DESIGN AND PERFORMANCE OPTIMIZATION OF THREE PHASE SQUIRREL CAGE INDUCTION MOTOR FOR RURAL AREA APPLICATIONS

A Thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy

In
Electrical Engineering

BY
Raj Kumar Saini

August 2020

SUPERVISORS

Dr.Devender Kumar Saini
Dr.Rajeev Gupta
Dr. Piush Verma

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Department of Electrical and Electronic Engineering
School of Engineering
University of Petroleum and Energy Studies
Dehradun-248007: Uttarakhand

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Internal Supervisors
Dr.Devender Kumar Saini
Assistant professor-Selection Grade
Department of Electrical and Electronic Engineering
University of Petroleum and Energy Studies
And
Dr.Rajeev Gupta
Associate professor
Department of Applied Sciences
University of Petroleum and Energy Studies

External Supervisor
Dr. Piush Verma
Professor
Department of Electrical Engineering
National Institute of Technical Teachers Training and Research, Chandigarh

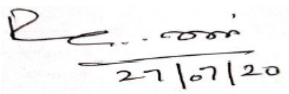
UPES
UNIVERSITY WITH A PURPOSE

Department of Electrical and Electronic Engineering
School of Engineering
University of Petroleum and Energy Studies
Dehradun-248007: Uttarakhand

2020, August
DECLARATION

I declare that the thesis entitled **"Design and performance optimization of three phase squirrel cage induction motor for rural area applications"** has been prepared by me under the guidance of Dr.Devender Kumar Saini, Assistant Professor of Department of Electrical and Electronic Engineering, University of petroleum and Energy Studies, Dr.Rajeev Gupta Associate Professor of Department of Applied Sciences, University of petroleum and Energy Studies and Dr.Piush Verma professor of Department of Electrical Engineering, National Institute of Technical Teachers Training and Research, Chandigarh . No part of this thesis has formed the basis for the award of any degree or fellowship previously.

Raj Kumar Saini



Department of Electrical Engineering,

Shoolini University

Solan, Himachal Pradesh

Date: 27/07/2020

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I certify that Raj Kumar Saini has prepared his thesis entitled **"Design and performance optimization of three phase squirrel cage induction motor for rural area applications"**, for the award of PhD degree of the University of Petroleum & Energy Studies, under our guidance. He has carried out the work at the Department of Electrical and Electronic Engineering, University of Petroleum & Energy Studies.

Internal Supervisor

Devender Kumar Saini
Department of EE and ECE
UPES, Dehradun
Date: 27/7/20

Internal Co-Supervisor

Dr. Rajeev Gupta
Department of Applied Sciences
UPES, Dehradun
Date: 27/7/20

CORPORATE OFFICE: 210, 2nd Floor, Okhla Industrial Estate, Phase III, New Delhi - 110 020, India.
T: +91 11 41730151/53, 46022691/5
F: +91 11 41730154

ENERGY ACRES: Bidholi Via Prem Nagar, Dehradun - 248 007 (Uttarakhand), India.
T: +91 135 2770137, 2776053/54/91, 2776201
F: +91 135 2776090/95

KNOWLEDGE ACRES: Kandoli Via Prem Nagar, Dehradun - 248 007 (Uttarakhand), India.
T: +91 8171979021/2/3, 7060111775

ENGINEERING | COMPUTER SCIENCE | DESIGN | BUSINESS | LAW | HEALTH SCIENCES

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External Supervisor

Dr.Piush Verma

Department of Electrical Engineering

NITTTR, Chandigarh

Date: 28-07-2020

ABSTRACT

Three phase induction motors are broadly used as a part of ventures and in residential purposes due to its techno-financial points of interest. The issues involved in the design of three phase induction is motor that the motors which are designed to operate at rated voltage, however are working under the rated voltages specific in the provincial zones far from the utility centers. Such types of motors when works under the rated voltages causes more copper losses, trouble in torque and wastage of energy.

The efficiency maximization of three phase induction motor working at rated to under rated voltage is carried out with the help of JMAG Express (An electrical motors design software tool).The design equations of three phase squirrel cage induction motor have been used to check the underlying shape and execution of the induction motor with the help of graphic user interface. The output data received from this software (GUI, appendix-II) is feed in the input requirements of JMAG Express for parameter figuring and performance optimization. To optimize the performance as a target work, the parameters of stator and rotor configurations are carried out in terms of sensitivity analysis by optimizing the neighborhood variables of the motor. The calculations for under rated voltages are primarily based on the averages voltages of the three phases coming at the motor terminals. The performance analysis of motors at rated to under rated voltage is completed by considering the copper and aluminum cage rotors individually. To reduce the drive crises, the focus of these research findings are used to break down the trouble and analysis of some new optimized parameters of stator and rotor of three phase induction motor, which can enhance the performance of the motors during its working at rated to under rated voltages. The summarized work as per the objectives of the thesis are as under.

To fulfill the prerequisites for the primary target of this research work, a mathematical modeling with the help of the output equations of three phase induction motor are formulated and the outcomes are carried out at rated to under rated voltages. To figure the positive outcomes toward this direction, a research article is composed to compute the performance of three phase squirrel cage induction motor which was intended at the rated voltage, but have to work under the rated voltage. The variable losses and performance in terms of efficiency of the motor are calculated at rated voltage and under rated voltages. The rectification of the voltage from the utility side is not much conceivable, but to save the energy crises the modification in terms of design of the motors are possible to achieve its desired performance during its operation at rated to under rated voltage. The objective of this research article is to alter the

dimensions of the motor to get its desired performance by modifying its ampere conductors and hence other dependent parameters. The change in parameters have been explored without change and with altered ampere conductors under the rated voltage. To concentrate the performance and others characteristic of three phase squirrel induction motor working under the rated voltage, around 56 (fifty-six) parameters have been observed, out of which 32 (Thirty two) noteworthy parameters are changed to build up the efficiency up to its rated efficiency. To cover the next destinations stator and rotor parameters are formulated at optimized efficiency. The proposed JMAG Express technique with genetic algorithm as an optimized tool is used for 7.5 kw squirrel cage induction motor to calculate its stator and rotor parameters in terms of sensitivity analysis at its rated voltage and under the variation of rated voltages. The detail work is carried out to give enhance efficiency as an object function with the help of various improved local parameters. These local parameters are optimized with the help of surface response method (SRM), while the procedure for overall optimizations are calculated with the help of genetic algorithm. This is assessed that the effectiveness of squirrel cage induction motor outfitted with copper cage is more when contrasted with the relative rating of induction motor having an aluminum cage rotor, however by assembling the mixer of rectangular type bar rotor with parallel tooth opening round base as a stator, the efficiency at the underlying phases of aluminum enclosure rotor is more when contrasted with copper cage motor. This is presumed that the torque developed by the aluminum cage rotor is more when contrasted with copper cage rotor at the underlying stages. However for financially point of view, assembling perspective of aluminum cage rotor has been given preference to compute the optimized results that are tabulated in detailed results. However to execute the proposed design approach for aluminum and copper cage rotors by using JMAG Express, the best execution of three phase induction motor at optimized iron losses are also carried out by using distinctive shape of stator and rotor design at room temperature to the working temperature of the motor. The objective of this research article is also have to investigate the efficiency .This is analyzed that under ordinary temperature, the efficiency of the motor at its rated speed and load is normal, however under an extensive variation of temperature this efficiency diminishes marginally, while this gap can be overcomes by optimized the iron losses.

During these research findings on three phase induction motor, this is also observed that the most effected parameter under the variation of voltages is the stator number of turns. According to the mathematical modeling of equations, it is observed that the number of turns of the stator winding would also be optimized, which largely affects the variables losses. To get the optimized efficiency, a combination of mathematical modeling and software approach is also adopted to optimize the stator and rotor dimensions by optimizing its stator number of turns under the variation of voltages. Voltage dependent stator nonlinear parameters are calculated at rated to under rated voltages with the help of mathematical modeling, while a software approach is applied for to optimize the stator and rotor parameters under the variation of voltages**.**

After optimization and implementation, the software results of one horse power of three phase squirrel cage induction motor are applied for the results of hardware approach and calculated the efficiency of a new constructed one horse power motor by operating it at rated and under the rated voltage. The results of new motor are compared with old one (conventional motor), which was to be operated at rated to under rated voltage. It is presumed that the new motor have better outcomes when contrasted with the old one.

From the above discussion, it is concluded that the attempts have been made to enhance the performance of such types of induction motors which are designed to operate at rated voltage, however are working under the rated voltages. This process of optimization can be applied for different types of rotating electric motors like single phase induction motor, synchronous motor, and direct current motors etc.

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Raj Kumar Saini

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

A_A	Slot pitch
A_s	Area of stator conductor
A_{br}	Area of each bar
ac	Electric loading
A_{cs}	Area of stator core
B_{av}	Specific magnetic loading
C_0	Output coefficient
C_s	Coil Spain factor
D	Diameter of core
D_{cs}	Depth of stator core
D_o	Outside diameter
D_r	Diameter of rotor core
Db_{r1}	Depth of rotor slot
D_{ed}	Depth of end ring
D_{co}	Outer diameter of end ring
D_{ei}	Inner diameter of end ring
D_{em}	Mean diameter of end ring
et al	el alia (and other authors)
f	Supply frequency
F	Flux per pole
F_{brd}	Flux density at the rotor of teeth

F_s	Flux in stator core
I_s	Stator current per phase
I_g	Air gap length
I_{br}	Current in each bar
I_{er}	End ring current
IM	Induction Motor
ipf	Total input at full load
K_d	Distribution factor
K_i	Stacking factor
K_p	Pitch factor
K_w	Winding factor
K_{ws}	Stator winding factor
L	Length of core
L_{mts}	Length of maximum turns
m	Number of phases
N_s	Synchronous Speed
$opfl$	Output at full load
p	Number of poles
P_i	Input power
P_f	Power factor
$plci$	Copper loss in two each rings
P_{LC}	Total copper loss in bars

$pscl$	Total copper losses
Q	KVA Input
q_s	Slot per pole per phase
R	Stator resistance per phase
R_{br}	Length of each bar
R_{ed}	Resistance of each end ring
S_f	Slip at full load
SC	Squirrel cage
S_r	Number of rotor slots
S_s	Number of stator slots
T	Total stator conductors
T_d	Flux density in stator teeth
W_d	Ventilating factor
W_{br}	Depth of rotor bar
W_{br1}	Width of rotor slot
Wb_{rt}	Slot width at the rotor of teeth
W_t	Teeth width
Yss	Stator slot pitch
Y_{sr}	Rotor pole pitch
Z_{ss}	Number of conductor per slot
η	Efficiency

CHAPTER-1

INTRODUCTION

1.1 CHAPTER OVERVIEW

Power is the main driving force of current life. It controls our production lines and lights up our homes. It fires up our portable PCs and charges our telephones. Without it, our everyday presence would be absolutely unrecognizable. It is the modest three phase induction motors that have the greatest single customer of power with electrical motor driven frameworks using more than 45% of aggregate worldwide power. This survey shows a reality that these motors are the workhorses of the cutting edge of modern world that are changing electrical energy into mechanical energy. It was in 1889, that the electrical architect Michael von Dolivo-Dobrowolsky licensed a productive AC motor. It had three phases and a rotor cage, it was less complex, more secure and calmer, and had less support issues. In 1961, Industries was framed in Brazil and accomplished prominent advances in the plan and creation of electric motors. Designers were at the front line to reduce its weight, trying different things with new materials like plastic, aluminum and new separators to make unique potential outcomes for the use of these machines. Today, it is possible to develop ideal and efficient motors to perform different operations, particularly tedious or very perplexing ones. Now it is also credible to construct heavy electrical machines for exceptional use in industries, control plants and farming. The key to outlining a more effective motor is to work out where the losses happen. The design engineers have examined various systems to fulfil this target. For example, reducing the resistance of stator winding, updating the shape of rotor bars, short out rings and many more. The electric motors have taken 200-years to achieve this stage, and there's no indication of this trip arriving at an end. Electrical machines have progressed because of the presentation of new materials. New electrical steels have decreased electrical losses and new compound magnetic materials have given a lossless wellspring of flux. Latest approach in development strategies have decreased winding losses.

Reports shows that the motor driven frameworks are the biggest electrical end user in the industrial sector. Therefore, by enhancing this factor, can really decrease the operational cost of any organization. Motor design, proper speed and way to utilize proper movable speed drives are some examples which can increase the overall performance of these rotating motors. Keeping in mind the above said examples, it is much essential to create and keep up motors design properly. Applying the right equations, recording the outcomes and recognizing the correct plan to redesign the motor are the best way of optimization. The most widely recognized kind of universally useful motors found in modern motor frameworks are squirrel cage induction motors. The squirrel cage name is gotten from the state of motor's rotor, which is molded like a chamber and developed from bars and rings, which looks like a hamster's enclosure. To upgrade framework efficiency, it is also vital to choose proper motor rating as per the applications of the work to be carried out.

The efficiency of motor is largely influenced by couple of losses, which includes copper losses, iron losses and mechanical losses. With a specific end goal to make these motors more proficient there is an extensive need to decrease these losses. Here are a few strategies or tips that can be used to enhance the factor of efficiency of these motors. The motor frame is a basic part of every electrical machine. Since it is in charge of exchanging the heat created inside the motor out to the edge surface where air passed up by the fan will scattered the heat. This should be in proper working condition. Another important tip is to hold least crevice among any dividers situated close to the back of the fan spread to permit air admission. Keep motor environment clean and check occasionally for any air blockage which can decrease the cooling framework execution. Therefore if the motor is running in a good cooling atmosphere, it will be having more life expectancy. The stator which is a main part of the motor is the reason for sixty percent losses. To reduce these losses, mass of stator winding must be kept bigger as this expansion in mass will reduce the electrical resistance. By using good quality of materials and quality control, core losses can be limited to enhance more efficiency. By lessening the thickness and increasing the length of laminations, we can limit the flux thickness additionally which will reduce the core losses, while eddy current losses can be reduce to a great extent by using legitimate protection between the sheets. Basically there are three fundamental viewpoints that must also be checked to improve the performance of these motors, these are (1) voltage quality (2) unbalance voltage (3) power factor. Voltage and current unbalance is a cause of connecting unbalance loads among the three phase system, and this can be rectified by distributing equal loads, while low power factor (PF) is possible due to inductive nature of motors and other overpowering decorations like inductive load on transformers etc**.** This can be improved by adopting various techniques of power factor improvements. **[1-3].**If these two factors are not treated properly, then there would be an origin of poor voltage quality, which can be a major factor of poor performance for these electrical motors. This is observed from the research survey **[42-68],** that the improvement in this direction from the utility side is not much possible particularly for the villages, which are situated away from the utility centers. In this situation the only way is to optimize the design of these motors according to the nature of the voltage supplied. To solve this problem, **"Design and performance optimization of three phase squirrel cage induction motor for rural area applications" will be a suitable title to analyze the research gaps**. Objectives are set accordingly to fill up the research gaps.

1.2 STATUS OF THREE PHASE INDUCTION MOTORS

Three phase induction motors represent around 45to 60 percent of worldwide modern power utilization. Beside from the industrial sector, induction motors finds broad use in the agriculture part to drive water system in rustic zones. In an agrarian nation like India, a large number of induction motors driven pump sets are in operation all over in the rural areas. Studies have been carried out in India by several Governmental and nongovernmental organizations that the poor performance of induction motor pump sets have been recognized as a basic factor for more power consumption and low power factor. Disappointments and obstructions like absence of capital, higher starting costs, absence of consideration by plant administrators and absence of power quality influences the performance of these motors. To control these barriers, rules have been set up in several nations, like least energy performance standards that require least performance level for electric motors to empower them to enter in the national market. This barrier can be a very effective tool to enhance the overall industry performance.

To increase the performance level of these motors, technically we have to extend the application area of electric drive system, secondly we have to integrate the combination of drive and driven load to get its maximum performance and finally we can increase the performance of the motors levels by its modified optimum design. Any electrical machine planned for the market or industry is decided by its performance criteria and efficiency. Decision regarding the proper selection of electric motors for the market or industry may be the beginning stage of reducing power consumption and its operating cost. For example, when the motors are not running at its rated speed, its performance decreases, which prompts to increased energy consumption. So as to spare the energy assets, European Union expressed that up to 2020, all motors in the field must be under motor productivity marking plan. (According to International Energy Agency IEA 2008). The capacity of this organization is to push on the worldwide joint effort into energy innovation. Motors are the essential part for the direction of movement of mechanical power in any enterprise. Size and classes of motors varies form one kilowatt to several megawatt operating at rated to under rated power. Distinctive boundaries and market disappointments are observed to be in charge for that, for example absence of consideration of the plant manager, higher starting cost for productive motors and many more. Much of the time, faulted motors are rewound and reused despite the fact that rewinding motors frequently decreases its efficiency. As a result, approaches, similar to least principles and motor marking plans, were presented in numerous nations around globally. Market change programs demonstrated that policy makers effectively changed the motors design towards their higher performance, while new rising motors with significantly higher performance are going to be enter the market. It must be understood that all the factors illuminated above must be recalled while picking a motor from the market and making it operational **[4-5].**

1.3 CONSTRUCTION AND WORKING PRINCIPLE OF THREE PHASE INDUCTION MOTOR

Three phase induction motors are the most broadly used electrical machine. Right around sixty percent of the mechanical power utilized by industries and agriculturist are covered by these three phase induction motors due to its simple construction and variable speed control. In such types of motors flux is transferred from stator to rotor by induction. When a three phase supply is given to the stator winding of three phase induction motor, then a rotating magnetic field will produced ,which rotates around the stator at a constant speed. This field crosses the air gap and enters on the stator conductors, since the winding of the rotors conductors are short circuited, therefore this current will produced e.m.f in the rotor conductors. The direction of induced e.m.f is such that it opposes the cause which produced it (Lenz’s law), and the rotor starts rotating in the same direction as that of stator filed. Induction motors are also called asynchronous motors because it can run at a speed other than the synchronous speed. Like some other electrical motors three phase induction motors also have two significant parts to be called as stator and rotor. Essential parts and cut view of three phase induction motor are shown in figure-1.1 and figure-1.2.

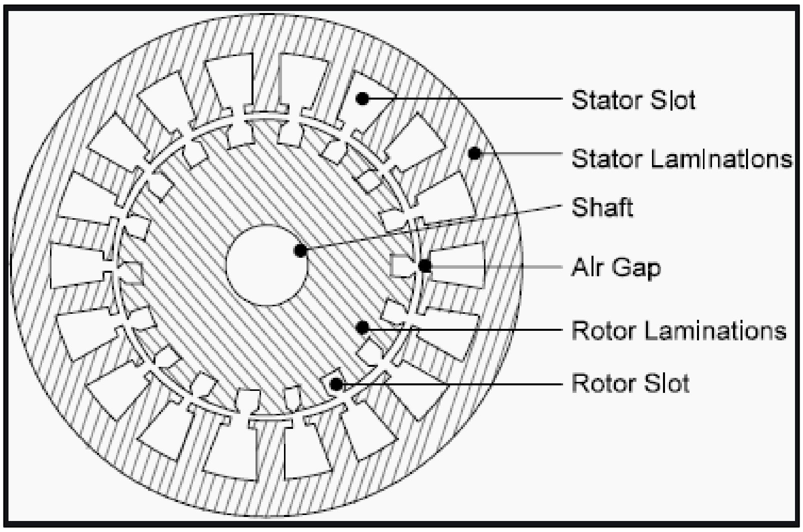

Fig.1.1: Main parts of three phase induction motor [9]

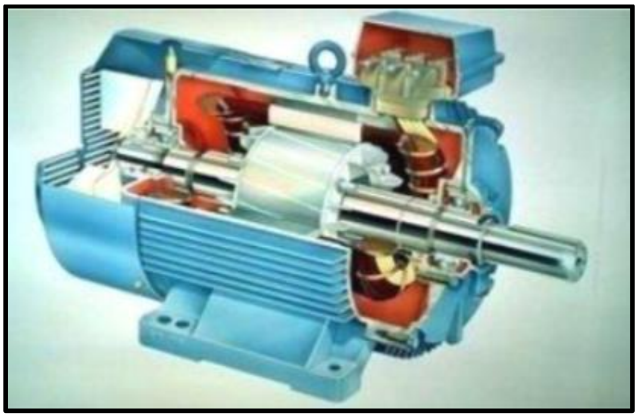

Fig. 1.2: Cut view of three phase induction motor [9]

Stator core: - Like its name appears, it is a stationary part of the motor. The poles windings are installed on the stator to generate the magnetic line of force. Three phase supply is given to the stator only. Stator laminations and stator core with yoke are shown in fig.1.3 (a) and fig.1.3 (b). The stator core of the motor carries the alternating flux which may produce eddy and hysteresis losses. To reduce these losses silicon steel punching are used, having a thickness of 0.33 mm to 0.65 mm. These punching are insulated from each other by coating a layer of varnish or oxide. Ventilating ducts are also provided along the length of the laminations to reduce the heat losses. The air gap between the stator and rotor are kept small to lower down the magnetizing currents. The three phase winding of stator are connected either in star or delta depending upon the rating of the motor.

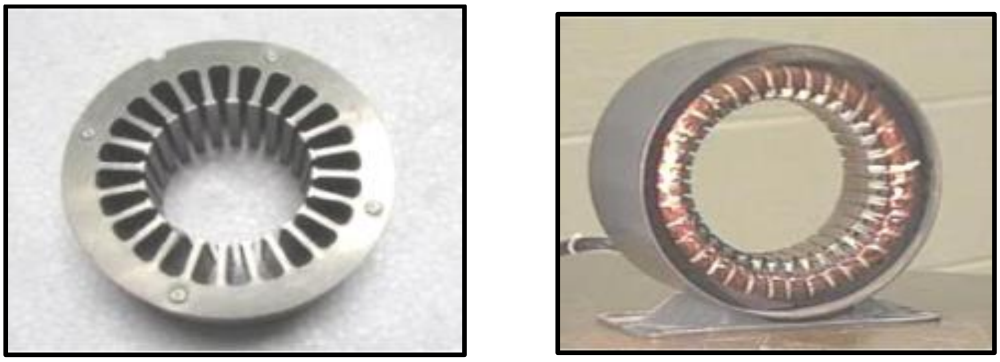

Fig. 1.3: (a) Stator Laminations [161] Fig. 1.3: (b) Stator core with yoke [161]

Rotor core:-It is a cylindrical laminated iron core same as that of a rotor of DC motor. To avoid the magnetic locking between stator and rotor, the number of rotor slots are kept smaller as compared to stator slots. Two types of rotors are possible in three phase induction motor.

(1) Squirrel cage rotor: - Ninety percent motors are provided with squirrel cage rotors in the market due to its simple construction and low cost. In such type of motors, the rotor bars are short circuits with copper rings as shown in fig.1.4 (a), the extra resistance cannot be added in the rotors circuits. The torque produced in such type of rotors will be less, because torque is directly proportional to the resistance of the rotor bars. The resistance of the rotor bars reduces due to short circuit of rotor conductors. Therefore we can use such type of motors having squirrel cage type rotor can be used in the industry, where we require less starting torque. It is made up of aluminum or copper.

Fig. 1.4: Squirrel cage type of rotor [8]

(2) Slip ring or wound rotor: - The induction motor having slip ring or wound type rotor, is shown in the fig 1.5. The starting torque of the motor can be improved by adding extra resistance through slip rings. Therefore such types of motors having slip ring or wound type rotor can be used in the industries, where we require high starting torque **[6-9].** In case of induction motor the torque equation is given by the relation,

$$Torque\,(T)\;\alpha\; E_2\, I_2 \cos\phi 2 \qquad \text{Eqn.1.1}$$

$Where\,,\, E_2 = E.m.f\,.induced\ in\ the\ rotor\,,\, I_2 = Rotor\,current\,,$

$\cos\phi 2 = power\ factor\,,\, I_2 = \frac{E_2}{Z_2}\ and\ \cos\phi 2 = \frac{R_2}{Z_2}$

By adding extra resistance through slip rings as shown in the fig.1.5, the power factor of the motor will become,

$$\cos\phi 2 = \frac{R_2 + R_{equ}}{Z_2} \qquad \text{Eqn.1.2}$$

$Where,\ R_{equ} = Extra\ equivalent\ resistance, added\ through\ slip\ rings$

From the above equations (Eqn.1.1and Eqn.1.2), it is concluded that, by adding extra resistance in the rotor circuit, the starting torque of the motor can be increased, where as in squirrel cage induction motors, this provision of adding the extra resistance is not possible.

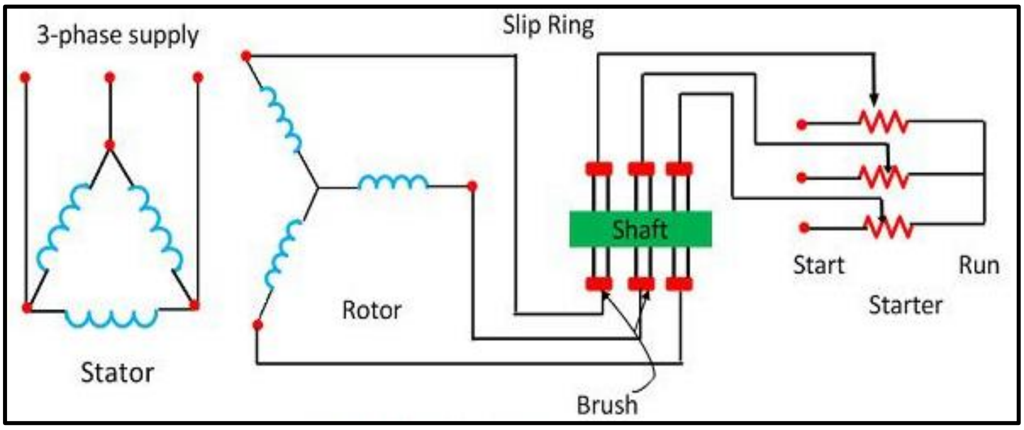

Fig.1.5: Slip ring type rotor [8]

1.4 MOTIVATION/NEED FOR THE RESEARCH

In the cultivating and business segments power consumption by induction motors are more as compared to other type of electrical motors. As India is a developing nation, request for power demand is more, however the generation of energy is still less. Rural areas are not getting adequate rated power particularly for farming on time due to over stacking of the transmission network. The induction motors which are designed at rated voltages, however working under the rated voltages. This is the time now to enhance the performance of such sort of motors in terms of optimum design **[15].** Even little modification in performance can change a major effect in energy saving. For example higher electrical conductivity and appropriate amount of copper used in the rotor structure of a squirrel cage induction motors can achieve a decrease in losses around 10% to 20%. The electric motors have a long history of advancement since its creation by Nicola Tesla in 1888. The requirements for higher proficiency ended up in between 1970's to 1980's. Presently the pattern is towards the design and assembling of motors with improved performance even at a little bit additional cost. It is needless to express that this additional cost could be acknowledged in the funds with the operating cost. There are many parts of induction motor in which losses happens. Lot of research have been carried out to decrease these losses and there is a need of more consideration for better execution to save energy and cost. The efficiency of variable-speed induction motor based on electronic drive segment is quite high and recent enhancements are pushing this drive efficiency even above eighty five percent, but this achievement is possible only by having a quality of power supply available, which is still not available in the villages. However there is a little room of optimization for these types of motors which are operating under the variations of voltages as discussed earlier. In short we can say that this would be the most ideal approach of optimization applied for three phase induction motors in terms of power saving, cost and to fill up the research gaps. [7-8], [11].

1.5 OBJECTIVES OF THE RESEARCH.

Based on the above discussed research gaps, the following objectives are formulated to fulfil the target.

1. To study the design parameters of three phase squirrel cage induction motor operating at rated to under rated voltages by using mathematical GUI model.

2. To study the performance and parameter variations of three phase squirrel cage induction motor operating at rated to under rated voltage using JMAG express under different combination of stator and rotor design.

3. Implementation of proposed design methodology for aluminum and copper cage rotor by using JMAG express.

4. Optimization of proposed design of three phase squirrel cage induction motor for higher efficiency in terms of sensitivity analysis operating at

rated to under rated voltage by using JMAG express and applying the software results for experimental model.

1.6 CHAPTER SUMMARY

In a developing country like India the demand of the power is still more as compared to its supply. It is vital to conserve electricity because of the natural resources that offer power and are being depleted faster than they can be regenerated. Up to some extent we can save the power by reducing the losses and improving the design of induction motors, which are mostly playing its part in industries and farming, thereby reducing the electricity demand up to some extent globally.

CHAPTER-2

LITERATURE SURVEY

2.1 CHAPTER OVERVIEW

To save the energy because of its increasing request, this research work relates to improve the performance of three phase squirrel cage induction motors working at rated to under rated voltages. JMAG Express (An electric motor design software) is used to verify the improved performance with the aid of graphic user interface and genetic algorithm (GA). The design of motor is made more significant with the help of JMAG express when compared with configuration in view of programming dialects. The literature review related to this research work is illustrate as under.

2.2 DIFFERENT MODELS BASED ON EFFICIENCY IMPROVEMENT

A range of models have been presented in this regard. For the study of efficiency improvement, various models are discussed by different authors. The brief description of these models are as below.

