CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Three phase Induction motors have been the workforce for several industrial, manufacturing, propulsion and transportation applications for the past several years. A rough estimate shows that about 64 percent of the industrial motors belong to induction motors. The operational modes of an induction motor in an industrial environment can be divided into three: 1) starting, 2) speed control and 3) energy efficient operation. In starting and speed control modes, the dynamic response of the drive is uppermost in the mind, whereas energy efficient operation is performed during steady state operation. Several papers have already been published in the above mentioned areas. This thesis work employs a few biologically inspired optimization algorithms towards the performance enhancement of the three phase induction motor during starting, speed control and energy efficient operations. The following sections carry out the literature survey on the above mentioned modes of operation of induction motor.

1.2 INDUCTION MOTOR STARTING

The energization of an induction motor can be carried out basically through the following methods:

Dick et al (1988) and Tempelaar et al (1988) described that the conventional starting elements require some type of mechanical switch or
contact and have several drawbacks such as need for frequent inspection and maintenance, non-simultaneous switching of motor phases to the supply, failure of the moving parts due to large amount of switching etc. Availability of high-power electronic devices has led to the development of solid state starters replacing conventional starters. The solid state starter consists of a pair of back-to-back connected SCRs and the firing angle of SCRs was varied to control the rate of change of KVA with respect to time. Such a scheme is examined for pulp and paper industry and was described by Bower find, and Campbell (1986). The concept of use of SCR voltage regulator with firing angle control for smooth induction motor starting is labeled as “soft starter” and a closed loop soft starter with fuzzy logic controller was presented by Iyengar and Sastry (1995). A closed loop optimal soft starting of ac voltage controller fed induction motor drive based on voltage across the thyristor was reported by Sastry et al (1997). The design and implementation of SCR based soft starter suitable for 25 HP to 1000 HP induction motor was explained by Mungenast (1974). Robbie and Toney (2001) had presented an overview of different starting methods (including soft start and VFD starting) and the effect of inertia on both acceleration time and motor heating are discussed. Finally, they discussed the factors to be considered while choosing a starter and recommendations are given.

While earlier works were confined to current limit starting, performance enhancement of starting torque profile was later addressed by Cadirci et al (1999), Zenginobuz et al (2001). Numerical solution method is attempted by Cadirci et al (1999) for improved starting current and torque profile whereas the method suggested by Zenginobuz and Cadirci (2001) consists of two parts: a linear initial firing angle scheme which eliminates starting torque ripples and a current control strategy which consists of successive co-sinusoidal and constant function segments of triggering angle of SCRs. Li et al (2004) proposed a soft starter with voltage and power factor
angle as feedback signals and described that the soft-start controller has better starting performances and it has smaller in-rush current and smaller mechanical impact, so it can also avoid current oscillation during soft starting, whereas starting torque optimization was carried out by Zenginobuz et al (2004). Adel Gastli et al (2005) proposed a novel artificial neural network (ANN)-based ac voltage controller which generates the appropriate firing pulses to thyristors and provides high accuracy compared to conventional mathematical calculation of the firing angle which is a very complex and time consuming task.

Soft starters are also employed for energy saving too which was reported by Blaabjerg et al (1997), Sundareswaran et al (2005). The work proposed by Pinjia Zhang et al (2008, 2009) indicates that soft starters are increasingly employed in industries nowadays. Kashif and Saqib (2008) presented a soft starter based on Artificial Neural Networks (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS) where the firing angle of thyristors of ac voltage controller is adjusted under different loading conditions. Rajaji et al (2008) proposed a new method of controlling soft-starter fed induction motor drive system using ANFIS. The schemes reported by Colleran and Rogers(1983), Bruce et al (1984), Bowerfind and Campbell (1986) are of open loop type, the soft starters proposed by Iyengar et al (1995), Zenginobuz et al (2004) work in closed loop mode. It is important to mention that the closed loop control strategies are generally obtained by repeatedly simulating the motor model several times and employing trial and error based approach. Pillay et al (2009) described about the different motors starters available; these include both conventional electromechanical starters and power electronic drives. The advantages, disadvantages and energy saving features of each type of starter are also discussed and an analysis of the industrial applications and the demand of these starters are also made and also provide a suggestion of which starter is most suitable for an application based
on the stated constraints. Nafeesa and Saly George (2012) proposed a fuzzy logic based ac voltage controller to improve the starting performance of induction motor, and establishes the fact that optimum firing angle of the AC voltage controller depends on the motor parameters. Recently fault-tolerant soft starter control was presented by Chia-Chou Yeh and Nabeel Demerdash (2009) demonstrated that is more dynamic, effective and reduced motor starting transient torque pulsations as well as reduced motor inrush current magnitude. Li Tie and Jiang le jia (2010) developed a Adaptive Neuro Fuzzy based Soft Starting of DC Motor and have been compared with the conventional soft starter and the main advantages of the proposed system are its simplicity, stability, and accuracy and fast response. Labid ghodhbani etal (2010) presented a useful comparison of performances during the start up of the induction machine by means of electronics starters such as discrete frequency control, soft starter and field oriented control. John Larabee et al (2005) presented a detailed report on various starting methods of induction motor and their characteristics.

