm including a latest adaptive scheme for a calculating time reduction. Its aim was to perfectly identify the parameters by using a non linear curve fitting problem.

Lindenmeyer *et al.* [15] proposed a new method which granted to build induction motor models from manufacturer data like data on nameplate, and motor performance characteristics for parameter estimation of an induction motors. This model could be used for black and emergency start studies with the Electromagnetic Transients Program (EMTP) software or with stability programs.

Unem *et al.* [16] discussed the paper in which differential evolution algorithm was used for parameter identification of induction motors. The experiments presented in this system used differential evolution, and was a follow up application of a correlation of stochastic search algorithms on the motor identification problems.

Toliyat *et al.* [17] provided a study of the considerable techniques that were used for the induction motor parameter calculation. The idea was studied throughout with practical and simulation examples, and correlates to other various parameters estimation techniques. Any discrepancy among the parameter values taken within the controller and the real parameter values in the motor led to a degradation in the drive performance.

Koubaa [18] investigated the use of linear parameter determination techniques to identify the rotor resistance, self inductance of the rotor winding, and the stator leakage inductance of a

three-phase induction machine. In order to calculate results with highest accuracy, some specific steps are taken to minimize the effect of the operating conditions of the estimates were also studied.

Sakthivel *et al.* [19] proposed an accurate approach for motor field efficiency estimation employing bacterial foraging algorithm. The approach relied on the measurement of the stator current, stator voltage, input power, stator resistance and rotor speed of the motor without conducting no-load and locked-rotor tests.

Sakthivel *et al.* [20] presented a non-intrusive method for motor efficiency estimation depends on the bacterial foraging algorithm. The proposed method had been studied and checked on a 5 hp motor that was directly supplied by the grid and the results were correlated with those calculated by particle swarm optimization method, immune algorithm method, ant colony optimization techniques and many other classical approaches.

Sakthivel *et al.* [21] presented a new stochastic optimization technique to determine the equivalent circuit parameters using bacterial foraging technique of an induction machines from the manufacturer data, such as nameplate data and other motor performance characteristics. The circuit parameters were derived as a solution for the error reduction function between the estimated and manufacturer data.

Sakthivel *et al.* [22] presented a method based on optimization using a PSO technique. Different induction motor models via approximate model, exact and deep bar circuit models were taken. The optimization problem was calculated as many-objective function to reduce the fault between the estimated and manufacturer data.

Sakthivel *et al.* [23] presented a field efficiency evaluation of induction motor using particle swarm optimization approach based on a modified induction motor equivalent circuit. The simulation results on a 3.75 kW motor were presented and correlated with the results of Equivalent Circuit Method (ECM) ,Torque Gauge Method (TGM), Slip Method (SM), Current Method (CM) and Segregated Loss Method (SLM) .

Sakthivel *et al.* [24] presented a new algorithm that was used to optimize the parameters of different IM models from the rated data and from the tests based on the Immune Algorithm (IA). The proposed IA approach had been tested and examined on two different sample motors. The

proposed approach results have been correlated with the classical parameter estimation technique as well as genetic algorithm (GA).

Marques *et al* [26] presented a method for determining induction motor parameters with the objective of using the motor as power, torque and speed calculating instruments. This paper aim on a process to get the parameters of the motor in whole operation range of work using the vector model referenced to stationary operation frame. Newly developed Harmony Search (HS) algorithm has been used in optimizing processes with positive results.

Prakash *et al.* [27] presented a Harmony Search Optimization (HSO) based design methodology for maximizing both the starting torque and the efficiency of Induction Motor (IM).

Babarinde *et al.* [28] discussed the dynamic modeling of two-phase induction motor. The 4th order Runge-Kutta method was employed to solve the model. Some dynamic behaviors of two-phase induction motors were investigated. The simulation results have shown that electrical parameter variation and the neglecting the saturation effect had considerable effects on the current in the rotor and stator phases.

PARAMETER ESTIMATION METHODS

From the literature review, it had been found that the parameter determination techniques of motor can be categorized into two viz. classical techniques and intelligent algorithm based approaches. A brief over review of these methods have been explained in the next section.

3.3. Classical Approaches

3.3.1. Equivalent circuit method

The motor behaves like the static transformer with expulsion that secondary winding is free to rotate. With the help of equivalent circuit different types of motor parameters are calculated which shows the behavior of induction motor at different stages

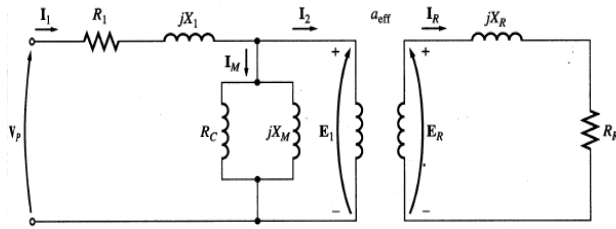


Fig. 3.1 Equivalent Circuit diagram of Induction Motor

X_R is rotor reactance & R_R is rotor resistance.

The similar is true for frequency, i.e. $f_r = s * f_s$ (3.1)

Its well known $X = \omega L = 2\pi fL$ so, the rotor circuit reactance also changes as the frequency of the induced voltage in the rotor changes $X_R = 2\pi f_r L_r = 2\pi s f_s L_r = s * X_{R0}$ Where X_{R0} is rotor reactance at the supply frequency.

Then, the equivalent circuit of rotor as drawn showed as follows:

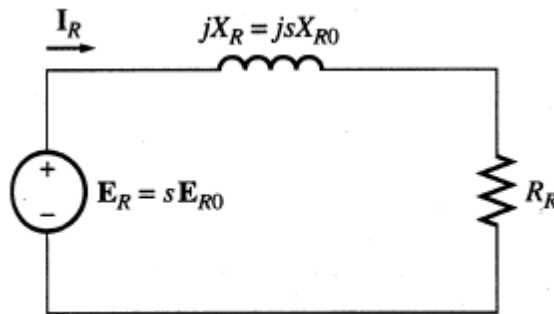


Fig. 3.2 Rotor Equivalent circuit

Where the rotor induced voltage is E_R and the rotor resistance is R_R

Now the rotor current can be estimated

$$I_R = \frac{E_R}{(R_R + jX_R)} \quad \dots\dots\dots (3.2)$$

$$= \frac{SE_{R0}}{(R_R + jsX_{R0})} \quad \dots\dots\dots (3.3)$$

Where the induced voltage is E_{R0} and

The reactance of rotor at blocked rotor condition ($s = 1$) is X_{R0}

Now the equivalent circuit of the rotor may be redrawn as shown in Fig. 3.3.

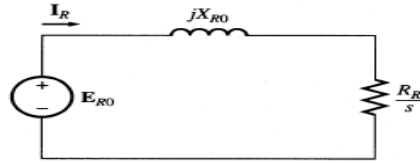


Fig. 3.3 Modified rotor equivalent circuit diagram

If we can combine equivalent circuits of rotor & stator in one equivalent circuit as drawn in below figure 3.4

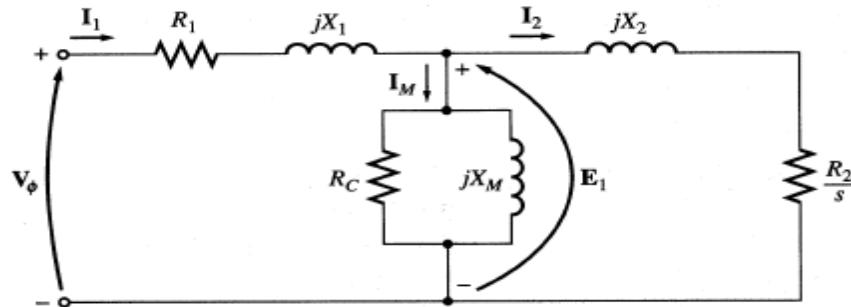


Fig. 3.4 Equivalent circuit diagram of induction motor

3.3.2 Segregated loss method

This method are most forthright because it is simply determine (segregate) the magnitudes of the all losses, called stator copper losses, rotor copper losses, core losses, stray load losses, and friction or windage losses. This method are normally accurate, despite some of method are quite complicated or invasive, while others depends on the empirical factor to determine the losses [23].

