# CHAPTER 1
# INTRODUCTION

## 1.1 CONSERVATION OF ENERGY

Conservation of electrical energy is a vital area, which is being regarded as one of the global objectives. Along with economic scheduling in generation of electricity and use of modern equipments in transmission and distribution network, it is also important to optimize the energy requirement of electric loads.

It is said that energy saved is energy generated. Improving the efficiency of electrical equipment is now recognized in many countries as a less costly means than construction of new power plants for meeting some of the increased demand for electricity services [1]. In today's energy scenario, industries are the major consumers of electric energy produced in any country. Electrical motors, being the most widely used energy converters in any industry, even a small percentage of energy saving in it is considered to be a big deal in existing industrial drive applications.

## 1.2 METHODS OF ENERGY CONSERVATION

In India, about 60 % of the generated electricity is consumed by 3 – phase squirrel–cage Induction motors installed in industrial, agricultural and other applications. It is estimated that, every one percent reduction in energy consumption by this electric drive would save around Rs.500 crore per annum [2].

Several measures can be adopted for reducing energy losses in Induction motors and improving energy conservation. The recommended ways to achieve this are:

( i ) By design modifications
( ii ) By constructional modifications
( iii ) By efficient operation

### 1.2.1 Design Modifications

Numerous noteworthy works have been carried out in the area of Induction motor design. One of the earliest was that of Erlicki and Applebaum [3] whose work focused on parameter optimization with relevance to consumer and national economy. The parameters so determined could ensure minimum cost_only and not the machine properties. Ramarathnam, et.al [4] optimized the Induction motor design, taking into account the active material cost alone. He used non – linear programming approach with different optimizing techniques. Chaoyang li and Arifur Rahman [5] presented a modified form of the Hooks and Jeeves approach . In most of the available literature , the main focus has been on the cost of the active material and not much on the operating cost . Bhimsing , et.al [6] have done optimization of Induction motor for various objective functions viz cost of active material , annual operating cost , overall cost , efficiency , power factor and the product of efficiency and power factor . In 1995 , J.W. Nims . et.al [7] did a work on Power Transformer design using Genetic Algorithm. In 1997, Kenneth Price and Rainer Storn[8] highlighted the potential of Differential Evolution for fast optimization.

### 1.2.2 Constructional Modifications

Developing Induction motors is a standard technology with existing manufacturing infrastructure. They are preferred for their higher reliability and maintenance free operation. However, they have the disadvantages of decrease in speed with increase in load, slip-dependent rotor copper loss and low power-factor of operation. On the other hand, Synchronous motors have constant speed operation and better power-factor. But, they require DC excitation and extra starting arrangement. Permanent Magnet Induction - Synchronous Motor (PMISM) combines the advantages of both the above mentioned conventional motors. Permanent Magnet AC motors are attracting growing international attention for a wide variety of industrial applications, ranging from general-purpose line-start pump/fan drives [9] to high performance machine tool servos [10]. New development of more powerful and cost-effective PM materials is serving to accelerate those motor development efforts [11]. Combination of squirrel cage rotor with interior permanent magnet geometry provides possibilities for efficient steady state operation and robust line-starting [12,13]. Different models of PMISM were tried by various groups [14, 15, 16].

The conventional submersible motor pumping systems are inefficient due to the limitation in speed and usage of higher number of stages in deep wells [17]. The performance of the pumping system can be improved considerably when operated at higher speeds i.e. more than 3000 rpm (synchronous), which is the limiting speed for a 50 Hz motor with 2-pole construction. Running the motor pump at a higher speed can be realized by increasing the supply frequency, which yields reduction in number of stages in pump and volume of active material used in motor [18].

### 1.2.3 Efficient Operation

Variable voltage operation of partly loaded Induction motor attracted the attention of many researchers as a means of energy saving in this context [19-22]. In earlier works, the control strategy employed is basically a search technique, where the stator voltage is decreased in steps, until the motor current settles down to the lower value, for a given load. The search technique takes more time for reaching the optimum point than can normally be allowed. Also, no clear-cut design procedure for the controller is presented. Many step changes in motor voltage lead to poor dynamic response and also takes more time for reaching the optimum point. The fuzzy logic control approach is very useful for Induction motor drives since no exact mathematical model of the Induction motor or closed-loop system is required [23].

## 1.3 SCOPE OF THE THESIS

This thesis deals with the investigation that has been carried out with the aim of energy conservation in electric drives. Development of different prototype energy efficient electric drives fulfills the aim. Also, a novel method for predicting energy efficient operation of 3-phase Induction motor is established.

With the aim of developing Energy Efficient Induction Motor (EEIM) , design optimization is proposed to be carried out . Optimal design problem is considered as a non-linear multi – variable constrained problem. Imposition of a multitude of constraints makes optimization tedious. In this work, the following well established robust and optimization techniques are proposed for developing EEIM:

* Genetic Algorithm Technique
* Differential Evolution Technique

Based on the optimal design results obtained by Genetic Algorithm Technique, two EEIMs are proposed to be developed. Their ratings are 11 kW and 3.7 kW , 415 V , 3-phase , 50 Hz , 4-pole.