Ademir Nied (2010) developed a simple technique based on stator-flux estimation to control the electromagnetic torque of induction motors during soft starting. The inherent problems related to pure integration of the back electromagnetic force to estimate the stator flux are minimized using the low-pass-filter approach. Jiang Du (2009) proposed a constant-current soft starting based on fuzzy control strategy. In this method, the fuzzy control rules are adjusted based on the changes of the starting current in time, which effectively eliminates current and torque oscillation compared with the traditional PID control soft starting. Michael Melfi and Stephen Umans (2012) discussed the various techniques to ameliorate the effects of the starting process, including reduced voltage and soft starting, and in contrast to reduced-voltage starting, soft starting using a motor drive, in which the motor voltage and/or frequency are varied during the starting process, which can
significantly reduce the inrush current, voltage sag, and transient torques produced during starting without lengthening the starting time. Min ZHU (2009) explained the application of intelligent soft starter to the pump load and demonstrated the advantages of intelligent soft starter such as advantages of no contact, no noise, light weight, small size, starting current and start-up time can be controlled, a smooth start-up process, etc. Juxing Yang (2012) developed a Multi-slope limiting current fuzzy control algorithm that is applied to motor soft starter and can control the starting of current more effectively than fuzzy algorithm and slope voltage control method.

While the soft-starter has been increasingly employed in the industries now-a-days, the design procedure of feedback controller for rated current starting is not available in literature. This is important in particular because, ac voltage controller fed induction motor drive system is described by a fifth order differential equation and is highly non-linear during starting due to continuous and large variation of motor speed. This demands a detailed design and implementation of a feedback controller for soft-starter fed induction motor drive. Hence in thesis an attempt is made to apply intelligent techniques for soft starting of three phase induction motors.

1.3 SPEED CONTROL OF INDUCTION MOTORS

When an induction motor is applied from a constant voltage constant frequency source, the speed of the motor remains constant near to the synchronous speed for all load conditions. To be precise, the full load slip of a commercially available induction motor is always lower than 5 percent. Several manufacturing processes and industrial applications require variable speed operation and hence in this context, an induction motor is not a promising candidate for such applications. The evolution of power electronic devices and development of several novel power electronic converters had changed this scenario. The variable voltage variable frequency (VVF)
inverters have been successfully employed for the variable speed operation as well as speed reversal of induction motor drives. With the availability of advanced control techniques, high precision speed and torque control in an induction motor is now possible with variable frequency inverters. The inverter fed induction drive is a matured technology and is commercially available in the market.

It is important to mention that, in spite of the wide spread use of the induction motor drives where precise speed control is possible; there are a few applications which do not demand such a precision. Typical examples in this category are fan and pump drives. In these applications the costly inverter can be replaced or dispensed with simple SCR based ac-ac converters. For example, the domestic fans, air conditioners and washing machines employ ac to ac power converter either employing a single triac or back-to-back connected SCR pair. The ac to ac power converters, commonly known as ac voltage controllers or ac voltage regulators are very cheap, largely reliable and compact in size in comparison with variable frequency inverter. The above mentioned applications therefore continue to use ac voltage regulators as a power converter for speed control. Though the ac voltage control of induction motor drive is easy to implement, the transient as well as steady state analysis is largely complex. Several papers have been published in the past regarding the analysis and speed control of ac voltage controller fed induction motor drive.

AC voltage controller was first used for speed control of induction motors in the late 60’s and 70’s. This was followed by mathematical analysis of such drives under steady state conditions. Later ac voltage controller was utilized for energy efficient operation of lightly loaded induction motors. The stator voltage control of induction motors using ac voltage controller is the cheapest and most reliable scheme and is increasingly employed particularly for fan load. The stator voltage control of induction motor is achieved by
connecting back to back connected SCRs in series between supply mains and motor terminals and the stator voltage is controlled smoothly at line frequency between zero and full value by symmetrically controlling the SCR firing angle. The fundamental relation between motor slip and motor current is derived by Paice (1968). It is shown here that, peak current is inversely proportional to the square root of resistance, which emphasizes that this method of speed control is suitable for motors with high rotor resistance. The closed operation of speed control of induction motor with stator voltage control employing digital phase locked loop scheme was reported by Kenley and Bose (1976). Here, complete model of speed control of three phase induction motor drive is designated and the scheme is evaluated experimentally. When compared to conventional method using analog devices, this method is found to exhibit precise control. The use of power transistors for induction motor voltage control was described by Alexander Mozder and Bose (1976).

