CHAPTER 1

INTRODUCTION

1.1 MOTIVATION FOR THE THESIS

Model order reduction of systems concerns the transformation of a higher order model into a lower order model through some sort of computation. A certain relationship between these two models exists and it exhibits same characteristics under consideration. Methods to reduce the order of systems are often utilized for alleviating computational complexity, simplifying system analysis, and thus minimizing time and costs. In converter fed drive system studies, developing a dynamic model of converter fed drives is the very first step for system stability study, dynamic behaviour analysis, or other system functional tests. As systems become larger, their complexity likewise increases and the converter fed drive system analysis has to be tackled for higher order model analysis. However, computation on higher order model is highly complex task besides the results of final analysis may have unnecessary complications leading to high investments but with no apparent advantages. In this case obtaining a lower order model that maintains the main characteristics of the higher order system, such as stability, certain time or frequency response characteristics that can replace the original system naturally simplifies the computational problem of complex higher order model.
In power electronics and drive system operation and control, stability is the first concern. If system performance cannot satisfy the specification, then a stabilizing controller must be used to regulate system dynamic characteristics. Since stability is the most important feature of any dynamic system. In general analysis of control system dynamics starts with a mathematical description of the individual elements of the system as well as the whole system. Next feedback controller is designed to adjust the closed loop parameters to meet the design specifications. The most important application of the reduced order model is the design of a suitable controller for the original higher order system. The reduced order model that maintains the main characteristics of the higher order system can significantly simplify the design of the controller.

The main objective of this thesis is to discuss a control design approach for the reduced order drive system dynamic model and thus to simplify the controller design. The proposed approach consists of two parts: one concerns with the application of model order reduction and the other focuses on the design of a speed controller for converter fed drive systems.

1.2 MODEL ORDER REDUCTION

Every physical system can be described by a set of differential (or difference) equations referred to as the mathematical model of that particular system. This model can be obtained either from basic physical principles or from a series of experiments. This mathematical modeling of systems often gives differential equations of higher order which are difficult to analyze. A measure of complexity of the system model is the number of first order equations used in its description which is often referred to as the ‘order’ of the system.
In modeling physical systems, the order of the system gives an idea of the measure of accuracy of the modeling of the system. The higher the order, the more accurate is the model that describes the physical system. But in several cases the amount of information contained in a complex model may obfuscate simple insightful behaviours which can be better captured and explored by a model with a much lesser order. Thus by approximating a higher order system to a suitable lower order system, a much better understanding of the system is achieved. Hence the process of Model Order Reduction (MOR) involves studying the properties of a complex dynamic system for reducing its complexity, while preserving (to the maximum possible extent) its input output behaviour. Depending upon the practical application, preservation of certain specific properties of the higher order complex system into the new reduced order model is achieved. There are several model reduction techniques which are flexible enough to capture the essential behaviours of the complex system as per the demand of the practical situation.

Reduced order modeling aims at studying the nature and the dynamic response of a complex higher order system and then copies the essential features of the complex system into the reduced order model. Some of the reasons for using reduced order models of higher order linear systems are:

- For better understanding of the complex system
- To decrease the computational complexity
- To reduce the hardware complexity in realization of the system
- To make feasible controller design
There are several methods prevalent to achieve this model order reduction of highly complex systems. Each of these methods has its own significant advantages in generating reduced order models. In this thesis, a new model order reduction technique proposed by Ramesh et al (2011), called Cross Multiplication of Polynomials (CMP) is examined. In particular its application to controller design for converter fed various electric drive system is investigated.

1.3 ELECTRIC DRIVE SYSTEM

A modern variable speed drive system has four components:

(i) Electric machines-ac or dc
(ii) Power converters - Rectifiers, choppers, inverters and cycloconverters
(iii) Controllers-Matching the motor and power converter to meet the load requirements
(iv) Load

These above mentioned electric drive system components are explained one by one as below

1.3.1 Electric Machines

The electric machines currently used for speed control applications are the following:

(i) DC machines-Shunt, series, compound, separately excited dc motors and switched reluctance machines.
(ii) AC machines-Induction, wound rotor synchronous, Permanent magnet synchronous, synchronous reluctance, and switched reluctance machines.

(iii) Special machines-Switched reluctance machines.