3.3.3 Slip Method (SM)

The SM [23] depends on a motor speed measurement technique. The main advantage is easiness. The percentage load is supposed to proportional to the ratio of slip measured to a slip at full load. Although, the calculated error is relatively much bigger when correlated to shaft torque measurement and the air-gap torque technique.

3.3.4 Shaft Torque Method

The shaft torque technique [23] determines shaft torque and speed of rotor directly from shaft without necessary to find the losses. this offer a most exact field efficiency estimate, but its also

highly invasive. It is tremendous price of the torque transducers made this technique not adequate for industrial applications.

3.3.5 Current Method

As similar to slip method, the current method use minimal determination and manufacturing data to calculate the efficiency. These current method assumes that percentage of load is proportional to a ratio of current measuring to current at full rated load. In actual, the current -load curve is somewhat non-linear. hence the motor efficiency can't be estimated correctly by using this methods [23].

3.4 Intelligent algorithms based approaches

The utilization of optimization techniques in field of engineering [35] can be found in many analysis problems that come in engineering model development. This parameter estimation problem naturally converts to an optimization problem to estimate the parameters of some semi-theoretical model function given in a set of test data, because the model parameters must be chosen so that the model apt the data as closely as attainable. A common formulation of nonlinear constrained optimization problem is determined as:

$$\text{Minimize } F(x) \text{ for } x = (x_1, x_2, \dots, x_N) \quad \dots \quad (3.4)$$

$$\text{Subject to } g_j(x) \geq 0 \text{ for } j = 1, 2, \dots, J \text{ and } h_k(x) = 0 \text{ for } k = 1, 2, \dots, K \quad \dots \quad (3.5)$$

Where x variables (a set of design parameters)

F(x): is objective function to be minimized

$g_j(x)$: is inequality constraints

$h_k(x)$: is equality constraints

The calculation of the parameters might be carried out employing the strategy of minimizing the total of quadratic errors of the nearby values with respect to the exact values.

$$F(x) = \sum_{i=1}^N [y_i - f(x, \theta_i)]^2 \quad \dots\dots (3.6)$$

Where, y_i is the test data at test condition θ_i

$F(x, \theta_i)$ is the predicted values at test condition θ_i

The difference $y_i - f(x, \theta_i)$ between the test data y_i and the predicted value $f(x, \theta_i)$ calculates how close the prediction is to the test data and is called the residual. The total of the squares of the residuals at all the test points tells an indication of goodness of the fit.

This data-fitting problem can therefore be seen as optimization problem in which $F(x)$ is minimized by nearby choice of x .

3.5 Soft Computing Techniques

The soft Computing Techniques [34] has been selected to assist the fault-measurement task to perfectly interpret the incorrect data, such an expert system, fuzzy logic system, fuzzy neural network, Artificial Neural Network (ANN), Genetic Algorithm (GA), Bacterial Foraging Algorithm (BFA), and Simulated Annealing (SA) etc.

3.5.1 Fuzzy system for parameter identification

A higher order fuzzy system identification [34] method was determined using subtractive clustering which was an extended utilization of subtractive clustering and a advanced powerful and pliable fuzzy algorithm for the nonlinear dynamic system identified. Usage of linear parameter estimation method to calculate rotor resistance R_R , self inductance of rotor winding, and the stators leakage inductance of the induction machine was inspected.

To carry out fault analysis on an induction motor adopting both experiments and simulation, and to review failure identification techniques used for condition monitoring of the motor and lastly to sketch an On-line condition monitoring system, fuzzy logic controller using Lab aspect was used .

A latest two - step formulation for basic fault measurement in the stator winding of an induction machines was determined. A determined deals with problem of fault detection as problem of change point finding over a time series of a root mean square (rms) values of a stator current of IM. During working of a induction motor, stator resistance was changed constantly with the change in temperature of a working motor. This position may produce an error in rotor resistance (R_R) estimation of the same value and would produce an error among the existing or calculated motor torque could lead to motor breakdown in unfavorable cases.

3.5.2 Bacterial Foraging Optimization Algorithm (BFOA)

This bacterial foraging optimization algorithm is latest type of evolutionary algorithm which depends on the process of the foraging nature of e- coil bacteria existing inside of the human body [19-21]. This BFOA was conveniently used for solving different kind of scientific and engineering cases. This algorithm gives better performance in conditions of quality of solution and speed than the other different type of optimization algorithm. The foraging action of these bacteria can be restrained by a control system and this control system can be divided into four actions that are chemotaxis, swarming and elimination dispersal.

Chemotaxis – In this type action is accomplished by swimming or tumbling via flagella. Depends upon the movement of flagella in every bacterium, it tells whether it must move in the predefined direction (swimming) or altogether in directions (tumbling) in their entire process.

Swarming - During process of going toward a best food location, always aimed that the bacterium which was find out the best path must try to give an attracted signal to other bacteria, so they move together to find the desired food location. In this method, the bacteria assemble into different groups and hence move as c patterns of different groups with large bacterial density.

Reproduction - The lowest healthy bacteria die and other healthiest bacteria every will divide into two bacteria, which are located in same location. This makes population of the bacteria stable.

Elimination and dispersal - In bounded environment of bacteria, the life of bacteria population may changes continuously (e.g., via consumption of rich nutrients) or abruptly due to some different control. All bacteria is in a bounded region which may be died or group also be scattered into the newest location in a environment. They had the affect of possibly spoiling the

chemotaxis progress, but it must have the effect of assist in chemotaxis, since dispersal may produce bacteria near good food source.

Bacterial foraging algorithm

Step 1: Initialized parameter P , s , N_{re} , N_{ed} , P_{ed} , $C(i)$

Step 2: Eliminated-dispersal loop: $l = l + 1$

Step 3: Reproduce loop: $k = k + 1$

Step 4: Chemotaxis loop: $j = j + 1$

Step 5: If $j < N_c$, then go for step 4.

Step 6: Reproduction:

Step 7: If $k < N_{re}$ go to 3.

Step 8: Elimination- dispersal

3.5.3 Genetic Algorithm (GA)

This genetic algorithm technique [10- 12] is nontraditional optimization technique which is based on evolutionary algorithm. In this technique we try to mimic the behavior of nature. In this search technique used in computing true or also approximate solution to find and search cases. It is based on the survival of fittest concept.

It had produce good results in different types practical cases and was became a powerful device to solve a systems of nonlinear equation. The outstanding application of the Gas is that it does not require to differentiate the objective function or also constraints of the case nor to required a best initial estimation. The GAs manipulate consists of binary digits and measures each string's with a good fitness value. Finally one string comes as the best string. Another important advantage is that it produces a cascade search which may overcame local optima and also then finally find the universally optimal solution.

The procedures of the GAs, involve nothing greater than copying strings, random number generation, and also swapping partially string. A common genetic technique algorithm is made of three different operators: reproduction, crossover, or mutation.

Basic steps included in the algorithm are:

- 1) Problem representation
- 2) Initialization of the population
- 3) Evaluation function
- 4) Selection strategy
- 5) Crossover operation
- 6) Mutation operation
- 7) Implementation of the method

GA based in situ parameter estimation of Travelling Wave Tube (TWT) has given better results than other conventional optimization methods. The logic is that that in GA method the search starts parallel at different points in the solution space and it exploits the ancient information of better individuals to survive and recreate to provide still better solutions. This helped the search to come out of local optimum solutions and converge to global optimum solutions in view of the presence of non-linear parameters and the parameters with large magnitude difference.

The main advantage of using GA is that it can obtain global optimum solution rather than just providing local minima. GA has its main application in image processing, system identification, and fuzzy logic controller design.

Possibilities of genetic algorithms application [34] for parameters identification of induction motor was given by Edina Bajrektarević. The basic steps to generate a genetic were described and the examples of its utilization for parameter identification were introduced. Ordered to make easy the offline measurement of induction motor parameters, technique depends on optimization using a multi objective GA was propose by Tahir Sag and Mehmet Cunkas. The flux linkage model and also torque model of the induction motor were used for estimation.