An experimental closed loop variable speed operation was developed by Shepherd and Stanway (1967). The drawback of the above operation is that an analytical relationship could not be established between induction motor torque and applied voltage with thyristor excitation and hence an empirical approach was used. Further, motor parameter variation with different operating points is not considered.

Despite the simplicity of SCR controlled induction motor drive system, the analysis of such a scheme is extremely difficult due to nonlinear and complex nature of induction machine equations. This problem was compounded in earlier days due to large computation time required by the computer. Different mathematical models were used to study the dynamic response of the drive with voltage control. The simulations results provide useful information on the total system designed with various operating conditions. An earlier attempt in this direction was discussed by Sheperd
(1968). However the solution of the resulting equations is not carried out owing to their complexity. Nowotny and fath (1968) have used state-space approach and matrix methods and brought out steady state solutions subject to switching constraints. Lipo (1971) used this technique for the analysis of SCR controlled drive and the boundary conditions for the matrix differential equations are expressed as a function of system parameters. Fourier series method is also adopted for the steady state analysis of such drives Mcmarray (1974), Ramamoorthy and Samek (1976) Dewan and Straughen (1975), Malik et al (1985), but computation is found to be tedious and results were not satisfactory as compared to the one obtained using state-space approach. Padiyar and Prabhakaran (1998) explained the motor was considered as a passive resistance-inductance load and the motor response was determined. A full fledged analysis of ac voltage controller fed induction motor drive was presented by Hamed and Chalmers (1987), which is based on the representation of rotor with a sinusoidal EMF in series with resistance-inductance circuit. In the development of this circuit, magnetizing current and stator resistance are included and the amplitude and phase of the EMF are determined as functions of motor torque and speed. However, the main drawback of these works is that, only steady state solution is obtained with large number of system variables. Sousa (1994) presented that fuzzy logic is gaining importance in process control applications. The fuzzy control was extended to current and speed loops replacing conventional PI control method. Lee (1990) had proposed a new methodology of fuzzy control design. Here the phase plane is used to bridge the gap between the time response and rule base. The rule base is easily built using the general dynamics of the process and readily updated to obtain improved dynamic characteristics. An implementation of this scheme was reported by Chang-Ming Liaw and Jin-Biau Wang (1991) where a limit-cycle controlled induction motor drive with two inverters and a fuzzy controller is designed and implemented. Recently Ashok et al (2010) developed a novel design of a
takagi-sugeno fuzzy strategy for induction motor speed control and yields excellent results, especially in the settling times of the various responses. Kratiger (2004) had presented a case study of evaluation, selection criteria and approach to successful integration of on electric adjustable speed drive system in retrofitting steam turbines. Finch and Giaouris (2008) discussed the various control techniques which are being applied to make AC drives suitable for practical applications in the industry with good dynamic behavior making them a rapidly growing area. Hussein Sarhan (2011) described a control scheme based on search method taking advantage of the fact, that at a certain torque and speed (operating point) there is only one value of stator voltage that operates the motor at optimal efficiency. Nasir Uddin (2007) proposed a novel adaptive Neuro-Fuzzy based speed control of an induction motor and the proposed controller incorporates fuzzy logic laws with a five-layer Artificial Neural Network scheme. This method is found to be more robust as compared to conventional PI and FLC controllers and hence, suitable for high-performance industrial drive applications. Leposava and Borislav (2011) proposed a control strategy for the system of belt conveyors (BCs) with adjustable speed drives based on the principle of optimum energy consumption. Fuzzy logic controller is used in the algorithm for generating the reference speed and the developed control strategy will reduce the energy consumption and improve the efficiency of the mining process. Asija (2010) presented a rule-based Mamdani type fuzzy logic controller applied to closed loop Induction Motor model. The motor model is designed and membership functions are chosen according to the parameters of the motor model and the results obtained in the simulation are interesting, considering the presence of strong non-linearities in the induction motor model.

Boldea (2008) explained a few control issues in ASD, such as performance indices, three-phase ac motor control principles, wide constant power speed control, motion-sensorless control of ac drives, variable-speed ac
generator control, and linear motor drives control, and discusses their basics, recent progress, and a few directions of ASD research and industrial development for the near future. Faa-Jeng Lin (2008) in their study brought out the design and implementation of a FPGA-based robust RBFN control system for the position control of a Linear Induction Motor drive system. Feng Zhuang and Liu shu (2012) developed a strategy of applying fuzzy PID instead of traditional PID into control process of the soft-starter and observed soft-starting, smooth running and soft-stopping of induction motor. Ramdan Razali et al (2012) explained the main importance of efficient motors and its drive systems and also discussed the optimization of Squirrel cage induction motor efficiency using intelligent techniques.