2.2.1 Efficiency improvement for general purpose motors

M. S. ERLICKI et al. presented a model based on optimization techniques of three phase squirrel cage induction motor. The objective of optimization was to ensure reduction in cost **[12]. R.Ramarathnam et al.** worked on a comparative study of five different unconstrained minimization techniques both by direct and indirect search techniques. It has been found that direct search technique is the best and suitable technique for the types of functions occurring in rotating machine design problems **[13]. N.N. Fulton et al.** described a method of minimizing the material cost in small three phase squirrel cage induction motor by optimizing (1) turns per coil (2) wire diameter and (3) stack length **[14]. K. Hasuike et al**. introduced a research article related to efficiency improvement of three phase squirrel-cage induction motor operating at low voltage. This article reported twenty five input elements which directly relates to the efficiency improvement **[15]. David C. Montgomery** calculated the efficiency and operating cost of three phase squirrel cage induction motor that was rewound two to three times during its lifetime and compared the results between rewound motor and a new motor **[16]**. **While N.H. Fetih et al** reported that the annual price for a three phase induction motor is taken as a sum of annual cost depreciation of the motor's material cost, annual cost of the energetic power loss and the yearly electricity cost required to supply such kind of power loss **[17]. L. Sridhar et al.** presented a model related to the design of three phase induction motor operating under different field conditions for irritation purposes. A new design of the motor is compared with the standard one and their salient features are discussed in detail. **[18]. Min-Kyu Kim et al.** presented a research article by considering the primary dimensions of the induction motor as variables factors and alternate dimensions that have little impact on the target work as a constant factors. A model is set up for efficiency improvement based on the above said conditions **[19]. Davar Mirabbasi et al.** pointed out that the unbalanced voltages in the voltage source may bring troubles like more copper losses, over voltage and mechanical oscillations .The performance of motor is calculated based on the above said conditions [**20]. Jawad Faizin et al.** presented a paper based on optimized designed of three-phase squirrel cage induction motor and compared the results of this model with a conventional motor, by considering three objectives functions namely efficiency, cost and combination of both. In this article Hooke Jeeves search routine is used for optimization purpose **[21]. P.Pillay et al.** additionally presented the results of unbalanced voltages in the presence of over- and below rated voltages. Differences among the definitions of unbalance voltages are also discussed **[22]. Annette Von Jouanne et al.**presented a research article by objecting a few reasons for voltage unbalance and has characterize its subsequent effects on power framework **[23]**. **A. Ansari et al.** additionally displayed a research article showing the impacts of unequal voltages ranging from 3.05% to 3.94% **[24]. Mehmet cunkas et al.**presented an ideal plan strategy to upgrade three phase induction motor with GA as an optimized tool. The optimally designed motor is compared with the exiting one and furthermore, find out that the advance model have more efficiency when compared with the exiting one **[25]**. **Jawad Faiz et al.** concluded that the unbalanced voltages builds up more heat losses in the motors, which reduces its efficiency and life span also. Study demonstrated that even under unbalanced voltages the performance of motors may be improved more by making alternate arrangements as compared to the motors working under balanced voltages **[26]**. **Pragasen Pillay et al.**presented a model to calculate the losses in induction motor at constant temperature and under the variation of temperature with time. The electrical model and thermal aging equations are used to estimate the insulation life of the motor **[27]**. **M Sharma et al.**presented a research article on the stator design of three phase squirrel cage induction motor which clams for satisfactory performance at various supply voltages (under and over the rated voltages), even when it works without any automatic protection **[28]**. **P. Giridhar Kini et al.** find out that variation of voltages and variations in load, both factors are essential to check its performance. **[29]**. **S.S.Sivaraju et al** presented an optimized design of three phase squirrel cage induction motor to enhance its proficiency and power factor by lessening the total losses of the machine for variable load application **[30]. C. Thanga Raj et al.** a 7.5 KW three phase induction motor has been optimized for textile spinning load and its outcomes obtained by the calculations are compared with the typical industrial motor **[31]. A.Raghuram et al.** additionally offered an optimized layout of induction motor by means of the usage of simplified technique of Genetic set of rules and completed the outcomes with the goal of maximizing efficiency **[32]. Krishna Moorthy et al.** presented a research paper on an ideal design of three phase squirrel cage induction motor using Genetic Algorithms (GA).Eleven parameters having predominating impact on the performance of the motor are recognized by considering cost minimization as an objective function **[33]**. **Ramandip Singh et al.** calculated that rewound motor consumes 1.5 times to 3 times extra energy than a branded new motor. Its future review on power factor are also examined. **[34]**. **DeepaVincent et al.** added a software program technique for the development of three phase squirrel cage induction motor by a windows programming. **[35]. W. Abitha Memala et al.** also investigated the way to calculate turn to turn fault that occurs in the winding of three phase induction motor at no load conditions **[36]. Govindasamy. K. Sathishkumar et al.** find out a finite element strategy for the design of three phase 5 H.P squirrel cage induction motor. Both Simulation and experimental results are compared to observe efficiency and torque **[37]**. Meanwhile **Vladimir Sousa Santos et al.** introduced another method on 1.5 kw three phase induction motor to ascertain the efficiency and other trademark by using BFA technique. **Saini Raj Kumar and Tiberiu Rusu Tiberiu Rusu et al.** analyzed the performance and design modification of three phase induction motors by using JMAG Express technique **[38-41], [165-169].**

2.2.2 Models based on unbalanced voltages and efficiency improvement

Different models are discussed by various authors on unbalanced voltages and efficiency improvement. The brief description of these models are as below.

Williams et al. calculated abatement in efficiency of three phase squirrel cage induction motor working under unbalance voltages **[42]. Gafford WC et al.** shows a noteworthy temperature rise and shorter existence time of the motors affected by unbalance voltages **[43]. Berndt NL et al.** also investigated that the motors working with unbalanced voltages additionally diminishes its performance. However a short description was given **by Woll. RF1 et al.** to study the impact of unbalanced voltages and its negative impact on the protection of the motor. Methods of protections against these impacts are proposed **by Cummings et al.** The authors also describe that in agribusiness country like India tremendous number of induction motor pumps sets are working under the rated voltage. The capability of these motors can be extended only by reducing the losses **[44-46].Kersting WH and Gillbert AJ.et al.** concluded that the presence of unbalanced voltage at the motor terminals increases rotor losses more as compared to its stator losses. **[47]- [48]. Wallace A et al.** experimentally concluded that the motors working with unbalance voltage have 2% less efficiency as compared to the motors working with balance voltages **[49]**.**Fermandez XML et al.** Worked out on insulation failure of induction motors working under unbalanced voltages **[50]**. **Jalilian A et al.** Concluded that the aggregate losses of the motor can be measured tentatively by considering its losses equal to its rated losses of the motor and considering its current equivalent to its rated current **[51]**. **Jawad Faiz et al.** also pointed out that the efficiency of three phase induction motor decreases by increasing the voltage unbalance, which promotes the overall losses of the machine **[52]. J. Faiz et al.** evaluated the induction motor capacity when it is provided by unbalance voltages, over-or under voltages. The loss of life was assessed for nonstop motor operation at consistent temperature and furthermore when the temperature changes with time. **[53]**. **P. Pillay et al.** published a research article about the impact of unbalanced supply voltage on induction motor. An experimental study was done, where the rotor currents of wound type motor are measured under various unbalance conditions by applying positive and negative sequences of voltages. **[54]**. According to **Hugo Morais et al.** reactive power management is a very important task in large power distribution networks. Power compensations equipments and methods are discussed in this research article. Reactive power management can be maintained by providing the facilities with transmission and distribution system **[55]**. **Makbul Anwari et al.** worked on an article based on unbalanced voltages and the impacts of positive sequence voltage on the induction motor temperature rise. The author also stated that this voltage must be considered for the calculations of accurate results. **[56]. A. M. S. Mendes, et al.** concluded that the voltage and load variations both factors should be considered for the accurate calculation of the efficiency **[57].**According to **E. C. Quispe, et al.** Pointed out that none of the current techniques discovered are capable to give the exact data of the negative impact of unbalance voltage. Further, different precision to evaluate the level of unbalance voltages have been talked about additionally **[58]**. A model is presented by **Allan A. et al.** which was based on the voltage unbalanced and harmonic distortion. Both the factors (voltage unbalanced and harmonic distortion) are taken together to calculate the overall performance **[59]**.

2.2.3 Models based on optimum design and efficiency improvement

Different models are discussed by various authors on optimum design and efficiency improvement of three phase induction motors. The brief research findings of these models are as below.

Goodwin GL et al. concluded that there has been an increasing enthusiasm for the ideal design of three phase induction motor to reduce the overall operating cost of the machines. **[60]**. **Ramarathnam et al**. concluded that direct research technique is the best way to judge the functioning of rotating electrical machines. **[61]. Fetih NH et al.** carried out work on the optimized plan of three phase induction motor by minimizing the annual operating cost of the motors **[62]. Appelbaum J et al.** concluded that the best optimum design of the motor depends upon the two factors, one is variables and second one is a constant factor **[63]. Fci R et al.**worked out on efficiency, power factor and cost of material in a view of optimization process **[64]. Li C, et al.** worked on Hooke-Jeeves research techniques to find out the optimized efficiency **[65].** However **Faiz J. et al.** also worked on Hooke-Jeeves strategies **[66],** while **Vier GF et al.** worked on GA for optimum design of induction motors **[67]. Jawad Faiz et al.** also worked on optimum design of three-phase squirrel cage induction motor and the results are contrasted with a conventional motor having similar evaluations **[68**]. **MR. Fevzi et al.** worked on three optimized techniques for the design of stator slots and the outcomes were contrasted with the current manufacture's information. The results demonstrated a sensible change of the motor efficiency and also the manufacturing cost **[69]. Jae-Woo Kim et al.** also worked on the optimum design of stator slots of three phase induction motor with the help of software approach. The software results so obtained are compared with the experimental model **[70]**.While **Thomas Bellarmine et al.** Proposed a technique by using a Radial Basis Function organize for the optimized design of induction motor is used. This strategy was used to locate the ideal plan parameters of the motor. **[71]. Yon-Do Chun et al.** gave a multi target optimized strategy based on GA calculation **[72].** Also **Radha Thangaraj et al**. gave a GA and PSO optimization techniques for the design of spinning mill, three phase induction motor. The outcomes so obtained are contract with the universal drive motor. Authors found better outcomes by using improved methods **[73].** Meanwhile **V.P. Sakthivel et al.**gave a research article which introduced another organically roused approach, called "bacterial foraging" advancement calculation to enhance the design of three-phase induction- motor for vitality conservation. The BF calculation can be utilized as a worldwide analyzer giving attractive solutions contrasted with the other evolutionary algorithms **[74].** A GA-based optimization techniques is applied for a 7.5-kW, 4-pole, squirrel cage induction motor by **S. S. Sivaraju et al.** They worked on a software approach and validate the results with experimental model. **[75]. R.L.J. Sprangers et al.** introduces an Expert System (ES) for investigation and design streamlining of three phase induction motor. **[76].Pratyush Prasanna Das et al**. worked on an optimized design of poly phase induction- motor with the aid of Artificial Bee Colony Algorithm **[77].**

2.2.4 Models based on power quality

In manufacturing systems, electric power frameworks have turned out to be contaminated with undesirable variations in the voltage & current flag. Power quality issues are more because of expanding request of inductive power. Three phase system is exposed with unbalance loads. The short portrayal of models in light of power quality are talked about in the accompanying references.

I. Hunter et al. said that the power quality issues are often due to constantly growing resources of disturbances that arise in interconnected power grids, which include massive numbers of electricity resources, transmission lines, transformers and inductive loads In addition, such systems are also uncovered to environmental disturbances like lightning strikes etc. **[78]. MS. Kandil et al.**pointed out the power quality issues like harmonics and poor power factor. The authors also suggested the modified processes to improve these factors in power system **[79]. M .Kezunovic** et **et al.**discussed the advanced applications of neural network and fuzzy logic in the power system. This paper shows an overview of ideal models like fuzzy logic, neural systems and GA in power control quality. **[80-81]. M.H.J. Bollen** discussed on voltage dips and harmonic distortion **[82]. T. Lin et al.** gave a research article based on real time measurement. It plays a very important role to measure protection and fault location under abnormal conditions **[83]**. **M. H. J. Bollen et al.**highlighted the modern methods to resolve the power quality issues. **[84]-[85].**While a framework was planned **by Augusto S. Cerqueira et al.** to classified the power quality disturbance based on real data system **[86].**This is also observed by **Mansour Ojaghi et al.** that the conduct of induction motors because of voltage droops can be studied by using simulation models. **[87].** In the meantime a research article based on frequency/sequence selective channels have been presented by **Mahesh Illindala et al.**The circuits have band pass and band stop filters used for three phase space vectors. Simulation and experimental results are validated **[88].** The working behavior of three phase induction motors are studied by **Morteza Ghaseminezhad et al.** under voltage fluctuations by using dynamic theory and equivalent circuit diagrams. The power factor and efficiency of the motors are validated theoretically and practically. To improve the power quality issues, voltage restorer (DVR) is used with PWN controller. This combination is suitable for low voltage load applications **[89]**. **Amir Hameed Abed and Vicky T. et al.** also studies the impact of power quality for three phase induction motor by using "Fast Fourier Transform analysis" (FFTA) and the results are obtained in terms of harmonic distortions. These results are also validated with MATLAB **[90-91].**

2.2.5 Models based on voltage fluctuations & three phase induction motors

Poly phase induction motors are used in the industries and agriculture purposes are exposed to various voltage fluctuations. The nature of these motors working under voltage fluctuations are studies by different researchers under voltage fluctuations. The short description study of these models are as below.

Aleksandar M. Stankovic and Timur Aydin et al. presented a simulations model based on unbalanced voltage faults having three phase synchronous generator connected to a transmission line with infinite bus bars. It is observed that models based on dynamic phasors provides an accurate details of transients. **C.A.G. Medeiro and Gucci et al.** also studies the behavior of equipments under voltage fluctuation by considering different load conditions. The voltage fluctuations and low voltage effects the working of induction motors in terms of speed fluctuations, noise and mechanical stress. The goal of this article was to evaluate these effects by an experimental analysis **[92-95]. G.Bhuvaneswari et al.**also studied that the active filters can reduced the starting currents and unnecessary torque in the large rating of induction motors. This can be an effective tool where the large number of poly phase motors are working in the industries which are being run by soft starters. **[96].N. Eghtedarpour et al.**

studied on a method to locate the flicker source in the distribution system which can be located with the help of Artificial Neural Network (ANN) **[97]. Krause, Gnacin ski and Marcin Peplin ski et al.**concluded that the efficiency, stator & rotor losses of three phase asynchronous motor can be calculated under the influence of fluctuated voltages**,** while the effect of voltage sub harmonic, current and temperature rise can be studied on the cage of poly phase asynchronous motor **[98-99]. S.Tennakoon and Ta. Yang, et al.** additionally studied the influence of voltage dips on the overall performance of the machine. The traditional methods are leaded by dynamic phasor models in case of voltage disturbance analysis **[100-101].**

2.2.6 Miscellaneous models based on efficiency improvement of induction motors.

Miscellaneous models are used by the scholar to make the base of research objectives meaningful. The brief description of these reference models are as below.

K. **Hasuike, et al.** concluded that apart from the industrial sector, induction motors find extensive use in the agricultural sector to drive irrigation pumps in rural areas even operating under the rated voltage. The authors describe some strategies to improve the performance of three phase induction motor running at low voltages in industries and agriculture purposes. In this research article twenty five parameters have been taken in order to calculate the design of the motor and twelve variable elements have been taken which affects the efficiency of the machine. These twelve variables are valued independently to study the effects on the efficiency and characteristic of the motor **[102]. L. Sridhar et al.** additionally done a detail examine for the alteration of a poly phase induction motor under the wide range of load and supply voltage and concluded that the outcome of another new motor is about 2.5% more than that of the old motor, but also investigated that the cost of proposed design is about 15% more than that of the standard design and also concluded that this extra cost may be pay back within a reasonable period of time **[103]**. **CY Lee et al.** said that unbalanced voltages also decreases the performance of the motor by increasing the positive succession of the voltage. Decrease in power factor additionally have been investigated **[104]. P.Gnacinski et al.** also concluded that worst scenario will appears for the motors when under voltages and over voltages appears with unbalanced voltages simultaneous **[105]. Jawad Faiz et al.** pointed out that the available definitions of unbalanced voltages are uncompleted. To prove the claim, a three phase 25-hp squirrel cage induction motor is analyzed under the unbalanced voltage and verified the theoretical results with experimental one **[106].** IEEE112-B, IEC34-2 and JEC37international standard for induction motor efficiency are evaluated by, **Aldo Boglietti et al.** and found that the evaluated performance of the motor relies on the standard pursued. On the bases of the results IEEE112-B can be considered, the best appropriate standard for the stray loss estimation, hence for motor efficiency measurement IEC34-2 and JEC 37overestimate the motor efficiency because they only define instead of measuring the stray load losses. **[107]**. **Yaw-Juen Wang et al.**said that he energy efficiency of continuous motor (S1) is a subject of more interest as compared to intermittent duty motors (S3). The efficiency of such types of motors can be increased by proper selection of stack length and rotor material of the machine **[108]. A. Repo et al.** concluded with the help of analytical and experimental study that the derating factor depends upon voltage unbalanced factor and magnitude of positive sequence voltage and also suggested that positive sequence voltage must be consider together with unbalanced voltage factor. The main focus of this paper was to calculate the performance of induction motor under the variation of load with the variation of unbalanced, over and under voltages **[109]**. **Enrique C. Quispe, Giridhar Kini, P and Jawad Faiz, et al.** also concluded that the unbalanced voltages will lead to change in characteristic of an induction motor, due to this reason the real and reactive power consumption of an induction motor will also be changed which will affect the voltage stability margin because of positive succession voltage, which is more than that of the rated voltage might be the another reason for unbalance voltages. The voltage unbalance cases may be due to single phase, two phases, three phases under-voltage unbalanced and over voltage unbalanced. To calculate the unbalanced voltages different definitions are discussed by different authors. The definition of voltage unbalanced generally used by the power community is the ratio of "negative to the positive sequence voltage”. However the community of electrical machine used the definitions of IEEE and NEMA **[110-112]**.

Jawad Faiz, et al. also concluded that to decrease the energy utilization, Hooks Jeeves research technique is a best optimized technique **[113].** However attempt was made by **C.Li et al.** to proof that the old H.J strategy is increasingly helpful when contrasted with recently used strategies. **[114].**While**Thangaraj Radha et al.** used GA and PSO optimization techniques for the desin of the spinning mill induction motor what's more, the results are compared with the ordinary machine **[115].Nagrial MH et al.** consider cost of dynamic material as a target work is carried out by using complex technique. **[116].** similarly three optimum systems are used by **Faiz Jawad et al**. for the structure of the spinning mill asynchronous motors and the outcomes so got are compared with the universally useful motor. To decrease the error between the assessed and assembling information, PSO method is used for three diverse enlistment models with sensitivity analysis **[117].** More compressive study is carried out by **Thanga Raj C et al.**using optimization techniques which incorporates the tie-up between efficiency, power factor and cost **[118].** The two optimist methods Powell and boundary techniques are used by **VP.Sakthivel et al.** to calculate the optimized design of three phase induction motor **[119]. J.Appelbaum et al.** used an optimized efficiency strategy for a vector controlled synchronous reluctance motors **[120].**While **R.Fci** and **GK. Kim et al.** carried out state characteristic for a new plan motor and its material is selected by using finite element method **[121-122]. MA.Abido and C. Huang, et al.**concluded that GA have been positioned as the best optimized tool for advancement system **[123-124].** Nonlinear- programming (NPL) are talked about by **GF.Uler et al.** what's more, included that for optimization process it doesn't require the use of derivatives of the functions **[125].** An advanced plan was created by **N.Bianchi and S. Bolognani** for a three phase induction motor by decreasing the general expense of the machine, however not guaranteeing about the overall execution of the motor **[129].** Advanced outcomes are carried out by **JP.Wieczorek et al**.by varying the voltage with load and proofed that these two factors are essential for best outcomes **[127].Pant Millie et al.** introduced another calculation which was an adjusted adaptation of price strategy at low voltage

[128]. For a good torque- speed features an ideal structure of rotor is developed by **MS.Erlicki et al.** with the help of initial reference design **[129]**.while **Giridhar Kini P et al.** developed a new geometry for slots design to get better efficiency **[130].A.Daidone and Dianhai Zhang et al.** proofed that a motor operating at unbalance voltage might be more effective than a motor dealing with balanced or rated voltages **[131-132]. Zaixun Ling and Libing** concluded a few techniques to enhance the performance of squirrel cage induction motor working under the rated voltages. **[133]. "**JMAG designer"software is used by **K.Govindasamy et al.** to play out the electromagnetic investigation to optimize the parameters of three phase induction motor.**[134-135], Abitha Memala W and Rajini** find out the best approach to figure out the fault that happen at no load conditions **[136]. Sabaghi Masood and Farahani Hassan Feshki** find out a method to calculate the stator resistance under different voltage conditions with the assistance of DC flag **[137].Pandian G and Rama Reddy S** worked out on harmonic distortion by using multiple level inverter instead of classical one **[138]. Ghate VN and Dudu w**orked together to locate the on line fault detection in three phase induction motor by using embedded system **[139].**

R.Saidur et al.also pointed out that in the ongoing past years interest for an ideal structure of three phase induction motor have been increased to decrease the energy crises and expanding cost of material used [**140].** However, **KatsumiYamazaki et al.** worked on the circuit parameters of high speed induction motor feeded by the investors are calculated by including load and harmonic torque **[141]**.**Pragasen Pillay et al.** worked on the life loss of induction motor operating at constant temperature and under the variation of temperature. Thermal model and thermal aging equations are used to estimate the insulation life of the motor **[142].** However in another research article **Ing Huaia, et al**. exhibited a general methodology to calculate the temperature rise in induction motors and the outcomes so calculated are compared with the results of experimental model **[143]**. **S. Wahsh and M. El-Bakry** pointed out that it is not possible to calculate the exact value of iron losses in induction motors, because it depends upon the material used, however on the bases of theoretical and empirical formulas some limits have been calculated within which these losses are accepted to lie **[144]. Emanuel L. Brancato et al.** calculate the life time expectations of motors are discussed under the variables conditions like temperature rise and variable load **[145].** In the meantime, **ldo Boglietti et al.** presented a research article based on a new approach for the prediction of iron losses in soft magnetic materials having a direct mathematical relationship between iron losses and supply voltage. For this purpose eight magnetic materials of different thickness and alloys composition are used **[146]. Zbigniew Gmyrek et al.**presented a time domain iron loss estimation method **[147]. E. Dlala et al.** estimated that **t**he core losses will increase on increasing the load due to that of harmonic content generated by the slot geometry and also proved that closed rotor geometry have less harmonic content as compared to open slots **[148]. Aldo Boglietti et al.** also proposed a method for the predictions of iron losses by supplying PWM supply through a magnetic materials. In fact a percentage error of 5% between the predicted and measured results have been calculated **[149].** Recently **D. Schmitz et al.**presented a new testing device called tester have been developed to measure the magnetic losses in yoke and teeth of the motor. The new designed three phase tester have an ability to generate the magnetic flux that would be created by the motor under regular functioning, **[150].** Domain finite element is presented by **K.Govindasamy et al.** for the design of three phase 5 H.P squirrel cage induction motor, **[151]. Sridhar and CS.Jha et al.** presented that energy conservation is an urgent step towards overcoming the increasing issues of the industries development. By reducing the wasteful energy the performance of the electrical machines can be improved up to some extent. The authors portrayed that the three phase induction motors assumes an essential part for the improvement of production in the industries. The horticulture nation like India a large number of enlistment motors are quickening pump sets in the rustic zones are working under the rated voltages. The performance of the motors can be increased by lessening the losses, flux density, improving the cross-section of the conductors and modifying the design of the motor. Due to unbalance voltages current leads to exclusive losses in the stator and rotor which relates to inefficiency of the induction motors. The motor unbalanced may also occur due to the problem of manufacturing process such as unequal number of turns in the rewinding process of the machines **[152]-[153]. Von Jouanne and Williams et al.** concluded that unbalanced voltages also increases the temperature of the motors which prompts to decrease in productivity and life span of the machine. **[154-155].** A complete investigation is done by **YJ.Wang et al.** on the three phase induction motor by considering a complex unbalanced voltage factor **[156]. B. Emmanuel et al.** presented that by increasing the stack length, the efficiency and power factor can be improved up to some extent **[157]. Vladimir Sousa Santos et al**. also presented a new technique on 1.5 kW induction motor to calculate the efficiency and other characteristic by using a bacterial foraging algorithm (BFA) and also consider harmonic distortion conduction as one of a factor under distorted grid voltages **[158]. P.Gnacinski et al.** presented a research article on the prediction of temperature rise in the winding of the machine due to harmonics, without having much knowledge of thermal properties of the machine under distorted voltage **[159]. Ke Lia et al.** presented a research article on the performance of bearing less induction motor by using magnetic wedges in the semi closed slots. Air gap reluctance can be reduced by this process, which reduces the losses and hence efficiency of can be increased. **[162]. Amir Nikbakhsh et al.** concluded that measurement of rotor temperature by direct method with the help of thermal sensors are costly. The authors proposed some suitable methods like parameter estimation methods, thermal model-based estimation methods, and hybrid methods. Advantages and draw backs of previous methods with new one are compared **[163].Emad Jamila et al.** presented a research article on power quality improvement in power grid. Three different systems were developed for the effectiveness of the STATCOM to improve the voltage regulation and stability **[164].**

2.3 CHAPTER SUMMARY

Different models based on three phase induction are presented in the literature survey to know how much work has been done to improve the performance of motors using different techniques. To find out the research gaps, models based on unbalance voltages, power quality, GA and PSO techniques are studied in details. To fill up the research gaps, GA with the aid of JMAG Express (Software tool for design of motors) is used for the optimized design of three phase induction motor under the conditions when the voltage varies from rated to under rated voltages.

CHAPTER-3

MODELING OF INDUCTION MOTOR PARAMETERS (METHODOLOGY)

3.1 CHAPTER OVERVIEW

To decrease the power consumption, the design of electric motors needs to be improved in terms of overall performance. To save the energy because of its increasing request this research work relates to upgrade the performance of three phase induction motors, which are designed at rated voltage but working under the rated voltages. JMAG express (An electric motor design software) is used to find out the improved performance of three phase squirrel cage induction motor with the aid of graphic user interface. The design of motor is made easier with the assistance of JMAG express when compared with configuration in a view of programming dialects.

3.2 ABOUT GRAPHIC USER INTERFACE

To develop a graphical user interface for mathematical modeling and input requirements for JMAG express, a MATLAB program (Appendix-1) is framed and a developed software has been checked out for valid results. Every one of the equation have been connected with the created graphic user interface for mathematical modeling **[160].**

3.3 INPUT/ OUTPUT DESIGN EQUATIONS

The following input /output equations are used for the design purpose of three phase squirrel cage induction motors which will give the output parameters after putting the desired input data in JMAG express. These Input/output design equations are used to write up the graphic user interface (GUI) program on the MAT Lab. The desired input data required for the JMAG express have been selected from the output of GUI results for design and performance check of three phase induction motors. Except this the impacts of voltage variations on the performance of three phase induction motor can also be carried out easily with the help of this software [41].