Determination of parameters of induction motor in order to produce on-site energy audit in current motor was used for a cost savings. This method used only a few of data (voltage, and current, and speed ,power factor and torque if possible) from the field test of motor (on-site), inspite of the no load and blocked rotor tests, connected with the genetic algorithm for calculating equivalent circuit parameters.

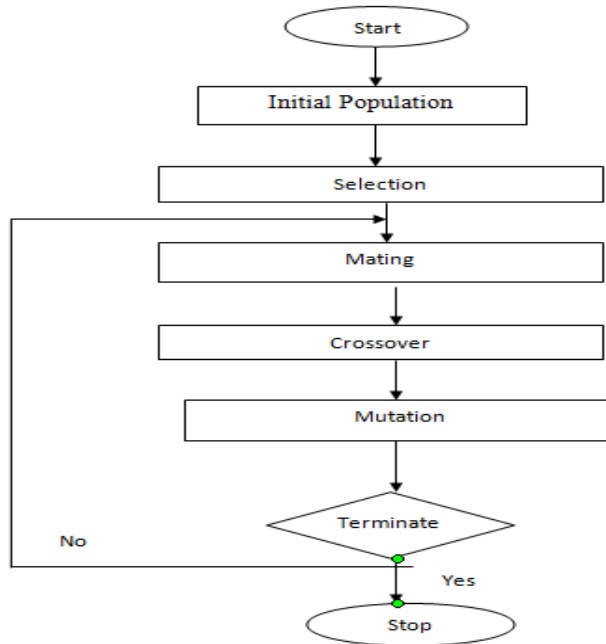


Fig 3.5: Flow Chart of Genetic Algorithm

Algorithm: Pseudo code for the Genetic Algorithm [32].

Input: Population_{size}, Problem_{size}, P_{crossover}, P_{mutation}

Output: S_{best}

Population ← Initialize Population (Population_{size}, Problem_{size});

Evaluate population (Population);

S_{best} ← Get best solution (Population);

While ¬ Stop condition () do

Parents ← Select parents (Population, Population_{size});

Children ← ∅;

For each Parent₁, Parent₂ ∈ Parents do

Child₁, Child₂ ← Crossover (Parent₁, Parent₂, P_{crossover});

Children ← Mutate (Child₁, P_{mutation});

Children ← Mutate (Child₂, P_{mutation});

end

Evaluate population (Children);

S_{best} ← Get best solution (Children);

```

Population ← Replace (Population, Children);
end
return  $S_{best}$ ;

```

3.5.4 Simulated Annealing (SA)

Simulated annealing [32] is the somatic process of annealing and was initially proposed in the area of statistical mechanics as a means of miniature the natural operation of solidification and layout of crystals. During the cooling operation, it is pretend that thermal equilibrium conditions are sustained. The cooling operation ends when the material reached out a state of lower energy, which, in principle, similar with a perfect crystal. It is known that fault-free crystals are more likely to be produced under a slow cooling operation. The two important features of the simulated annealing operation are the transition mechanism among states and the cooling schedule. When apply on to combinatorial optimization, this process aims to determine an optimal configuration”) of a complex case. The main function of an optimization problem similar with the loose energy of the material. An effective solution is companion with a perfect crystal, where as a crystal with fault a corresponds with a local optimum solution.

The basic steps involved in the algorithm are:

Step 1: Read transformer data, self dependent variables, constrains and set, premier temperature.

Step 2: Formulate of the empirical function (i.e., initial mass of core and of the copper) and measures the initial mass of core and copper used in transformer.

Step 3: Set $i=1$ compute $X_i = X_i + \Delta X$ and measure the value of empirical function ($F_{i_{new}}$)
Also measure $\Delta F = F_{i_{new}} - F_1$.

Step 4: Accept or reject every point by using mepropol’s criterion.

Step 5: Check if the number cycles is more than maximum number of cycles pass to next step.
Unless go to step 3.

Step 6: settle step size, reset number of cycle.

Step 7: Check if number of step adjustment is more than maximum number of cycles pass to next step. unless go to step 3.

Step 8: Decrease temperature, reset number of adjustment to zero. Set current point as optimum.

Step 9: Stop, if low temperature else go to step 3.

3.5.5 Particle Swarm Optimization (PSO)

Particle swarm optimization [22, 23] first invented by Kennedy and Eberhart, and is one of the archaic heuristic algorithms. It was designed through simulation of a streamline social system and has been mainly used in solving non-linear problems. This method can be used to given high-quality solutions with very low consume able time and stable convergence diagnostic than the all other optimization methods. This is a population-based optimization algorithm, which was basically develop on the social and genetic behavior of animals like fish schooling or bird flocking. In PSO, every particle has its own opinion using its experience and also interact with neighbor's experiences. The main advantages of this algorithm are: easy to use, very easy to implement, no problem to control parameters and also mathematical efficiency.

The Particle Swarm Optimization algorithm [32] is consist of a number of particles that place around the search space impact by their own best past place and the best past place of the whole swarm or a close neighbor. Each repetition a particle's velocity is updated by using:

$$v_i(t+1) = v_i(t) + (c_1 \times rand() \times (p_i^{best} - p_i(t))) + (c_2 \times rand() \times p_{gbest} - p_i(t)) \quad \dots (3.7)$$

where $v_i(t+1)$ is the latest velocity for the i^{th} particle, c_1 and c_2 are weighting coefficients for the personal best and the global best positions similarly, $p_i(t)$ is the i^{th} particle's place at time t , p_i^{best} is the i^{th} particle's best known place, and p_{gbest} is the best place known to the swarm. The $rand()$ function produces a uniformly scattered variable $\in [0, 1]$. Variants on this modernize equation accounted best positions within a local neighborhood particles at time t .

A particle's position is modernize using:

$$p_i(t+1) = p_i(t) + v_i(t) \quad \dots (3)$$

3.5.6 Artificial Neural Network (ANN)

Artificial neural networks [4] are those computing systems whose structures are influenced by a simplified miniature of the human brain. Figure 2.2 shows a two-layer ANN. It is made up of two hidden layers of unusual processing units (termed as nodes or neurons). Each input is joined via a weight to every (hidden) node in the layer. Each hidden neuron is, in turn, joined via a weight to every (output) neuron in the output layer. The output of hidden neuron j is premise by $h_j = a(z_j)$ where a is known the activation function and is shown the activation of neuron j and is the weighted sum of inputs x_i to neuron j and threshold μ_j , of neuron j .

$$z_j = \sum_i w_{ji} x_i + \mu_i \quad \dots\dots\dots (3.9)$$

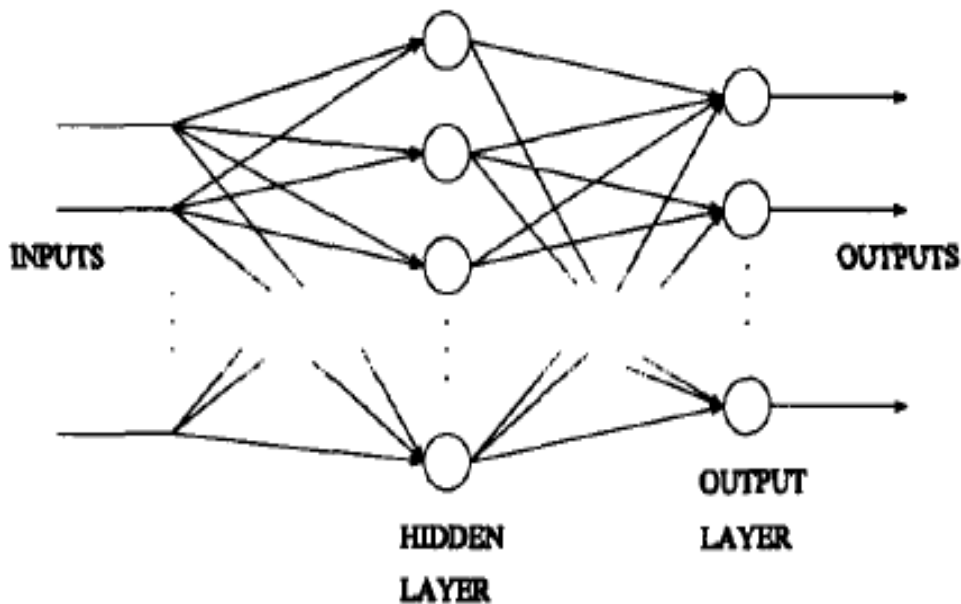


Fig 3.6: Typical two layer ANN

Artificial Neural Network (ANN) [34] is a system developed on the operation of biological neural networks; it is an conceptual simulation of a real nervous system. ANN's have been applicable with astonishing succeeded in fields ranging from Computer, Engineering to Medicine. Now days the most stimulating and also profitable development is raise usage of ANN in various applications of electrical machines and control system.