As mentioned above, induction motor is a non-linear device and the incorporation of thyristor voltage regulator with an Induction motor makes the system more complex and difficult to analyze. Hence the design of a feedback controller for speed regulation of an ac voltage controller fed induction motor drive is a major challenge. Most of the earlier works linearized the motor models for the controller design. In this thesis, a new small signal model of Induction motor drive is first derived and Ant Colony Optimization (ACO) is employed for the tuning of an optimal controller.

1.4 ENERGY EFFICIENT OPERATION OF INDUCTION MOTORS

The earliest attempt in energy saving of induction motor drive with variable voltage was reported by Nola (1977). Here, the motor voltage is adjusted for each load change such that the power factor is maintained at a constant value. Improved load power factor will reduce reactive power requirement from the source and further this reduces transmission and distribution losses. However, it is observed that a constant power factor did not result in optimal efficiency of the drive for all load conditions.
Mohan (1980) has proved that minimization of motor current using voltage control results in energy efficient operation and has suggested that the optimum voltage for the given load can be obtained through “hill climbing technique”, which refers to the search algorithm. It is observed here that stator voltage reduction reduces the power consumption as much as 25% of the rated full load output and savings are possible for all loads. Further, except on no load, more than 50% reduction in stator voltage tends to stall the motor. Rowan and Lipo (1983) described a quantitative analysis of energy saving of thyristor controlled induction motor using different control strategies such as minimum motor current, minimum input power, constant power factor and optimum slip operation is presented. Minimum input power and maximum efficiency criteria are shown to yield perceptibly different results and further, a constant power factor controller results in an operating regime, which is substantially poorer than operation at either minimum input power or maximum efficiency. But the problem of measuring input power or efficiency in a practical closed loop mode is not addressed here. Optimum slip operation of adjustable amplitude sine wave fed induction motor drive was discussed by Jian et al. (1983). Typical optimum values of slip for minimum motor current, minimum power input and for maximum efficiency are derived in terms of motor equivalent circuit parameters, assuming that the motor parameters remains constant for different stator voltage. It is found that motor efficiency is independent of output power, when a variable voltage controller changes motor voltage approximately the square root of load torque to maintain the required slip constant during part-load operation. The major demerit observed here is that the theory developed is devoted only for adjustable amplitude sine considered. The cost effectiveness of incorporating ac. voltage controller for efficiency maximization was explained by Binns (1987). The energy losses in induction motor is quantified from its declared performance data coupled with duty cycle and load duration distribution. It is assessed that energy savings up to 15% are indicated with voltage controller fed operation when compared to
rated voltage operation. Further, it is pointed out that extra cost involved with voltage control circuits can well be balanced in a short span of time due to saving in energy bills. A closed loop operation of thyristor controlled induction motor drive using two point current minimization techniques was reported by Sastry et al (1997). Here, induction motor performance enhancement is obtained by monitoring a new variable, namely voltage across the non-conducting thyristor. Even different schemes have been employed for energy efficient operation in variable frequency drives. While in constant speed drives, efficiency improvement is achieved by adjusting the stator voltage, in variable speed drives it is achieved through a combination of varying stator voltage and frequency. A practical method for achieving the optimal efficiency control of variable voltage, variable frequency inverter fed induction motor was described by Kirsschen (1987). The proposed controller adaptively adjusts the motor air gap flux level based upon the direct measurement of input power for efficiency maximization. Famouri and Cathey (1991), proposed a microprocessor based adaptive controller for minimum loss operation of an inverter fed induction motor drive, while maintaining a particular speed-torque point constant. The optimum efficiency point is obtained by searching for minimum input power. The greatest potential for energy saving is found to exist for the case of loads with non-linear torque-speed characteristics, such as fan and pump drives. The loss minimization control using search controller in a scalar controlled induction motor drive was reported by Kioskerdis and Margaris (1996). This paper highlighted the advantages of using minimum motor current rather than minimum input power for efficiency enhancement. The current can be easily measured compared to the measurement of input power. Further, the minimum input power is not distinct, which will result in near optimum point operation. While search method is adopted for identifying the maximum efficiency point in the works Sastry (1997), Kirsschen (1987), Famouri and Cathey (1991), Kioskerdis and Margaris (1996), a neuro-fuzzy based search
algorithm is developed by Bose, (1997). Bose (1997) developed a fuzzy logic search controller with adaptive step size of control implementation. Extensive simulation studies show excellent performance of the drive. However, a closer look at the dynamic response of the drive reveals that the time of search is not reduced significantly.