3.3.1 Assumed data for Input requirement [6-7]

$Input\ power\left(P_i\right)$

$Number\ of\ phases\left(m\right)$

$Supply\ frequency\left(f\right)$

$Synchnous\ speed\left(N_s\right)$

$Efficiency\left(\eta\right)$

$Power\ factor\left(P_f\right)$

$Specific\ magnetic\ loading\left(B_{av}\right)$

$Electric\ loading\left(ac\right)$

$Winding\ factor\left(K_w\right)$

$Stacking\ factor\left(K_i\right)$

3.3.2 Equations for stator design [6-7]

$$poles\ of\ the\ machine\left(p\right)=\frac{120\times f}{N_s} \quad \text{Eqn. (3.1)}$$

$$Input\ Kva\left(Q\right)=\frac{p}{n\times pf} \quad \text{Eqn. (3.2)}$$

$$Output\ cofficient\left(C_0\right)=\frac{11\times B_{av}\times ac\times K_w}{1000} \quad \text{Eqn. (3.3)}$$

$$Diameter\ of\ core\left(D\right)=\left(\frac{D^2L}{a}\right)^{1/3} \quad \text{Eqn. (3.4)}$$

Where,

$$a = \left(\frac{C \times \pi}{p} \right)$$ Eqn. (3.5)

$$product\ of\ D_2L = \frac{Q}{C_0 \times N_s}$$ Eqn. (3.6)

$$Length\ of\ core\ (L) = (a \times D)$$ Eqn. (3.7)

$$Net\ iron\ Length\ (L) = Ki\ (L\ (n_d - W_d))$$ Eqn. (3.8)

Where,

$$n_d = Integral\ value\ of\ \left(\frac{L \times 1000}{120} \right)$$ Eqn. (3.9)

$$W_d = Ventilating\ \ factor$$

$$K_i = Stacking\ \ factor$$

3.3.3 Output equations

$$Flux\ per\ pole\ (F) = B_{av} \times L \times \tau$$ Eqn. (3.10)

$$Turns\ per\ phase\ (Stator) = \frac{E_s}{4.44 \times f \times F \times K_w}$$ Eqn. (3.11)

$$Number\ of\ stator\ slots\ (S_s) = (m \times p \times q_s)$$ Eqn. (3.12)

Where,

$$q_s = slot\ per\ pole\ phase$$

$$Stator\ slot\ pitch\ (Yss) = \left(\frac{\pi \times D}{S_s} \right)$$ Eqn. (3.13)

$$Total\ stator\ conducrors (T) = (6 \times T_s)$$ Eqn. (3.14)

$$Number\ of\ conductor\ per\ slot (Z_{ss}) = \left(\frac{T}{S_s} \right)$$ Eqn. (3.15)

$$Coil\ spain\ (C_s) = \left(\frac{S_s}{p}\right)$$ Eqn. (3.17)

$$Polepitch(K_p) = Cos\alpha / 2$$ Eqn. (3.18)

$$Distribution\ factor\ (K_d) = \frac{Sin(q_s)\times(\pi/2\times C_s)}{q_s \times Sin(\pi/2\times C_s)}$$ Eqn. (3.19)

$$Stator\ winding\ factor\ (K_{ws}) = (K_p \times K_d)$$ Eqn. (3.20)

$$Stator\ current\ per\ phase\ (I_s) = \frac{1000}{q_s \times Sin(\pi/2\times C_s)}$$ Eqn. (3.21)

$$Area\ of\ stator\ conductor\ (A_s) = \left(\frac{I_s}{I_d}\right)$$ Eqn. (3.22)

$$Diameter\ of\ stator\ conductor\ (d) = (4\times A_s/\pi)^{0.2}$$ Eqn. (3.23)

$$Slot\ pitch\left(A_A\right) = \frac{\pi(D\times 1000)}{S_s}$$ Eqn. (3.24)

$$Teeth\ width\ (W_t) = (A_A - W_{ss})$$ Eqn. (3.25)

$$Flux\ density\ in\ stator\ teeth\ (T_d) = F \times P \times \frac{1000}{(S_s \times W_t \times L_i)}$$ Eqn. (3.26)

$$Length\ of\ \max imum\ turns\ (Lmts) = (2\times L\times 2.3\times\tau + 0.24)$$ Eqn. (3.27)

$$Flux\ in\ stator\ core\ (F_s) = \left(\frac{F}{2}\right)$$ Eqn. (3.28)

$$Area\ of\ stator\ core\ (A_{cs}) = \left(\frac{F_s}{F_{ds}}\right)$$ Eqn. (3.29)

$$Depth\ of\ stator\ core\ (Dcs) = \left(\frac{A_{cs}}{L_i}\right)$$ Eqn. (3.30)

$$Outer\,diameter(D_o) = (D \times 100) + 2\left(d_{ss} + D_{cs} \times 1000\right)$$ Eqn. (3.31)

$$Air\,gap\,length\left(I_g\right) = 0.2 + \left\{\left(2 \times \left(D \times L\right)\right)\right\}^{0.2}$$ Eqn. (3.32)

$$Diameter\,of\,rotor\,core\left(D_r\right) = \left(D \times 1000\right) - 2Ig$$ Eqn. (3.33)

$$Number\,of\,rotor\,slots\left(S_r\right) = \left(S_s + \frac{P}{2}\right)$$ Eqn. (3.34)

$$Rotor\,pole\,pitch\left(Y_{sr}\right) = \left(\frac{\pi \times D_r}{S_r}\right)$$ Eqn. (3.35)

$$Current\,in\,each\,bar\left(I_{br}\right) = \left(2 \times m \times K_{ws} \times T_s \times I_s \times p_f\right)$$ Eqn. (3.36)

$$Area\,of\,each\,bar\left(A_{br}\right) = \left(\frac{I_{br}}{I_{dr}}\right)$$ Eqn. (3.37)

$$Depth\,of\,rotor\,bar\left(W_{br}\right) = \left(\frac{A_{br}}{D_{br}}\right)$$ Eqn. (3.38)

$$Width\,of\,rotor\,slots\left(W_{br1}\right) = \left(W_{br} + 1\right)$$ Eqn. (3.39)

$$Depth\,of\,rotor\,slots\left(Db_{r1}\right) = \left(D_{br} + 3\right)$$ Eqn. (3.40)

$$Slot\,pitch\left(AA_{br}\right) = \pi \times \left(D \times 1000\right) - \left(\frac{2 \times D_{br1}}{S_r}\right)$$ Eqn. (3.41)

$$Slot\,width\,at\,the\,root\,of\,teeth\left(Wb_{rt}\right) = \left(AA_{br} - Wb_{r1}\right)$$ Eqn. (3.42)

$$Fiux\,density\,at\,the\,root\,of\,teeth\left(F_{brd}\right) = \left(\frac{F \times P}{S_r \times L_i \times Wb_{rt}}\right)$$ Eqn. (3.43)

$$Length\,of\,each\,bar\left(L_{br}\right) = \left(L \times 1000\right) + \left(2 \times 20 + 10\right)$$ Eqn. (3.44)

$$\mathrm{Re}\,sis\tan ce\,of\,each\,bar\left(R_{br}\right) = \left(0.021\right) \times \left(\frac{L_{br}/1000}{A_{br}}\right)$$ Eqn. (3.45)

$$Total\,copperloss\,in\,bars(PLC) = \left(S_r \times I_{br} \times R_{br}\right)$$ Eqn. (3.46)

$$End\ ring\ current(I_{er}) = \left(\frac{S_r \times I_{br}}{I_{erd}}\right)$$ Eqn. (3.47)

Where,

I_{erd} = *Assumed current density in the end rings*

$$Depth\ of\ end\ rings\left(D_{ed}\right) = \left(\frac{A_{er}}{T_{ed}}\right)$$ Eqn. (3.48)

Where,

T_{ed} = *Input thickness of end ring*

$$Outer\ diameter\ of\ end\ ring\ (D_{co}) = \left(D_r - \left\{2 \times W_{br1}\right\}\right)$$ Eqn. (3.49)

$$Inner\ diameter\ of\ end\ ring(D_{ei}) = \left(D_{co} - \left\{2 \times D_{ed}\right\}\right)$$ Eqn. (3.50)

$$Mean\ diameter\ of\ end\ ring\left(D_{em}\right) = \left(\frac{D_{co} + D_{ei}}{2}\right)$$ Eqn. (3.51)

$$Resistance\ of\ each\ end\ ring\left(R_{ed}\right) = 0.021 \times \left(\frac{D_{em}/1000}{A_{er}}\right)$$ Eqn. (3.52)

$$Copper\ loss\ in\ two\ end\ rings\left(plci\right) = \left(2 \times I_{er} \times I_{er} \times R_{ed}\right)$$ Eqn. (3.53)

$$Stator\ resistance\ per\ phase\ (R) = \left(\frac{0.021 \times Ts \times Lmts}{A_s}\right)$$ Eqn. (3.54)

$$Total\ stator\ copper\ losses\ (pscl) = \left(3 \times I_s \times I_s \times R\right)$$ Eqn. (3.55)

$$Total\ copper\ loss\left(plc_2\right) = \left(Plc + plci + pscl\right)$$ Eqn. (3.56)

$$Output\ at\ full\ load\left(opfl\right) = p_i \times 1000$$ Eqn. (3.57)

$$Slip\ at\ full\ load\left(S_f\right) = \left(\frac{plc_2 / P_i \times 1000}{1 + plc_2 / p_i \times 1000}\right)$$ Eqn. (3.58)

$$Total\ input\ at\ full\ load\left(ipfl\right) = \left(opfl + plc_2 + Al_r I_s + Fwll\right)$$ Eqn. (3.59)

$$Efficiency = \left(\frac{opfl}{ipfl} \times 100 \right) \quad \text{Eqn. (3.60)}$$

3.4 ABOUT JMAG EXPRESS DESIGN

It is a set of integrated software tools which have an aim to support electric motor designers throughout the complete design process .This can be utilized not just for the design of three phase induction motor, but this software can also be used for all types of electrical motors like brushless motors, synchronous motors, single phase air conditioning motors and DC motors etc. This software embedded the response surface method and genetic algorithm (GA) as the optimization engine. It generates the parameters in terms of sensitivity analysis by using correlation matrix and generates Pareto curves by using response surface method **[102-114].**

3.5 JMAG EXPRESS AND THREE PHASE INDUCTION MOTOR

This is an electric motor design tool that covers all the functions of concept design to advanced design. This cover the design in two modes (1) quick mode and (2) power mode. Quick mode covers the basic calculations in a very short time, whereas power mode covers the magnetic flux and core loss density in advanced stage. The information prerequisite for the JMAG express are as under.

- Rating of the machine
- Torque
- Rated speed in R.P.M
- Maximum speed in R.P.M
- Number of poles
- Number of slots
- Number of bars
- Power supply in volts
- Current rating
- Outer diameter of the motor
- Cage type.

3.6 EVALUATION OF STATOR AND ROTOR DESIGN

With the help of quick design process we can create a motor geometry by using quick mode operation after selecting a modified combination of stator and rotor design. This combination of stator and rotor design can be saved as a template as shown in Figure-3.1.The dimensions of stator and rotor can be changed as per the desired geometry size.

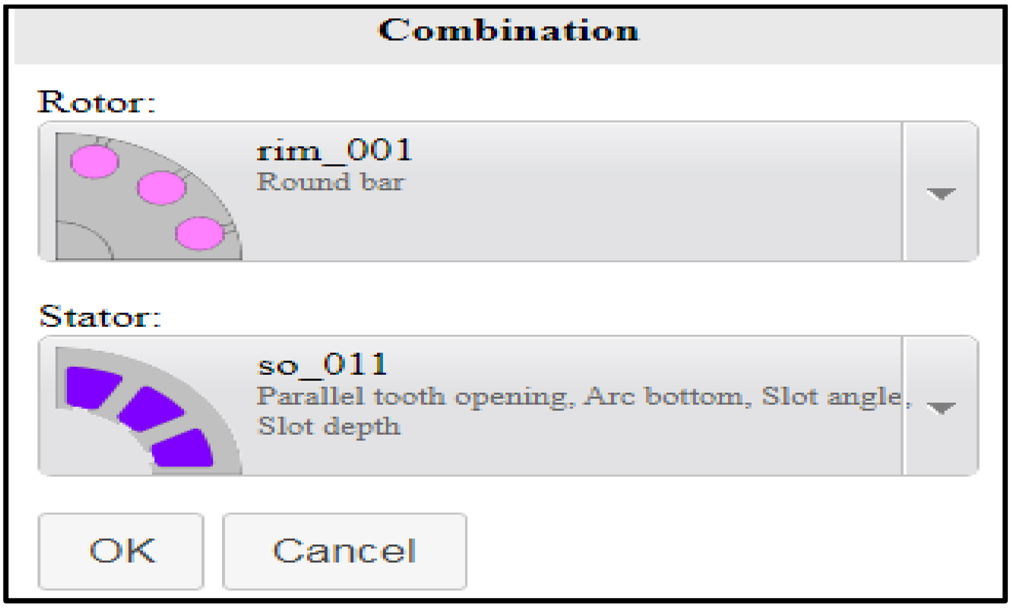

Fig.3.1: Selection and redesign of stator and rotor combination [41]

3.7 OPTIMIZATION PROCESS

The optimization process that can be carried out in terms of sensitivity analysis is shown in Figure-3.2.To get the optimized design in terms of sensitivity analysis we can choose the objective function from the variable list. One objective can be picked up and programmed one time only. In this software the rundown of target capacities are accessible as under

- Torque
- Efficiency
- Copper losses
- Iron losses
- Primary leakage reactance
- Secondary reactance
- Primary resistance

- Secondary resistance
- Excitation suspectance
- Primary current
- No Setting.

By selecting the objective function, the input variable are to be put in the parametric range as shown in Figure-3.3.Optimization process is carried out with the assistance of inbuilt device of JMAG express as talked about in subsections 3.7.1 and 3.7.2 [41],[161].

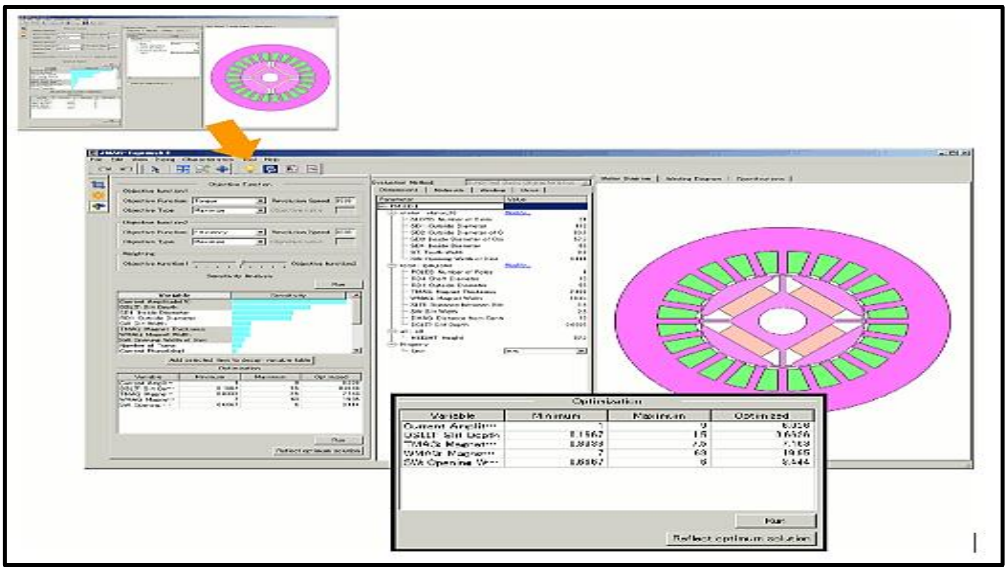

Fig.3.2: Optimization process [41].

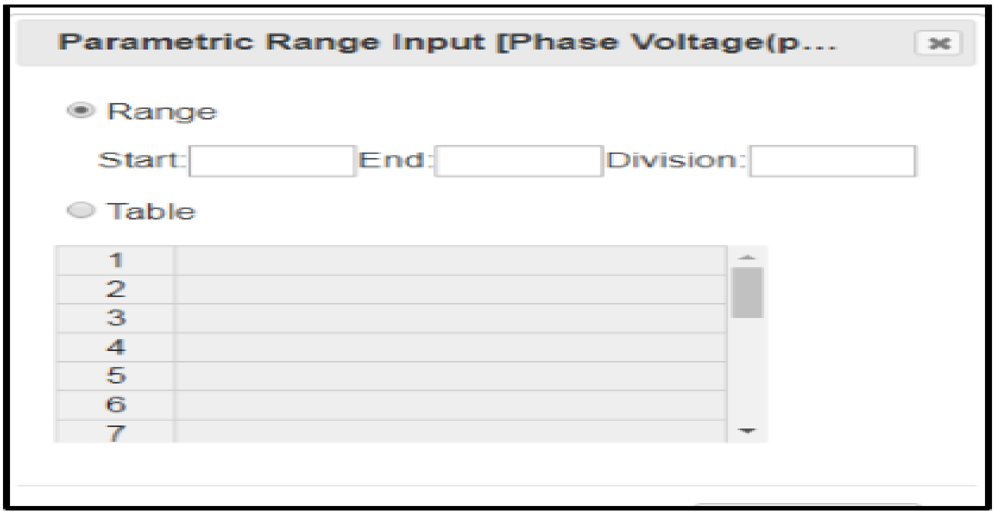

Fig.3.3: Parametric range [41]

3.7.1 Sensitivity Analysis

Because of nonlinear parameters conduct of three phase induction motor, this is hard to get accurate estimation of parameters. The parameters modification can be obtained by a set of adjustment factors obtained from the sensitivity analysis, while the response surface technique will be a helpful tool to study the local parameter variations. Sensitivity analysis are completed with the help of correlation matrix. In another words we can say that it is the relationship between independent and dependent variables, when the parameters are fixed under a given set of assumptions. The value of output parameters in terms of sensitivity analysis also depends upon the input variables fixed within a certain boundaries. Sensitivity analysis also depends upon the factor, change the model and observe the parameters. Sensitivity can be calculated by dividing the percentage change in output to the percentage change in input. Mainly there are two techniques to measure the sensitivity analysis: local sensitivity and global sensitivity analysis. First one is a derivate based techniques. This techniques is used for a single cost function and the derivate is taken for a single point. Second technique uses a Global set of samples to explore the design. Second technique is used for this research work with the help of correlation analysis. As already discussed correlation helps in developing the relationship between dependent and independent variables. **[38-41].**

3.7.2 Genetic Algorithm

Genetic Algorithm (GA) is an inbuilt tool of JMAG express particularly helpful for complex optimization issues when the parameters are large. This is one of the enhancement strategies enlivened by normal hereditary qualities. Genetic algorithm is a coordinated irregular search system that is generally connected in optimization issues, because of GA's capacity of finding the worldwide ideal in the wide scope of the capacities, it has various applications in the advancement issues. In this strategy the utilization of random but clever search is a predefined region, due to this reason this method can be used to solve nonlinear equations. There are three basic operators involved in the search process of GA approach. These are: selection, crossover and mutation. The steps for the implementation of GA are as below.

1. Identify parameters and objective functions
2. Generate population randomly
3. Evaluate population as per the objective functions
4. Test conversion for satisfaction, if satisfied
5. Start reproduction, which includes selection, crossover and mutation.
6. For continuous process, follow step no.3

For a good optimization results, the description of the three operators are as below.

1. ***Selection:*** It is a process in which individuals strings are selected according to the fitness function. The selection probability can be defined as

$$P_j = F(x_1) / \sum_{i=1}^{n} F(x_1) \qquad \text{Eqn. 3.1}$$

P_j is the selection probability and $F(x_1)$ is the objective function.

2. ***Crossover:*** This is the most powerful genetic operator. In this technique single point cross over is the commonly used method. A cross over point is selected between the first and last bit of chromosome. The exchange process of chromosome is shown in table 3.1.

Table -3.1: Exchange process of chromosome [66]

Crossover point		
Chromosome-1 0010010	Offsprings-1 0010010	100
Chromosome-2 0101011	Offsprings-2 0101011	101

3. ***Mutation:*** This is the common genetic manipulation operator. This is a random alteration of genes during the process of coping of chromosome from one generation to the next generation. For example 1000**0**010 changes to 1000**1**010 **[60-77].**

3.8 CHAPTER SUMMARY

From the above discussion it is concluded that how the design of three phase induction motors can be optimized according to the nature of the supply voltage. How the modeling and simulation can be carried out by using software approach. It is also concluded that how the design of motor can be made more truthful with the help of JMAG express in terms of GA and sensitivity analysis.

CHAPTER-4

OPTIMIZATION OF INDUCTION MOTOR PARAMETERS (RESULTS AND DISCUSSIONS)

4.1 CHAPTER OVERVIEW

Three phase induction motors which are designed at rated voltage, however are working under the rated voltages specific in the rustic zones, which prompts decrease in general performance of the machine. A long away from the utility centers the voltage profile in the vast majority of the circulation systems is poor because of reactive power demand. The objective of this research work is to design a three phase induction motor which can give desirable performance at rated to under the rated voltages, even when working with no protection framework. The proficiency amplifications of three phase induction motor working at rated to under rated voltages are carried out with the help of JMAG Express. (Design software tool for electrical rotating machines). A MAT-LAB program based on the design equations of three phase squirrel cage induction motor have been created with the help of graphic user Interface (GUI). To check the underlying plan and performance of induction motor the output of interface is feed in the input requirements of JMAG express for parameter figuring and effective improvement. To advance the performance as an objective work, the parameters of stator & rotor are resolved in terms of sensitivity analysis to get its maximum efficiency when the motors runs at rated to under rated voltages . Calculations for under rated voltages are carried out by taking the average voltages of all the three unbalanced phases. In this research article the main focus is given to check the variations in parameters when the motor have to work under the broad range of variation of voltages. The hardware results will come on the real model of the motor, will empowers us to give more ideas with respect to its performance. The description of the model as per the first objective is as below.

4.2 MODEL BASED ON THE IDENTIFICATION OF PARAMETERS OF THREE PHASE INDUCTION MOTOR AT RATED AND UNDER RATED VOLTAGES [39].

In order to investigate the performance of the three phase squirrel cage induction motor in terms of rated and under the rated voltage, the input information required for three phase induction motor are tabulated in Table-4.1.

Table -4.1: Input description (IS 900:1992) [39].

Particulars	Inputs
Rating of the machine(Pi)	2.2Kw
Number of phases (m)	3
Supply voltage (Es)	415V
Power factor (pf)	0.825
Supply frequency (f)	50
Full load efficiency (n)	0.8
Synchronous speed (Ns)	1500
Electric Loading (ac)	21000

4.2.1 Analysis of efficiency at rated and under rated supply voltage

In this research model the performance of three phase squirrel cage induction motor operating at rated to under rated voltages have been carried out. It is observed that in the rural areas phase to phase voltage (line voltage) present in the three phases are less when compared with the rated voltage. The variable losses and effectiveness of the motor are being examined at rated and under the rated voltages as talked about in table 4.2. Constant losses have been taken as 2.5 percent of the output of the machine (see appendix-II).The rectification of the voltage from the utility side isn't much possible, however to save the energy crises the modifications in terms its design is possible to attain their desired performance, when these motors have to work under the rated voltages. The only focus of this exploration article is to investigate and alter the plan of three phase induction motor by changing its ampere conductors with respect to its non-uniform related parameters. The ampere conductors are fixed according to the variation of voltages and all other parameters of stator and rotor are fixed as per the variation of ampere conductors to get the desired efficiency and power factor.

4.2.2 Analysis of parameters at rated and under rated supply voltage.

In table 4.3, the alteration in parameters of 2.2 kw induction motor have been investigated without changed and with altered ampere conductors under its rated to under rated voltage. To study its performance around fifty six parameters are observed. These parameters are ordered into three groups. The primary group have twelve parameters which have no impact on its performance at rated voltage (415V) to under rated voltage (368V). In second and third group there are twenty and twenty four parameters whose value decreases and increases respectively at rated to under rated voltage. The parameters belongs to second and third group are variable parameters, which are only responsible to increase the efficiency of the motor as talked about in table 4.3. At the motor terminals coming voltages in the three phases are being checked out experimentally and hence unbalance voltage, average voltage, stator losses, rotor losses and percentage efficiency are calculated as shown in table 4.2.

Table-4.2: Estimations of unbalanced, average voltage, variable losses and efficiency under rated voltages [39].

S.No	V_{ab}	V_{bc}	V_{ca}	Unbalanced Voltage	Average Voltage	Stator losses	Rotor losses	Percentage Efficiency
1	362	365	362	0.55	363	226.96	145.22	80.69
2	369	378	365	1.97	370.67	222.27	142.25	80.91
3	373	378	364	1.70	371.67	226.34	144.82	80.72
4	365	380	365	2.70	370.00	222.18	142.5	80.89
5	372	375	365	1.16	370.67	222.27	142.25	80.91
6	371	372	379	1.33	374.00	220.29	141.00	81
7	365	366	365	0.18	365.33	225.51	144.30	80.76
8	365	366	366	0.09	365.67	225.3	144.17	80.77
9	376	380	3 70	1.06	376.00	219.12	140.26	81.06
10	375	380	372	1.15	375.67	219.31	140.38	81.05
11	370	380	371	1.69	373.67	220.48	441.12	80.99
12	365	365	367	0.36	365.67	225.3	144.17	80.77
13	382	376	368	1.77	375.33	219.51	140.51	81.04
14	361	362	366	1.10	362.00	227.59	145.61	80.66
15	378	380	366	1.42	374.67	219.89	140.75	81.02
16	360	360	365	0.92	361.67	227.78	145.74	80.65
17	364	360	363	0.46	362.33	227.38	145.48	80.67
18	366	380	366	2.51	370.67	222.27	142.25	80.91
19	360	364	367	0.91	363.67	226.54	144.95	80.71
20	365	366	370	0.81	367.00	224.49	143.65	80.80
21	359	365	366	0.73	363.33	226.76	145.09	80.69
22	365	364	367	0.45	365.33	225.51	144.30	80.76
23	360	371	365	1.55	365.33	225.51	144.30	80.76
24	365	381	362	3.15	369.33	223.07	142.76	80.87

4.2.3 Choice of ampere conductors

By choosing a large value of electric loading implies higher copper losses and substantial temperature rise. A small value of electric loading ought to be taken for those machine which are designed at rated voltage, but are working under the rated voltages. Substantial estimation of electric loading implies large leakage reactance there by decreasing the over load limit of the machine. The estimation of amperes conductors for electric loading lies "between" 5000 to 45000**.** The change in parameters have been investigated in table no 4.3 at rated voltage 415V and under the rated voltage 368V, with modified ampere conductors and without modified ampere conductors [135].

Table-4.3: Calculations for stator and rotor parameters at rated and under rated voltage [39].

Parameters	**Computer added parameters at (415V)**	**Unmodified parameters at (368V)**	**Modified parameters at (368V)**	**Percentage Change in parameters**
Number of poles	4	4	4	Nil
KVA input	3.330	3.330	3.330	Nil
Output coefficient	97.066	97.066	92.444	(-)4.99%
Product ofD^2 L	0.0014 m	0.0014 m	0.0014 m	4.86%
Diameter of core	0.1052 m	0.1052 m	0.1069 m	1.60%
Length of core	0.1239 m	0.1239 m	0.1259m	1.58%
Net iron length	0.1023m	0.1023m	0.1039m	1.53%
Flux per pole	0.004507 web/m	0.00450 web/m	0.004656web/m	3.20%
Stator turns per phase	434	434	373	(-)16.35%
Number of stator slots	24	24	24	Nil
Stator slot pitch	0.01377 m	0.01377 m	0.01399 m	1.57%
Total stator conductors	2604	2604	2238	(-)16.35%
Conductors per slot	2604	2604	2238	(-)16.35%
Coil span or slot per pole	6	6	6	Nil
Pitch factor	0.96596	0.96596	0.96596	Nil
Distribution Factor	0.96675	0.96675	0.96675	Nil
Stator winding Factor	0.933847	0.933847	0.933847	Nil
Stator current per phase	2.677Amp	3.019Amp	3.019Amp	Nil

Area of stator conductor	0.669	0.754	0.754	Nil
Diameter of stator conductor	0.9684	0.992	0.992	Nil
Slot pitch	13.785mm	13.785mm	14.0113mm	1.61%
Teeth Width	4.985mm	4.985mm	5.211mm	4.33%
Flux density in stator teeth	1.473web	1.473 web	1.432web	(-) 2.86%
Length of maximum Turn	0.6779 m	0.6779 m	0.6851 m	1.19%
Area of stator core	0.00187 m^2	0.00187 m^2	0.00194m^2	3.60%
Depth of stator core	0.01836m	0.01836 m	0.01866 m	1.60%
Stator Resistance/phase	9.231 ohms	8.1860 ohms	7.1099 ohms	(-) 15.13%
Outer diameter of laminations	159.597 mm	183.997 mm	186.325mm	1.24%
Total copper loss in stator	198.524 watts	233.879 watts	194.45 watts	(-) 20.27%
Air gap length	0.428 mm	0.428 mm	0.432mm	0.93%
Diameter of Rotor core	104.413 mm	104.413 mm	106.131 mm	1.61%
Number of Rotor slots	26	26	26	Nil
Rotor pole pitch	12.609 mm	12.609 mm	12.817mm	1.62%
Current in each rotor bar	206.589 Amp	232.974 Amp	200.229 Amp	(-) 16.35%
Area of each bar	34.431 mm2	38.829mm2	33.371mm2	(-) 16.35%
Depth of Rotor bar	3.130 mm	3.529 mm	3.033 mm	(-) 16.35%
Width of rotor slots	4.130 mm	4.529 mm	4.0337 mm	(-)12.29%
Depth of Rotor slots	14 mm	14 mm	14 mm	Nil
Slot pitch at the root of teeth	11.636 mm	11.636 mm	11.844 mm	1.75%
Slot width at the root of teeth	7.506 mm	7.106 mm	7.811 mm	9.03%
Length of each bar	173.955 mm	173.955 mm	175.987 mm	1.15%
Resistance of each bar	0.000106096 ohms		0.000110746 ohms	--
Total copper loss in bars	117.73 W	132.766 W	115.439 W	(-)15.00%
End ring current	427.652Amp	482.271Amp	414.486 Amp	(-)16.35%
Area of each end ring	71.275mm^2	80.378mm^2	69.081mm^2	(-)16.35%
Depth of end ring	7.919mm	8.931 mm	7.675 mm	(-)16.35%

Outer Diameter, end ring	96.152 mm	95.312 mm	98.0638 mm	2.80%
Inner diameter of end ring	80.313 mm	77.411 mm	82.712 mm	6.40%
Mean diameter of end ring	88.233 mm	86.422 mm	90.388 mm	4.38%
Copper loss in two end rings	9.508 W	10.503 mm	9.441 mm	(-) 11.24%
Total copper loss	127.239 W	143.269 W	124.88 W	(-) 14.72%
Slip at full load	5.42%	6.06%	5.32%	(-) 13.85%
Speed at full load	1418.76 r.p.m	1409.14 r.p.m	1420.18 r.p.m	0.77%
Rotor frequency	2.708 Hz	3.0286 Hz	2.66 Hz	(-)13.83%
Torque Developed	7.909 Nm	7.749 Nm	7.728 Nm	(-) 0.25%
Full load torque	7.702 Nm	7.541 Nm	7.728 Nm	2.41%
Full load Efficiency	82.05%	80.83%	82.24%	1.71%

Table-4.4: Copper Losses and efficiency of 2.2 KW three phase squirrel cage induction motor with and without alteration of ampere conductors under the rated voltage [39].

S.No	Average voltage (V)	Modified ampere conductors	Losses without modified parameters	Losses with modified parameters	%age efficiency without modified parameters	age% modified efficiency
6	374	20000	361.29	319.25	81.00	82.24
11	370.67	19080	364.52	319.57	80.01	82.24
12	367.33	19070	367.8	319.05	80.81	82.25
13	365.67	19065	369.47	318.77	80.77	82.26
1	363	19061	372.18	319.38	80.69	82.24
14	362	19059	373.2	319.39	80.66	82.24

In table 4.4, six estimations of average voltages are applied from table- 4.2, to see the variation in performance with adjusted and without altered the estimation of ampere conductors and other related parameters as talked about in table 4.3. This is observed that the efficiency of motor can be enhanced up to its rated efficiency with the alteration of the ampere conductors. To compute the unbalanced voltages, different definitions are examined by various authors. The meaning of voltage unbalanced for the most part utilized by the power network can be written as “The ratio of negative to the positive sequence voltage”. If the motor have to work under the rated voltages, it diminishes the motor performance by causing additional warming in it, which additionally impact the hardware life of the motor by increasing its working temperature, and disintegrate the oil or oil in the bearing and de-rate the motor windings also. The results based on the above said model are as below.