ANN's attempts to give model of the human brain structure and are developed on self-learning. It is consist of a large number of widely interconnected processing elements known as nodes working in unison to solve out a particular problem. The structure is widely parallel, resulting in capability to self organizes to describe information and fastly solved out problems in real life. Basically, application of the ANN can be distributed into the following categories:

- (i) Pattern recognition
- (ii) Grouping
- (iii) Association
- (iv) Control
- (v) Prediction
- (vi) Approximation of functions
- (vii) Optimization

Neural networks theory has been a functioning research area in recent years. Due to the assistive ability of a networks learning process, applying networks to dynamics system determination or control has become challenging alternate to process control. Two approaches have been addressed in a neural network literature to cope with the assistive control problem.

Firstly, some design parameters are learned off-line by measuring the input-output signals and here the motor behaviour, in some key events. In the different approach, an commonly used leaning is developed and also the control input is intended on-line as the output the various neural network

The motor is a nonlinear randomly dynamic system with factors that changes with frequency temperature, operating point saturation. Seeing that induction motors are broadly used in industrial applications, these parameters have an important effect on the accuracy and efficiency of the induction motors and, eventually, the overall machine performance.

Therefore, it is necessitate to develop algorithms for online parameter estimation of the induction motor. These algorithms can be executed in real time because of the progress in the use of digital signal processors (DSPs) and microelectronics.

The Luenberger observer scheme is intended for flux estimation, and also the speed observer system is used for rotor-speed measurement. The rotor factors are most essential factors for the different controls of the motor drives. The rotor resistance also be change up to the 150% over

the whole operation. A differ number of ways that are both used for the finding of the rotor factors and the prevention of its changes have been debated.

In, the rotor parameter estimation is propounded by estimating the rotor temperature. This depends on the action that the temperature affects the elemental frequency component of the terminal voltage for a given input current. This is a very boring process in which temperature of the rotor windings has determined each and every time. Different types of papers have describes the effect of motor various factors on the quality of speed estimation and also flux in vector control systems.

The online determination of the mutual inductance and rotor resistance are organized. Artificial neural networks (ANNs) also be used to single out and control of the nonlinear dynamic systems because they can outright a large range of nonlinear functions to any required degree of accuracy. Moreover, these can be used in parallel and, due to which, smaller computational time can be concluded.

Since the 1990s, several experiments into the applications of various neural networks in the field of electrical machines and power system have come into the light. In last years, many papers have given which deal with use of ANN in modulation systems, in control, in the estimation of state variables, in breakdown detection, of motor parameters. In different papers, the use of ANN has been used for determining the rotor angular speed.. One is based on the machine model, and the other one contains stator currents and voltages for direct speed estimation.

ANN has attained favour over different techniques, as it is more efficient in ascertaining similarities among wide bodies of data. It is a best alternative for achieving motor fault detection while avoiding mathematical model. As the ANN can adapt to learn imperiously complicated nonstop nonlinear functions,

In addition, the ANN also perform this function online go through the use of cheap monitoring devices. These devices obtain the necessitate measurements in a non invasive manner. The goal was to develop an alternative NN based fault-detection scheme that overrides the drawbacks of the present schemes.

It was observed that presented schemes were expensive and applicable for large motors; moreover many design parameters are demanded. In particular, concerning to long-time operating machines, these parameters cannot be available easily. In some existing schemes,

either a particular mathematical model was required or many features had to be reduced, for which costly instrumentation was required.

In this scheme, only stator current was acquired, and simple statistical parameters of current waveform were used as inputs to detect the four conditions of motor. As compared to existing schemes, the propounded scheme was simple, to the point, responsible, and economical. For demonstration of parallel NN-based fault classifier, developmental results were used rather of simulation to make the classifier more functional. A new adapted control scheme, consist of a neural identifier and a nonlinear controller, apply on a linear induction motor

3.5.7 Integration of ANN & FS

Prof. L.A. Zadeh proposed fuzzy logic as the model of a human reasoning for nonlinear mapping of the different input specific space into an output space. Artificial Neural Networks (ANNs) are additional with largish number of varied architectures and learning strategies. By joining these two different approaches into the neuro-fuzzy technique, it is feasible to come at control structures with enrich characteristics of the motor. ANNs and fuzzy logic are mainly used in the fields of control of nonlinear systems, modelling.

The various classes of ANNs that has taken considerable immersion in these years are the recurrent neural networks. Study on fuzzy logic operations in control structure design deflects a couple of generic trends. The oldest one is devolved on heuristic knowledge and proficiency of a human expert with observes to the system behaviour. Systematic approaches use operation defined in deterministic manual or different optimization techniques, such as genetic algorithms, or simulated annealing.

The most optimistic approach encompasses numerous techniques for self-organizing fuzzy model produce on the basis of applied input-output numerical data. A most prosperous realization of the self-declaring fuzzy models are usually obtained by using clustering methods for dividing the input-output space, consist with genetic algorithms (GA), least-squares (LS), or gradient descent-LS optimization techniques for model parameter adjustment.

However, there are small numbers of techniques that can give us true on-line adjustment process of a fuzzy model. One of common examples is Neuro FAST, a Takagi–Sugeno–Kang fuzzy model, in which the input space is automatically divided by use of a latest fuzzy adaptive

resonance theory. In order for the necessitate system performance to be protected, it is a function that computationally efficient and accurate identification models are in subsistence.

The vector control method, which is made upon the field orientation principle given by Haase in 1968 and Blaschke in 1970, separates the flux control and also the torque control in an induction motor drive.

Although, fuzzy logic control or ANN have its own limitations, which could not be evaded and neglected. A fuzzy controller used in the various motor drive speed control having a very narrow speed operation and also be required much more manual adjusting by different trial and error if high quality performance is required.

On the other side, it is really tough to make a training data for ANN which can manage all the operating systems. A neuro-fuzzy controller (NFC) used for motor drive has the vantages of FLC and also ANN. Over the last few years, researchers perform on the application of NFC for random speed drives. Although, the popular NFCs used in earlier works a great number of functions or also rules.

CHAPTER 4

HARMONY SEARCH ALGORITHM

4.1. Introduction

Many scientific and engineering problems have been solved by using calculus. Sometimes this technique of differential calculus malfunctions when the objective function is discontinuous or when the decision variables are not continuous in nature [29]. Thus a new metaheuristic algorithm has been developed by the researchers to overcome this drawback of differential calculus. The metaheuristic algorithms are based on natural phenomenon like animal behavior or evolution. These nature based meta-heuristic algorithms are used to solve many optimization problems more efficiently. Its working relies on population of individuals and these individuals are initialized randomly where each of the individual shows a solution to a given problem. Then by using fitness function a solution of problem is evaluated. A new population is then formed using a selection process. This procedure of algorithm is repeated again and again till convergence rules are met.

4.2. Harmony Search Algorithm (HSA)

A latest developed algorithm called harmonic search was made on the basis of connection between a beautiful piece of music and optimal solution. Harmony search was first studied by Geem et al. in 2001 [29]. This algorithm is music based meta – heuristic algorithm and has many advantages and applications and many optimization problems are solved using this algorithm like modeling of ground water, energy saving dispatch, function optimization and others [29]. As in optimization process, we find optimality, a similar effort is required to determine the harmony in music. We intend to produce the best solution from both the processes.

When a new pitch is improvised by a musician, he or she might traverse three ways, firstly playing any note exactly from memory or playing a nearby note from memory or composing arbitrary notes. And these become: use of harmony memory, adjusting the pitch, and randomization [25].

The parameter adopted by harmony search algorithm r_{accept} ranges from [0, 1] but typically we use $r_{\text{accept}} = 0.7$ to 0.95 and are called accepting rate. The second is r_{pa} called pitch adjustment rate. The beat can be rectified linearly or non linearly but in actual linear rectification is taken.