Cássio et al (2009) in their study brought out the fact that three-phase induction motors appear as the largest consumer of electricity because they are responsible for the largest percentage of about 30% of the energy consumption in the world. A novel technique was developed by Sundareswaran (1999) for energy efficient operation of voltage controlled induction motor drive using fuzzy logic principles. In the proposed method, the time required to converge to the best efficiency point of the drive is minimum and the machine is subjected only to one step change of voltage irrespective of load change. Energy savings by voltage control of induction motors can be achieved by reducing the applied voltage if the load torque requirement can be met with less than rated flux was presented by Mohan(1980). By this way the core loss and stator copper losses can be reduced. Roman and Lipo (1983) used the combination of current minimization and power factor maximization concepts thereby energy saving was found to be good, however the dynamics of the system was poor. It is reported that a very good response is achieved by ac voltage controller fed induction motor and is also used for energy efficient operation as reported by Sundareswaran (1998), Casadei (2010), Anibal (2003).

Thanga Raj et al (2009) presented a review of the developments in the field of energy optimization of three phase induction motor using optimal design and control techniques bringing out the salient features of each method. Also, a brief review of Artificial Neural Network, Fuzzy Logic, Expert systems and nature inspired algorithm was presented. Hassan et al (2009) suggested the need of providing energy awareness for saving energy.
Xue et al (2006) proposed a control scheme to implement the energy-savings of three-phase induction motors when they operate under long-term light-load or small duty ratio load. The proposed scheme is based on the principle of variable voltage control (VVC) at constant speed. The possibilities of applying off-line trained artificial neural networks in creating the system inverse models, that are used in designing the control algorithm for a non-linear dynamic system were described by Zilkova, Timko and Girovsky (2006). Osama (2010) investigates the opportunity of energy saving in three phase induction motor driving pump load and he proposed an improved loss model control (LMC). Braslavsky et al (2006) proposed a voltage ramp optimization based on genetic algorithm during starting in soft-start systems based on thyristor voltage converter and induction motor (TVC–IM). It is shown that optimum voltage ramp provides the 10-15% reduction of losses in comparison with direct start. Gan Shihong (2011) presented the concept of the energy-saving controller of ac motor based on the constant power factor and also shown that such a controller can be used for energy-saving with optimum control.

1.5 DRAWBACKS OF EARLIER WORKS

The literature survey carried out in the above sections indicate that there are few drawbacks associated with ac voltage controller fed induction motor drive and are listed below:

1. While several papers have been published on soft starting of induction motor drives, the major drawback in the above works is that the strategy for tuning the controller is largely trial and error based approach after simulating the induction motor model several times.
2. In some works, small signal model of induction motor is employed to obtain the constants of current regulator. It may be noted that induction motor starting process is largely nonlinear due to variation of motor speed from zero to no load value and the small signal model will not truly represent the induction motor behavior.

3. From the above two points, it can be concluded that optimization methods have not been employed for optimal tuning of the PI controller for induction motor soft starting.

4. With regards to speed control of induction motor using stator voltage control, either small signal model or linearised state space model had been employed. These models are approximate and will cause poor dynamic response.

5. With regards to energy efficient operation, the best efficiency point is obtained by gradually changing the SCR firing angle. This search algorithm is similar to trial and error based one and hence in the previous works no clear cut design procedure for the controller is presented.

6. The search technique takes more time for reaching the optimum point than can reasonably allowed. More the time required, less will be the energy saved.

7. The stepwise change in stator voltage proposed in earlier works, results in poor dynamic response of the drive performance. This is more predominant in motors with low moment of inertia.

8. In search technique, the exact point of minimum current may be missed if the change in voltage is large since the voltage-
current characteristics curve is more flat in optimum efficiency region. Furthermore, by this method, this minimum current point is never reached and only persistent oscillations about this point are observed which requires an additional controller.

9. Fuzzy logic based search does not result in reducing the time of convergence to the best efficiency point.

1.6 OBJECTIVES OF THE THESIS

As explained in the previous sections, there are a few handicaps in the starting, speed control and energy efficient operation of induction motor drives. With the existing methods, ac voltage controller fed induction motor drive is still preferred over costly, inverter fed variable speed drives in certain applications such as fan and pump drives. AC voltage controller is cheap, compact and hardware requirement is simple and easily implementable. Unfortunately, AC voltage controller fed induction motor drive is largely complex and is described through fifth order differential equations.