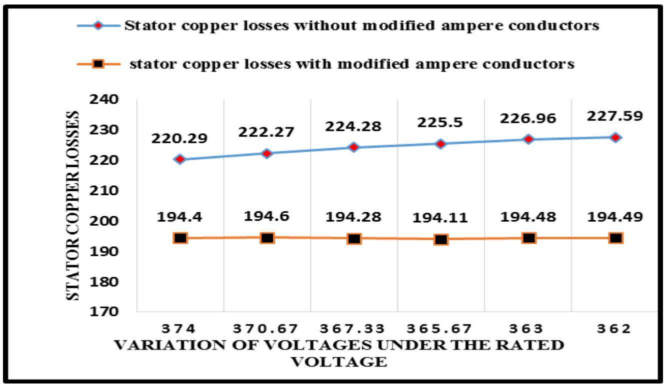

Fig.4.1: Stator copper losses Vs variation of voltages [39].

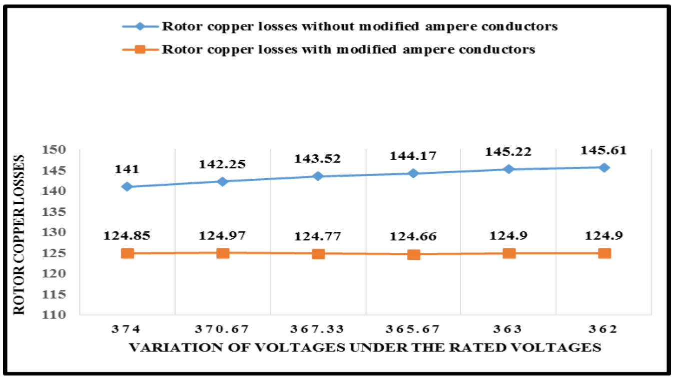

Fig.4.2: Rotor copper losses Vs variation of voltages [39].

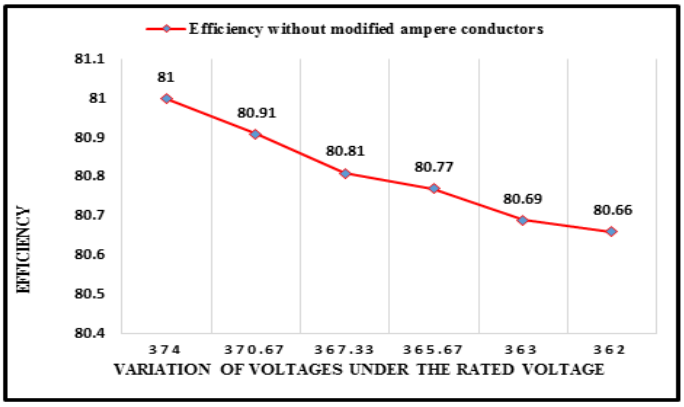

Fig.4.3: Efficiency Vs Variation of voltages [39].

Fig. 4.1 to 4.4 presents the losses and efficiency variation of the motor under the variation of voltages. However by decreasing the losses, the performance of the motor can be accomplished up to its rated efficiency by changing the ampere conductors and controlling all others parameters as talked about in table- 4.3. (See-appendix-II).

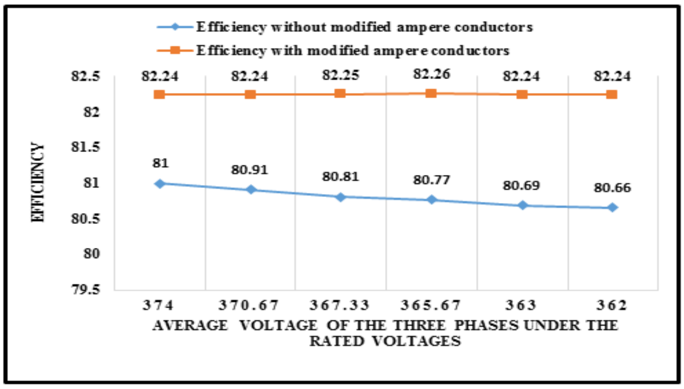

Fig.4.4: Modified efficiency Vs Variation of voltages [39].

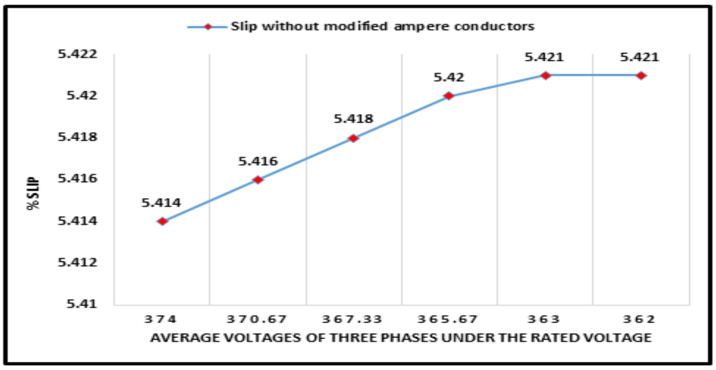

Fig.4.5: Unmodified slip Vs Variation of average voltage [39].

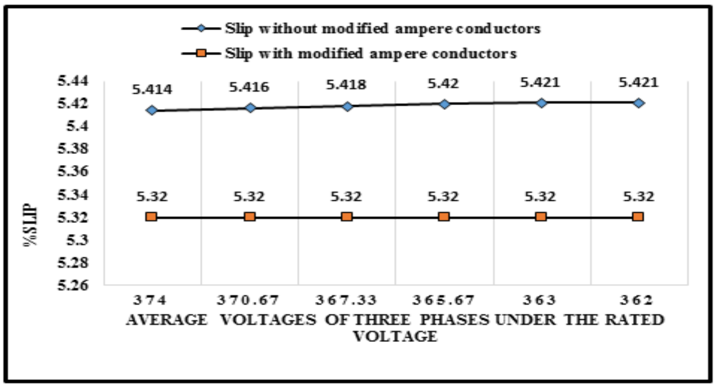

Fig.4.6: Modified slip Vs Variation of voltages [39].

Fig. 4.5 and Fig.4.6 present the variation of slip under the variation of voltages. The slip of the motor can be kept up stable by choosing the ampere conductors under the variation of voltages there by controlling the other parameter as talked about in table- 4.3 (Appendix-II).

From the above discussion it is concluded that the performance of three phase induction motor diminishes while working under the rated voltages. This decrease in performance prompts an expansion of overall losses of the motor. This type of study is very important for those rural areas where the network of power distribution is poor. To get the maximum efficiency, further scope of research related to this article is to optimized and reduce the number of parameters which affects the efficiency when the motor operates under the rated voltages. Further work for improvement analysis related to this model will be talked about in the next model.

4.3 MODEL BASED ON OPTIMIZED DESIGN OF THREE PHASE SQUIRREL CAGE INDUCTION MOTOR [165].

To enhance the performance of three phase squirrel cage induction motor working at rated to under rated voltage, a three phase squirrel cage induction motor have been suggested with the following information as tabulated in Table- 4.5.

Table- 4.5: Input description (IS 900:1992) [165].

Particulars	Values
Rating of the machine	7.5kw
Rated speed	1425 R.P.M
Maximum Speed	1500 R.P.M
Number of poles	4
Number of slots	36
Power supply	415 V
Maximum current	15Amp
Stator slot design	Parallel tooth opening round bottom
Rotor slot design	Rectangular type bar

4.3.1. About JMAG Express

It is a cordial client programming software. This software can be used for three phase induction motor, yet it tends to be used for other electrical rotating motors. Inbuilt tool of this software have more prominent flexibility for the selection of variables with different blend of stator - rotor setup. This software is used to figure the improved outcomes.

4.3.2 Motors working under the evaluated voltages

The overall losses of the motor increases because of the presence of low voltage. The variable losses affect the performance of the motors when contrasted with its constant losses. The windage and friction losses are for the most part announced as one to two percent of the output of the machine, while the constant losses changes from two to three percentage only. Calculations are accomplished for percentage unbalance voltage, average voltage and percentage below the rated voltage with rise in temperature as appeared in table- 4.6. These observations are based on experimental calculations **[15].**

Table- 4.6: Calculations for percentage unbalance voltage, average voltage and percentage below the rated voltage with rise in temperature [165].

S.No	V_{ab}	V_{bc}	V_{ca}	Percentage unbalance	Average voltage	Percentage below rated Voltage	Percentage rise in temperature
1	360	363	360	0.55	361.00	9.75	0.6
2	375	378	362	1.7	371.67	7.08	5.78
3	365	366	365	0.18	365.33	8.66	0.064
4	355	361	360	0.64	360.00	10.00	0.81
5	361	364	367	0.82	364.00	9.00	1.34
6	363	360	360	0.64	360.33	9.08	0.81
7	381	360	362	1.55	363.33	8.66	4.8
8	369	360	366	1.46	363.67	9.08	4.26

4.3.3 Simulation Results

The suggested JMAG Express strategy is used for 7.5-kw induction motor to compute the optimized structure of stator and rotor design at its rated voltage, under rated voltage and under the variation of rated to under rated voltages. The module is worked to give optimized performance as a target work with various improved parameters as tabulated in table-4.12.These variables are determined in terms of sensitivity analysis under the variation of rated to under rated voltage. Normal parameters figuring at rated and under rated voltage are being calculated by using copper and an aluminum cage rotors as presented in table no. 4.7 to table no. 4.10. While the process of optimization of efficiency under the variations of rated to under rated voltages are carried out with the help of JMAG- express as shown in table-4.11.

Table- 4.7: Normal performance calculation for 7.5- KW, 50- Hz, 4- pole induction motor by selecting copper cage at the rated voltage (415V) [165].

Speed (R.P.M)	Percentage Efficiency	Copper Losses (watts)	Iron Losses (watts)	Magnetizing Current (Amp)
75	3.63	748.035	3.4	0.220
225	11.55	700.863	3.54	0.224
450	23.28	623.65	3.83	0.233
600	31.98	564.79	4.12	0.242
750	41.23	496.30	4.53	0.254
900	50.99	417.11	5.10	0.269
1050	61.49	318.00	5.94	0.290
1200	74.14	196.49	7.45	0.319
1425	87.67	23.93	9.36	0.365

As per the rule of performance of the three phase induction motor having a copper cage rotor is high when compared with a motor having an aluminum cage rotor. However by assembling a mix of rectangular sort bar rotor with parallel tooth opening round base as a stator, the performance of the underlying phases of aluminum cage rotor is more as compared with copper cage rotor. The power developed by having an aluminum cage rotor is also more when contrasted with a copper cage rotor at its underlying stages. But the occurrence of losses are more with high magnetizing current in an aluminum cage motor as compared with a copper cage motor with marginally low power factor, however there is a advantage of better beginning of torque with an aluminum cage rotor **(See figs.4.11 to 4.14)**. The copper cage motors are not appropriate for the generation of a large number of motors created every year. For financially better assembling, in this exploration article the motors having an aluminum cage rotor has been the preference to figure the improved results and same are presented in Table-4.12.

Table- 4.8: Normal performance calculations for 7.5kw three induction motor by selecting an aluminum cage rotor at its rated voltage (415V) [165].

Speed (R.P.M)	Copper losses (Watts)	Iron losses (Watts)	Magnetizing Current (Amps)	Percentage Efficiency
75	795.22	4.16	0.244	4.012
225	708.71	4.32	0.249	12.25
450	582.89	4.67	0.259	25.18
600	498.70	5.00	0.268	34.22
750	411.64	5.44	0.279	43.64
900	327.84	5.92	0.291	53.22
1050	237.40	6.59	0.307	63.21
1200	140.95	7.50	0.328	73.56
1425	18.36	9.13	0.362	86.56

Table- 4.9: Normal performance calculations for 7.5 kW, three phase induction-motor by selecting copper cage rotor under the rated voltage (363V) [165].

Speed (R.P.M)	Copper Losses (Watts)	Iron Losses (Watts)	Magnetizing Current (Amp)	Percentage Efficiency
75	752.035	5.40	0.240	1.60
225	705.863	5.55	0.226	8.52
450	628.65	4.84	0.235	20.24
600	567.79	5.14	0.244	28.90
750	499.30	5.56	0.256	38.20
900	420.11	6.30	0.271	48.93
1050	321.00	7.99	0.350	59.47
1200	200.49	8.47	0.322	71.12
1425	27.93	10.38	0.367	84.62

NOTE: -From Table 4.7 to Table 4.11, losses are calculated from starting speed to its rated speed at no load condition, however the efficiency is calculated by considering the windage and friction equal to 2.5% of the output of the machine. The variation of efficiency from no load to full load is shown in the fig. 4.14.

Table 4.10: Normal performance calculations for 7.5kw, three phase induction motor by selecting aluminum cage rotor operating under rated voltage (363V) [165].

Speed (R.P.M)	Copper Losses (Watts)	Iron losses (Watts)	Magnetizing Current (Amp)	Percentage Efficiency
75	797.21	5.16	0.246	2.01
225	710.70	5.32	0.251	10.23
450	584.85	5.67	0.260	23.15
600	499.70	6.02	0.269	32.20
750	414.62	6.44	0.280	40.62
900	329.82	6.92	0.294	50.20
1050	239.40	6.59	0.309	60.19
1200	142.92	7.50	0.330	70.54
1425	20.38	10.13	0.364	83.52

Table- 4.11: Optimized performance calculations for 7.5- KW, three phase induction motor by selecting an aluminum cage rotor operating under the variation of voltages (415V - 363V) [165].

Speed (R.P.M)	Copper Losses (Watts)	Iron losses (Watts)	Magnetizing Current (Amp)	Percentage Efficiency
75	642.44	3.46	0.218	5.017
225	573.95	3.60	0.222	13.26
450	473.59	3.89	0.231	26.21
600	405.90	4.17	0.24	35.26
750	335.50	4.54	0.25	44.68
900	267.51	4.94	0.261	54.25
1050	194.09	5.49	0.275	64.22
1200	115.58	6.26	0.293	74.56
1425	15.056	7.63	0.324	87.58

The dimensions of a new combination of stator and rotor in terms of sensitivity analysis are determined and are exhibited in table-4.12.Outcomes demonstrate that the “stator bore diameter,” “outside diameter of rotor” and “width of stator tooth” are exceedingly delicate which impacts the effectiveness of the motor. Fig.4.7 exhibit that the temperature will rise up on account of the nearness of unbalance voltages in the phases, which extends the general losses of the motor and henceforth drop down the performance of the motor. Furthermore the existence expectancy of the motors are specifically relative to its working temperature.

Table 4.12: Calculation for stator and rotor dimensions of 7.5-kw three phase induction motor with sensitivity analysis at its efficiency- maximization and under the variation of voltages from rated to under rated voltage [165].

Parameters	**Values**
Rotor bar width	3.14 mm
Rotor slot opening width	0.77 mm
Stator slot width	6.17 mm
Rotor bar thickness	13.60 mm
Stator tooth opening width	1.33 mm
Stator core back width	19.11mm
Stator inside diameter	107mm
Rotor outside diameter	105 mm
Stator outside diameter	210 mm
Stator tooth tang depth	2.64 mm
Number of turns /phase	230
Shaft diameter	31.5 mm

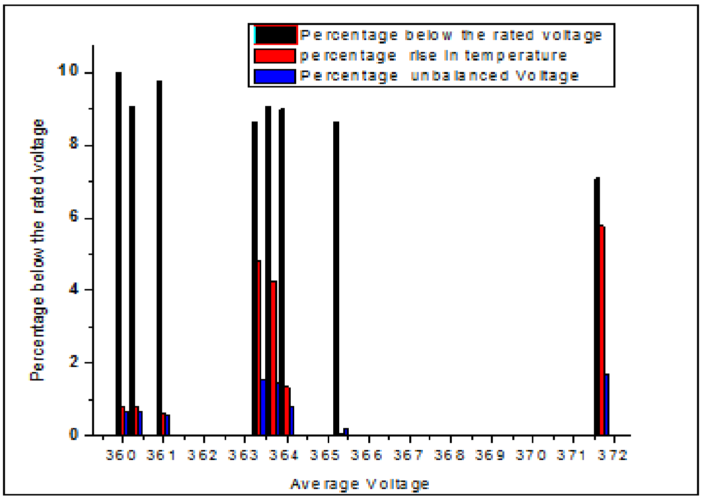

Fig.4.7: Average voltage Vs under rated voltage [165].

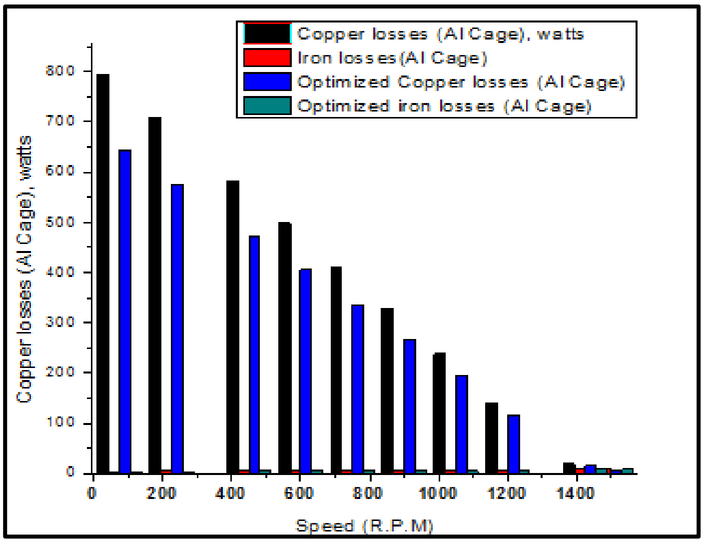

Fig.4.8: Copper losses Vs Speed [165].

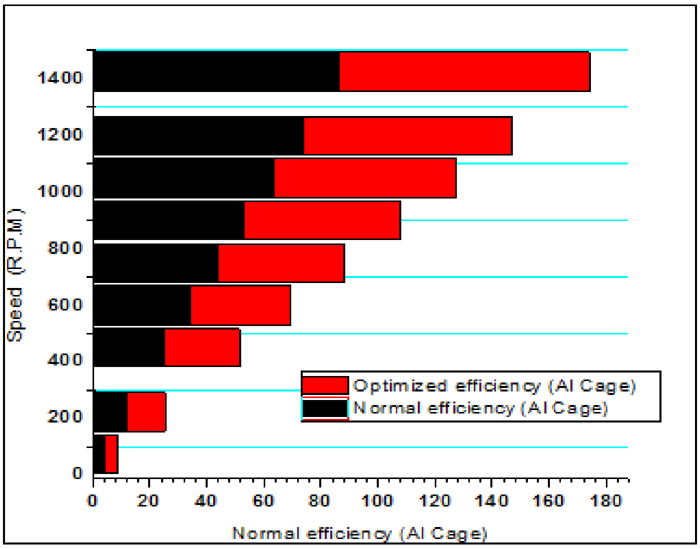

Fig.4.9: Efficiencies Vs Speed [165].

Fig.4.8 shows the relationship between speed and copper losses with and without optimization process. Additionally figure-4.9 shows the conventional and optimized outcomes by using an aluminum cage rotor, likewise fig.4.10 demonstrates the aftereffects of normal and optimized efficiency with normal and optimized copper losses.

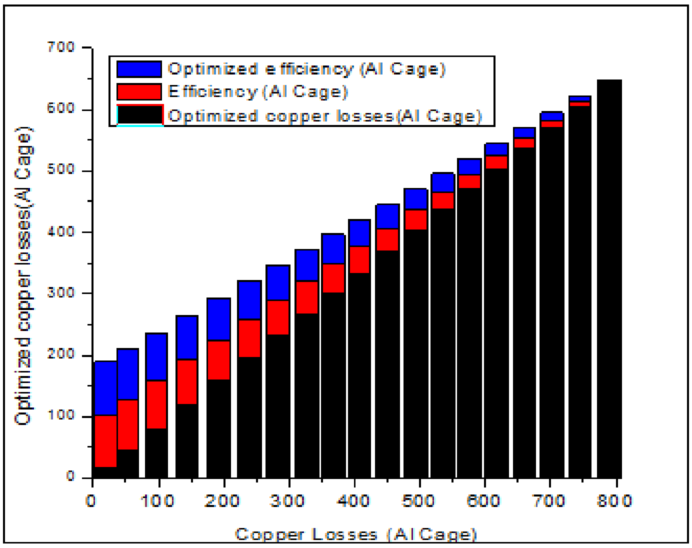

Fig.4.10: Copper losses Vs Optimized copper losses [165].

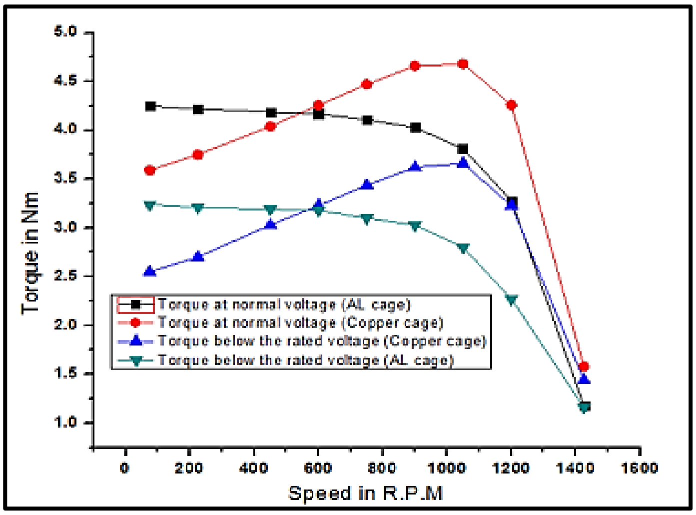

Fig.4.11: Speed Vs Torque [165].

Fig.4.11 demonstrates the variation of torque with its rated speed at no load conditions, to check the preliminary strength of the motor at full load conditions. This is observed that by using an aluminum cage rotor, the beginning torque of the motor is more when contrasted with a motor having copper cage rotor. This is because of having high resistance of the aluminum cage rotor when contrasted with copper cage rotor. This is also observed that the induction motors having an aluminum cage rotor have better starting torque, however under ordinary running conditions the efficiency of the induction motor having copper cage rotor is more when contrasted with induction motor having an aluminum cage rotor. This comparison is carried out at normal voltage (415V) and under the rated voltage (363V) as talked about in fig- 4.11 and fig.4.12.

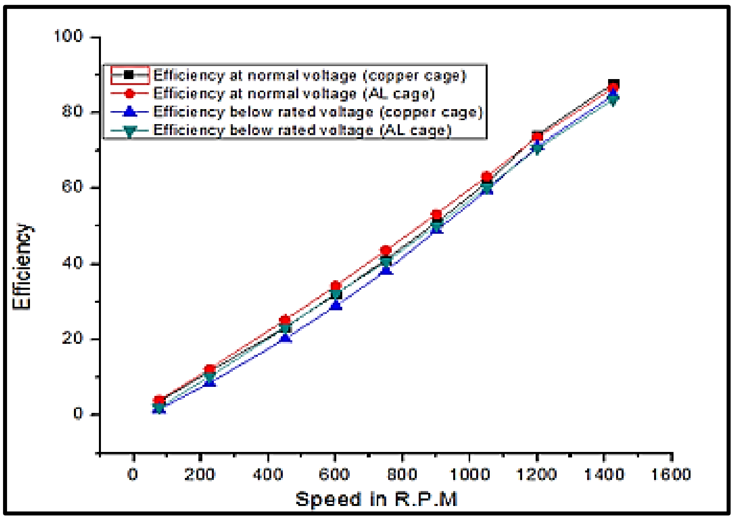

Fig.4.12: Efficiency Vs Speed [165]

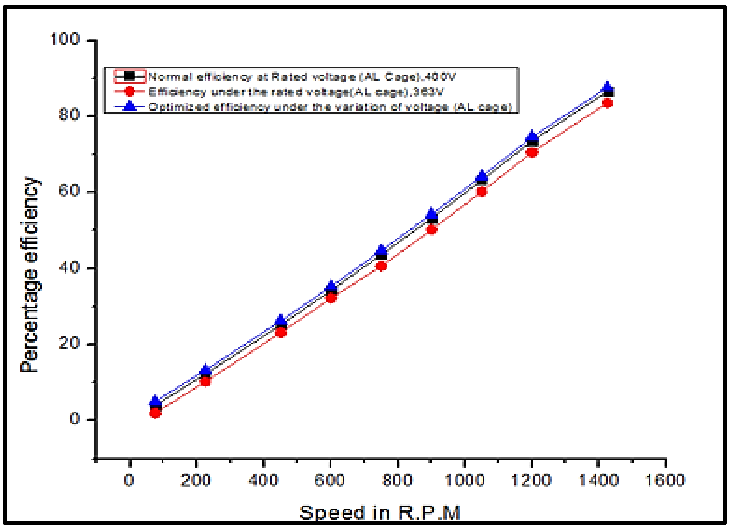

Fig.4.13: Percentage efficiency Vs Speed in R.P.M [165]

Fig.4.13 shows the relationship between efficiency of induction motor having an aluminum cage rotor at its rated speed, when the motor runs at rated and under rated voltages. While the process of optimization is completed under the variation of voltages from its rated to under rated voltage. Fig.4.14 shows the relationship between efficiency of induction motor under variation of load. To get maximum efficiency, mostly three phase induction motors are intended to keep running at 75% to 100% load. At no load the power factor of the motor will be very low due to the presence of magnetizing components of input currents large as compared to total input current of the motor.

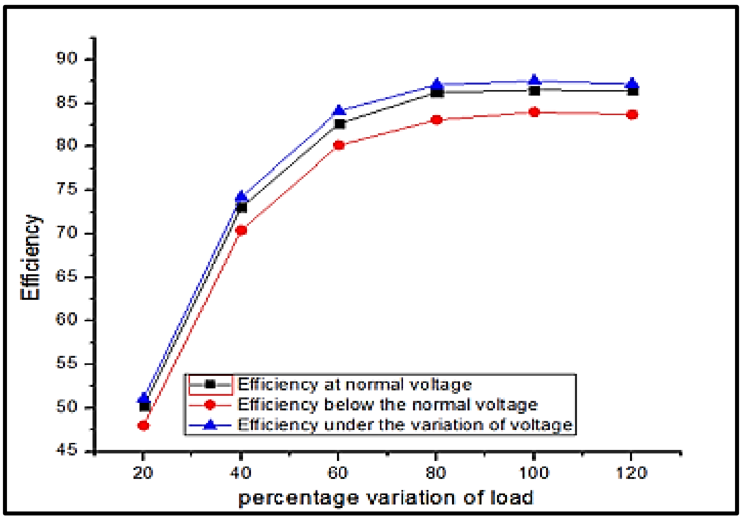

Fig.4.14: Efficiency Vs percentage variation of load [165].

When the load on the motor increases, the line current taken by the motor will be more, which will enhance the power factor of the machine and henceforth the efficiency of the motor will be fabulous stable from 75% to 100% load.

4.4 MODEL BASED ON PREDICTION OF EFFICIENCY OF "THREE PHASE SQUIRREL CAGE INDUCTION MOTOR" AT OPTIMIZE IRON LOSSES - A SOFTWARE APPROACH DESIGN [166].

4.4.1 Losses and temperature in induction motors

It has been found that the effectiveness of the motor can be upgrade only by changing the motor plan with optimization techniques. In electrical rotating motor there are mainly two types of losses: fixed losses and variable losses. Fixed losses consists of magnetic core losses, friction and windage losses. Magnetic core losses also consists of eddy and hysteresis losses in the body of the motor. These losses depends upon the material used and power quality. The variable losses depends upon the load and these are the losses present in the stator and the rotor of the motor. The variable losses are proportional to the square of the current and resistance of the material, while the stray losses which is a part of the variable losses are difficult to measure and calculate. Steinmetz develop an empirical formula to calculate the hysteresis losses **[161].**

$$p_h = k_h \, f \, B_m^{\ k} \qquad \text{Eqn.4.1}$$

Where ,

$p_h = Hyteresis\,losses$

$B_m = flux\,density\,in\,wb/m^2$

$k_h = steinmetz\,coefficient$

$f = frequency\,in\,Hz$

The total eddy current in a sheet of one meter length and one meter width is given by the relation

$$P_e = \int_{x=0}^{x=t/2} \frac{4\pi^2 f^2 B_m^{\ 2}}{\rho} \, l \, b \, x^2 dx \qquad \text{Eqn.4.2}$$

Where ,

$\rho = \mathrm{Re}\,gistivity\,of\ allow$

$l = length\,of\ lam\mathrm{in}\,ation\,sheet$

$b = width\,of\ La\,\mathrm{min}\,ated\ sheet$

$x = Thickness\,of\ sheet$

$dx = Thickness\,of\ element\,taken$

And eddy current loss /unit volume is given by the relation

$$p_e = k_e \, f^2 B_m^{\ 2} \, w/m^2 \qquad \text{Eqn.4.3}$$

Where ,

$$Ke = \frac{\pi^2 f^2}{6\rho}$$

Total iron losses is given by the relation

$$p_t = k_h f B_m^{\ k} + k_e f^2 B_m^{\ 2} \ \ w/kg \qquad \text{Eqn.4.4}$$

The calculation of temperature rise is not so simple due to complex heat flow process. The main reason of temperature rise in motors are due to bearing friction, windage losses, copper losses and stray losses. Only stray and copper losses vary with load variations. Copper losses occurs in the winding of the motor, however these losses can be calculated with the help of resistance method. This method is applicable only for winding temperature measurement. For practical purpose the following relation can be used for the calculation of temperature rise. The primary reason of temperature ascend in motors are because of bearing rubbing, windage losses, copper and stray losses. Stray and copper losses change with the variations of load. Copper losses happens in the winding of the motor, anyway these losses can be determined with the help of resistance method, but this method is applicable only for winding temperature measurement. Clearly, motors don't run persistently at one temperature, since loads and encompassing temperatures fluctuate. The mathematical equations for temperature rise measurement in electrical machines are as below.

$$\psi = \psi_2 - \psi_a = \frac{\alpha_2 - \alpha_1}{\alpha_1}\left(235 + \psi_1\right) + \psi_1 - \psi_a \qquad \text{Eqn.4.5}$$

Where,

$\psi = Temperature\, rise$

$\psi_2 = Temperature\, rise\, at\, the\, end\, of\, the\, test$

$\psi_a = Temperature\, of\, the\, cooling\, media$

$\alpha_1 = Initial\, resis\tan ce\, of\, the\, winding$

$\alpha_2 = Temperature\, of\, the\, winding\, at\, the\, end\, of\, the\, test$

$\psi_1 = Temperature\, of\, the\, cold\, winding$

4.4.2 About JMAG express and its optimization tool

It is a set of integrated software tools which have an aim to support electric motor designers throughout the complete design process. This software allows calculations for the basic motor properties in very short time, just by entering the input parameters. This may be used no longer most effective for the design of three phase induction motor, however it could be used for all rotating kind of electric machines. This software embedded the response surface method and genetic algorithm (GA) as an optimization engine. It generates the parameters in terms of sensitivity analysis by using correlation matrix and generates Pareto curves by using response surface method. Genetic Algorithm (GA) is an inbuilt tool of JMAG express particularly valuable for complex optimization issues when the parameters are large. This is one of the improvement techniques enlivened by the natural hereditary qualities. Genetic Algorithm is a coordinated irregular research strategy that is broadly connected in optimization issues. Because of GA's capacity of finding the worldwide ideal in the wide scope of the capacities. In this approach the utilization of random however wise seek in a predefined location is applied. It has numerous programs within the improvement issues. The parameters of the proposed capacity lead to their optimum value .This technique is an ordinary strategy to workout nonlinear conditions. In Genetic algorithm the search of the optimal solution is largely performed proceeding from one organization (populace) of viable points in the seek space to every other. Since being discharged in 1983, JMAG has been utilized in businesses and educational institutes worldwide and has added to the improvement of thousands of items.