All the machines are commercially available from fractional kW to MW ranges except permanent magnet synchronous, synchronous reluctance, and switched reluctance machines which are available up to 150 kW level. The latter machines are available at higher power levels but would be expensive from a commercial point of view because they require custom design. A number of factors go into the selection of a machine for a particular application:

(i) Cost
(ii) Thermal capacity
(iii) Efficiency
(iv) Torque-speed profile
(v) Acceleration
(vi) Power density, volume of the motor
(vii) Ripple, cogging torques
(viii) Availability of spare and second sources
(ix) Robustness
(x) Suitability for hazardous environment
(xi) Peak torque capability

They are not uniformly relevant to anyone application. Some could take precedence over others. For example, in a position servo application, the peak torque and thermal capabilities together with ripple and cogging torques
are preponderant characteristics for application consideration. High peak torques decrease the acceleration/deceleration times, small cogging and ripple torques help to attain high positioning repeatability and high thermal capability leads to a longer motor life and a higher loading. In this thesis, the three drive systems of dc, induction and permanent magnet synchronous machines are considered and their steady state and dynamic models are derived. The synchronous reluctance and switched reluctance machines and their drive systems are fairly recent but yet to establish themselves in the market. Very few engineers are involved with these topics whereas a large number of engineers are employed in dc, induction, permanent magnet synchronous and brushless dc machines industrial sectors and therefore only those drive systems are covered in this thesis.

1.3.2 Power converters

The power converters driving the electrical machines are:

(i) Controlled rectifiers

They are fed from single and three-phase ac mains supply and provide a dc output, for control of the dc machines or sometimes input dc supply to the inverters in the case of ac machines.

(ii) Inverters

They provide variable alternating voltages and currents at desired frequency and phase for the control of ac machines. The dc supply input to the inverters is derived either from a battery in the case of the electric vehicle or from a rectified ac source with controlled or uncontrolled (diode) rectifiers. Because of the dc intermediary, known as dc link, between the supply ac source and the output of the inverter, there is no limitation to the attainable
output frequency other than that of the power device switching constraints in the inverters.

(iii) Cycloconverters

They provide a direct conversion of fixed frequency alternating voltage/current to a variable voltage/current variable frequency for the control of ac machines. The output frequency is usually limited from 33 to 50% of the input supply frequency, to avoid distortion of the waveform and therefore they are used only in low speed but high power ac motor drives. These power converters can be treated as black boxes with certain transfer functions for the analysis of stability of them.

1.3.3 Controllers

The controllers embody the control laws governing the load and motor characteristics and their interaction to match the load and motor through the power converter. The controller controls the input to the power converter. Very many control strategies have been formulated for various motor drives and the controllers implement their algorithms. For instance, the control of flux and torque requires a coordination of the field and armature currents in a separately excited dc motor. In the case of an ac induction motor, the same is implemented by coordinating the three stator currents whereas the synchronous motor control requires the control of the three stator currents and its field current too. The laws governing their control are complex and form the basis of this thesis.

The controller input consists of the following:

(i) Torque, flux, speed and/or position commands
(ii) Their rate of variations, to facilitate soft start and preserve the mechanical integrity of the load

(iii) The measured torque, flux, speed and/or position for feedback control

(iv) Limiting values of currents, torque, acceleration and so on

(v) Temperature feedback and instantaneous currents and/or voltages in the motor and/or converter

(vi) The constants in the speed and position controllers such as Proportional, integral and differential gains.

The controller output determines the control signal for voltage magnitude, $V_c$ in the case of inverters and the control signal for determining the frequency, $f_c$ in the case of cycloconverters. These functions can be merged and only the final gating signals might be directly issued to the bases/gates of the power converter. It may also perform the protection and other monitoring functions and deal with emergencies such as sudden field loss or power failure.

The controllers are realized with analog and integrated circuits. The present trend is to use microprocessors, single chip microcontrollers, Digital Signal Processors (DSPs), VLSI, and special custom chips also known as Application Specific ICs (ASICs) to embody a set of functions in the controller. The real time computational capability of these controllers allows complex control algorithms to be implemented. Also, they lend themselves to software and remote control hence paving the way to flexible manufacturing systems and a high degree of automation.
1.3.4 Load

The motor drives a load that has a certain characteristic torque-vs.-speed requirement. In general, the load torque is a function of speed and can be written as \( T_1 \propto \omega_m^x \), where \( x \) can be an integer or a fraction. For example, the load torque is proportional to speed in frictional systems such as a feed drive. In fans and pumps the load torque is proportional to the square of the speed. In some instances the motor is connected to the load through a set of gears. The gears have a teeth ratio and can be treated as torque transformers. The gears are primarily used to amplify the torque on the load side that is at a lower speed compared to the motor speed. The motor is designed to run at high speeds because it has been found that the higher the speed, the lower is the volume and size of the motor. But most of the useful motion is at low speeds, hence the need for a gear in the motor load connection. The gears can be modeled from the following facts (Dewan et al 1984):

(i) The power handled by the gear is the same on both the sides.