This thesis proposes the application of few biological inspired optimization algorithms namely Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for the performance enhancement of ac voltage controller fed induction motor drive. This thesis also exploits the intelligent techniques such as Fuzzy systems and Neuro Fuzzy systems for the improved performance of thyristorised control induction motor drives. To be precise, the objectives of the thesis work is

1) Design and Implementation of Genetic Algorithm and Particle Swarm Optimization for rated current starting of ac voltage controlled fed induction motor drives.
2) Development of speed controller design methodologies for ac voltage controller fed induction motor based on fuzzy set theory and ant colony optimization.

3) Development of novel Neuro-Fuzzy system for energy efficient operation of induction motor drive during light load conditions.

1.7 REVIEW OF BIOLOGICALLY INSPIRED ALGORITHMS

For the past few decades, several intelligent computing techniques, based on evolutionary computing and Swarm Intelligence (SI), have been introduced to solve a variety of engineering applications. Some of the algorithms, which have been proved to be efficient and widely used, are Genetic Algorithm (GA) Oh et al (1999), Hassanzadeh et al (2008), Particle Swarm Optimization (PSO) Parsopoulos and Vrahatis (2002), Umarani and Selvi (2010) and Ant Colony Optimization (ACO) Purnamadjaja and Russell (2005), Bianchi et al (2006), Fox et al (2007). The major inspiration for all these methods stems from biological systems in nature. Some of the common characteristics of all these non-conventional algorithms are that they are all population based, independent of derivatives and have employed probabilistic approach. These algorithms start with a set of solutions (called a parent population) instead of one trial solution, and generate a new set of trial solution by carrying out proper transition, which is unique for each algorithm, in a stochastic manner.

Genetic algorithm (GA) was proposed by Holland at the University of Michigan in 1975. This algorithm derives its strength from Darwinian principle of “survival of fittest” mechanism. The GA generates solution strings at random; each solution is called a chromosome. The chromosome set-called as population-is forced to undergo three steps normally (i) selection (ii) crossover and (iii) mutation. The selection mechanism is such that it
favors chromosome with higher fitness and selects them to be propagated into the next generation. The selected individuals undergo crossover and mutation. These operation and propagation are repeated until an individual matches the termination criterion. The genetic operations help the algorithm to prune the search space and plausible solutions emerge at the end. Recently the concepts of GA have been widely used in power electronics systems Mahony (2000), Bose (2005), Wang (2003).

Among the swarm intelligence technique, most referred techniques are Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO). In 1995, Kennedy and Eberhart introduced the concept of PSO. Particle Swarm Optimization posses many similarities with evolutionary computation techniques such as Genetic Algorithms. Particle Swarm Optimization has no evolution operators such as cross over and mutation. This algorithm relies on social behavior of flocking of mechanisms such as swarms of birds and fish schools. In PSO, each swarm consists of many particles. Each particle is a potential solution to the problem and is associated with a velocity vector and a position vector. The velocity of each particle is dynamically altered in the search space to find newer solutions. Many sophisticated works are available, wherein PSO is effectively employed for solving various issues in power electronic systems. In the last few years many modified version of PSO are also developed Chen Yonggang (2006). The main strength of PSO is its fast convergence, compared with many global optimization algorithms like Genetic algorithms, Simulated Annealing and other global optimization algorithms.

The origin of Ant Colony Optimization (ACO) stems from the foraging behavior of certain and species Dorigo (1997). When a group of ants set out from the nest to search food, they use a special kind of chemical called pheromone to communicate each other. Ants follow paths which have pheromone trails and as this process advances, most of the ants tend to choose
the shortest path as this path accumulates huge amount of pheromone. The concept of ACO has been increasingly employed as seen in the literature Dorigo and stutzle (2004), Sim and sun (2003), Fan et al (2003), Sundareswaran et al (2007), Fox et al (2007), Wang et al (2009).

1.8 REVIEW OF ARTIFICIAL INTELLIGENT TOOLS

In the present work, artificial intelligent tools, namely, fuzzy logic, neural networks are employed for efficiency enhancement of voltage controlled induction motor drives. Hence a review of the principles of these artificial intelligence techniques is presented here.

Artificial Intelligence tools such as expert systems, fuzzy logic and neutral networks have opened a new era in power electronics and drives area Bose (2007). These areas have advanced significantly in the past few years and researchers have started using these methods very extensively in power electronics and drives. An entirely new way of structuring software which closely resembles human thinking process and the same was called as “Expert Systems”. In the 1980’s, Expert System applications proliferated in industrial process control, agriculture, military applications, space technology etc.