Usually we take $r_{pa} = 0.1 \sim 0.5$ in many applications. The other one is the randomization, which is to increase or maximize the iterations of the solutions.

The probability of the randomization is:

$$P_{random} = 1 - r_{accept} \quad \dots\dots (4.1)$$

and the probability of the pitch adjustment rate is:

$$P_{pitch} = r_{accept} \quad \dots\dots (4.2)$$

4.2.1 Steps of Harmony Search Algorithm

The important steps in operation of Harmony Search Algorithm (HSA) are given as

Step1. Initialize the parameters of optimizing problem and Harmonic Search Algorithm.

Step2. Initialize and improvise Harmony Memory.

Step3. Amend the harmony memory.

Step4. See the stopping criteria.

(1) Initialize the Problem and Algorithm parameter

The problem is shown as follows:

Maximize subject to $y_i \in Y_i, i = 1, \dots, N$. where $f(y)$ is the objective function and y is the set of each decision variable (y_i), Y_i is the set of the range of values with in limit for each design variable, that is $Y_{iL} \leq Y_i \leq Y_{iu}$, Where Y_{iL} and Y_{iu} are the lower and upper boundaries for each decision variables. The parameters Harmony Memory Size (HMS), Harmony Memory Considering Rate (HMCR), Bandwidth (BW), Pitch Adjusting Rate (PAR), number of improvisations (NI) or stopping criterion and number of decision variables (N) of Harmony Search Algorithm (HSA) are also specified in this step [30].

(2) Initialize and improvise the Harmony Memory (HM)

The harmony memory is initializing as:

$$HM = \begin{bmatrix} h_1^1 & h_2^1 & \dots & h_N^1 \\ h_1^2 & h_2^2 & \dots & h_N^2 \\ h_1^3 & h_2^3 & \dots & h_N^3 \\ \vdots & \vdots & & \vdots \\ h_1^{HMS} & h_2^{HMS} & \dots & h_N^{HMS} \end{bmatrix} \dots\dots (4.3)$$

A new harmony is generated known as improvisation. A new harmony vector is $h' = h'_1, h'_2, \dots, h'_n$, is generated [28].

Memory consideration

The data for the first variable h'_1 for the new vector is selected from any of the values in the given range of harmony memory. Values for other variables are chosen in the same way. The HMCR that lies between 0 and 1 is the rate of choosing a value from harmony memory, while (1-HMCR) is the rate of randomly choosing a value from the possible range of values.

Pitch adjustment

Every component is pitch adjusted based as

If (rand () < PAR)

h'_i tends to $h'_i \pm \text{rand} () * BW$

where BW is the arbitrary band width

(3) Amend the harmony memory

From the point of view of given function value, If the latest harmony vector, $h' = (h'_1 + h'_2 \dots h'_N)$ is accurate than the worst harmony in the HM, then the latest harmony is included in the HM and the existing worst harmony are excluded from HM.

(4) See the stopping criteria

If the total number of improvisations is satisfied, process is halt. Otherwise, step 2 and 3 are repeated.

4.2.2 Flow chart of Harmony Search Algorithm:

The flow chart of the harmony search algorithm is shown below in figure:

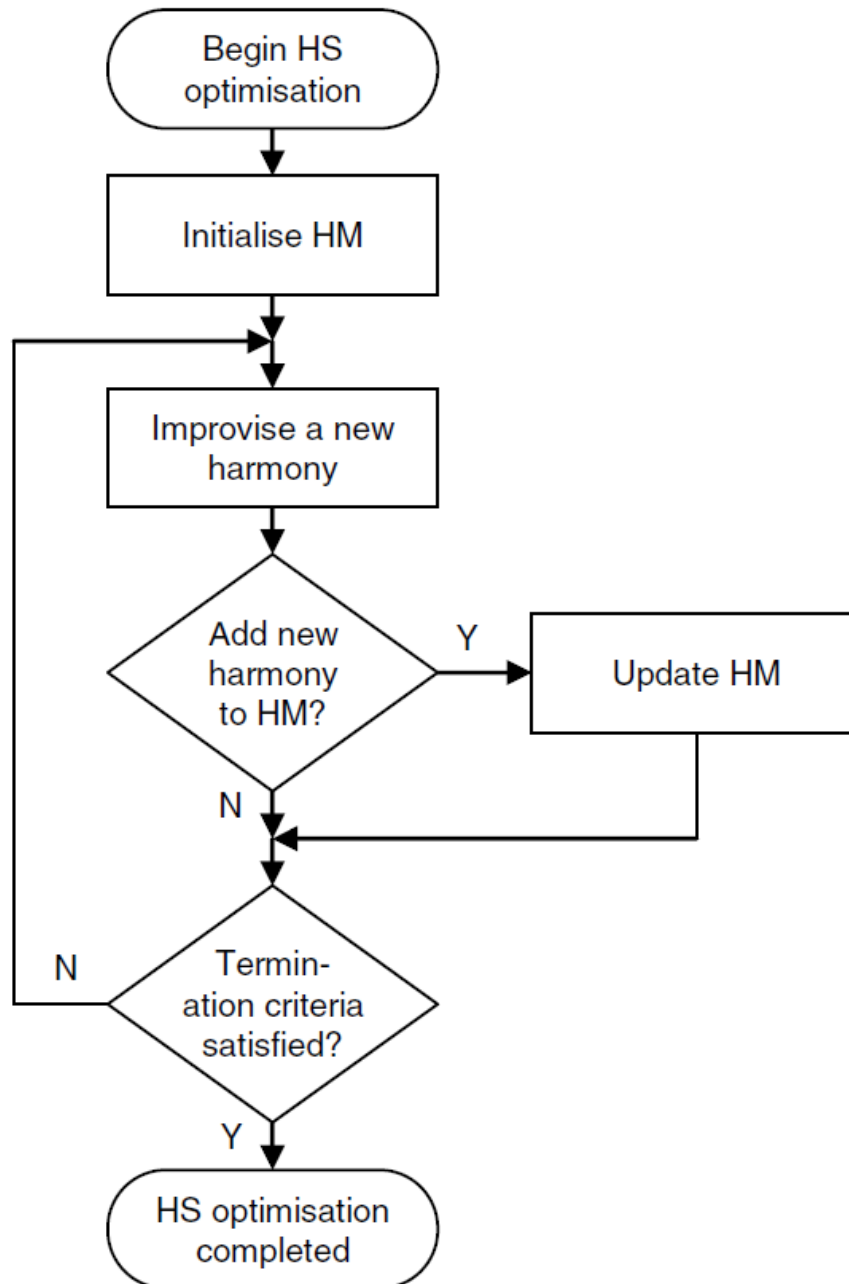


Figure 4.1: Flow Chart of Harmony Search Algorithm

4.2.3 Algorithm: Pseudo code for Harmony Search [32]

Input: Pitch_{num}, Pitch_{bounds}, Memory_{size}, Consolidation_{rate},
Pitchadjust_{rate}, Improvisation_{max}

Output: Harmony_{best}

Harmonies \leftarrow Initialize harmony memory (Pitch_{num}, 1 Pitch_{bounds}, Memory_{size});

Evaluate harmonies (harmonies);

for i to Improvisation_{max} do

Harmony $\leftarrow \emptyset$;

Foreach Pitch_i \in Pitch_{num} do

if Rand() \leq Consolidation_{rate} then

Random $harmony_{pitch}^i$

Select random Harmony Pitch (Harmonies, Pitch_i);

if Rand() \leq Pitch Adjust_{rate} then

$harmony_{pitch}^i$

Adjust Pitch (Random $harmony_{pitch}^i$);

else

$harmony_{pitch}^i \leftarrow$ Random $harmony_{pitch}^i$;

end

else

$harmony_{pitch}^i \leftarrow$ Random Pitch(Pitch_{bounds});

end

end

Evaluate harmonies (Harmony);

if Cost (Harmony) \leq Cost(Worst(Harmonies)) then

Worst (Harmonies) \leftarrow Harmony;

end

end

return Harmony_{best};

4.3 Advantages of Harmonic Search Algorithm

- Harmonic search is not a gradient-based search algorithm.
- And also Harmony search has less no of mathematical calculations, and also, it can be also used with various complex objective functions whether the function is continuous or discontinuous function, linear or nonlinear function, or stochastic with noise.
- Harmony search could be effectively more efficient and accurate then other intelligent algorithms because harmony search does not use binary encoding and decoding, but it does have many solution vectors. Therefore harmony search can perform rapidly during each iteration. Thus operation in HS algorithm is easy to implement.

