1.1 ELECTRIC DRIVES

An electric drive consists of load, motor, power converter, source, control unit and sensing unit. A power converter is interposed between the source and the motor to convert electrical energy of the source into the form suitable to the motor and also to match the speed-torque characteristics of the motor with that of the load. Block diagram of an electric drive is shown in Fig.1.1. Based on the type of motor used, electrical drives are classified as dc drives and ac drives [1,2].

In many modern drives, the demand is for precise and continuous control of speed, torque or position with long term stability, good transient performance and high efficiency. DC motors satisfy some of these requirements and hence play a significant role in many industrial drives. The methods of speed control are normally simple and less expensive than that of ac drives. DC motors have good starting, running and braking characteristics. However, due to the presence of commutator and brushes, dc motors are not suitable for very high speed applications and require regular maintenance. Also, this results in high cost for the machine, sparking at the brushes, low power/weight ratio and low operating voltage. Hence, dc drives are being replaced by ac drives [1-5].

AC drives have now proven technically and economically attractive for many industrial applications. The ac machines, especially the cage type induction motors, seem to possess several distinct virtues in comparison with dc machines. These relate to lower cost and weight, lower inertia, higher efficiency, improved ruggedness and reliability, low maintenance requirement and the capability to operate in a dirty and explosive environment due to the absence of commutator and brushes.
As a result, there is now spectacular growth in industrial application of ac drives. It is predicted that ac drives, mainly induction motor drives, will replace dc drives even in variable speed application [1-5].

1.2 ENERGY CONSERVATION IN ELECTRIC DRIVES

In recent years, there is an increased emphasis on the energy saving and performance improvement of electrical apparatus and systems. Improving the efficiency of electrical equipments is now recognised in many countries as a less costly means than construction of new power plants for meeting some of the increased demand for electricity services. Electric drives are now used at all power levels in a variety of industrial applications. A major proportion of the electric energy produced is consumed by electric drives. The importance of electric drives to Indian industry is evident from the fact that they account for an estimated 74% of all industrial electricity use as shown in Fig.1.2 [6]. Out of this, 3-phase squirrel cage induction motors alone accounts for an estimated 70% because of their wide use in industries. Significant amount of electric energy can be saved by the use of efficient and right type of electrical drives [1,6,7].

Different measures can be adopted for the energy conservation in electric drives such as the use of efficient power converters, energy efficient operation of electric drives, improvement of power factor etc. [1].

In many applications, induction motors work at rated load during only part of the load cycle. So, during the periods of reduced loads, saving in energy can be achieved by operating the motor at low voltages. Reduction in voltages increase the copper loss but reduces the core loss by a large amount. For each loading, there is an optimum value of voltage for which the loss is minimum. Substantial energy saving is
achieved by operating the motor at optimum voltage value. This also improves the power factor.

Many drives operate at low power factor leading to lower overall efficiency. Due to the widespread use of electric drives, improvement in power factor has become an important issue. Good power factor help in saving energy, stabilising the system voltage, reducing the load on transmission and distribution equipments, transformers etc.

In this context, it was thought prudent to undertake research on the energy efficient operation of some of the electric drives. AC drives employing induction machines and ac series motors find wide application in commercial as well as domestic appliances. Hence, it was considered appropriate and worthwhile to carry out certain investigations on the performance improvement of these drives.

1.3 AC VOLTAGE CONTROLLER FED AC DRIVES

There are several methods for controlling the speed of ac drives such as variable voltage constant frequency control, variable voltage variable frequency control etc. Among these methods the variable voltage control at constant frequency using phase controlled static ac voltage controllers is the simplest and economical method for the control of ac drives employing induction motors, ac series motors etc. In this scheme, the stator supply voltage is controlled at line frequency by symmetrically controlling the trigger angles of three-phase, line commutated, antiparallel thyristors as shown in Fig.1.3 for a three phase induction motor. A single phase ac voltage controller can be employed for controlling the voltage fed to the ac series motor as shown in Fig.1.4. In low power application, triacs can be used giving further simplification to the power and control circuitry. The stator voltage can be varied steplessly between zero and full value giving the circuit a 'solid -state variac' characteristic [8-13].
Although large amounts of ac power can be controlled economically by this technique, it has several limitations due to the inherent characteristics of phase control. A phase control circuit presents a lagging power factor at the input even if the load power factor is unity. Harmonic currents flowing through the machine windings cause undesirable heating and contribute to pulsating torque. The response of phase controlled circuit is slow due to inherent dead time lag. The line side power factor is poorer because of the added harmonics and the additional reactive power taken by the converter due to phase control [8-10].