4.4.3 Input data

To optimize the iron losses a three phase squirrel cage induction motor have been suggested with the accompanying data as presented in table 4.13.

Table- 4.13. Motor description (IS 900:1992) [166].

Particular	**Values**
Rating of the induction machine	11kw
Rated speed of the motor	1425 R.P.M
Maximum Speed	1500 R.P.M
Number of poles	4
Number of slots	36
Supply voltage	400 V
Maximum current	20Amp
Stator design	so_016 straight teeth, round bottom, teeth width, slot depth
Rotor design	rim_006 parallel sided tooth

4.4.4 Simulation Results and discussion

The proposed techniques is used for 11kw, three phase squirrel induction motor by applying rated voltage under the variation of base temperature of $20^{\circ}C$ to the maximum working temperature of $70^{\circ}C$.The JMAG express is used to optimized the iron losses as an objective function .This programmable software can be used as a basic tool to check the performance of newly design electric motors. Normal and optimized parameters are calculated by selecting copper and aluminum cage rotor, and are discussed in tables- 4.14 to 4.17. Due to nonlinear conduct of three phase induction motor it is difficult to get precise estimation of parameters. The parameters alteration can be achieved by a lot of modification factors got from sensitivity analysis, while the response surface method is a useful tool to think about the neighborhood variations. The primary restricting element for how much an electric machine can constantly be stacked, is generally the temperature.

NOTE: - From Table 4.14 to 4.17 losses of the motor is calculated at its approximate starting speed to its rated speed, however the efficiency is calculated by considering the windage and friction losses also.

Table 4.14: Normal parameter calculations for 11- kW, 50-Hz, 4 pole three phase induction motor by selecting copper cage rotor at its base temperature of $20^{\circ}C$ [166].

Speed (R.P.M)	Iron Losses (Watts)	Copper Losses (Watts)	Percentage Efficiency
75	4.77	2239.39	3.65
300	5.11	1917.77	15.17
450	5.42	1702.22	23.37
525	5.61	1592.09	27.66
675	6.08	1363.10	36.61
825	6.71	1124.61	46.08
975	7.56	866.51	56.12
1125	8.73	577.13	66.87
1275	10.25	276.87	78.31
1425	11.84	48.83	88.75

Table 4.15: Normal parameters Calculation for 11- kW, 50-Hz, 4-pole three phase induction motor by selecting aluminum cage rotor at its base temperature of $20^{\circ}C$ [166].

Speed (R.P.M)	Iron Losses (Watts)	Copper Losses (Watts)	Magnetizing Current (Amps)	Percentage Efficiency
75	5.87	2069.52	0.489	4.022
300	6.19	1661.79	0.502	16.508
450	6.5	1410.97	0.514	25.22
525	6.69	1289.71	0.521	29.69
675	7.14	1052.16	0.539	38.93
825	7.68	830.81	0.559	48.43
975	8.32	618.82	0.582	58.23
1125	9.19	401.83	0.612	68.47
1275	10.32	192.07	0.648	79.09
1425	11.52	37.11	0.685	87.95

A three phase, 50Hz, 4 pole induction motor rated at 11 kW is used to investigate the normal parameters by using copper and aluminum cage rotors as discussed in table 4.14 and Table- 4.15.The iron losses which occur only due to main and leakage fluxes depends upon the quality of the power supply. In this research article it is observed that the core losses are more in aluminum cage rotor as compared to the copper cage rotor. The second major loss is the copper loss, which occur due to current loss in stator and rotor winding. This loss is less in aluminum cage rotor as compared to copper cage rotor. Similarly primary current is more but power and torque developed is less in case of copper cage rotor. Moreover efficiency of copper cage rotor is more as compared to the aluminum cage rotor at its rated speed.

Table 4.16: Optimized parameters Calculation for 11- kW, 50-Hz, 4-pole, three phase induction motor by selecting copper cage rotor at its base temperature of $20^{\circ}C$ to the working temperature of $70^{\circ}C$ at optimization iron losses [166].

Speed (R.P.M)	Iron Losses (watts)	Copper Losses (Watts)	Magnetizing Current (Amps)	Percentage Efficiency
75	4.47	2339.01	0.424	3.28
300	4.79	2008.65	0.439	13.78
450	5.08	1786.34	0.452	21.42
525	5.27	1675.56	0.46	25.45
675	5.72	1435.62	0.479	34.006
825	6.33	1189.21	0.504	43.21
975	7.15	922.39	0.536	53.17
1125	8.3	621.22	0.577	64.11
1275	9.86	304.47	0.629	76.05
1425	11.65	57.81	0.706	87.16

Table-4.16 and table- 4.17 depicts the performance characteristic of multiple optimized parameters in terms of its rated speed. Iron losses in case of copper cage rotor are less as compared to the aluminum cage rotor under the variation of temperature, But copper losses are much less in case of aluminum cage rotor as compared to the copper cage rotor. Similarly the primary current in aluminum- confine rotor is less as compared to copper- confine rotor. In the ongoing past years there has been an expanding enthusiasm for the ideal structure of induction motor to lessen the vitality crises and expanding cost of material utilized. In a view of the dialog it was also observed that the motors which are not utilized at the full load have less efficiency as compared to the motors operating at full load.

Table 4.17: Optimized parameter calculations of 11- kW, 50-Hz, 4- pole three phase induction motor by choosing an aluminum cage at its base temperature of $20^{\circ}C$ to the working temperature of $70^{\circ}C$ at optimization iron losses [166].

Speed (R.P.M)	Iron Losses (watts)	Copper Losses (watts)	Magnetizing Current (Amps)	Percentage Efficiency
75	5.53	2112.71	0.475	3.72
300	5.86	1706.47	0.488	15.4
450	6.16	1454.61	0.501	23.67
525	6.35	1332.32	0.508	27.97
675	6.8	1091.84	0.526	36.91
825	7.33	876.66	0.546	46.72
975	7.98	652.28	0.57	55.92
1125	8.86	29.21	0.601	66.27
1275	10.04	210.04	0.639	77.19
1425	11.39	44.29	0.79	86.29

Also the power and torque develop in copper cage rotor are more as compared to aluminum cage rotor. Therefore, it will give better performance for large loads. Similarly the power factor of copper enclosure rotor is better as compared to aluminum enclosure rotor. The magnetizing current and efficiency in case of aluminum cage rotor are slightly less as compared to copper cage rotor. The overall performance of copper cage motor seen to be better as compared to aluminum cage rotor. The performances characteristic of both type of motor have been discussed in figures-4.15 to 4.19. Figure- 4.15 shows the results between iron losses Vs speed. In case of normal parameter calculations at base temperature of $20^{\circ}C$, the iron losses are less instance of copper cage rotor as compared to aluminum cage rotor. Also at optimization stage under the variation of temperature from base temperature to maximum working temperature, the losses occur in copper cage rotor is less as compared to aluminum cage rotor. Overall results shows that copper cage rotor is suitable to reduce the losses under the variation of temperature. Similarly the results presented in figure-4.16 shows that the power developed in case of copper enclosure rotor is more as compared to aluminum enclosure rotor.

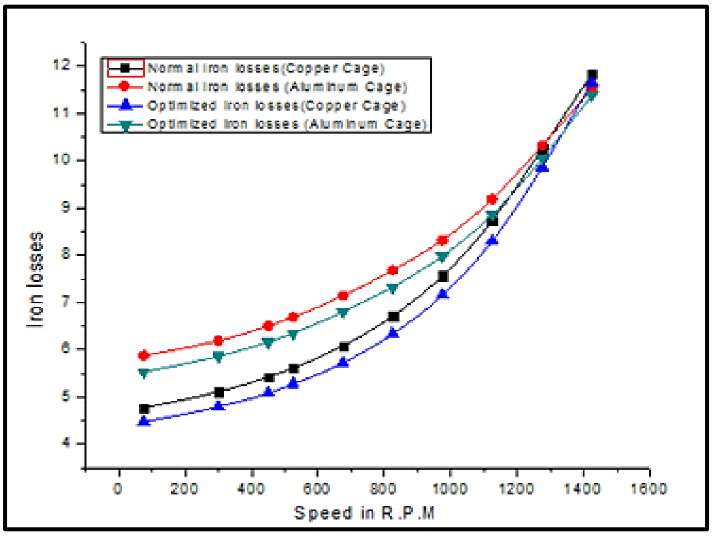

Fig. 4.15: Losses Vs Speed [166]

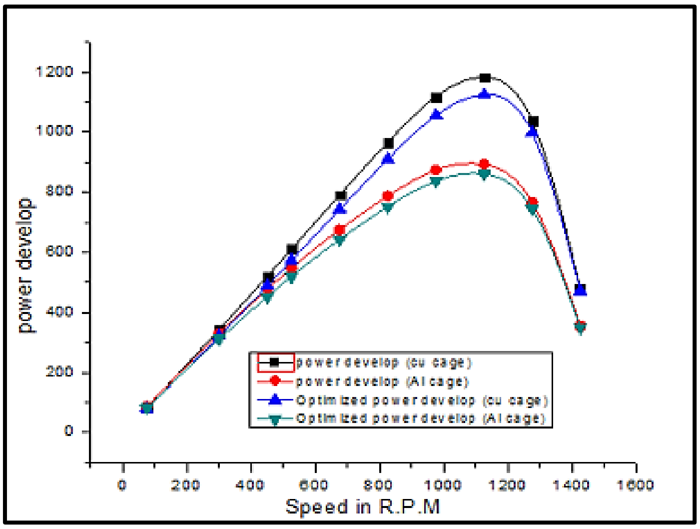

Fig 4.16: Speed Vs power develop [166]

Fig.4.17 presents the relationship between speed with magnetizing current .Magnetizing current in case of copper cage rotor is less in both the condition i.e.at base temperature and under the variation of base to the working temperature, which shows the better results in terms of power factor presented in Fig.4.18. However the results presented in fig.4.19 shows that the overall efficiency of copper cage rotor is more as compared to aluminum cage rotor at its rated speed under both the conductions of temperature variation.

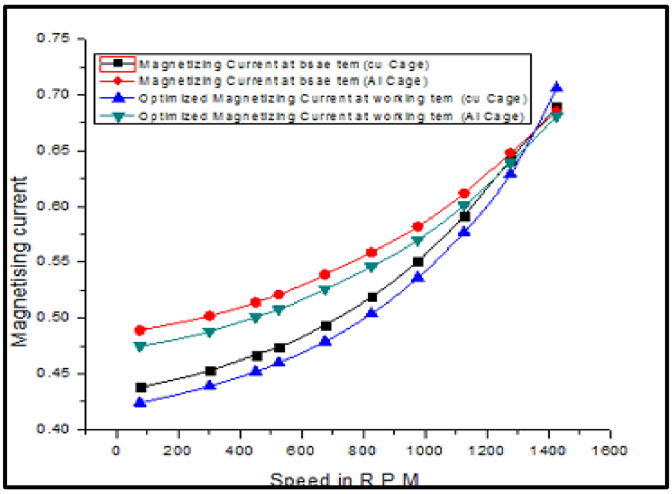

Fig. 4.17: Magnetizing losses Vs Speed [166]

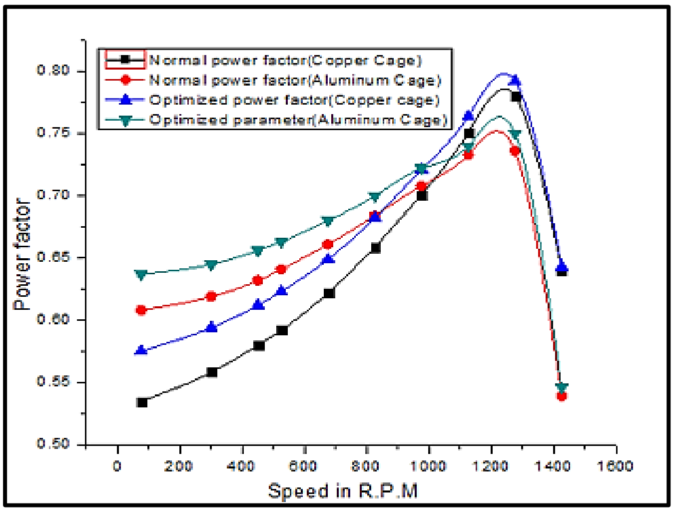

Fig. 4.18: Power factor Vs Speed [166]

In table- 4.18, Sensitivity parameters are calculated at optimized iron losses by using copper and aluminum cage rotors. The variable values of stator and rotor are same in both the cases of rotor, but the order of sensitivity of variables have been changed. In case of copper cage rotor the "width of stator tooth," "rotor slot opening" and "depth of stator slot" are highly sensitive variables, while in case of aluminum cage rotor width of stator tooth, rotor outside diameter and rotor slot opening are highly sensitive variables. Calculations of sensitive variables plays a very important role to get the desired efficiency at optimized iron losses under the variation of temperature i.e. form base temperature to the maximum working temperature.

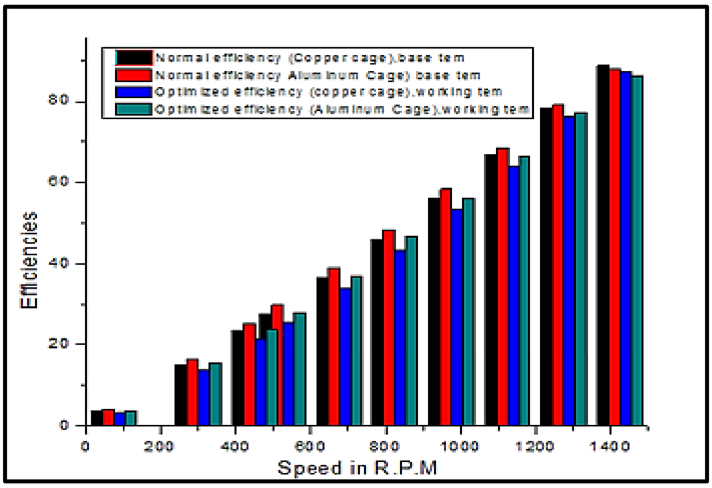

Fig. 4.19: Efficiency Vs Speed

Table- 4.18: Calculation for optimized stator and rotor dimensions of 11kw, 50-Hz, 4- pole three phase induction motor in terms of sensitiveness, using copper and aluminum cage rotor under the variation of temperature [166].

Parameters (copper cage)	**Values**	**Parameters (Aluminum Cage)**	**Values**
Width of stator tooth	7.5 mm	Width of stator Tooth	7.5 mm
Rotor slot opening width	1.29 mm	Rotor outside diameter	175 mm
Depth of stator slot	57.17 mm	Rotor slot opening width	1.29 mm
Rotor tooth tang thickness	2.63 mm	Depth of stator slot	57.17 mm
Rotor outside diameter	175 mm	Stator bore diameter	178.5 mm
Rotor tooth width	6.56 mm	Rotor tooth tang thickness	2.63 mm
Stator bore diameter	178.5 mm	Rotor tooth width	6.56 mm
Stator outside diameter	350 mm	Stator outside diameter	350 mm
Phase voltage (amp)	400V	Phase voltage (amp)	400V
Rotor bar thickness	23.6 mm	Height of stator tooth -tang	4.73mm
Height of stator tooth -tang	4.73 mm	Rotor bar thickness	23.6 mm
Rotor shaft diameter	52.5 mm	Rotor shaft diameter	52.5 mm
Air Gap length	1.75mm	Air Gap length	1.75mm

4.5 MODEL BASED ON DESIGN, ANALYSIS AND ASSESSMENT OF EFFICIENCY OF THREE PHASE SQUIRREL CAGE INDUCTION MOTORS OPERATING UNDER THE RATED VOLTAGE: A DESIGN CONSIDERATION FOR RURAL AREAS [167].

4.5.1 Effects of under voltages

Because of unbalanced voltages, the sum of average voltages present in the three phases are generally low, which increases the aggregate losses of the machine. These losses are divided in three sections, specifically stator-rotor copper losses, core losses and mechanical losses. When the machine works under the rated voltages, it will affect the variable losses more as compared to its constant losses. The grinding and windage losses (mechanical losses) as a rule happen in the scope of one to two percent of the total output of the machine. The constant losses relies on the constructional feature and it fluctuates in the scope of two to three percentage. In this research article for a 3.75 kW squirrel cage induction motor core and mechanical losses are accounted for as 198 watt and 45 watt **(see appendix –II)** while the stray losses have been disregarded. Keeping in mind the end goal to dissect the performance of three phase induction motor working at rated to under rated voltage, a 3.75 kw three phase squirrel cage induction motor have been suggested with the accompanying information as tabulated in table 4.19.Results are calculated with the help of mixed approach (mathematical and software approach).

Table -4.19: Input Prescription (IS 900:1992) [167].

Particulars	Input values
Rating of machine (pi)	3.75KW
Number of phases (n)	3
Voltage (Es)	400V
Frequency (f)	50 Hz
Full load efficiency (n)	0.8
Synchronous speed (Ns)	1500 R.P.M
Electric loading (ac)	21000
Magnetic loading (Bav)	0.45
Winding factor (Kw)	0.955

4.5.2 Discussions and recommendations

The calculation for unbalanced voltages due to which the motor is operating under the rated voltages have been investigated experimentally with the help of digital voltmeter at the motor terminal over a period of 5 days and 3 times in a day from 8 am to 10 pm. The percentage calculations for average voltages and percentage below the rated voltages of three phases have been calculated to calculate the variables losses of stator, rotor and efficiency for the said motor as shown in the Table 4.20.This is observed that the most effected parameter under the variation of voltages is stator copper material. The selection of number of turns of the stator winding will depends upon the voltage, which affects the variables losses and hence changes the others parameters also. At rated voltage, the rated efficiency of the motor is anticipated as 84.64%. This is also determined that by applying 10% less voltage of the rated voltage i.e. at 360V, the efficiency of the motor can likewise be carried out up to its rated efficiency with the accompanying modifications inside the stator parameters of the motor as talked about in Table-4.21. (For mathematical calculations see appendix-1I)

Table- 4.20: Calculations for average voltages, variables losses and efficiency

S.NO.	Average Voltage (V) of three phases	Stator copper losses without modified stator parameters	Rotor copper losses with modified stator parameters	percentage efficiency
1	361	314.83	186.69	83.75
2	371.33	306.08	181.57	84.01
3	371.67	305.8	181.41	84
4	370	307.18	182.22	83.98
5	371.67	305.8	181.41	84.02
6	371.33	306.08	181.57	84.01
7	365.33	311.11	184.51	83.61
8	365.33	311.11	184.51	83.61
9	373	304.72	180.78	84.04
10	375.67	302.55	179.51	84.11
11	375.67	302.55	179.51	84.11
12	366.33	310.26	184.01	83.88
13	375.33	302.83	179.67	84.1
14	360.67	315.14	186.86	83.75
15	372.67	304.99	180.93	84.04

Table- 4.21: Mathematical calculations for percentage change in parameters at rated and under the rated voltage. (For mathematical calculations see appendix-1I) [167].

Parameters calculation at rated voltage (400V)	Parameters calculation under rated voltage (360V)	Percentage Change in parameters
Stator turns per phase=310	Stator turns per phase =279	(-) 10%
Total stator conductors=1860	Total stator conductors=1860	(-) 10.53%
Conductors per slot=74	Conductors per slot=69	(-) 6.75%
Current per phase=1.88Amp	Current per phase=5.43Amp	(+) 10.13%
Diameter of stator conductor=1.092 mm	Diameter of stator conductors=1.116 mm	(+) 2.15%
Stator resistance/phase=3.970	Stator resistance/phase=3.21	(-) 18.56%
Efficiency at rated voltage=84.64%	Efficiency under rated voltage=84.64%	Nil

Nine perceptions in terms of average voltage are chosen from table-4.20, to watch the variation of losses and efficiency with adjusted and without change in stator turns. This is observed that with adjusted stator turns as per the variations in voltage, the efficiency can be increased as talked about in the following figs.

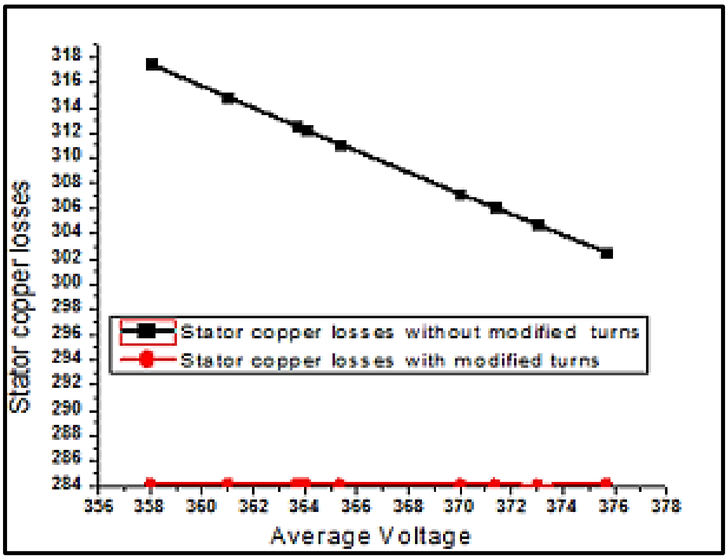

Fig.4.20: Stator copper losses Vs Average voltage [167]

As already discussed, because of unbalanced voltages present in the three phases, the sum of average voltage are generally low, which expands the aggregate losses of the machine. These losses can be reduced by optimizing the stator number of turns and all others parameters of stator as discussed in table 4.21.

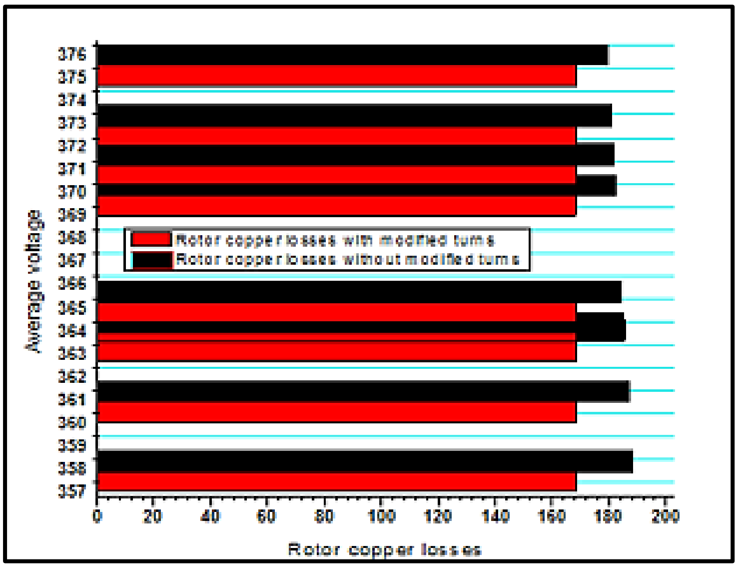

Fig.4.21 Rotor copper losses Vs Average voltage [167]

Fig.4.20 and Fig.4.21 demonstrate that the stator and rotor copper losses increases with the variation of voltages. These losses can be kept up stable with upgraded stator turns and others parameters as shown in table 4.22, while by lessening the stator and rotor copper losses the performance of the motor can be enhanced as shown in Fig.4.22.

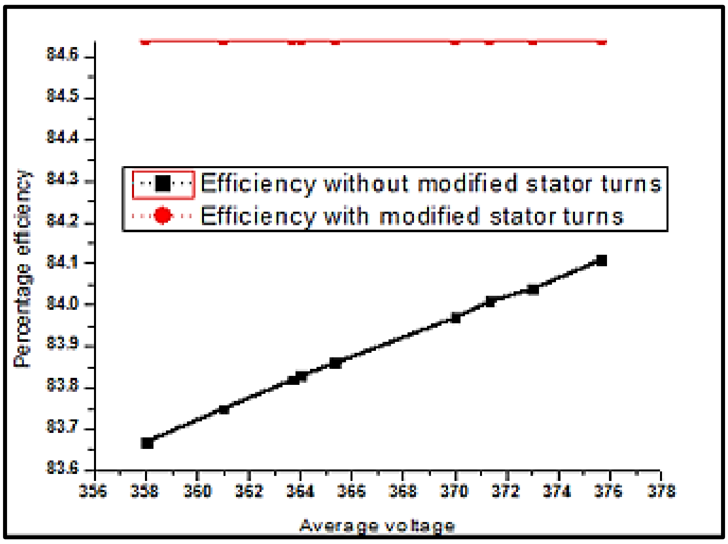

Fig.4.22: Efficiency Vs Average voltage [167]

4.5.3. Performance optimization

This model of examining the performance of three phase squirrel cage induction as discussed above depends on the mathematical equations (see appendix-II), however to get the more helpful outcomes, the exhibited scientific model will be more valuable as compared to the model discussed above. The geometrical parameters of stator and rotor both are upgraded under the variations of voltages from rated to under rated voltages at maximized efficiency as an objective function. The JMAG express (an electric motor design software) is used for this purpose also. The geometrical parameters of stator and rotor are calculated in terms of sensitivity analysis as discussed in table no. 4.22. For this purpose a combination of stator and rotor (rim_001with round bar rotor is used with So_013 parallel tooth opening, round base) is used, so as to reduce the air cups and hence to reduce the magnetising currents. To reduce the losses and running cost of the motor, higher efficiency is required. This is the reason that we have selected efficiency maximization as an objective function. The fitness function for an objective function is given by the relation.

$$\eta = \frac{1000P_o}{1000P_o + S_{cl} + S_{ir} + R_{cl} + W_f} \qquad \text{Eqn. (4.6)}$$

$P_o = Output\,power\,of\,the\,machine\,(KW)$

$$Stator\,copper\,loss(S_{cl}) = 3{I_{ph}}^2\,\mathrm{R_{eq}} \qquad \text{Eqn. (4.7)}$$

$$Stator\,iron\,losses\left(S_{ir}\right) = w_t * W_{tk} + W_c * W_{ck} \qquad \text{Eqn. (4.8)}$$

$W_t = Weight\,of\,stator\,teeth$

$W_{tk} = losses\,in\,stator\,teeth$

$W_c = weight\,of\,stator\,core$

$W_{ck} = losses\,in\,stator\,core$

$$Rotor\,copper\,loss\,(R_{cl}) = \frac{\rho_R * R_s * {I_{br}}^2}{a_b}\left(Lc + \frac{2De}{P}\right) \qquad \text{Eqn. (4.9)}$$

$\rho_R = is\,a\,cons\tan t\,quantity\,(0.021)$

$R_s = number\,of\,rotor\,slots$

$I_{br} = Rotor\,current$

$L_c = length\ of\ core$

$D_e = Diameter\ of\ end\ ring$

$P = Number\ of\ poles$

Since JMAG express in an in-built tool, which can be used for the design of electrical machines. As already discussed, in this tool, response surface method is used to optimize the local parameters (constraints). These local parameters which can directly affect the performance of the motors are, stator and rotor temperature, primary current taken by the motor, flux density, Full load efficiency, magnetizing currents and power factor. These all are out put variables, which are influenced by the input variables. These output variables are directly related to the performance of the motors. A set of X variables of stator and rotor dimensions (for the selected design of stator and rotor), are optimized with the help of GA in terms of sensitivity analysis, as formulated in table no.4.22 of this article.

Table- 4.22: optimized stator and rotor dimensions of three phase squirrel under the variations of voltages [167].

Variables	Values
Bore diameter of stator	122.5 mm
outside diameter of rotor	120 mm
Stator tooth width	5.13 mm
Bar Diameter of rotor	4.42 mm
Slot opening width	1.33 mm
Depth of stator slot	26 mm
Stator tooth height	4.36 mm
Width of stator slot	8 mm
Stator outside diameter	240 mm
Angle of stator Tooth	22.9 degree
Bar center Depth	7.2 mm
Air Gap length	0.470mm
Number of turns	300
Shaft Diameter	36 mm

The optimized efficiency at its rated speed is also shown in the table 4.23.

Table 4.23.Calculation for optimized efficiency, efficiency at rated voltage and under rated voltage [167].