(ii) Speed on each side is inversely proportional to its tooth number.

To model the motor drive it is essential to have a physical model of its load with the characteristics of friction, inertia, torque-speed profile and gears and backlash.

1.4 LITERATURE REVIEW

1.4.1 Model Order Reduction

The Model Order Reduction (MOR) techniques used for continuous system can be broadly classified into two types:
i. Time domain techniques

ii. Frequency domain techniques.

A number of investigations have been carried out in approximating higher order linear systems to lower order. Since systems of practical importance are all of high dimensionality, several model order reduction methods have been developed during the past three decades which include time domain and frequency domain methods. The fundamental methods in the area of model order reduction were published in the eighties and nineties of the last century. However, the basis for many of today’s MOR techniques is rooted in the Arnoldi (Arnoldi 1951) and Lanczos (Lanczos 1950) algorithms first developed back in the 1950s. These techniques were used to reduce a matrix to Hessenberg and tridiagonal form, respectively. These techniques were not applied to produce a reduced order model until the mid-1990s.

Methods based on Truncated Balance Realisation (TBR) (Moore 1981) and Proper Orthogonal Decomposition (POD) (Sirovich 1987) were proposed, as a means to produce reduced order models.

TBR (Joel Phillips and Miguel Silveira 2005) is a method developed in the area of system and control theory and is applied to Ordinary Differential Equation sets (ODEs). The TBR method calculates the largest singular values of a system and uses a similarity transform to achieve a reduced order model. POD was developed within the area of computation fluid dynamics and is applied to nonlinear Partial Differential Equations (PDEs). These methods use the time response outputs of a system to certain inputs as a means to build an orthogonal basis onto which the system may be projected. These projections are subsequently used to create the reduced order model.
In 1989, Model Based Parameter Estimation (MBPE) (Burke et al 1989) was introduced. It is primarily used in conjunction with the Method of Moments (MoM) (Reddy and Miller 1998). This method creates a reduced order model by matching a rational polynomial to data available from the MoM. A model is interpolated between or extrapolated from samples of this data. The major drawback of this technique is that the sampling points and interpolation order are not known a priori. Therefore the procedure is not automated and essentially requires running several simulations before choosing the best reduced order model. The following year, the first category methods based on the Asymptotic Waveform Evaluation (AWE) (Pillage and Rohrer 1990) were published. The focus of this method was the explicit computation of moments which are then converted into a Pade approximation. AWE was introduced to perform MOR on circuit analysis problems by matching moments in a Taylor series for the system transfer function. However the use of this approximation is limited to the radius of convergence of the Taylor series. In such cases, the rational function approach is used to improve the accuracy of the numerical solution. The Pade representations have a larger radius of convergence and therefore can provide a broader extrapolation as they include poles as well as zeros in the response and as such can match the resonant behaviour far better than a truncated power series (Wan and Liang 2004).

Then in 1994 techniques based on the Lanczos process were introduced. The proposed Pade Via Lanczos (PVL) (Feldmann and Freund 1993) method developed the relation between the Pade approximation and the Krylov subspaces without explicitly forming the ill-conditioned moments. In 1995 another Krylov based method, the Projection Via Arnoldi (PVA) (Odabasioglu and Celik 1998) method based on the Arnoldi methods of the early 1950s, was introduced. These techniques were initially applied to circuit analysis but later were adopted for use in computational electromagnetics.
(Gallivan et al 1994). However, PVL and PVA methods suffer from an inherent limitation which requires the original model to be a linear function of the reduced order model varying parameter.

In more recent years much research has been done in the area of MOR. Many of these new techniques are tailored to specific applications and formulations while others are more general. The use of Krylov subspace techniques is widely accepted as being the most flexible and computationally efficient approach to MOR and has been widely used in various formulations and applications. Since the essential features of the original system are captured at the early stage of the iteration, Krylov subspace algorithms can produce very accurate lower order models.