Another 11 kW , 415 V , 3-phase , 50 Hz , 4-pole EEIM is also proposed to be developed with the results obtained by Differential Evolution Technique.

For most of the industrial applications, Induction motors are preferred due to their robust construction, higher reliability and maintenance free operation. However, they have the disadvantages of decrease in speed with increase in load and low power factor. To overcome the above disadvantages it is proposed to develop a Permanent Magnet Induction – Synchronous Motor (PMISM ). The proposed PMISM integrates the features of Permanent Magnet ( PM ) motors with those of conventional Induction and Synchronous motors. Combination of squirrel cage rotor with interior permanent magnet geometry provides possibilities for efficient steady state operation and good line starting. The synchronous operation eliminates the rotor copper loss which leads to improvement in efficiency. A prototype 1-phase, 0.75 kW, 230 V, 50 Hz , 2-pole PMISM is intended to be developed.

Attention was also given to Induction motors employed in agricultural pumping sector. In order to utilize the available ground water below 120 m depth, efficient bore-hole multistage submersible pumps are required. Due to the limitations in the diameter, the number of stages required in the conventional pumping system is very large for the high head applications (12–24). This leads to more moving parts and low efficiency. The performance of the pumping system can be improved considerably when operated at higher speeds i.e. more than 3000 rpm, which is the limiting speed for a 50 Hz motor with 2-pole construction as already mentioned. It is proposed to develop single stage submersible motor pumps of 2.2 kW for 100 mm size and 9.3 kW for 150 mm size bore wells for heads of 60 m, 2.0 lps and 120 m, 4.0 lps respectively in stainless steel body. They are to be operated with a microprocessor based controller capable of varying frequency up to 200 Hz . When the rotor speed is increased, say to 11 000 rpm, the rise in each stage is found to be very high. This will lead to reduction of number of stages to either 1 or 2.

Variable voltage operation of partly loaded Induction motor has attracted the attention of many researchers as a means of energy conservation . In a lightly loaded Induction motor , a large amount of energy is wasted which can be conserved by voltage control. There is a distinct stator voltage for each load condition for optimum performance. The fuzzy logic control approach is found to be very useful for Induction motor drives since no exact mathematical model of the Induction motor or the related closed loop system is required . A laboratory prototype fuzzy logic controller is proposed to be designed, developed and tested with 0.37 kW , 3-phase , 50 Hz , 4-pole Induction motor . The fuzzy logic controller will adjust the terminal voltage of the motor continuously, based on sampled values of current feedback , to maximize the efficiency of operation at any given load.

Modern computer and telecommunication systems place heavy demands on the availability and quality of the power supply . Invariably Uninterruptable Power Supply (UPS) system is used everywhere as a power conditioner. This work proposes the augmentation of solar photovoltaic supply with Electricity Board (EB) supply through supervisory controllers for energy conservation . A battery monitoring circuit in the proposed controller will sample the battery voltage , solar panel voltage and the EB supply in order to switch over between two modes ( stand alone mode or grid interface mode) or sound an alarm if both the primary source (EB supply / solar photovoltaic supply) and secondary source (battery) fails. Energy conservation can be achieved by the proposed controller.

A novel prediction method for energy efficient operation of 3-phase Induction motors is also proposed which will greatly simplify the concept of voltage control in partly loaded condition . The prediction method is based on the standard approximate equivalent circuit model of 3-phase Induction motor. The variation of shunt branch elements of the equivalent circuit with the supply voltage is taken care of. New equation for slip at which the motor operates at its maximum efficiency ( $S_{em}$ ) for a given input voltage is to be arrived at. With this equation , the voltage required to be applied to the motor for any desired power output can be predicted for energy efficient operation.

## 1.4 ORGANISATION OF THE THESIS

Following the introductory remarks and scope of the thesis in the present chapter, Chapter 2 deals with design, development and testing of energy efficient Induction motor implementing the powerful optimization techniques namely GA and DE at the design stage. Comparison of main dimensions and performance of the proposed motors with that of conventional motors of similar ratings are also presented.

Obtaining energy efficiency by constructional modification is presented in Chapter 3, with the design, development and testing of a prototype permanent magnet Induction Synchronous motor.

In Chapter 4, development works related to high frequency, energy efficient submersible motor pump system with suitable controller is discussed.

Chapter 5 deals with development of prototype fuzzy logic controller for energy efficient operation of partly loaded 3-phase Induction motor. The test results showing the improvement in efficiency are also provided.

Energy conservation procedure through solar power aided UPS with the developed controller is presented in Chapter 6.

In Chapter 7, a novel prediction method for energy efficient operation of 3-phase Induction motors is presented. A new equation for slip at which the motor operates at its maximum efficiency for a given input voltage is derived. Test results, obtained from several motors validating the newly derived formula, are also presented.

Summarization of the investigations carried out in this thesis is provided in Chapter 8.