Speed (R.P.M)	75	225	375	525	675	825	1125	1275	1425
Efficiency at rated voltage	3.99	12.12	20.46	29.04	37.91	46.82	64.92	74.71	84.04
Efficiency under rated voltage	2.65	10.89	18.65	27.07	44.54	53.36	62.04	72.38	82.30
Optimized Efficiency	4.97	13.14	21.48	30.04	38.94	47.84	65.96	75.74	85.16

4.6 CHAPTER SUMMARY

The above presented articles demonstrates that the decrease in performance of three phase induction motor because of low voltage can be enhanced up to its rated efficiency by optimizing its stator and rotor dimensions. This sort of study will be a beneficial tool specific for those villages where the electrical supply is poor because of reactive power demands etc. The proposed design will not only save the operating cost of the motors, but it will also increase the operating life of the motors with more warranty period**.**

CHAPTER-5

DESIGNING OF UNDER RATED VOLTAGE THREE PHASE INDUCTION MOTOR

5.1 CHAPTER OVERVIEW

This research article deals with the modified and optimum design parameters of 1HP three phase squirrel cage induction motor working at rated to under rated voltages. The simulated results are calculated with the help of JMAG Express. 1 HP three phase squirrel cage induction motor is casted in the industry based on the simulated results of stator and rotor design. The experimental results of a new 1 HP motor are compared with experimental results of a conventional motor of the same rating which was designed at rated voltage. The after effects of new planned motor was better when compared with old one. These types of low rating induction motors can be used in the villages for agribusiness and domestic purposes to show the signs of improvement effectiveness, where the supply voltage is not up to the mark.

5.2 VALIDATION OF SOFTWARE RESULTS OF 1H.P THREE PHASE INDUCTION MOTOR WITH EXPERIMENTAL MODEL [169].

5.2.1 Specifications of motor

The motors working at other than its rated voltage, certainly influences its cost and working life. The input specification of 1 HP three phase squirrel cage induction motor is shown in the table 5.1.

Table- 5.1: Input data (IS 12615:2018) [169].

Particulars	Values
Rating of induction motor	1H.P
Supply voltage applied	370 Volt
Rated speed of the motor in R.P.M	1440
Number of poles	4
Number of slots	36
Number of bars	38
Cage type	Aluminum

5.2.2 Simulation Results

The working performance of any electrical motor also depends up on the stator and rotor design. Thus it is critical to choose appropriate design of stator and rotor with proper selection of slots. The motor should draw low magnetizing current, for this purpose rim_003 rectangular bar with so_001 parallel tooth opening arc bottom stator and rotor combination is used for 1 HP three phase squirrel cage induction motor as shown in Figure-5.1.

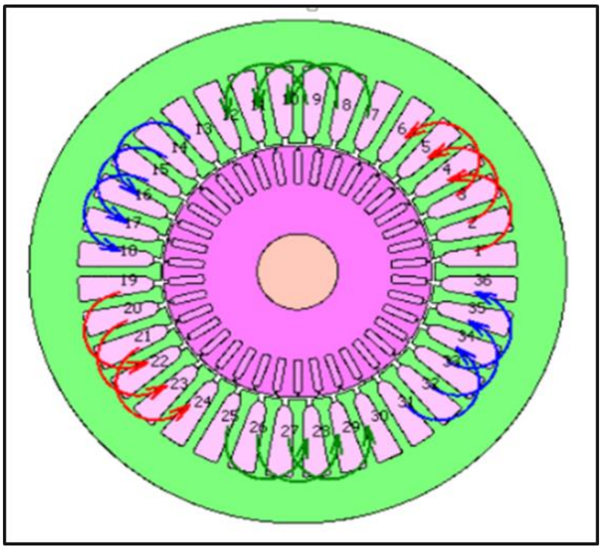

Fig.5.1: Stator and rotor slots design [169]

The arrangement of stator winding system is shown in Figure-5.2.The winding is distributed in all the thirty six slots by making a combination of parallel paths one and series path twelve in delta connections. Generally this kind of windings can be carried out in small rating of three phase inductions motors. These types of motors have low efficiency as compared to high rating induction motors, because in such types of motors the magnetizing component of input currents are large as compared to input current taken by the motors. To compensate this magnetizing current the line current which will be in phase with the applied voltage can be increased by modifying the series and parallel combination of stator slot windings, as discussed in Figures-5.2 to 5.5.The results based on original and modified stator winding design are shown in Figs-5.6 and 5.7.The dimensions of stator and rotor design are also optimized with the help of Genetic

Algorithm under the variation of voltage from its rated to under rated voltage, while the response surface method is used to calculate the primary objectives. The stator and rotor dimensions are calculated at optimized efficiency as shown in Table- 5.2.

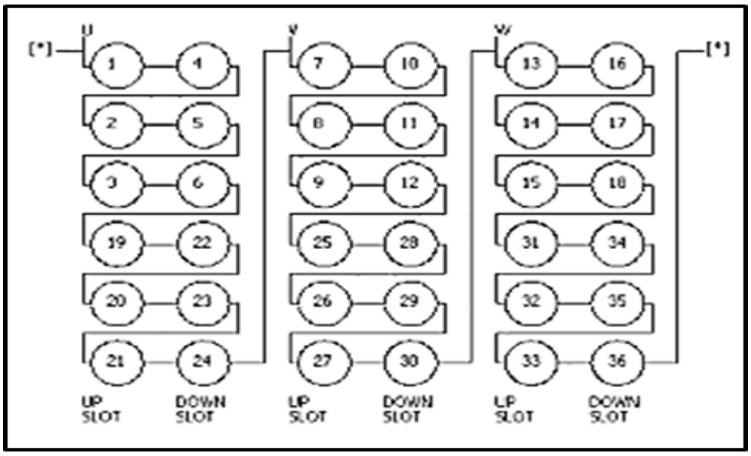

Fig.5.2: Stator winding arrangements with parallel no.1 and series no. 12

Stator winding arrangement with parallel number one and series number twelve are arranged in different slots, from slot number one to slot number thirty six. Since the motor is of low rating, therefore winding is carried out by making delta connections only. Balanced winding is used in the stator slots with a slot angle of 180 degree per pole pitch (Electrical degrees).

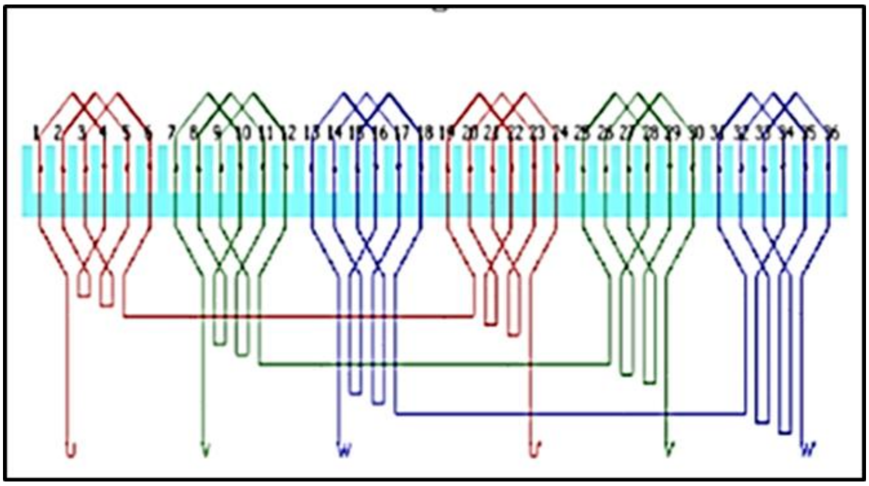

Fig.5.3: Stator slot winding arrangement with parallel no. one and Series no.twelve [169].

Figure-.5.3 demonstrates the arrangement of three phase stator winding by considering parallel path one and series path twelve. The performances of this winding arrangement are discussed in Figures-5.6 to 5.8.

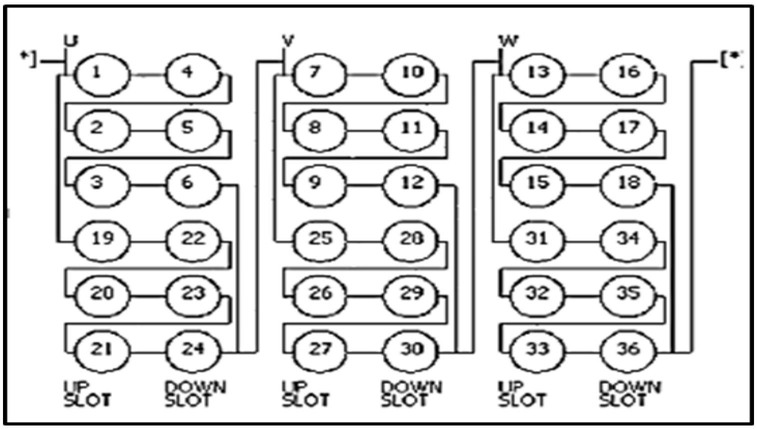

Fig.5.4: Modified stator winding arrangements with parallel path two and series Path three [169]

Similarly Figure-5.4 demonstrates the stator winding arrangement with parallel path two and series path three. Since the current drawn by this low rating squirrel cage induction motor will be low, but will be in phase with the applied voltage. The magnetizing current drawn by the motor in comparison with this current will be high (due to air gap), which influences its performance. To compensate this magnetizing current, parallel paths for the winding are increased in comparison with series paths. Stator winding arrangements are shown in Figure-5.5.

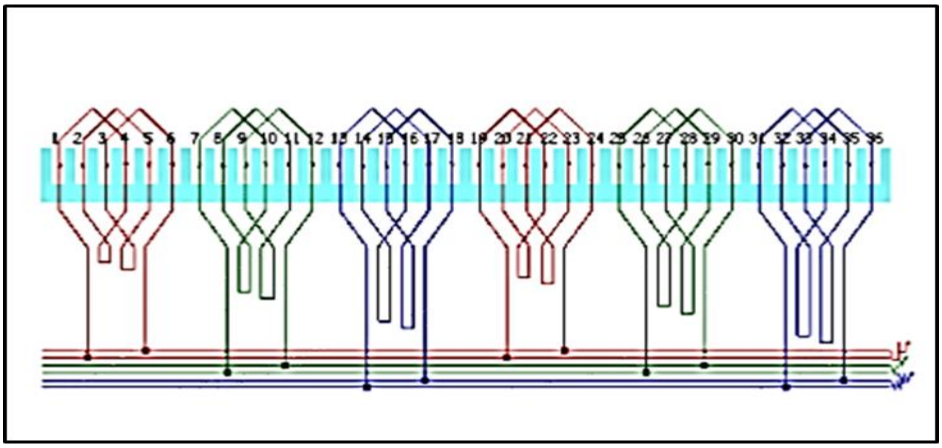

Fig.5.5: Modified stator slot winding diagram with parallel no.two and Series no. three [169]

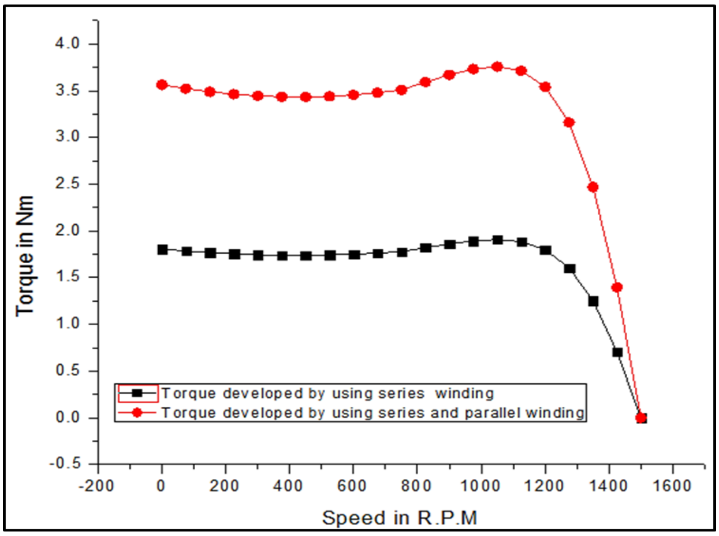

Fig.5.6: Torque Vs Speed [169]

Figure-5.6 explains the relationship between torque and speed. Starting torque to the maximum torque can be increased by using second option of stator winding arrangement. More magnetizing components will be compensated if we adopt the second optional of stator winding arrangement.

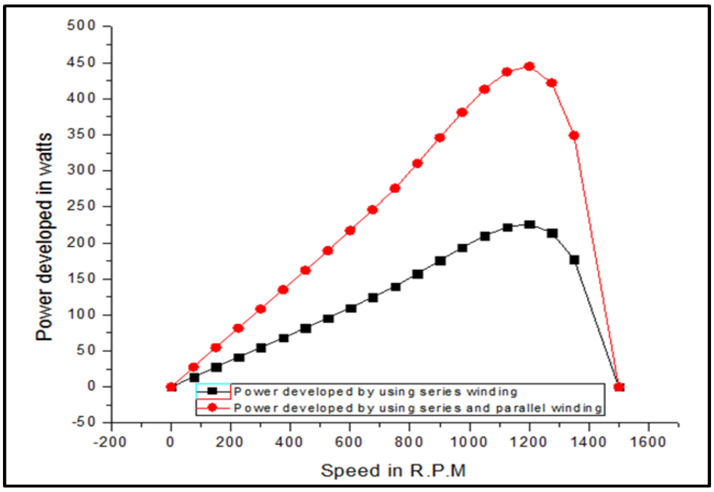

Fig.5.7: Power Vs Speed [169]

Similarly Figure-5.7, demonstrates the relationship between power developed and speed of the motor. Magnetizing currents of the motor are compensated by the current taken by the motor. Therefore power developed by the motor will also be more if we go with the second option of stator winding arrangements.

The current taken by the motor will be in phase with the applied voltage, while the magnetizing components are out of phase with the applied voltage.

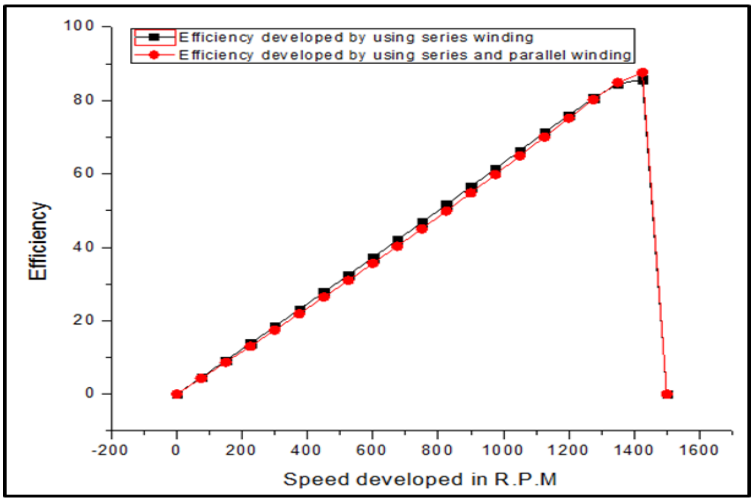

Fig.5.8: Efficiency Vs Speed [169]

Based on the above discussed results, we observe that the efficiency of the motor can also be improved by adopting the second option of stator winding arrangement. The comparison of efficiencies as discussed in Fig.5.8 are more illustrated in section 5.2.3.

Table 5.2: Stator and rotor dimensions of 1 HP three phase squirrel induction motor at optimized efficiency, under the variation of voltages (370V to 415V) [169].

Main dimensions	**Optimum value**
Outer diameter	125 mm
Air Gap Length	0.625 mm
Stack height	150 mm
Number of poles	4
Number of stator slots	36
Stator bore diameter	63.75 mm
Depth of stator slot	19.18 mm
Width of stator slot (bottom)	6.68 mm
With of stator slot opening	1.51mm
Height of stator tooth tang	1.70 mm
Angle of stator tooth tang	49.72 deg
Number of secondary conductors	38
Outer diameter of rotor	62.5 mm
Shaft diameter	18.8 mm
Bar width	1.85 mm
Bar thickness	8.13 mm
Bar Tooth tang thickness of rotor	1.25 mm
Slot opening width	0.461 mm

5.2.3 Experimental Results

Based on the second option of stator winding arrangement, the no load test and blocked rotor test are being carried out to determine the performance of a new constructed software based 1 H P three phase squirrel cage induction motor. It has been observed that the efficiency obtained by experimental calculations under the rated voltage (370V) is 74.88%, while by using the software approach it was 83%. At rated and under the rated voltages the performance test is also carried out on an old motor of the same rating. The efficiency of this motor based on semi closed stator slots with series winding was found to be 75.76% at its rated voltage (415V), while under the rated voltage its efficiency was 71.39%. This is observed that the new constructed motor based on a new combination of stator, rotor and winding design have an excellent performance in terms of improved torque, power and efficiency as compared to the old designed motor. The results in terms of torque, power and efficiency are already discussed in figs.5.6 to fig.5.8. Experimental set up for a new and an old deigned motors are shown in fig.5.9 and fig. 5.10.

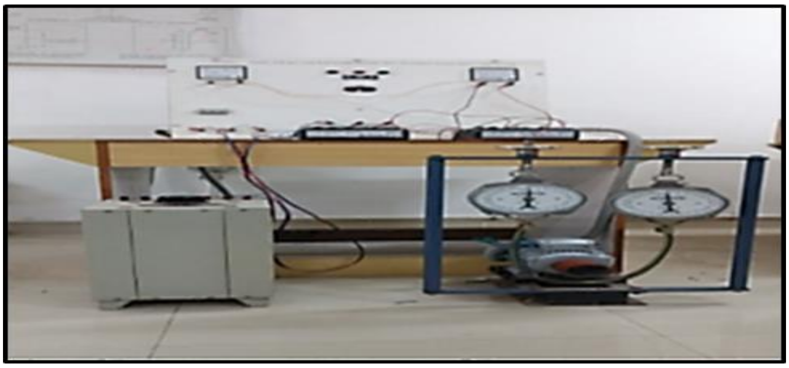

Fig.5.9: Experimental set up for new design 1 H.P Motor [169]

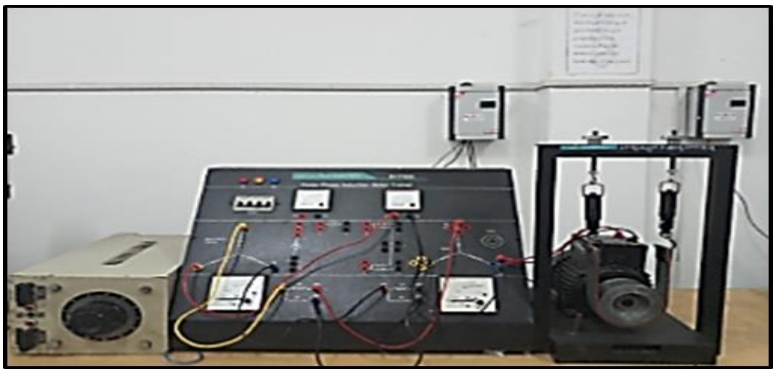

Fig.5.10: Experimental set up for old design 1 H.P Motor [169]

Table 5.3: Experimental calculations for constant and variable losses, when 1 HP (New) induction motor operating at under rated voltage [169].

Applied Voltage & rated current	Current (Amps)	W_1 (watts)	W_2 (watts)	S_1 (kg)	S_2 (kg)	Efficiency
370V	0.5	180	(-) 120	0	0	74.88%
Rated current	1.9	40	144	1.2	6.5	

Table 5.4: Experimental calculations for constant and variable losses, when 1 HP (New) induction motor operating at rated voltage [169].

Applied Voltage & Rated current (V)	Current (Amps)	W_1 (watts)	W_2 (watts)	S_1 (kg)	S_2 (kg)	Efficiency
415	0.9	184	(-) 121	0	0	75.76%
Rated current	2.2	44	146	1.2	6.5	

Table 5.5: Experimental Calculations for losses and efficiency, when 1 HP (conventional) induction motor operating at under rated voltage [169].

Applied Voltage & Rated current	Current (Amps)	W_1 (watts)	W_2 (watts)	S_1 (kg)	S_2 (kg)	Efficiency
370 V	1.02	180	(-)120	0	0	71.39%
Rated current	2.4	50	190	1.2	6.5	

Fig.5.11, demonstrates the relationship between efficiency and variations of voltages ranging from 370 volt to 415 volt for one hourse power three phase conventional motor.The variation of effciency differs from 71.39% to 75.76%, while figure-5.12,demonstrates the relationship between efficiency and variation of voltages for one hourse power energy efficient optimized motor. The efficiency of this motor varies from 74.88 % to 76.05%. Fig. 5.13, shows the combined relationship between efficiency and variation of voltages for software and experimental results of conventional and energy efficient optimized motor.Inspite of software results as discussed above,the optimized motor with a new combination of stator and rotor desgin have better outcomes under the rated voltages (370V) when compared with the old one, which was to

be operated at rated voltage (415V),while table- 5.6 and table 5.7 demostrate the losses and efficiency under the variations of voltages.

The efficiency of three phase induction motor depends upon various parameters like power quality, quality of bearings, the nature of materials used and winding sort which are inserted in stator slots. The overall performance of three phase induction motor is carried out by using two kinds of stator winding arrangement and optimizing the stator and rotor design parameters as discussed in table 5.2. Experimental calculations for 1 HP conventional and energy efficient motor at full load operating at rated to under rated voltages is shown in the table5.6.

Table 5.6: Experimental Calculations for losses & full load efficiency of 1 HP conventional motor operating at rated to under rated voltages [169].

Applied voltage (V)	Iron Losses (Watts)	Copper Losses (Watts)	Percentage Efficiency
370	60	240	71.39
380	64	217.83	72.58
390	68.5	193.88	73.98
400	71.15	182.98	74.59
410	74.60	174.33	74.98
420	78.98	169.68	75.00

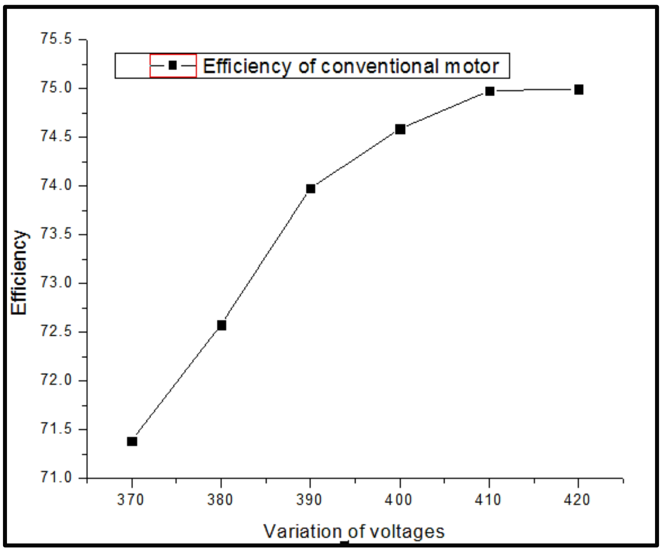

Fig.5.11: Efficiency Vs Voltage [169]

When a three phase induction motor are exposed to voltages below the nameplate rating, some of the motor's characteristics will change significantly. To drive a mechanical load, a motor must draw a fixed amount of power. When the motor operates below the rated voltage, the current taken by the motor will also be increased, which will be dangerous to the motor winding in terms of its life and efficiency. To avoid this situation the motor parameters are optimized under the variation of voltages for maximum efficiency as an object function.

Table 5.7: Experimental Calculations for losses & full load efficiency for 1 HP energy efficient motor operating at under rated voltage to rated voltage [169].

Applied voltage (V)	Iron Losses (Watts)	Copper Losses (Watts)	Percentage Efficiency
370	60	184	74.88
380	64.12	175.21	75.71
390	68	168.87	75.90
400	72	163.83	75.98
410	73.33	161.99	76.02
420	75.66	159.27	76.05

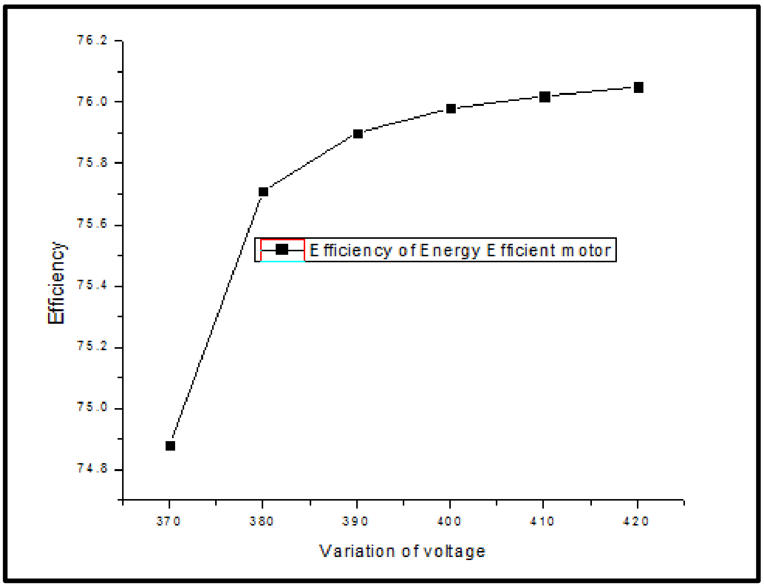

Fig.5.12: Efficiency Vs voltage [169]

Since the motor is of low rating, therefore winding is carried out by making delta connections only. Balanced winding is used in the slots with a slot angle of 180 degree per pole pitch (Electrical degrees).

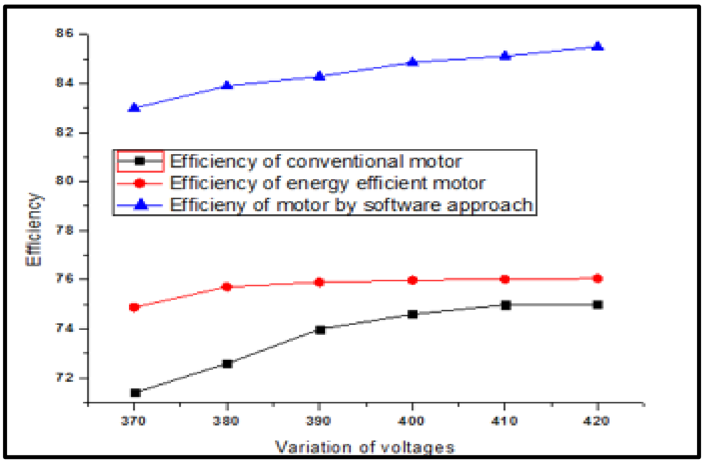

Fig.5.13: Comparison of efficiencies Vs Voltages [169]

5.2.4 Applications of three phase induction motors in rural areas

As already discussed three phase induction motors plays a very important role in agriculture pumping particularly in rural areas. The main applications of these motors are as below.

Table: 5.8 Table for type of bore well and power range of motors [169].

Type of bore well	Range of motors
Up to 100 mm (Diameter)	1 H P to 3 H P
Up to 175 mm (Diameter)	2 H P to 20 H P
Up to 150 mm (Diameter)	5 H P to 20 H P
Up to 200 mm (Diameter)	10 H P to 40 H P

Applications

1. For agriculture and irrigation.
2. Public water supply.
3. Water circulating system.
4. Filling of storage tanks.
5. Lifting of water for high raise buildings.

From the above discussion it is concluded that the results of a new motor are better when compared with conventional one. It is presumed that the new motor have better outcomes in terms of torque, power and efficiency when compared with the old one as shown in fig.5.13.

5.3 MODEL BASED ON IMPROVED STATOR- ROTOR DESIGN OF THREE PHASE INDUCTION MOTOR -A SOFTWARE APPROACH

Because of reactive power requested by the industrialists and agriculturists, three phase induction motors composed at rated voltage are working under the rated voltage particular in the rural areas, a long way from the utility focuses. The target of this research article is to enhance torque, effectiveness, power developed and power factor by using double cage winding with a new combination of stator and rotor design. The rim_003 rotor bar is used with so_012 parallel tooth opening flat bottom stator with different arrangements of stator winding which is used for 5 HP three phase squirrel cage induction motor. JMAG express is used to figure the performance enhancement of motor at rated to under the rated voltage. Energy protection is an essential development venture towards beating the creating issues of businesses enhancement. By decreasing the wasteful imperativeness the performance of induction motor can be upgraded up to some extent.5 HP three phase squirrel cage induction motor have been proposed with the accompanying info details as shown in the table-5.9

Table -5.9 Input specifications **(IS 12615:2018)** [168].

Particulars	Values
Rating of the machine	5 HP
Rated speed	1440 R.P.M
Maximum Speed	1500 R.P.M
Number of poles	4
Number of slot	36
Number of bars	38
Power supply	370V-415V
Maximum current	10 Amp
Stator design	rim_012 parallel tooth opening, flat bottom
Rotor design	so_003 rectangular bar
Cage	Aluminum
Winding layer	Single/Double series parallel combinations

5.4 SIMULATION RESULTS AND DISCUSSION

The proposed JMAG Express software is also used for 5 HP three phase squirrel cage induction motor to figure out the stator and rotor dimensions at maximized torque, efficiency, power developed and power factor. Working performance of the motor much relies on the outline of stator and rotor design. To decrease the magnetic current, rim_012 parallel tooth opening, flat base stator with so_003 rectangular rotor bar is used according to the geometry as shown in figure-5.14. Two sorts of windings are used to check the performance of the motor under the rated voltage. During single layer winding the space is secured by just a single loop side, while in two layer winding one curl side of each loop is set in top portion of the space and other loop side is set lower half of the opening. Torque and power can be enhanced by using two layer wingdings for the most part, when the motors are to be worked under the rated voltages. The aim of this research article is to reduce the resultant magnetizing current there by increasing the current drawn by the motor during its operation. This current will be in phase with the applied voltage, which will compensate the magnetizing current (out of phase components) and hence the overall performance of the motor can be improved. To fulfil this requirement step by step processes are being followed as below.

Fig.5.14 and Fig.5.17 shows the stator and rotor design by using single and double layer winding.