In time domain technique the main idea is to retain dominant eigen values of the system in higher order models. In this line, Davison (1966) gave lower order model representing higher order system which produced satisfactory dynamic response. The principle of this method is to retain only dominant eigen values of the system and avoid the eigen values that are farthest away from the origin. In the same lines Davison and Chidambara (1967) had suggested an approach for model order reduction. The transient response of the unused eigen values are omitted but their contribution in steady state is considered to reduce the steady state error seen in Davison technique. Alternate ways to compute the reduced order model were proposed by several authors (Marshall 1966). This method is similar to the Chidambara technique since it too takes the steady state values of unused eigen values in to account. Some other model reduction schemes for continuous system are claimed to be applicable to discrete system with bilinear transformation. Therapas (1984) developed a direct technique without any transformation.
Krishnamoorthy et al (1978) have developed a method of model reduction based on Routh stability criterion. In this method the reduced order transfer function is determined directly from the elements in the Routh stability array of the higher order denominator and numerator. A model reduction method based on differentiation of polynomials had been introduced in the later stage (Gutman et al 1982). The reciprocals of numerator and denominator polynomials of the higher order transfer function are differentiated suitably many times to yield the coefficients of the reduced order transfer function.

One of the more popular methods for large scale system order reduction has been the continued fraction technique first introduced by Chen and Shieh (1968) and extended by other researchers. The original technique is based on a Taylor series expansion of the systems. Lucas (1983) had suggested the concept of expanding the system transfer function about the origin and about a general point for model reduction. Subsequently in the same year, he presented an algorithm which produces biased models such as combinations of retained time moments in which macro parameters may be varied. Lucas (1983) had proposed an algorithm by continued fraction expansion about the origin and general point. He (1984) proposed a continued fraction about three points and later he proposed a method which uses factor division method.

Prasad et al (2003) have recently presented a method in which denominator is obtained by using Mihailov criterion and numerator is found by using factor division method. The design of controllers and compensators for higher order stable LTIDS can be simplified with the help of suitable lower order models. Earlier several authors had presented methods for the reduction of linear discrete time based on a modified Routh stability criterion (Shamash and Feinmesser 1978). Some other model reduction schemes for
continuous systems proposed by Shamash were found to be applicable to
discrete system with bilinear transformations. Prasad (1993) had proposed a
mixed method for the model order reduction for discrete system using
stability equation method and weighted time moments. This method involves
the application of bilinear transformation. All these techniques involve special
procedures leading to large computational complexity.

Further the method of model order reduction by least squares
moment matching was generalized (Lucas and Munro 1991) including the
Markov parameters in the process to manage with a wider class of transfer
functions. On the other hand, Aguirre (1994) had argued that one of the chief
advantages of the Least Squares Pade (LS-Pade) method is that the additional
information concerning the original system over the mid frequency range is
included in the simplified model and consequently better approximations are
often obtained. The simplification of Squared Magnitude Functions (SMF)
using the LS-Pade method was proposed by Aguirre (1994) as a new
procedure for model order reduction, which overcomes the \( j_\omega \)-axis problem encountered in model simplification by means of SMF.

In the method proposed by Bosley and Lees (1974) the moment
matching concept was introduced and was based on determining a set of time
functions for the full model and matching them to a simple model by
choosing a number of appropriate parameters without having to obtain the
higher order systems time or frequency responses. The technique is
essentially a match of time moments of the higher order models impulse
response to those of the reduced order model. The concept of order reduction
by least squares moment matching and generalized least squares methods
employed in Beat (1990) and Lucas (1991) has been extended about a general
point ‘a’ in the method proposed by Mukherjee et al (2008), in order to have
better approximations of higher order linear, time invariant dynamic systems.
Some heuristic criteria have been employed for selecting the linear shift point ‘a’, based upon the means (arithmetic, harmonic and geometric) of real parts of the poles of higher order system.

As digital control systems having many advantages over analog ones, the convenience of handling a discrete system model is obvious and consequently interest in discrete system order reduction is justified. A scanning of literature since seventies shows that work in the area of discrete system order reduction started in different directions like using continued fraction (Shih et al 1973) and (Shamash 1974), Padé approximation (Chuang 1975) and (Lucas 1993), Moment matching (Shih et al 1975) and using stability equation (Chen et al 1979) and (Therapos 1984). A direct method for model reduction of discrete systems was also proposed by Therapos (1984). Parthasarathy et al (1977) improved the work of Shamash (1974) using modified Cauer form.