To overcome some of the above problems, voltage controllers using Power Transistors and MOSFETs, employing chopping technique and operating in a high frequency time ratio mode were designed [14-17]. AC switches connected in series and in shunt are controlled so that a lagging reactive load of any power factor angle could be satisfactorily handled. The circuit was capable of handling several kilowatts of power at any lagging load power factor angle and the output voltage could be smoothly controlled from zero to full supply voltage. The circuit had inherently fast response and the high frequency ripple at the output could be easily filtered [16,17].

In addition to the above mentioned speed control applications, such controllers have been found useful in the energy efficient operation of ac drives [1,18,19]. With induction motors, this technique is found to improve not only the efficiency but also the power factor at light load conditions. Recently, the introduction of ac voltage controllers has been suggested for the power factor improvement of grid connected induction generators [20-23]. Though the induction motor application was well established, not much work has been reported so far on the analysis of induction generators with voltage control. Again, the performance evaluation of these converters employed for the economical and efficient speed control of ac series motor was also remaining uninvestigated.
In this context, a study of ac voltage controllers feeding machines like induction machines and ac series motors is considered as very appropriate. The efficient use of ac voltage controllers for the performance improvement of these drives is chosen as the topic of research. When fed by such power converters, it is more appropriate to represent these machines by their RLE equivalent circuits [24-28]. Hence, to start with, investigations are carried out on ac voltage controllers with a general RLE load and then extended to induction machines and ac series motors.

1.4 AC VOLTAGE CONTROLLERS

AC voltage controllers are ac-ac converters which can be used to convert the constant ac voltage to variable ac voltage at the same frequency using ac switches. They are widely employed for the speed control of ac series motors and induction motors, heating and lighting controls and for obtaining regulated ac supplies. Conventional ac voltage controllers employing phase control (or phase angle control) strategy can be used to control large amount of power economically. They can be realised by connecting an ac switch in series with the supply and the load as shown in Fig. 1.5. Back to back connected SCRs or Triac are commonly used as ac switches in phase angle control. In this type of control, the rms value of the load voltage is varied by varying the angle at which the ac switch is turned on. When the switch is on, the load voltage is the supply voltage and when it is off, the load is disconnected from the supply[29-32].

These conventional voltage controllers are reliable and have the ability to control large amount of power economically. However, their output voltage is load dependent and the amount of harmonics introduced in the supply as well as in load side is high especially at large firing angles, and the input power factor is low.

The performance of ac voltage controller can be improved considerably by employing chopping technique. Such ac voltage controllers are called as ac
choppers. AC choppers can be realised by using two ac switches, one connected in series with the load and the other across the load as shown in Fig. 1.6. S1 is the main switch and S2 is the freewheeling switch. S2 should be off whenever S1 is on and vice versa. When S1 is on, the load voltage is the supply voltage and when it is off, S2 is on and hence the load voltage is zero. The load voltage can be controlled by varying the on and off time of switch S1. With the development of new power devices such as Power Transistors, MOSFETs, IGBTs and GTOs, the chopper control can be easily implemented. AC choppers are found to be capable of controlling the output voltage independent of the load. They reduce many lower order harmonics depending upon the control strategy employed and the input power factor is better. Depending upon the number of switchings per half cycle, they can be classified as single pulse width modulated and multiple pulse width modulated ac choppers. As the number of pulses per half cycle of the chopper is increased, the harmonics introduced by the controller can be reduced considerably [33-35].