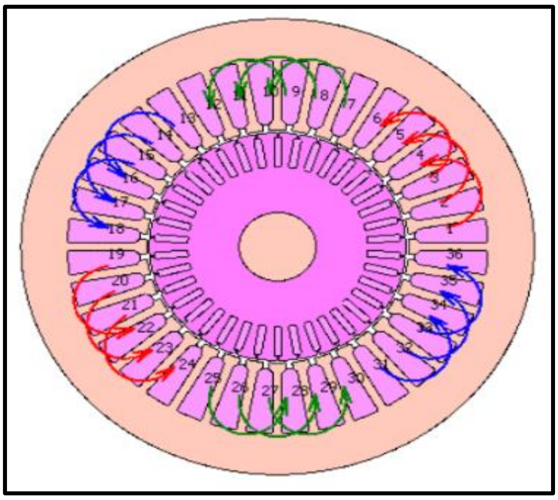

Fig.5.14: Stator and rotor design with single layer winding [168]

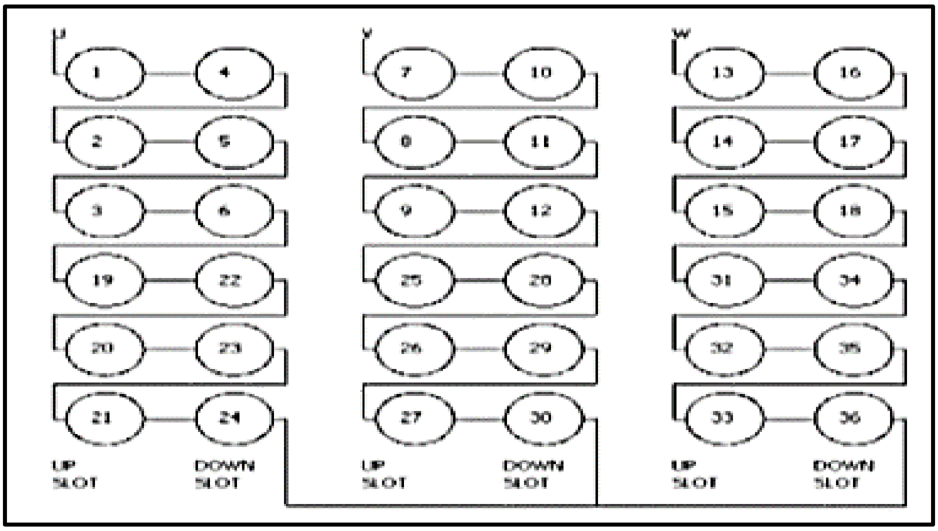

Fig.5.15: Single layer stator winding arrangement with parallel no.one and series no. twelve (Star connected) [168]

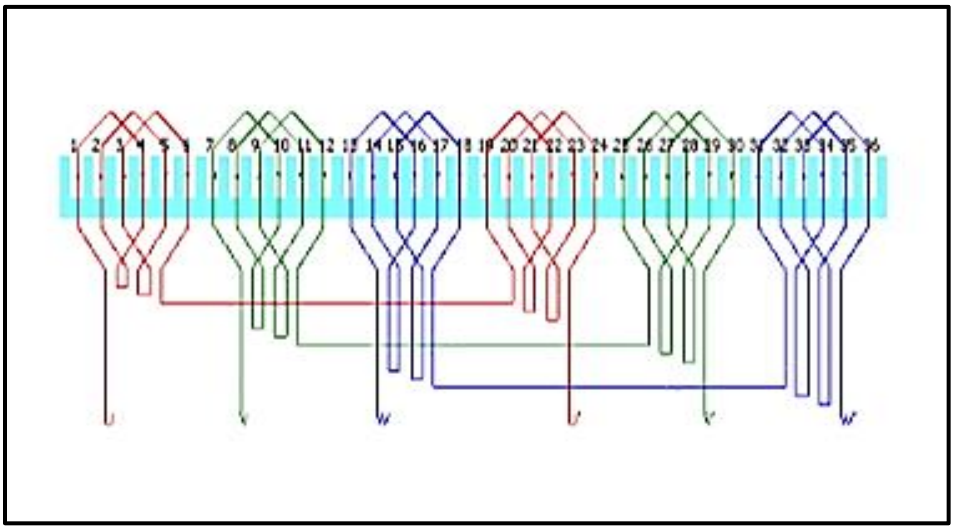

Fig.5.16: Single layer stator slot winding diagram with parallel no.one and Series no.twelve (Star connected) [168]

Fig.5.15 and Fig.5.16 show the stator winding and stator slot winding arrangements, when the winding is connected in star with parallel number one and series number twelve. Generally single layer winding is used in small rating ac motors working at rated voltages, but when the motors having this type of winding have to work under the rated voltages specific in the villages, the torque and power can't be obtained as given on the name plate of the machine, which specifically influence the performance of the motors.

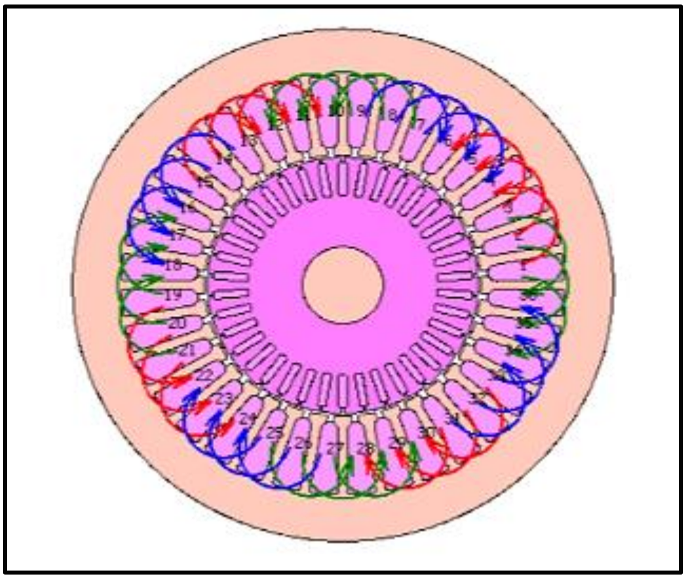

Fig.5.17: Double layer stator and rotor design winding diagram
(Star connected) [168]

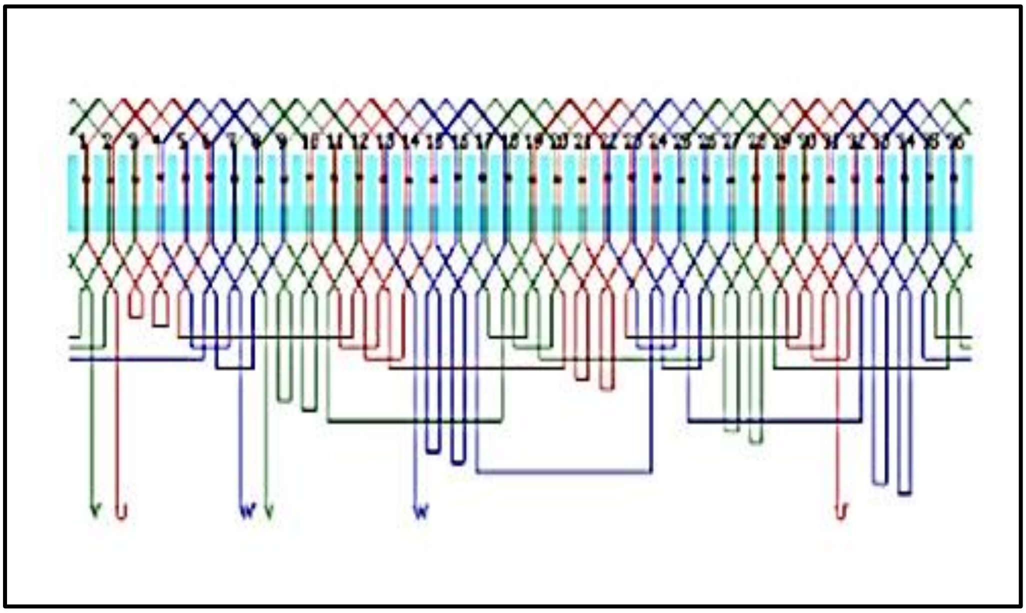

Fig.5.18: Double layer stator slot winding arrangements with parallel number one and Series number twelve (Star connected) [168]

Fig.5.18 demonstrate the stator slot winding arrangements, when the winding is associated with parallel number one and series number twelve, while Fig.5.19 shows the stator slot winding arrangements for parallel number two and series number six.

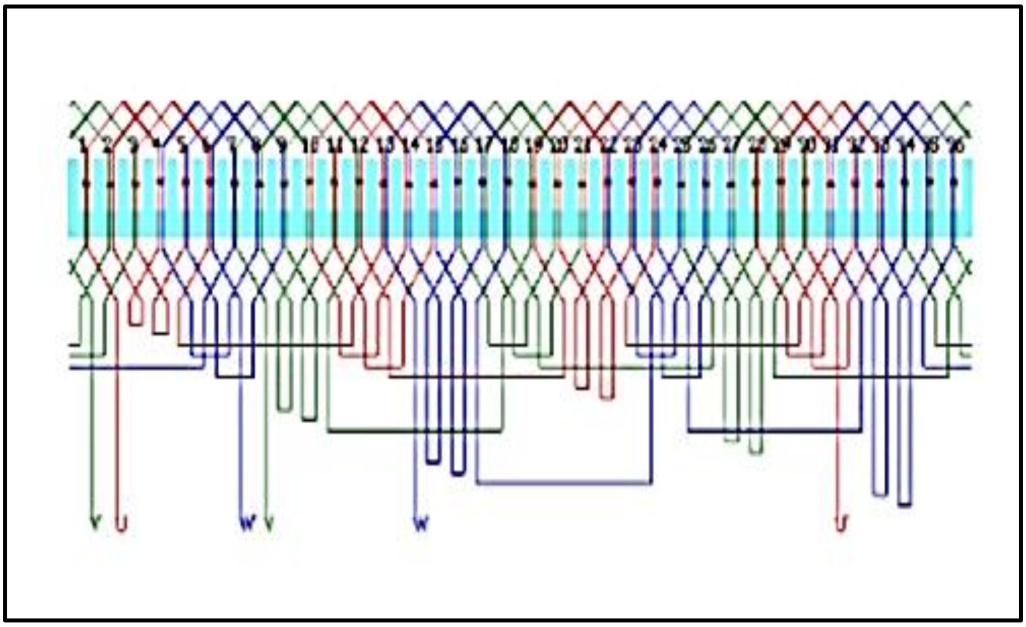

Fig.5.19: Double layer stator slot winding arrangement with parallel number two and Series number six (Star connected) [168]

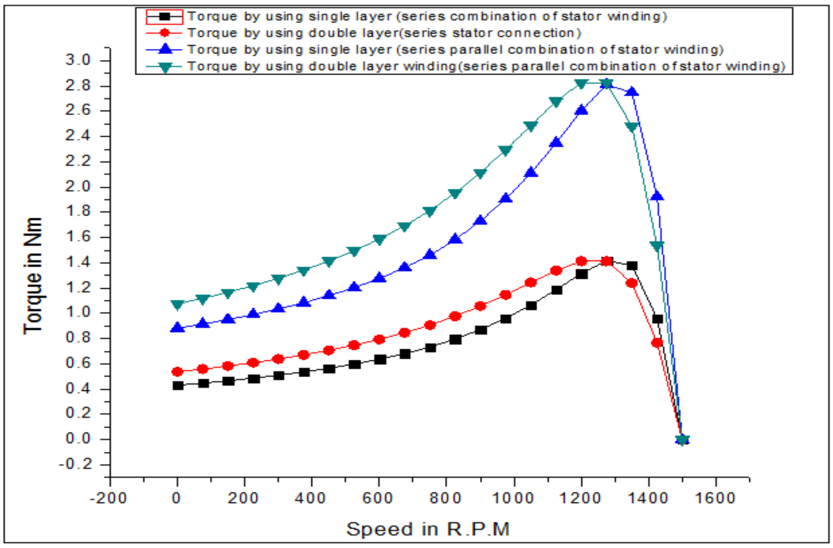

Fig.5.20: Torque Vs Speed [168]

Fig.5.20 demonstrate the torque and speed relationship for single layer and double layer winding in two modes. In first mode the stator winding is carried out by making parallel path one and series path twelve. Under this arrangement of winding when the motor is operating under the rated voltage the starting and maximum torque was 0.430 Nm and 1.187 Nm for single layer winding while it was 0.538 Nm and 1.339 Nm for double layer winding at its rated speed without load. In second mode the winding is connected in parallel path two and series path six. In this mode starting and maximum torque was measured 0.883 Nm and 2.34 Nm for single layer winding, but when double layer winding is used, the starting and maximum torque both can be improved up to 1.076 Nm and 2.67 Nm respectively.

Fig.5.21 also demonstrates the relationship between power developed and its rated speed, similarly by considering the same modes of arrangement of winding as discussed above. If we consider the first mode of winding arrangement, the maximum power developed was 195.082 watts and 175.359 watts respectively, but by we consider the second mode, it can be raised up to 388.373 watts and 350.704 watts respectively, however starting power developed in case of double layer winding is much better in both the cases.

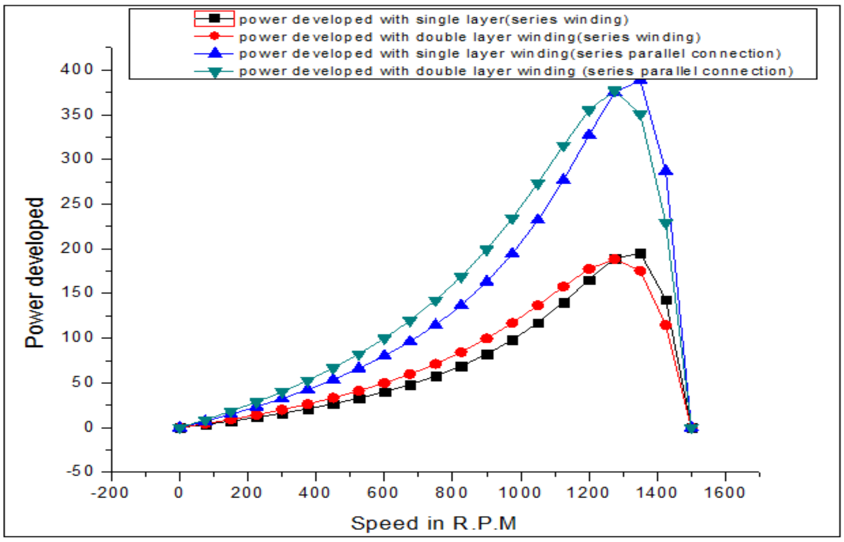

Fig.5.21: Power developed Vs Speed [168]

Basically there are two types of losses which occurs in three phase induction motors, one loss is a constant loss which depends on the development features of the motor and it varies in the extent of 2-3 percent and another one is the variable loss which depends on the load and voltage conditions. The occurrence of friction and windage losses are just 0.5-1 percent or may be neglected for small rating of machines. The capability of these motors can be extended by diminishing the losses, improving the cross section area of the conductors and changing the parameter measurements of the motors according to the assortment of the voltages.

It is also already concluded that the supply voltage lies under the rated voltage in the provincial zones, because of reactive power request by the clients. The change of supply voltage isn't much possible from the utility side, anyway the performance of thousands of induction motors which are working under the rated voltages, can be improved by adjusting the stator and rotor structure at improved value with another mix of stator winding plans. In the above investigated articles it is concluded that the general performance regarding torque, control created and efficiency of induction motor can be enhanced even when these types of motors are working under the rated voltage.

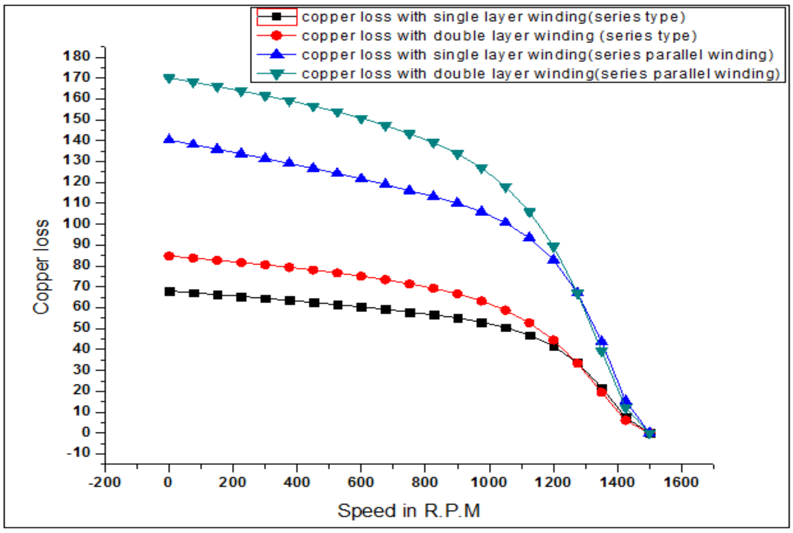

Fig.5.22: Copper losses Vs Speed [168]

Fig.5.22, demonstrates the relationship between copper loss and its rated speed. By considering the same modes as discussed above, due to high starting torque and power developed in both the cases, the copper losses will be slightly high at the time of starting of the motor in case of double layer winding as compared to single layer winding, but at rated speed almost copper losses become same in both the cases.

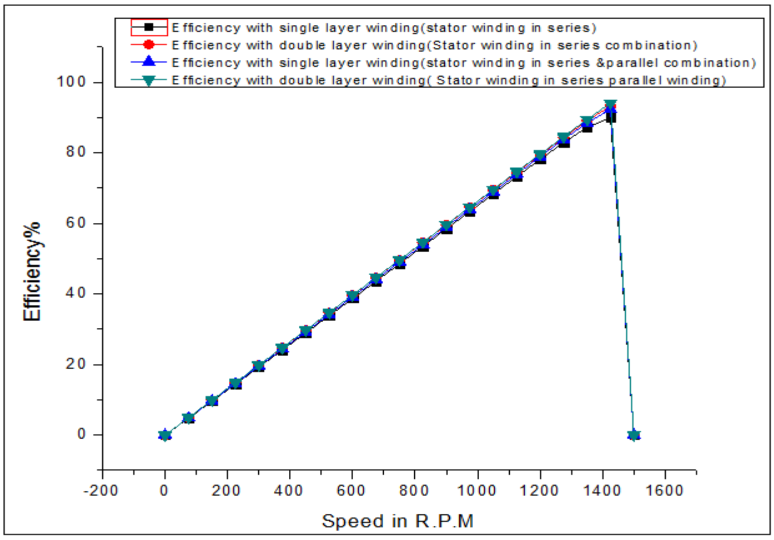

Fig.5.23: Efficiency Vs Speed [168]

Fig. 5.23, demonstrate the relationship between efficiency and speed on the same mode as discussed above. By considering the first mode the efficiency at its rated speed comes out to be 90.052% and it can be improved up to 94.131% by considering the second mode, while figure-5.24, illustrates the relationship between primary current taken by the motor Vs its rated speed. In both the modes current taken by the motor in case of single layer windings is more as compared to the double layer winding, which results in more power, better power factor and efficiency.

Table 5.10: Maximum value of main parameters, improved parameters at rated voltage and under the rated voltage at no load conditions **[168].**

At Normal voltage (415V)		Below normal voltage (370V)		Below normal voltage (370V) with improved value	
Parameters	Maximum value	Parameters	Maximum value	parameters	Max improved Value
Torque	1.776Nm	Torque	1.417 Nm	Torque	2.820 Nm
Power	245.54 watt	Power	195.082 watt	Power	350.704 watt
Power factor	0.72	Power factor	0.61	Power factor	0.78
Efficiency	90.19%	Efficiency	88.72%	Efficiency	94.13%

From table 5.10 it is observed that by using modified stator winding, the main parameters which directly relates to the efficiency of the motor can be improved even when the motor is operating under the rated voltage. The overall performances of the motor as discussed above depends upon the optimized stator and rotor parameters as tabulated in table 5.11

Table-5.11, demonstrates the design parameters of 5 HP three phase squirrel cage induction motor. The performances as discussed in fig.5.14 to fig.5.23 all are relies on these designed parameters.

The motors operating other than its rated voltage and rated frequency definitely affects its significant in terms of cost, characteristic and life. As a user's view point of view performance, life cycle, cost and reliability are the key elements for the success of any electrical motor in the market.

Design parameters of 5 HP three phase squirrel cage induction motor are calculated in table 5.11.

Table 5.11: Design parameters of 5 HP, 50 Hz, three phase squirrel cage induction motor operating under the variation of voltages [168].

Particulars	**Values**
Outer diameter	240 mm
Gap length	1.2 mm
Number of poles	4
Number of stator slots	36
Stator bore diameter	122.4 mm
Angle of slot	10.1degrees
Depth of stator slots	37.09 mm
Width of stator slot bottom	12.81 mm
Width of stator slot opening	3 mm
Height of stator tooth tang	3.2 mm
Angle of stator tooth tang	42.8 degrees
Fillet radius at stator slot bottom	0.72 mm
Fillet radius at stator slot top	0.36 mm
Number of secondary conductors	38
Outer diameter of rotor	120 mm
Shaft diameter	36 mm
Bar width	3.55 mm
Bar thickness	15.6 mm
Rotor tooth tang thickness	2.4 mm
Rotor slot opening width	0.88 mm
Rotor teeth	0.22 mm
End ring height	5.03 mm
Upper width of end ring	15.09 mm
Lower width of end ring	15.09 mm

5.5 OPTIMIZATION SCHEME

There are large number of design parameters of three phase induction motor. The selection of objective functions, constraints and variables plays a very important role for its optimum design. Nonlinear objectives functions are given by nonlinear programming problems, which are to be maximized/minimized with respect to the variables. To reduce the losses and running cost of the motor, higher efficiency is required. This is the reason that we have selected efficiency maximization as an objective function. The fitness function for an objective function is given by the relation.

$$\eta = \frac{1000P_o}{1000P_o + S_{cl} + S_{ir} + R_{cl} + W_f} \qquad \text{Eqn. (5.1)}$$

$P_o = Output\,power\,of\,\,the\,machine\,(KW)$

$$Stator\,copper\,loss(S_{cl}) = 3I_{ph}{}^2\,\mathrm{R}_{eq} \qquad \text{Eqn. (5.2)}$$

$$Stator\,iron\,losses\left(S_{ir}\right) = w_t * W_{tk} + W_c * W_{ck} \qquad \text{Eqn. (5.3)}$$

$W_t = Weight\,of\,\,stator\,teeth$

$W_{tk} = losses\,in\,stator\,teeth$

$W_c = weight\,of\,\,stator\,core$

$W_{ck} = losses\,in\,stator\,core$

$$Rotor\,copper\,loss\,(R_{cl}) = \frac{\rho_R * R_s * I_{br}{}^2}{a_b}\left(Lc + \frac{2\,De}{P}\right) \qquad \text{Eqn. (5.4)}$$

$\rho_R = is\,a\,cons\tan t\,quantity\,(0.021)$

$R_s = number\,of\,\,rotor\,slots$

$I_{br} = Rotor\,current$

$L_c = length\,of\,\,core$

$D_e = Diameter\,of\,\,end\,ring$

$P = Number\,of\,\,poles$

Since JMAG Express is an in-built tool, which can be used for the design of electrical machines. As already discussed, in this tool, response surface method is used to optimize the local parameters (constraints). These local parameters which can directly affect the performance of the motors are, stator and rotor temperature, primary current taken by the motor, flux density, Full load efficiency, magnetizing currents and power factor. These all are out put variables, which are influenced by the input variables. These output variables are directly related to the performance of the motors. A set of X variables of stator and rotor dimensions (for the selected design of stator and rotor), are optimized with the help of GA in terms of sensitivity analysis, as formulated in table no.5.10 of this article. The flow chart for optimization process is shown in the fig-5.24.

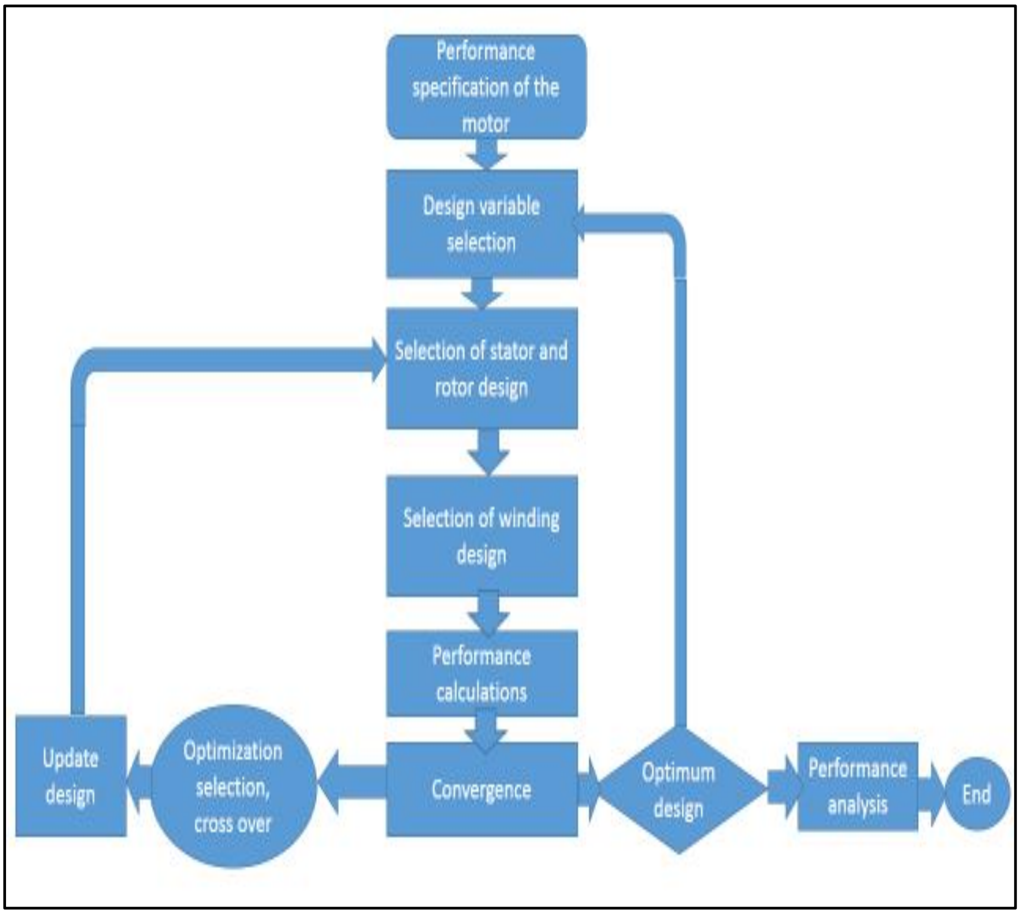

Fig: 5.24: Flow chart for optimization process [168]

5.6 CHAPTER SUMMARY

From the above discussion it is concluded that the performance of three phase induction motor decreases while working under the rated voltages. This decrease in performance prompts an expansion of aggregate power losses. It is also concluded that the performance of 1 H.P three phase squirrel cage induction motor operating under the rated voltage can be improved by optimizing the dimensions of a new combination of stator and rotor design, thereby making the alternate arrangements in its stator winding as discussed earlier. Based on the improved model, the software results of one horse power of three phase induction motor are applied for the results of hardware approach and calculated the performance of a new constructed motor by operating it under rated to rated voltages. The results of new motor was better when compared with conventional one. The performance of such types of induction motors which are working under rated voltages, can be improved by modifying the stator and rotor designed at its optimized value. The simulation results of 5 H.P three phase induction motor are also calculated in terms of better torque, power developed and efficiency even when the motor operates under rated voltages. However when the software results are to be compared with a real model, the results may differ from 5% to 10%, because this optimized model is based on the software approach at no load conditions. When the software approach of this model (1 HP motor) is applied for the hardware approach, the results of a new energy efficient motor in terms of efficiency was approximate 3.5 percentage more as compared to the conventional motor even when operating under the rated voltage.

CHAPTER-6

CONCLUSION AND FURTHER RESEARCH

6.1 CONCLUSION

Three phase induction motors which are designed at rated voltage, however are working under the rated voltage specifics in the rustic zones from the utility centers. There are a few change techniques which can improve the concept of the supply voltage from utility side, but the modifications in terms of parameters is the best way to enhance the performance of such types of motors which are design at rated voltages, but operating under the rated voltages. The objective of this research work was to plan a three phase induction motor which can give the best performance under the variation of voltages. The efficiency improvement and optimized parameters of three phase squirrel cage induction motor working at rated to under rated voltages have been calculated with the help of JMAG Express. As already discussed this software embedded the response surface method and Genetic Algorithm (GA) as the optimized engine, which can generates the parameters in terms of sensitivity analysis by using correlation matrix. The summarized work as per the objectives of the thesis are as under.