4.4 Applications of Harmony Search

Electrical engineering problems

- Electrical energy system dispatch
- Photo-electronic detection
- Design of power system
- Optimization of multi-level inverter
- System Identification

Civil engineering problems

- Structural design
- Design of water network
- Scheduling of dam
- Flood model calibration

Computer science problems

- Web page clustering
- Summarization of text
- Internet routing
- Tracking of visuals

- Field of robotics

Bio & medical applications

- Prediction of RNA structure
- Hearing aids
- Medical physics

Mechanical engineering problems

- Design of heat exchanger
- Design of Satellite heat pipe
- Design of offshore structure

4.5 Standard functions

4.5.1 Sphere function

Sphere function is also known as De Jong's function as it is the first function of De Jong. It is one of the easiest benchmark functions. This function is continuous, unimodal and convex. It's general definition given below [31].

$$f(x_1, x_2) = x_1^2 + x_2^2 \quad \dots\dots (4.4)$$

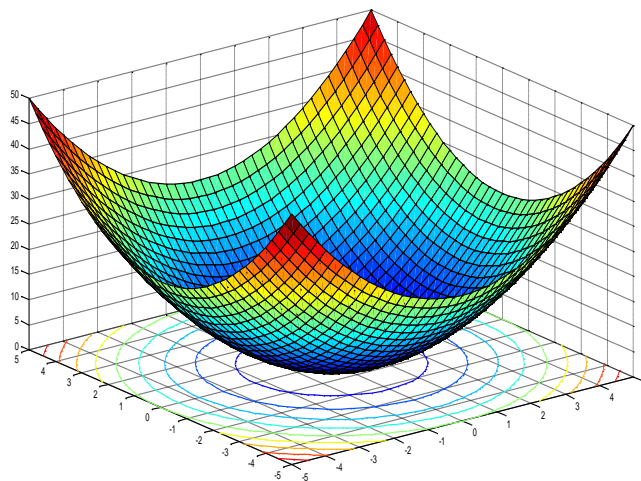


Figure 4.2 Three dimension plot for Sphere Function

4.5.2 Rastrigin's function

Rastrigin's function depends on the function of De Jong also with the use of cosine modulation in order to get frequent local minima. Therefore, the test function is immensely multimodal. However, the locations of the minima are evenly distributed. The definition of the function is given below [31]

$$f(x) = 10 \times 2 + [x_1^2 - 10 \cos(2\pi x_1)] + [x_2^2 - 10 \cos(2\pi x_2)] \quad \dots\dots\dots (4.5)$$

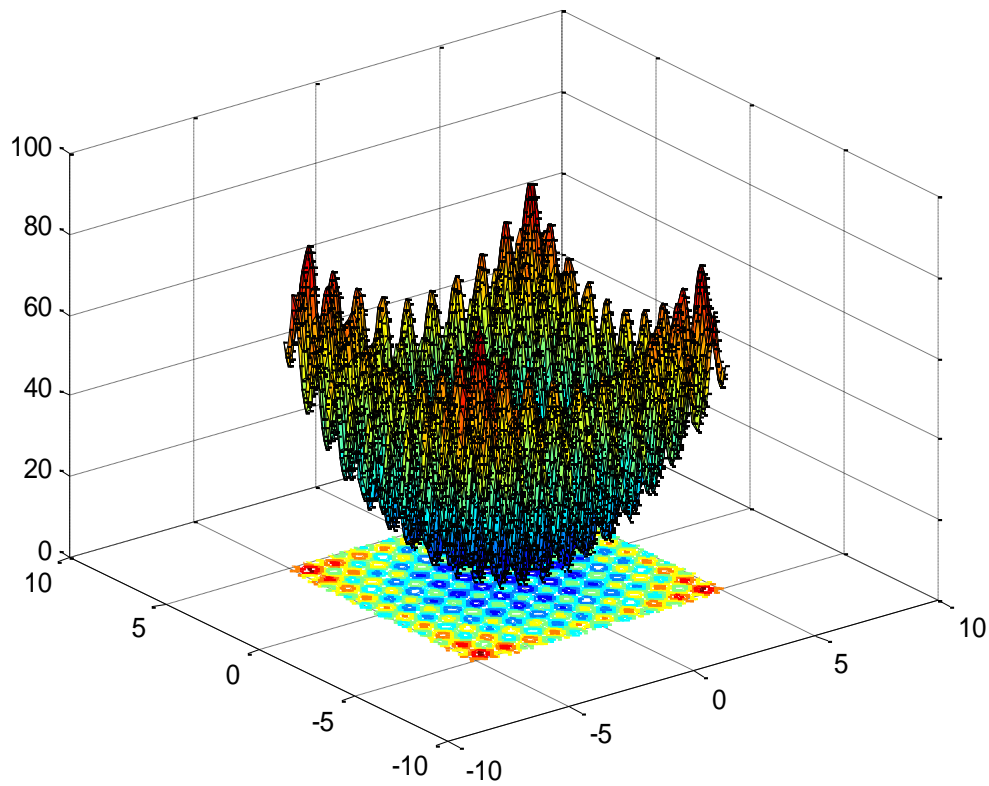


Figure 4.3 Three dimension plot for Rastrigin's Function

4.5.3 Ackley's Function

Ackley is mostly used as test function. It is most difficult function to optimize. The definition of Ackley function is given below [31].

$$f(x) = \left(-20 \exp\left(-0.2 \sqrt{\frac{1}{2} (x_1^2 + x_2^2)}\right) \right) - \left(\exp\left(\frac{1}{2} (\cos(2\pi x_2))\right) + 20 + \exp(1) \right) \quad \dots (4.6)$$

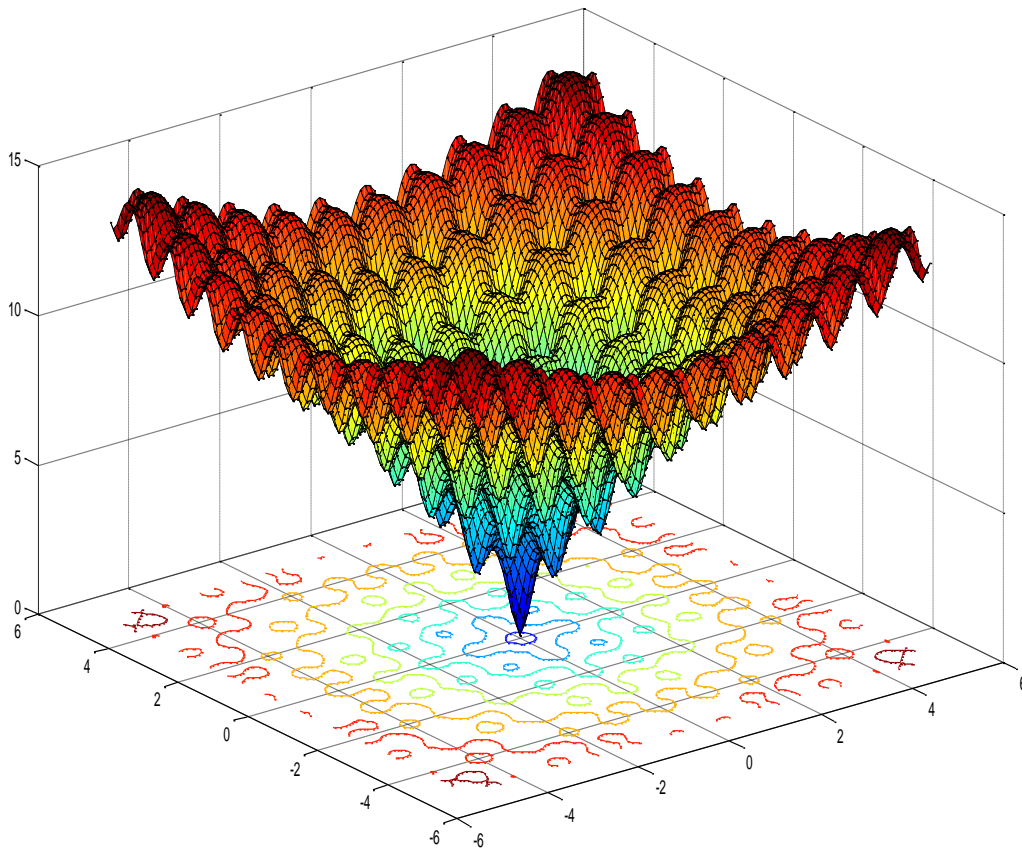


Figure 4.4 Three dimension plot for Ackley's Function

4.5.4 Rosenbrock's function

Rosenbrock's valley is used as classic optimization problem, also known as banana function or the second function of De Jong. The Rosenbrock's valley function is defined below [31].