Besides the research in the area of interest in this work, i.e., response matching method, started perhaps by Aplevich (1973) through a method which optimally approximates the given system with respect to the sum of squared output errors of the impulse response. Chung et al (1981)
have reported a method where the concept of Edgar (1975) used for order reduction of continuous system was improved and extended to discrete system. On similar areas work was reported by Cheng et al (1991) where a method was proposed for both continuous and discrete system using linear programming technique to find a squared magnitude function such that its response clearly approximates that of the squared magnitude function of the original system in some design sense. The model obtained was always stable.

Many systems have coefficients that are constants but uncertain within a finite range. Those systems can be modeled as interval systems. Recently, several model reduction methods for interval systems have been considered in the literature for discrete and continuous systems categories. In the method proposed by Ismail et al (1997), the denominator polynomial of a reduced order model was obtained so that dominant poles of the original system are preserved in the reduced order model. The numerator polynomial was then determined by matching some initial time moments. In methods proposed in Dolgin et al (2003) and Yang (2005), a technique was suggested to construct the interval Routh array from which a stable denominator polynomial for the reduced order model can be obtained.

The method proposed by Ismail et al (1997) can be used for continuous systems. However, the approach followed in Dolgin et al (2003) and Yang (2005) cannot be applied to discrete systems. Younseok Choo (2007) discusses the method of Ismail et al (1997) in the viewpoint of stability of the reduced order model. In Ismail et al (1997), the interval poles of the original system were obtained using the results of method proposed by Deif (1991). Then the denominator polynomial of a reduced order model was computed by applying interval arithmetic (Alefeld et al 1983), to dominant poles. The conventional mathematical optimization techniques, problem formulation must satisfy mathematical restrictions with advanced computer algorithm requirement and may suffer from numerical problems.
In contrast to linear models, the reduced order model cannot technically be precompiled in nonlinear case but must be updated constantly because the parameters change in time. Reconstruction of the reduced order model is computationally demanding and leads to procedures that may require as much computation as the original higher order model. Thus, the use of reduced order models for nonlinear systems is a challenge, though a number of approaches have been developed to address this issue. One such technique for the reduced order modeling of nonlinear systems is based on linearized or polynomial expansion of the nonlinearity and application of Krylov based projection methods (Chen and Kang 2000, Peaceman 1983). A limitation of these approaches is that the reduced order model is valid only around the initial operating point of the nonlinear system which limits the application of the reduced order model to weakly nonlinear systems and limited input disturbances.

Balanced truncation was also applied for nonlinear systems. Condon and Ivanov (2004) proposed a new approach to construct empirical controllability and observability gramians. They reported that the method is successful if the state space of the nonlinear solution is well defined. However this is not the case for all nonlinear systems and the method is thus applicable for systems in which the nonlinearities are not too severe.

Proper orthogonal decomposition is probably the most popular method for the reduced order modeling of nonlinear systems. Since the basis functions are computed from the snapshots (which are recorded from the actual simulation of the nonlinear model), the POD based reduced order model thus inherits the stability and some of the behaviour of the original system (Rowley et al 2000) even though the reduced order models discussed above can be used for nonlinear problems, their performance generally degrades significantly relative to that for linear cases (Rewienski 2003, Astrid
To overcome these limitations a linearization method (Rewienski 2003) developed that approximates the nonlinear system with a weighted combination of linearized models generated and saved from training simulations of the system.

Further in a complex system consisting of number of controllers, the optimization of several controller parameters using the conventional optimization is a very complicated process and sometimes gets struck at local minima resulting in sub optimal controller parameters. In recent years, one of the most promising research fields has been “Heuristics from Nature”, an area utilizing analogies with nature or social systems. Application of these heuristic optimization methods may find a global optimum that can produce a number of alternative solutions, has no mathematical restrictions on the problem formulation and are numerically robust.

Several modern heuristic tools have evolved in the last two decades that facilitate solving optimization problems that were previously difficult or impossible to solve. These tools include evolutionary computation, simulated annealing, tabu search, genetic algorithm, particle swarm optimization, etc. Among these heuristic techniques, Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Differential Evolution (DE) techniques appear as promising algorithms for handling the optimization problems. These techniques are finding popularity with research community as design tools and problem solvers because of their versatility and ability to optimize in complex multimodal search spaces applied to non differentiable objective functions.