1.5 RECENT TRENDS IN THE CONTROL OF AC DRIVES

The technology of solid state control of ac machines has made great strides during the last one and a half decades. The rapid technical advancements and declining prices of power semiconductor devices, microprocessors and microcontrollers have led to the world -wide application of many efficient controllers for ac motors. With power converters achieving popularity in the area of adjustable speed drives, the operational problems of motors with these converters have assumed significance. The ac motors are fed with non-sinusoidal voltages or currents which lead to additional losses and torque pulsations. The trend, now, is to design the motor as well as the converter to minimise these problems. PWM techniques have been developed, and the thyristors have been replaced by modern devices like MOSFETs and IGBTs. Many different control techniques of varying degrees of complexity have appeared. Vector control, margin angle control, model reference adaptive control and sliding mode control are some of them [36-40].
Digital control is slowly replacing analog control of drives. This has resulted in compact control systems for drives which effectively replace the complex hardware oriented control using analog discrete components. The advent of microcomputers has brought a new dimension to motion control technology. Also, CAD tools are playing an increasingly important role in motion control system design. Eventually, the simulation software will be downloaded directly to the prototype microcomputer memory and used as real time control software.

A significant advance has been made recently in control and CAD technique by the introduction of artificial intelligence or expert system. Artificial intelligence involves programming a computer so that it can mimic human thinking or it is the machine emulation of human thinking. A human expert has knowledge, an experience base, and the power of reasoning, judgement and intuition. Fuzzy logic and neural network theories have been developed for computers to quantify and objectively evaluate the subjective ambiguity of human thinking. Expert-system-based diagnostics can locate faults in a complex control system with extensive man-machine dialogues. In such a system, a controller can tune itself as it monitors the process and learns the dynamics of the operation, as much as an experienced human operator could do.

Artificial intelligence tools such as expert system, fuzzy logic and neural networks are expected to usher a new era in power electronics and motion control in the coming decades. These technologies have advanced significantly in recent years. Fuzzy logic has emerged as an important AI tool to characterise and control a system whose model is not known or ill-defined. It has been widely applied in process control, estimation, identification, diagnostics, agriculture etc. Similar to fuzzy logic, recently people's attention is focused on artificial neural networks which is capable of generating our thinking process. With these tools, a system is said to be "intelligent", "learn-
ing" or have "self organising" capability. Such systems can give the predicted performance even with wide range of parameter variation [41].

Hence, in this thesis, investigations are carried out on the application of these AI tools for the optimal control of voltage controller fed drives.

1.6 MODELLING AND SIMULATION OF DRIVE SYSTEM

The dynamics of the ac machine drive control system is extremely complex and the subject is receiving wide attention in recent years. The complexity arises because of the non linearity and discrete time nature of the converter-machine system. For this reason, simulation of the dynamic behaviour of complex electric systems with time varying parameters has always been considered important. Development of a new system often involves expensive trial and error experimentation with costly prototypes. Hence, the implementation of a new idea into a useful new product is usually expensive, long and tedious and involved process. It is convenient to design and simulate a newly developed control system on a computer before building on a breadboard. Through simulation, one can predict system behaviour over a broad range of operating conditions. The best way is to perform simulation and to adjust the control parameters inorder to optimise system performance. Customised programs are fast and efficient, but their development requires considerable time and effort. More and more powerful and user friendly softwares are appearing in the market[3,42].

Power electronic circuit design require accurate methods of evaluating the circuit performance. Because of the complexity of power electronic circuits, computer aided circuit analysis is essential and can provide information about circuit performance that is almost impossible to obtain with laboratory prototype measurements. The general purpose simulation program where the models of many components are available can provide help in such situation. For the simulation of electric drive systems, PSPICE software and SIMULINK platform in MATLAB are very
useful. PSPICE and MATLAB are widely accepted and commonly used simulation packages. They provide with a software breadboard for evaluating the circuit performance without touching the first piece of hardware. They contain many models for the implementation of electric machines as well as the power converter and help in simulating the behaviour of the drive system. The programs are accurate and user friendly. They are available in PC version. In the present work, PSPICE and SIMULINK are effectively used for simulating the drive systems [42-47].