$$f(x) = 100(x_1^2 - x_2)^2 + (1 - x_2)^2 \quad \dots\dots (4.7)$$

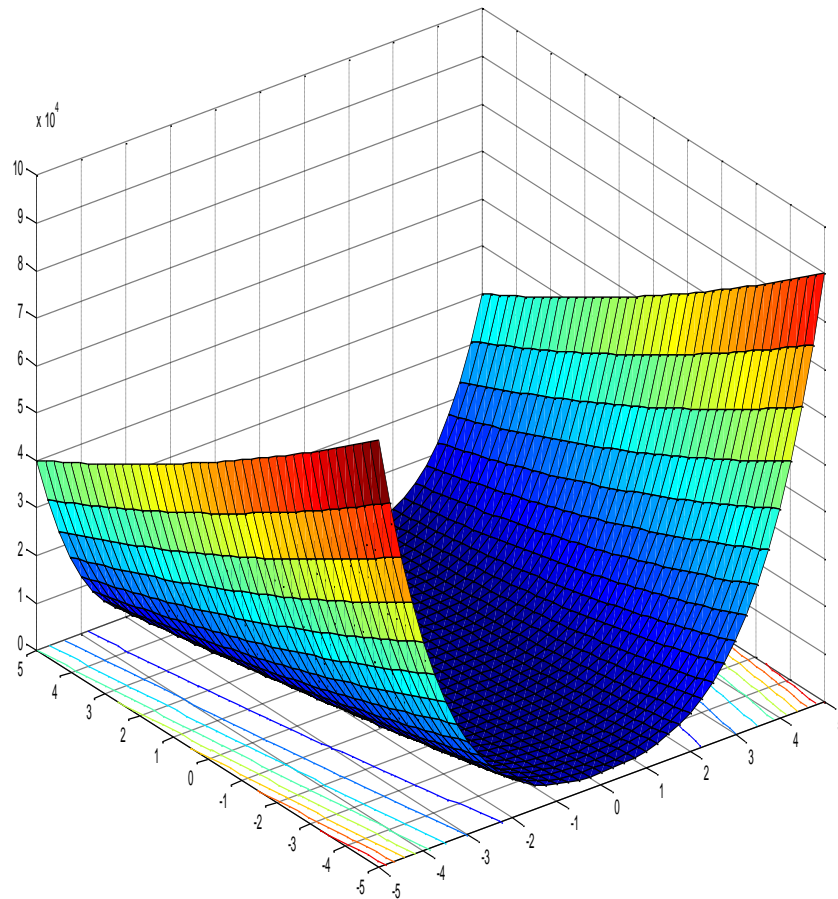


Figure 4.5 Three dimension plot for Rosenbrock's Function

4.6 Results

The variation of different harmonies using harmony search algorithm is shown in different figures given below:

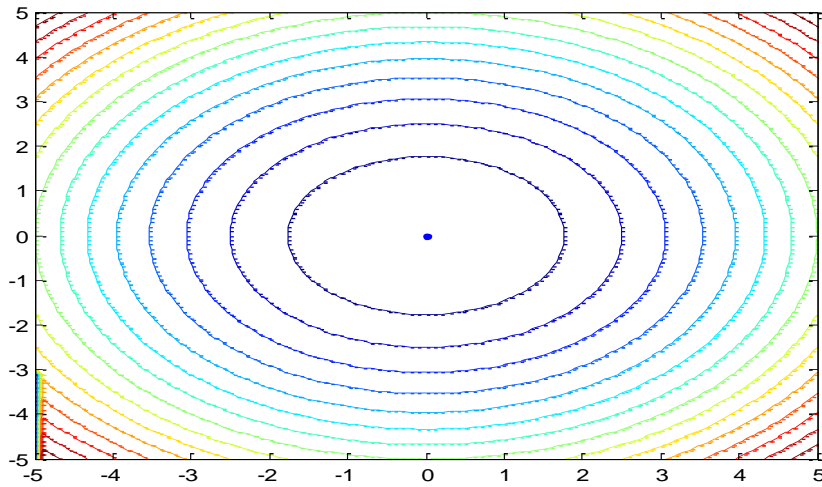


Figure 4.6 Two dimension plot of sphere function using harmony search algorithm

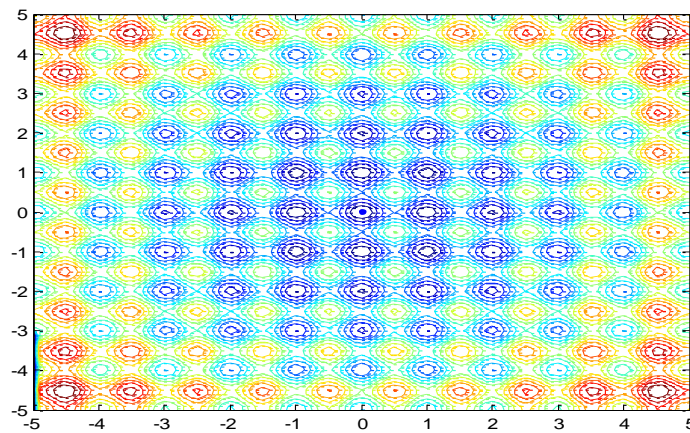


Figure 4.7 Two dimension plot of rastrigin function using harmony search algorithm