To fulfill the preliminarily target of this research work, a mathematical modeling in terms of the output equations of three phase induction motor of rating 2.2 kw are programmed (appendix-I and appendix-II) and the outcomes are carried out at its rated and under rated voltages. To figure the positive outcomes toward this direction, a research article is composed to compute the performance of this motor which was designed at the rated voltage, but working under the rated voltage. The losses and performance in terms of efficiency of the motor are calculated at rated voltage and under rated voltages. The objective of this research article was to determine the change in parameters of stator and rotor of this motor by modifying its ampere conductors. The change in parameters have been calculated without change and with altered ampere conductors at rated and under the rated voltage. The objective of this research article was to judge the linear and nonlinear parameters of this motor at rated and under rated voltage, so that we can optimize these parameters under the variations of voltages. To fulfill the next target a proposed JMAG Express technique with genetic algorithm as an optimized tool is used for 7.5 kw squirrel cage induction motor, The detail is worked out to give enhance efficiency as an object function with the help of various improved local parameters. These local parameters are optimized with the help of surface response method (SRM), while the procedure for overall optimization is carried out with the help of genetic algorithm under the variations of it's rated to under rated voltage. This is assessed that the performance of squirrel cage induction motor outfitted with copper cage rotor is more as compared to the motor having an aluminum cage rotor, however by assembling a mix of rectangular type bar rotor with parallel tooth opening round base as a stator, the efficiency at the underlying phases of an aluminum enclosure motor is more when compared with a motor having copper cage motor. This is presumed that the torque developed by a motor having an aluminum cage rotor is also more when compared with a motor having a copper cage rotor at its underlying stages. However for financially point of view, assembling perspective of an aluminum cage rotor has been given preference to compute the optimized results at rated to under rated voltage that are tabulated in detailed results. However for implementation purpose the best performance of three phase induction motor at optimized iron losses are also carried out 11 kw induction motor by using distinctive shape of stator and rotor design at room temperature to its working temperature of motor. The objective was to analyze the efficiency. Under an extensive variation of temperature this efficiency diminishes marginally, while this gap can be overcome by optimizing the iron losses. During these research findings on three phase induction motor, this is observed that the stator number of turns are also an effected parameter under the variation of voltages. According to the mathematical modeling of equations, it is observed that the number of turns of the stator winding would also be optimized, which largely affects the variable losses thereby changing

the other nonlinear parameters of the motor. To fulfill this objective a combination of mathematical modeling and software approach is also carried on 3.75 kw induction motor by optimizing stator turns at its rated voltage.
After optimization and implementation, the software results of one horse power of three phase induction motor are applied for the results of hardware approach and calculated the performance of a new constructed one horse power motor by operating it under rated voltage. The results of new motor was compared with the old one, which was to be operated at rated to under rated voltage. It is presumed that the new motor have better outcomes when compared with the old one. A software approach is also applied for the design of 5 H P three phase induction motor by making the alternate arrangement in the stator winding, so as to get its best performance at rated to under rated voltages. From the above discussion, it is concluded that the attempts have been made to enhance the performance of three phase squirrel induction motors which are designed to operate at rated voltage, however have to work under the rated voltages.

6.2 FURTHER RESEARCH

Since the efficiency of induction motors are all around characterized very well, however because of reactive power request, voltage fluctuates particular in the rural areas away from the utility centers. This is found that the performance of these induction motors won't be up to the mark, if they have to operate under the rated voltages. In this research work, attempts have been made by the scholar to enhance the performance of such types of induction motors which are composed at rated voltage, but are operating under the rated voltages and find out the virtual brings in this direction by considering every one of the objective as discussed earlier.

For further research this kind of technique for design improvement and optimization can also be applied for different types of rotating electric motors like single phase induction motors, synchronous motors, direct current motors and brushless motors etc. To verify the results a mathematical approach can also be applied for the above carried out results. By making more different arrangements in stator winding with modified stator and rotor design, the best performance can be carried out, even when these motors have to operate under the rated voltages.

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Appendix-A

PROGRAMING FOR GRAPHIC USER INTERFACE

```
m=str2double (get (handles.m,'string'));

f=str2double (get (handles.f,'string'));

NS=str2double (get ( handles.NS,'string'));

n=str2double (get (handles.n,'string'));

Pf=str2double (get (handles.Pf,'string'));

Bav=str2double (get (handles.Bav,'string'));

Ac=str2double (get (handles.ac,'string'));

KW=str2double (get (handles.KW,'string'));

Ki=str2double (get (handles.Ki,'string'));

Es=str2double (get (handles.Es,'string'));

qs=str2double (get (handles.qs,'string'));

c=str2double (get (handles.c,'string'));

Wd=str2double (get (handles.Wd,'string'));

Id=str2double (get (handles.Id,'string'));

dss=str2double (get (handles.dss,'string'));

Wss=str2double (get (handles.Wss,'string'));

Fds=str2double (get (handles.Fds,'string'));

Idr=str2double (get (handles.Idr,'string'));

Dbr=str2double (get (handles.Dbr,'string'));

Ierd=str2double (get (handles.Ierd,'string'));

Ted=str2double (get (handles.Ted,'string'));

Os=str2double (get (handles.Os,'string'));
```

```
ats=str2double (get (handles.ats,'string'));
ats1=str2double (get (handles.ats1,'string'));
ats2=str2double (get (handles.ats2,'string'));
Or=str2double (get (handles.Or,'string'));
IsrIst=str2double (get (handles.IsrIst,'string'));
FwL=str2double (get (handles.FwL,'string'));
Pi=str2double (get (handles.Pi,'string'));
TIL=str2double (get (handles.TIL,'string'));
%ATS1=str2double (get (handles.ATS1,'string')); %may be removed.......
XX=str2double (get (handles.XX,'string'));
%RT=str2double (get (handles.RT,'string'));
%Inputs For Main Dimensions (Stator)......
P=round ((120*f)/NS);
Q= (Pi)/ (n*Pf); %replace (HP*.746) by Pi %Q=P/(n*Pf);replace P by
    HP*.746).....
Co= (11*Bav*ac*KW)/1000;
DDL=Q/ (Co*(NS/60)); %NS divided by 60.....
a=(c*3.14)/P;
D=((DDL)/(a))^(1/3);%D=((P*DDL)/(4.7143))^(1/3);(DDL/a) replace.....
L=a*D; %L= (Q/ (Co*(NS/60)))/ (D*D); L=a*D......replace
Tq=L/C; %replaced......
Nd= (L*1000)/120;
Li=Ki*(L-(Nd*Wd));
%Inputs For Stator Design..............
F= (Bav*3.14*D*L)/P;
```

```
Rb=get (handles.Rb,'value');

If (Rb==0)

Ts=XX;

else

Ts=round (Es/ (4.44*f*F*KW)); %write round.......

end

T=6*Ts;

Ss=m*P*qs; %select the value of qs 2or 3....

Yes= (3.14*D)/Ss;

Zss=T/Ss;

Tc=Zss*Ss;

T1s=Tc/6;

Cs=Ss/P;

KP=cos (3.14/ (2*Cs));

Kd=sin (qs*(3.14285/ (2*Cs)))/ (qs*sin (3.14/ (2*Cs)));

Kws=KP*Kd;

Is= (Q*1000)/ (m*Es) ;%( Pi*1000)/ (m*Es*n*Pf) replaced.....

As=Is/Id;

d= ((4*As)/3.14285) ^ (0.2);

AA= (3.14285*(D*1000))/Ss;

Wt=AA-Wss;

Fd= (F*P*1000)/ (Ss*Wt*Li);

Lmts= (2*L) + (2.3*Tq) +.24;

R= (.021*Ts*Lmts)/As;

PSCL=3*Is*Is*R;
```

```
Fs=F/2;
Acs=Fs/Fds;
Dcs=Acs/Li;
Do= (D*1000) +2*(dss+ (Dcs*1000)); %replace 100 by 1000?????.....
X=[P Q Co DDL a D L Nd Li F Ts T Ss Yss Zss Tc T1s Cs Kp Kd Kws Is As d
    AA Wt Fd Lmts R PSCL Fs Acs Dcs Do];
%this is for the selection of the output............
zz=get (handles.output1,'value');
If (zz==1)
untitled1440(X);
end
%Inputs For Rotor Design..................
Ig= (.2+ (2*(D*L) ^ (.5)));
Dr= ((D*1000)-(2*Ig));
Sr= (Ss+ (P/2));

Ysr= (3.14*Dr)/Sr;
Ibr= (2*m*Kws*Ts*Is*Pf)/Sr;
Abr=Ibr/Idr;
Wbr=Abr/Dbr;
Wbr1=Wbr+1;
Dbr1=Dbr+3;
AAbr= ((3.14*(D*1000))-(2*Dbr1))/Sr;
Wbrt=AAbr-Wbr1;
Fbrd= (F*P)/ (Sr*Li*Wbrt);
```

```
Lbr= (L*1000) + (2*20+10);

Rbr= ((.021)*(Lbr/1000))/Abr;

PLC= (Sr*Ibr*Ibr*Rbr);

Ier= (Sr*Ibr)/(3.14*P);

Aer=Ier/Ierd;

Ded=Aer/Ted;

DCO=Dr-(2*Wbr1);

Dei=DCO-(2*Ded);

Dem= (DCO+Dei)/2;

Red= (.021*(Dem/1000))/Aer;

PLC1=2*Ier*Ier*Red;

PLC2=PLC1+PLC;

SLiP=(PLC2/((Pi*1000)+PLC2+(Pi*10)))*100;%((PLC2/(Pi*1000))/((1+PLC2)
    /(Pi*1000)));%Pi replaced by Q.....

N=NS*(1-(SLiP/100));

f2= (SLiP/100)*f;

Tz= (Pi*1000)/ (N*(1/60)*2*3.14);

Drc=5; %Value Change.............

Dcs1=5; %value change................

Drcia=Dr-(2*Drc)-(2*Dbr1);


z=[Ig Dr Sr Ysr Ibr Abr Wbr Wbr1 Dbr1 AAbr Wbrt Fbrd Lbr Rbr PLC Ier Aer
    Ded DCO Dei Dem Red PLC1 PLC2 SLiP N f2 Tz Drc Drcia];

if (zz==2)

untitled1443 (z);
```

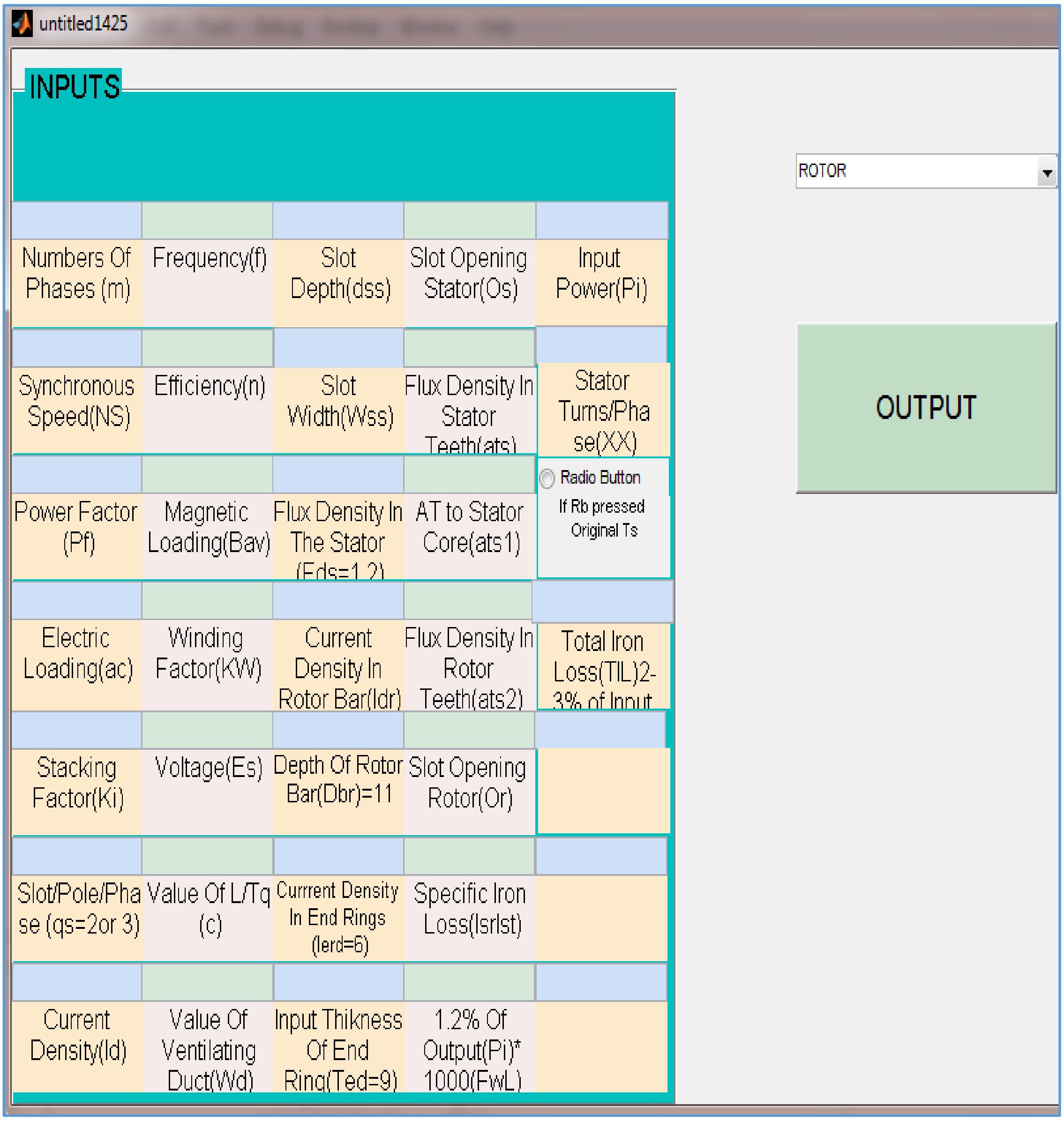
```
end
%inputs for No Load Current Calculation......
I=Os/Ig;
Kcs=1/ (1+5*(Ig/Os));
Kgss= (Yss*1000)/((Yss*1000)-(Kcs*Os));
I2=Or/Ig;
Kcr=1/ (1+ (5*(Ig/Or)));
Kgsr=Ysr/ (Ysr-(Kcr*Or));

Kgs=Kgss*Kgsr;
I3= (Wd*1000*2)/Ig;
Kcd=1/((1+(5*Ig))/(Wd*1000*2));
Kgd=(L*1000)/((L*1000)-(Nd*(Wd*1000)*Kcd));
Kg=Kgs*Kgd;
Ige=Kg*Ig;
AgP=L*Tq;
Bg=1.36*Bav;
ATS=(800000*Bg*Kg*Ig)/1000;
Wts= (3.14*(D*1000) + ((2*dss)/m))/(Ss-Wss);
Ats=(Ss*(Wts/1000)*Li)/P;
Bts=F/Ats;
Acs=(Dcs1*Li)/1000;
Bcs=1200000;
Lcs= ((3.14*(D*1000)) + ((2+dss) +Dcs1))/ ((m*Pi)*1000);
ATS2=ats1*Lcs;
```

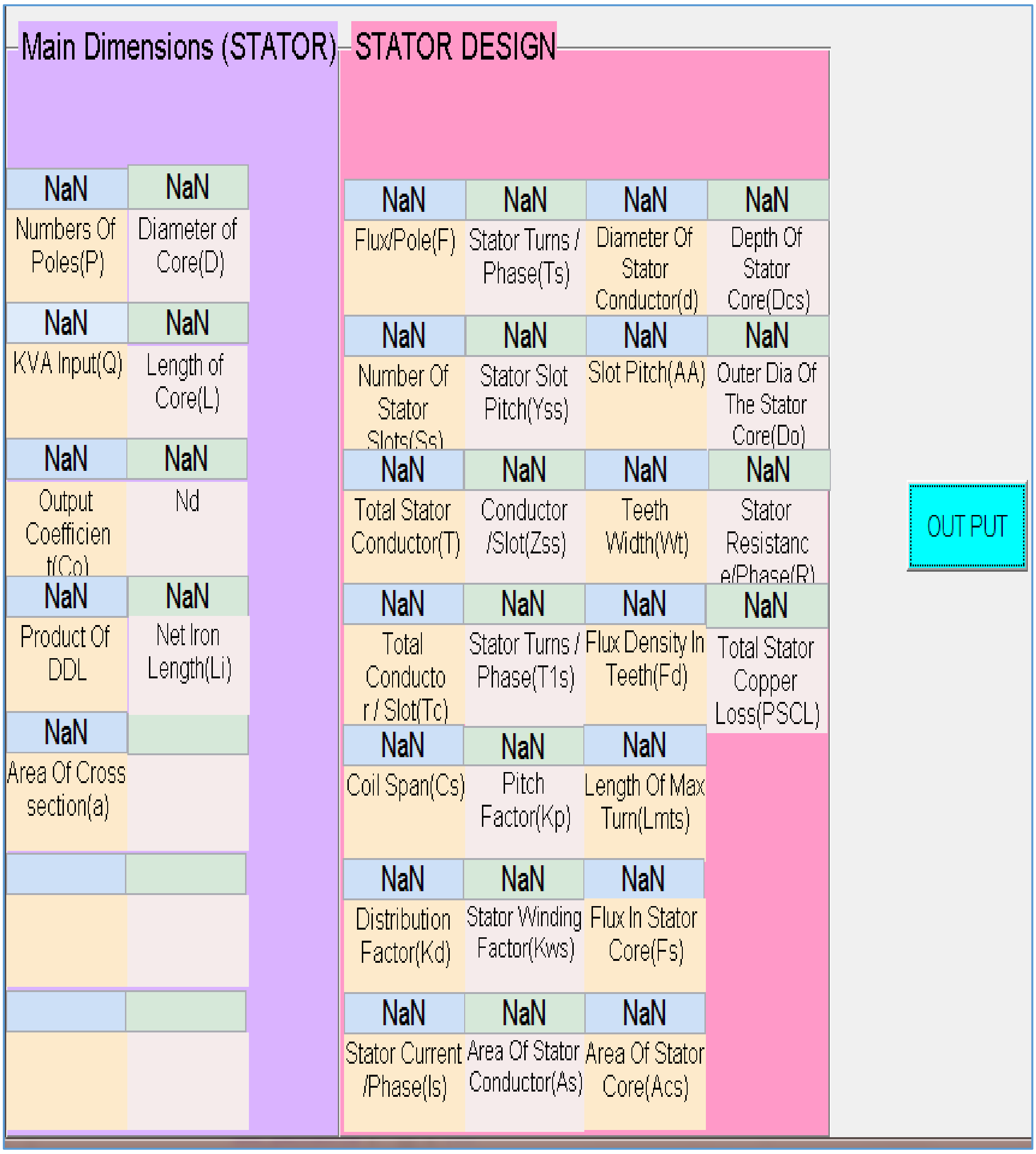
```
Wrt= (3.14*(Dr-((4*Dbr1)/m))/Sr)-Wbr1;

Art= (Sr*Li*Wrt)/(Pi*1000);

Brt=F/Art;

ATS3= (ats2*Dbr1)/1000;

Acr=Acs;

Bcr=Bcs;

art1=ats1;

Lcr= (3.14*((D*1000)-(2*Dbr1)-Dcs1))/(m*P);

ATS4=art1*Lcr;

ATS1= (ats*dss)/1000;

TATS=ATS+ATS1+ATS2+ATS3+ATS4;

Im= (.4238*P*TATS)/(Kws*Ts);

h=[I Kcs Kgss I2 Kcr Kgsr Kgs I3 Kcd Kgd Kg Ige AgP Bg ATS Wts Ats Bts
    Acs Bcs Lcs ATS2 Wrt Art Brt ATS3 Acr Bcr art1 Lcr ATS4 ATS1 TATS
    Im];

if (zz==3)

untitled1445 (h);

end

%Inputs for Loss Component.................

%West=Ss*(dss*1000)*(Wts*1000)*Li*(7.6*1000);

%Bstmax= (3.14*Bts)/2; %'all are remove & put a box in input window.....

%IrIst=IsrIst*West;

%PmSc= (3.14*(Do-Dcs1))/1000;

%Wesc=PmSc*Dcs1*Li*7.6;

%IrIsc=1.200*Wesc;
```

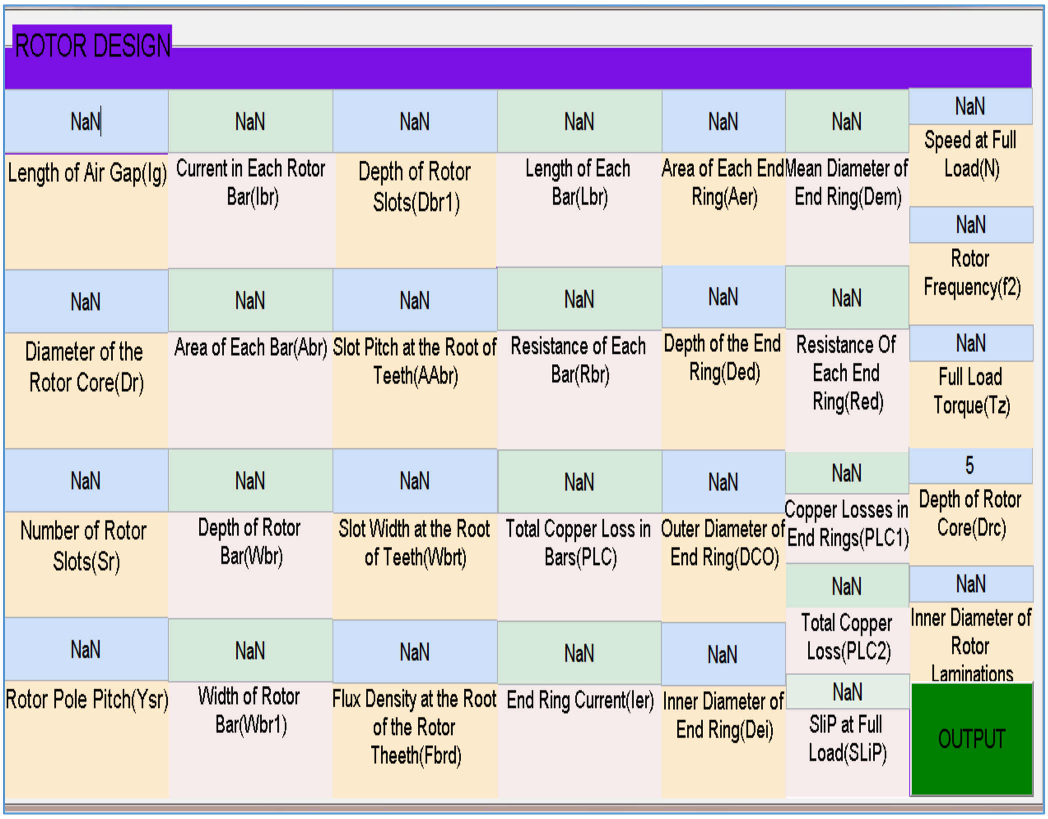
```
%TIrIs=IrIst+IrIsc;

%AIrIs=2*TIrIs;

%FWII= (FwL/100)*(Pi*1000);

%TnII=AIrIs+FWII;

%II=TnII/(m*Es);

%InI=Im.*Im+II.*II;

%PfnI=II/InI;

%R= (.021*Ts*Lmts)/As; %replace & put in Rotor window.....

%PSCL=3*Is*Is*R;

V1=Es/1.732;

P4=3*V1*Is*Pf;

Pg=P4-PSCL-TIL;

Pm= (Pg*(1-(SLiP/100)))-FwL;

ns= (2*f)/P;

Td=Pg/(2*3.174*ns);

n=ns*(1-(SLiP/100));

Tl=Pm/ (2*3.174*n);

%Inputs For Efficiency............

OPfL=Pi*1000;

IPfL=OPfL+PSCL+PLC+TIL+FwL;

Eff= ((OPfL)/ (iPfL))*100;

Eff1= (Pm/P4)*100;

m= [V1 P4 Pg Pm ns Td Tl OPfL iPfL Eff Eff1];
```

Appendix-B

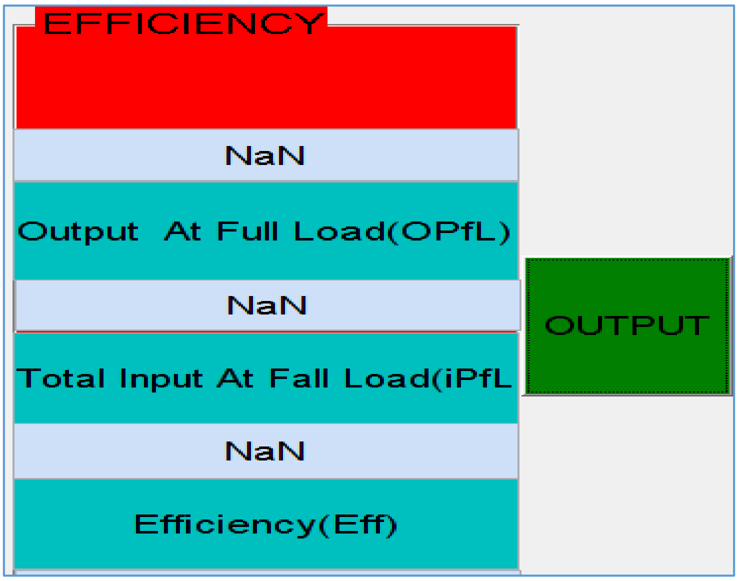
GRAPHIC USER INTERFACE (GUI) MODEL




Main Dimensions (STATOR)
STATOR DESIGN
NaN
Numbers Of Poles(P)
NaN
Diameter of Core(D)
NaN
KVA Input(Q)
NaN
Length of Core(L)
NaN
Output Coefficient(Co)
NaN
Nd
NaN
Product Of DDL
NaN
Net Iron Length(Li)
NaN
Area Of Cross section(a)
NaN
Flux/Pole(F)
NaN
Stator Turns / Phase(Ts)
NaN
Diameter Of Stator Conductor(d)
NaN
Depth Of Stator Core(Dcs)
NaN
Number Of Stator Slots(Ss)
NaN
Stator Slot Pitch(Yss)
NaN
Slot Pitch(AA)
NaN
Outer Dia Of The Stator Core(Do)
NaN
Total Stator Conductor(T)
NaN
Conductor /Slot(Zss)
NaN
Teeth Width(Wt)
NaN
Stator Resistance/Phase(R)
NaN
Total Conductor / Slot(Tc)
NaN
Stator Turns / Phase(T1s)
NaN
Flux Density In Teeth(Fd)
NaN
Total Stator Copper Loss(PSCL)
NaN
Coil Span(Cs)
NaN
Pitch Factor(Kp)
NaN
Length Of Max Turn(Lmts)
NaN
Distribution Factor(Kd)
NaN
Stator Winding Factor(Kws)
NaN
Flux In Stator Core(Fs)
NaN
Stator Current /Phase(Is)
NaN
Area Of Stator Conductor(As)
NaN
Area Of Stator Core(Acs)
OUT PUT



ROTOR DESIGN
NaN
Length of Air Gap(lg)
NaN
Current in Each Rotor Bar(Ibr)
NaN
Depth of Rotor Slots(Dbr1)
NaN
Length of Each Bar(Lbr)
NaN
Area of Each End Ring(Aer)
NaN
Mean Diameter of End Ring(Dem)
NaN
Speed at Full Load(N)
NaN
Rotor Frequency(f2)
NaN
Diameter of the Rotor Core(Dr)
NaN
Area of Each Bar(Abr)
NaN
Slot Pitch at the Root of Teeth(AAbr)
NaN
Resistance of Each Bar(Rbr)
NaN
Depth of the End Ring(Ded)
NaN
Resistance Of Each End Ring(Red)
NaN
Full Load Torque(Tz)
NaN
Number of Rotor Slots(Sr)
NaN
Depth of Rotor Bar(Wbr)
NaN
Slot Width at the Root of Teeth(Wbrt)
NaN
Total Copper Loss in Bars(PLC)
NaN
Outer Diameter of End Ring(DCO)
NaN
Copper Losses in End Rings(PLC1)
5
Depth of Rotor Core(Drc)
NaN
Total Copper Loss(PLC2)
NaN
Inner Diameter of Rotor Laminations
NaN
Rotor Pole Pitch(Ysr)
NaN
Width of Rotor Bar(Wbr1)
NaN
Flux Density at the Root of the Rotor Theeth(Fbrd)
NaN
End Ring Current(Ier)
NaN
Inner Diameter of End Ring(Dei)
NaN
SliP at Full Load(SLiP)
OUTPUT



EFFICIENCY
NaN
Output At Full Load(OPfL)
NaN
Total Input At Fall Load(iPfL
NaN
Efficiency(Eff)
OUTPUT

LIST OF PUBLICATIONS

1. Saini Raj Kumar, Saini Devender Kumar, Gupta Rajeev and Verma Piush, "Optimized design of three phase squirrel cage induction motor based on maximum efficiency operating under the rated voltage – based on software platform," Indian Journal of Science and Technology, vol. 9,no.21, pp. 1-7, June. 2016.

2. Raj Kumar Saini, Devender Kumar Saini, Rajeev Gupta and Piush Verma, "Design improvement and assessment of efficiency of three phase induction motor operating under the rated voltage," Advances in Intelligent Systems and Computing, vol. 479,pp.495-501, Sept.2017.

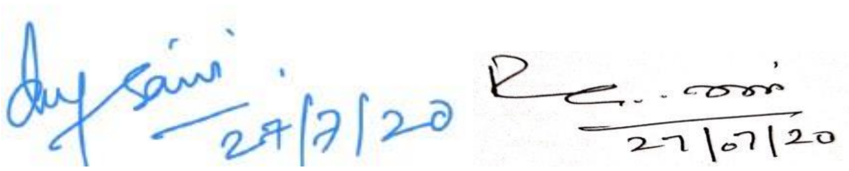
3. Raj Kumar Saini, Devender Kumar Saini, Rajeev Gupta and Piush Verma, "A software approach for the prediction of efficiency of three phase induction motor at optimize iron losses," IEEE International conference on power electronic, vol. 978,pp.1-7,Oct.2016.

4. Raj Kumar Saini, Devender Kumar Saini, Rajeev Gupta, R.P.Dwivedi and Piush Verma, "Design, analysis and assessment of efficiency of three phase squirrel cage induction motors operating under the rated voltage: a design consideration for rural areas application," Advances in Intelligent Systems and Computing, vol. 624, pp. 13-21, April,2018.

5. Raj Kumar Saini, Devender Kumar Saini, Rajeev Gupta, R.P.Dwivedi and Piush Verma, "A new design for low rating three phase induction motor with improved performance operating under rated voltage-a design consideration for rural areas," Journal on Electrical Engineering,vol.13, no.2,pp.11-17,Dec. 2019.

6. Raj Kumar Saini, Devender Kumar Saini, Rajeev Gupta, Piush Verma R.P.Dwivedi,Neeraj Gandotra, Robin Thakur, Ashwani Sharma, "Performance improvement of three phase squirrel cage induction motor operating under rated voltages- A design consideration for rural areas," advances in intelligent systems and computing,vol. 989,pp.1-11Jan.2020.

Plagiarism Report



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