1.7 SCOPE OF THE THESIS

This thesis report details the investigations that have been carried out on the steady state operation of phase controlled as well as chopper controlled ac voltage controllers connected to loads comprising of a resistance R, an inductance L and a sinusoidal back emf E.

Extensive investigations have been carried out on the phase control of ac voltage controllers with RL loads [48-53]. However, not much work has been reported for a load containing a sinusoidal back emf. Some investigations with RE and LE loads are reported in [31], but RLE load has not been considered. Hence, in this thesis, an attempt is made to carryout certain investigations on phase control of a single phase ac voltage controller with a load circuit of generalised nature, comprising of R, L and E. It is proposed to evaluate the performance quantities such as rms load voltage, rms current, power drawn from the ac mains, harmonic distortion and input power factor for various load conditions and present them in a graphical form. To supplement the theoretical analysis, it is desired to simulate the system using the software package PSPICE. It is also proposed to conduct experimental investigations using a thyristorised ac voltage controller with RLE load to check the validity of theoretical results.
AC chopper is found to have better performance compared to conventional phase control technique. Considerable work has been reported on the performance of ac choppers with RL loads[54-57]. However, not much work has been reported so far on the performance of ac chopper with a general RLE load. Hence, it is decided to analyse the performance of an ac chopper with RLE load and to compare with that of phase control to estimate the advantages of chopper control. Here again, simulation and experimental investigations are proposed to confirm the theoretical results.

An attempt is made to extend the above investigations to two practical applications, such as control of induction machines and ac series motors. AC voltage controllers are being used with induction motors to improve their performance[10-13,18]. At light load conditions, the motor voltage is reduced resulting in reduction of the magnetising current and hence improvement in power factor. Attempts have been made to use the same technique for improving the performance of grid connected induction generators[19-22]. However, a comprehensive analysis on the performance of grid connected induction generators with voltage control has not yet been reported. Hence, it is proposed to undertake a detailed study on the performance of grid connected induction generators with voltage control at light load conditions by representing the induction generator by its RLE equivalent. The feasibility of employing the ac voltage controller, used for the soft start of the induction machine as a motor in Wind Energy Conversion Systems, for the power factor improvement of the system is also to be studied. Experimental investigations are also proposed to be carried out on a three phase ac voltage controller fed induction generator.

AC voltage controllers employing phase controlled triac or back to back connected SCRs are widely used for the speed control of ac series motors in a number of applications. However, they are found to create some problems such as introduction of harmonics, poor supply power factor, interference to communication equipments and heating of the motor [58-61]. Hence, in this thesis, it is proposed to analyse these
problems in detail by representing the series motor by its RLE equivalent. Chopping technique employing PWM control strategy has been found to overcome some of the problems associated with phase control [52-57]. Hence, an attempt is made in this work, to introduce ac chopper for the speed control of ac series motor, the switching angles of the ac chopper being controlled optimally so as to get a smoother output wave form. The aim is to analyse ac chopper fed series motor extensively and to observe the improvements in performance that can be achieved by the introduction of chopper control. It is also proposed to simulate the complete drive system in PSPICE and SIMULINK. Further, experimental investigations are to be carried out on a power MOSFET based ac chopper fed series motor to validate the theoretical results.

Artificial intelligence (AI) tools such as fuzzy logic and neural networks are expected to usher a new era in power electronics and motion control in the coming decades [40,41]. These technologies have advanced significantly in recent years. Hence, it is decided to make an attempt to apply these AI tools for the optimal control of voltage controller fed drives.

A fuzzy control algorithm for a process control system makes use of the intuition and experience of an operator and designer. Fuzzy control is basically non linear and adaptive in nature and hence give good performance under parameter variations and load disturbances. Fuzzy logic can be applied to control, model and estimate the performance of power electronic systems [62-66]. A power electronic system, in general, has complex non linear model with parameter variation and the control need to be very fast. A fuzzy logic can provide fast and robust control. Hence, in this thesis, an attempt is made to introduce fuzzy logic for the closed loop speed control of induction motor. It is decided to apply fuzzy logic for the speed and current control and also to linearise the control characteristics of the ac voltage controller.