Fuzzy logic, unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty, or imprecision and uses membership functions (MF) with values varying between 0 and 1 Gang Feng (2006). Fuzzy logic tends to mimic human thinking that is often fuzzy in nature. In conventional set theory based on Boolean logic, a particular object or variable is either a member (logic 1) of a given set or it is not (logic 0). On the other hand, in fuzzy set theory based on fuzzy logic, a particular object has a degree of membership in a given set that may be anywhere in the range of 0 (Completely not in the set) to 1 (Completely in the set). This property allows fuzzy logic to deal with uncertain situations in a fairly natural way. A fuzzy
logic has the values which are expressed by natural English language like LOW, MEDIUM and HIGH etc. A process control algorithm that is based on fuzzy logic is called fuzzy control. A fuzzy control essentially embeds the intuition and experience of a human operator, and sometimes those of a designer and researcher. The conventional control is normally based on mathematical model of a plant, as mentioned before. If an accurate mathematical model of a plant is available with known parameters, it can be analyzed, for example, by a Bode or a Nyquist plot, and a controller can be designed for the specified performance. Often, the plant model is unknown or not well-defined. Even if the plant model known, there may be parameter variation taking place. Sometimes, the model is multivariable, complex, and nonlinear, such as the dynamic D-Q model of an induction motor. Various adaptive control theories, such as self-tuning regulation (STR), model reference adaptive control (MRAC), and sliding model control (SMC) have been developed to combat such problems. It can be shown that fuzzy control is basically adaptive in nature, and can give improved robustness in such problems.

Fuzzy logic can also be applied to modeling and estimation. The fuzzy estimation technique can be applied to a process where mathematical model is not known, ill-defined, or some parameter variation takes place. The relational method of estimation requires fewer rules, gives better accuracy, and algorithm development time is somewhat smaller than the rule based method. In the preset work, we have developed fuzzy logic based estimator for optimum voltage identification of voltage controlled induction motor. In spite of the advantages of fuzzy control, its main limitations are the lack of systematic procedure for design and analysis of the control systems. The heuristic and iterative approach to fine-tune the rule base and membership functions may be very time-consuming. A few other difficulties in fuzzy control are lack of completeness of the rule base and lack of define criteria for
selection of the shape of membership functions, their degree of overlapping, and the levels of data quantization. Recently, fuzzy neutral network (FNN) techniques have been developed to solve some of these problems. The application of fuzzy principles is established in drives and control such as generator excitation Bao Man and Guo Peiyuan (2010), D.C. Motor speed control Shaker and Al-khashab (2010), inverter fed-induction machine control Islam et al (2005) and motor efficiency optimization Rouabah et al (2008), Uddin and Khastoo (2012).

Artificial Neutral Network (ANN), as the name indicates, is the interconnection of artificial neurons that tends to simulate the nervous system of a human brain. The human brain is said to have around 100 billion neurons or nerve cells, and each neuron is interconnected to 1000 to 10000 other neurons. A biological neuron is a processing element that receives and combines signals from other neurons through input paths called dendrites. If the combined signal is strong enough, the neuron “fires,” producing an output signal along the axon that connects to dendrites of many other neurons. Each signal coming into a neuron along dendrite passes through a synaptic junction. This junction has an infinitesimal gap in the dendrite which is filled with neurotransmitter fluid that either accelerates or retards the flow of electrical charges and this neurotransmitter fluid produces electrical signals that go to the nucleus of the neuron. The adjustment of the impedance or conductance of the synaptic gap leads to “memory” or “learning” process of the brain. The model of an artificial neuron that closely matches a biological neuron is given by an op-amp summer like configuration. Each input signal flows through a gain or weight, called synaptic weight or connection strength whose function is analogous to that of the synaptic junction in natural neuron. The weights can be positive (excitory) or negative (inhibitory) corresponding to acceleration or inhibition respectively, of the flow of electrical signals. The summing node accumulates all the input-weighted signals and then passes to
the output through the transfer function which may be linear or nonlinear. The non-linear type includes sigmoid, inversetan, hyperbolic, or Gaussian type. The sigmoid function is non-linear, monotonic, differentiable, and has the largest incremental gain at zero signal, and these properties are of particular interest. In general, neural networks can be classified as feed forward and feedback types depending on the interconnection of neurons. At present, the majority of the problems (90%) use feed forward architecture and it is of direct relevance to power electronics and motion control applications.

1.9 ORGANIZATION OF THE THESIS

The work reported in the thesis is organized into 8 chapters.

Chapter 1 outlines review and survey of various soft starting and speed control methods applied to three phase induction motor drives. Selection of firing angle for ac voltage controller fed induction drive results in energy saving operation. A detailed review on soft starting of induction motor drives, stator voltage controlled induction motor drives and energy efficient operation of three phase induction motor is presented. This chapter also makes review on different soft computing techniques such as fuzzy logic, Neuro-Fuzzy, Genetic Algorithm, Particle swarm optimization and Ant Colony Optimization.