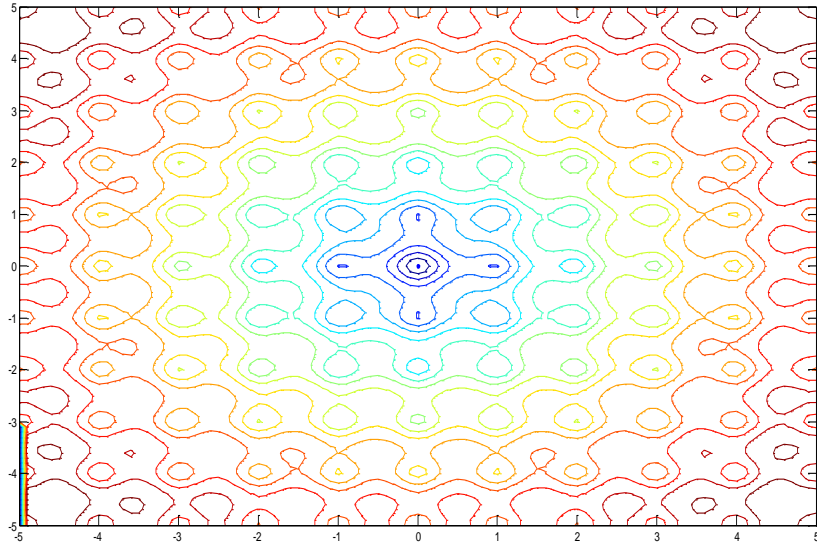


Figure 4.8 Two dimension plot of Ackley fuction using harmony search algorithm

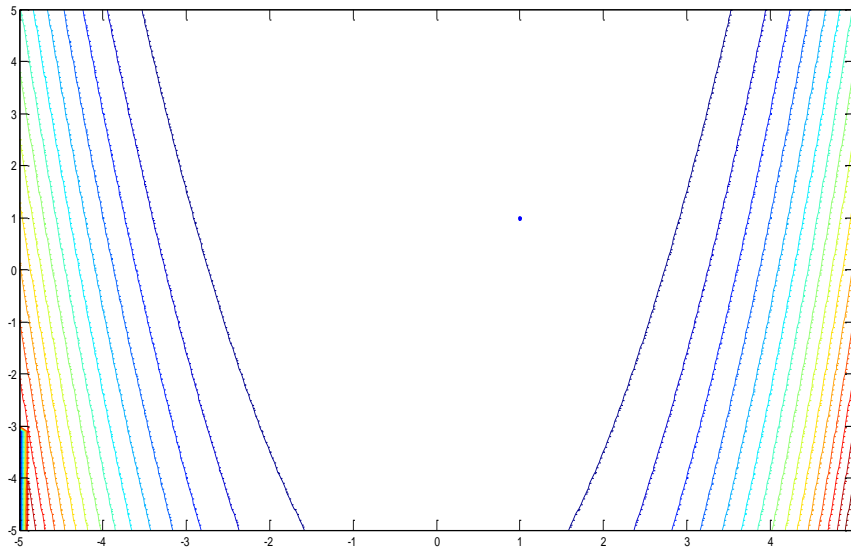


Figure 4.9 Two dimension plot of rosenbrock function using harmony search algorithm

Finally the results for different benchmark functions are calculated using harmony search algorithm and also CPU time and count no is analyzed.

Table 4.1: Results for Harmony Search Algorithm (HSA) for different benchmark function

Benchmark function	Search space	X₁	X₂	Fmin	Count	CPU Time (sec)
Sphere	[-5.12 ,5.12]	0.0028	-0.0001	$8.026*10^{-6}$	560	2.10
Ackley	[-32.76 ,32.76]	-0.00058	0.00913	0.028	5500	4.180
Rastrigin	[-5.12 ,5.12]	-0.0300	-0.0070	0.18802	13000	15.41
Rosenbrock	[-2.04 ,2.04]	0.997	0.995	$6.87*10^{-6}$	3224	2.67

4.7. Conclusion

In this chapter we have studied Harmony Search Algorithm and applied it to some nonlinear benchmark functions viz.: Sphere, Rosenbrock , Rastrigin , Ackley function. Thus, we can conclude that this algorithm provides optimum value or near optimum value of the given objective function in less amount of time. Further we will apply this algorithm to determine the parameters of Induction Motor.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In this chapter we are going to optimize the induction motor parameters viz. rotor resistance and reactance in order to achieve maximum starting torque for electric traction application. Further the stator and rotor copper losses of an induction motor are reduced to achieve maximum efficiency. Both the problems are addressed using harmony search algorithm.

5.2 Case Study 1: Here the objective is to determine the parameters of the induction motor in order to achieve maximum starting torque using harmony search algorithm. The program is being carried out using MATLAB Version 7.6.0.324 (R2008a) having License Number: 161051 on dual core processor of 2GB RAM. For solving this problem an induction motor [21] is taken with the rating given below:

Table 5.1: Name Plate Data of Test Machine

Specification	Motor
Capacity	5 hp
Voltage	400V
Current	8 A
Frequency	50 Hz
No of poles	4
Full load slip	0.07
Full load torque	25 Nm
Full load efficiency	88 %

5.3 Algorithm for the parameter estimation process

The steps for harmony search algorithm in order to estimate its rotor parameters are given as follows:

Step 1. Define the number of parameters to be estimated for an induction motor.

Step 2. Initialize the parameters of Harmony Search algorithm (HSA) viz. Harmony

Memory (HM), Harmony Memory Considering Rate (HMCR), Pitch adjusting rate (PAR), maximum iteration, stopping criteria.

Step 3. Define the objective function $f(x)$.

Step 4. Select the value of user defined parameter and also the range for the given objective function parameters.

Step 5. Generate the initial Harmony memory ($i = 1$: number of model parameters) of the model randomly within the range.

Step 6. Determine functional value of initial Harmony memory.

Step 7. Set iteration count, iteration =1

Step 8. Starting of Harmony Search, if generated random value $> HMCR$, Then select the value of parameter randomly as given,

$$x_{\text{new}} = L(x_{\text{old}}) + \text{rand} \in (0,1) * \text{bandwidth}$$

otherwise choose value from the Harmony memory and adjust the pitch as follows:

$$x_{\text{new}} = x_{\text{old}} + \text{bandwidth} (\text{rand} - 0.5)$$

Step 9. Update the value of objective function and replace the worst solution with new better solution.

Step 10. Check stopping criteria and iteration $>$ maximum iteration, if it is satisfied GOTO step 12.

Step 11. Advance the iteration count, iteration = iteration+1 and GOTO step 8.

Step 12. Find the optimal value of the function.

Step 13. Stop.

5.4. Parameters for Harmony Search Algorithm (HSA)

The following user defined parameters of harmony search algorithm are given below in Table5.2

Table 5.2: Harmony Search Parameters

Acceptance rate	0.9
PAR	0.7
Harmony size	20
PR	100

5.5 Results

After carrying out the MATLAB coding using harmony search algorithm, R_2 and X_2 are estimated to achieve maximum starting torque. Further the results obtained are also compared with some standard results obtained through Particle Swarm Optimization (PSO), Bacterial Foraging (BF) and Genetic Algorithm (GA) as cited in [21].

Table 5.3: Estimation of R_2 and X_2 using HS and its comparison with PSO, BF and GA

Parameters	Classical	PSO	BF	GA	HS
R_2	5.274	5.913	5.9	7.43	4.571
X_2	14.81	15.4583	15.4	15.8	18.87

The value of starting torque from the experimental set up is 15 Nm and from harmony search algorithm the value of starting torque is 19.39 Nm and the error is about 22%. Further the parameters estimated are nearly close to that of the analytical results.

5.6 Case Study 2: Here objective is to reduce the losses of an induction motor viz. stator copper loss and rotor copper loss in order to achieve maximum efficiency using harmony search algorithm. For solving this problem an induction motor [33] is taken with the following specifications.

Table 5.4: Specifications of given Test Induction Machine

Output Power	28KW
Stator copper loss	3KW
Rotor copper loss	2925W
No load loss	7871W
Efficiency	78%

As

$$efficiency = \frac{KW}{KW + P_t} \dots\dots\dots (5.1)$$

Where P_t = total losses = stator copper losses + rotor copper losses + no load losses

Therefore the calculated value of efficiency from this experimental data is 66%

So, to reduce the losses in order to achieve the maximum efficiency, harmony search algorithm is employed. The user defined parameters of harmony search algorithm are given below in Table 4.4.

Table 5.5: Parameters of Harmony Search Algorithm

Harmony Memory Size	10
Harmony Memory Acceptance rate	0.9
Pitch Adjustment Rate	0.5

5.7 Results

After carrying out the MATLAB coding using harmony search algorithm, stator copper loss and rotor copper loss are estimated to achieve maximum efficiency, the results of which are tabulated below:

Table 5.6: Estimated Stator and Rotor copper loss using Harmony Search Algorithm

Efficiency	63.98%
Stator copper loss	3.9366 KW
Rotor copper loss	3.9587 KW
Iteration	50,000
CPU time	21.9355 sec
Error	4%

The value of efficiency from the experimental set up is 66 % and by harmony search algorithm its value is deviated by only 4%.

5.8 Conclusions and Future Scope of Work

1. So far we have only found out the rotor side parameters, stator side parameters can also be optimized using Harmony Search Algorithm (HSA).
2. Power factor could be consider separate single unit objective function. The aim is to maximize the power factor because there are many disadvantages of low power factor viz. large conductor size, poor voltage regulation, more copper used, more losses etc.
3. So far single objective function have been solved, multi objective function have not be addressed which can be taken up in the future.
4. Fine tuning of parameters could have given better results.
5. New nature inspired algorithm like firefly algorithm, bat algorithm and cuckoo search algorithm can also be applied for obtaining more accurate results.
6. Even improved or modified versions of Harmony Search Algorithm can also be applied to estimate both single objective as well as multi objective functions.
7. In this dissertation work, only few benchmark functions have been tested using Harmony Search Algorithm. The work can further be extended for more complicated designs problems.

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