Further, it is proposed to apply fuzzy logic to the Wind Energy Conversion Systems (WECS). The performance of WECS depends upon the wind speed.
Since wind is an uncertainty, it is very difficult to have a well defined mathematical model for estimating the performance and hence the operator has to make use of his past experience. Under such circumstances, fuzzy control can be effectively employed to give an optimum performance. Hence, an aim is to introduce fuzzy logic for improving the performance of WECS. Special control rules are to be created for controlling the firing angle of the voltage controller according to the wind speed.

Artificial Neural Networks are becoming very popular recently because of their superiority with respect to speed, accuracy etc. over the other methods of control. They are being used in many applications including power electronics and motion control [67-74]. Once trained for a particular application, neural network based controller will be fast and found to give optimum performance. Hence, in the present work, an attempt is made to use neural network for the optimal control of the ac voltage controller. To check the validity of the theoretical results, simulation is also proposed using SIMULINK.

The main objectives of the thesis research are summarised as follows:

1. To carry out extensive investigations on the performance of phase controlled ac voltage controller with a general RLE load.

2. To observe the improvement in performance by introducing chopper control by extensively analysing single as well as multiple pulse width modulated chopper with RLE load.

3. To extend the above investigations to Wind Energy Conversion System and to observe the feasibility of introducing ac voltage controller for the power factor improvement of the system.

4. To identify the problems associated with the conventional controller for ac series motor and to try to overcome that by introducing chopping technique.

5. To study the improvement that can be obtained by introducing fuzzy and neural network based controller for ac voltage controller fed drives.
1.8 ORGANISATION OF THE THESIS

Following the introductory remarks and scope of the thesis in the present chapter, chapter 2 deals with the analysis of single-phase, phase controlled ac voltage controller connected to a general RLE load. The performance quantities are evaluated through digital computer simulation and characteristics are presented in a graphical form. Simulation and experimental verifications of single phase thyristorised ac voltage controller with RLE load are also presented in this chapter.

The discussions in chapter 3 concentrate on the analysis of single phase ac chopper with a general RLE load. The performance quantities are estimated and presented. The performance of an ac voltage controller employing chopping technique is compared with that of phase controlled one.

In chapter 4, the investigations are extended to the case of a grid connected induction generator. Discussions pertaining to the operation of a grid connected induction generator with ac voltage controller intended to improve the power factor are presented.

The coverage in chapter 5 has been directed towards the studies on the voltage controller fed ac series motor. The problems associated with conventional controller and the solution by introducing chopper control are discussed. Simulation results and experimental verification of the drive system are also reported in this chapter.

In Chapter 6, the application of fuzzy and neural network techniques for the control of ac voltage controller fed drives is discussed. Feasibility of applying fuzzy logic for the performance improvement of Wind Energy Conversion System is discussed. Further, neural network for the optimal control of the voltage controller is simulated and the results are presented in this chapter.
Design, fabrication and testing of a single-phase multiple pulse ac chopper with R, RL and RLE (induction motor) load are discussed in chapter 7. The performance comparison of conventional ac voltage controller and ac chopper with induction motor load is also presented.

The major contributions of the thesis work are summarised in chapter 7 together with suggestions for further work.

The PSPICE listings of various simulation studies are furnished in the appendices.

Following these appendices is given a list of references together with papers published/presented by the author based on the present work.
FIGURE 1.1 BLOCK DIAGRAM OF AN ELECTRIC DRIVE

FIGURE 1.2 INDUSTRIAL ELECTRICITY CONSUMPTION
FIGURE 1.3 AC VOLTAGE CONTROLLER FED INDUCTION MOTOR

FIGURE 1.4 AC VOLTAGE CONTROLLER FED SERIES MOTOR
FIGURE 1.5 SINGLE PHASE AC VOLTAGE CONTROLLER: PHASE CONTROL

FIGURE 1.6 SINGLE PHASE AC VOLTAGE CONTROLLER: CHOPPER CONTROL