In Chapter 2, the development of a comprehensive dynamic model of ac voltage controller fed induction motor drive in Matlab/Simulink is explained. A dedicated experimental setup was also developed in the laboratory and certain simulation findings were verified through experimental results.

In chapter 3, the concept of induction motor soft starting by optimal tuning of PI controller parameters is explained. GA is used for estimation of
feedback controller parameters for induction motor drive is described and the objective of optimal tuning of PI controller parameters are framed as an optimization task and the solution is sought through proposed GA. GA offers several advantages such as simple computational steps, derivative free optimization, reduced number of iterations and assured near global optima. GA perform search for a multidimensional space containing a hyper surface known as the fitness surface. For the implementation of GA to the problem, dedicated software in Matlab is developed. The parameters of GA such as crossover probability, mutation probability, population size and number of generations are selected by trial & error process to achieve the best solution set. It is observed that, the number of iterations required for all chromosomes to reach near-global optima is reasonably low. GA tuned controller parameters are suitably incorporated in the developed Matlab model for induction motor starting. From the simulation results and experimental results, it is seen that motor draws constant current during starting; thus validating the proposed approach.

PSO is largely employed for solving non-linear optimization problem. It has several advantages such as faster convergence, lesser operates etc. Hence, in chapter 4 an attempt has been made to develop improved optimization model for the soft starting application. The objective of optimal parameter tuning is framed and the solution is obtained by modified PSO. Thyristorized ac voltage controller is proposed to work in a closed loop mode with a (PI) controller for regulating the motor current at its rated value during starting. The control constants of the PI controller are obtained through PSO. To achieve this, the soft-starter fed induction motor drive together with PI controller is developed in Matlab and subsequently a suitable objective function is tailored for the estimation of optimal values of PI controller constants using PSO. Extensive simulation results along with measured results are provided to validate the proposed method.
The cheapest and most reliable scheme of speed control of induction motors is stator voltage control using back-to-back connected SCRs. This scheme is called as conventional method and widely used for certain types of loads such as fan and pump drives. However, little attention is being paid in the literature towards the design of controller for closed loop variable speed operation using the above scheme. Hence in chapter 5 fuzzy logic controller based thyristorised ac voltage controller fed induction motor drive for variable speed application is developed. A linear incremental model of voltage controlled induction motor drive is derived using the fifth order d-q axis model. This model is used for simulation study and it is observed that induction motor parameters vary widely with operating point. Thus the controller parameters obtained using conventional methods will not guarantee best possible dynamic response at all operating points of the drive. This requires tuning of the controller parameters at each operating point, which is very difficult to achieve on-line. The fuzzy algorithms are systematically derived from the intuition and experience from the motor drive dynamics obtained through a PI controller. Both from the simulation and experimental results it is observed that fuzzy controller nullifies the effect of parameter variation and rejects disturbances, resulting in excellent dynamic response at all operating points.

In Chapter 6, a novel optimization algorithm, named as Ant Colony Optimization, which is based on foraging behavior of natural ants, is developed for optimal tuning of controller parameters. A key aspect of ACO algorithms is the use of a positive feedback loop implemented by iterative modifications of the artificial pheromone trails that are a function of the ants' search experience; the goal of this feedback loop is to bias the colony toward the most promising solutions.

The newly developed ACO technique enforces continuous exploration of the solution space and identifies optimal controller structure.
The development of Ant colony optimization algorithm and its application to feed back controller design for a variable voltage induction motor drive is well documented in this chapter. The speed response curve with the ACS tuned controller parameters gives an excellent response at all operating points compared to that of a conventional PI controller. Experimental and simulation results were presented to validate the efficacy of the optimized controller.

Chapter 7 explains the development of Neuro-fuzzy controller for performance enhancement of voltage controlled induction motor drive. Improvement in motor efficiency and power factor is achieved by suitably adapting the motor flux to optimum point by stator voltage control. The optimum SCR firing angle for each operating point is readily estimated by the neuro-fuzzy system. The complete drive system together with neuro-fuzzy estimator is developed in Matlab / Simulink. Simulation results are presented and the results validate the proposed method. From the simulation results it is evident that the proposed neuro-fuzzy controller works well and the motor always operates in the energy efficient region.

The conclusions derived from the thesis are presented in chapter 8.

1.10 CONCLUSION

An overview of the problem under investigation, specific objectives of the work, organization of the thesis and a review of starting methods, speed control methods and energy efficient operation of induction motor drive are presented in this chapter.