In this thesis, a new model order reduction technique proposed by Ramesh et al (2011) is applied to get the reduced order system. This method is mixed method in nature and that is computationally simple to get a reduced order model from the given higher order system. And also this method
assures the accuracy and stability in the approximated models provided corresponding higher order model is stable. The proposed method is suitable for minimum phase transfer functions.

### 1.4.2 Controller Design for Converter Fed Electric Drive Systems

Conventionally the Proportional plus Integral (PI) type controller was used by Symmetric Optimum (SO) approximation method (Krishnan 2002). This method eliminates the effects due to disturbance very rapidly compared to other optimum techniques such as linear or modulus optimum method. However these methods are based on the assumption that the time constants of the systems are equal.

The study of controller design of electrical drives only very few authors have proposed some controller techniques. Pragasan Pillay and Ramu Krishnan (1990) carried out modelling, simulation and speed controller design of permanent magnet synchronous motor drives. Alok Ranjan Singh and Giri (2012) introduced design and analysis of DC motor speed control by GA based tuning of fuzzy logic controller. Tripura and Srinivasa Kishore Babu (2011) used intelligent speed control system based fuzzy logic for inverter fed indirect vector controlled induction motor drive. Amar Nath Tiwari (2011) studied controller design and simulation of PMSM drive. He used hysteresis current controller for inner current control and PI controller for outer speed control. Besides many researchers proposed new type of fuzzy model that has been proved to be effective to overcome tracking error and Integral Square Error (ISE) when the load varies fast and overshoot during transients. However, difficulty arises in obtaining enough input output data for identification of fuzzy model parameters.
1.5 SCOPE OF THE THESIS

The aim of this work is to use a model order reduction technique for the design of speed controller for converter fed separately excited dc motor drives, permanent magnet synchronous motor drives and vector controlled induction motor drives. The main contributions of this thesis are summarized as follows.

- A model order reduction technique which is cross multiplication of polynomials method is studied.
- Proportional Integral (PI) controller algorithm and controller parameter tuning using Genetic Algorithm optimization method is proposed.
- A mathematical model of the converter fed separately excited DC motor drive is derived and the reduced order model is obtained from the original higher order system. Also speed controller design for Converter fed DC motor drive system is carried out.
- Model order reduction and design of controller for converter fed Permanent magnet synchronous motor drive systems is achieved.
- Model reduction and design of controller for inverter fed indirect vector controlled induction motor drive systems is proposed.
- Genetic algorithm is employed at the tail end of the design of controller for reduced order model of the electric drive system.
1.6 ORGANISATION OF THESIS

The organization of the thesis is as follows:

Chapter 1 deals with literature survey of model order reduction methods and controller design of electric drive systems, the motivation, scope and organization of the thesis.

In Chapter 2 a new model order reduction method named as Cross multiplication of polynomials method proposed by Ramesh et al (2011) has been studied and compared with the existing model order reduction methods. This method of model order reduction has been applied to the order reduction of converter fed separately excited DC motor drive systems. This reduction technique is the reliable method to get a stable reduced order model from the given higher order drive system.

In Chapter 3 existing controller tuning methods such as Ziegler-Nichols method and Symmetric Optimum method are discussed and also new tuning technique based on genetic algorithm is proposed. This tuning method is compared with the existing tuning methods.

In Chapter 4 the cross multiplication of polynomials model order reduction technique is applied to the converter fed separately excited dc drive systems and the reduced order model of the converter fed dc drives system is obtained. Design of speed controller for the reduced system is carried out with the help of genetic algorithm based gain values. These gain values are applied to the higher order model of the converter fed dc drives system and the performance of the drive systems is compared with the conventional method.
In Chapter 5 model order reduction technique discussed earlier is applied to the converter fed permanent magnet synchronous motor (PMSM) drive systems and the reduced order model of the converter fed PMSM drive system is obtained. Design of speed controller for the reduced system is carried out with the help of genetic algorithm based gain values. These gain values are applied to the higher order model of the converter fed PMSM drives system.

In Chapter 6 the proposed model order reduction technique is applied to the inverter fed vector controlled induction motor drive systems and the reduced order model of the drive system is obtained. Design of speed controller for the reduced system is done with the help of genetic algorithm based gain values. These gain values are applied to the higher order model of the converter fed vector controlled induction motor drives system. The performance characteristics are compared with the existing method.

In Chapter 7 the pertinent conclusion from this work and suggestions for future research are included.