DSP BASED SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR

by

P.S.Maheswari
Reg. No 71203415008

of

KUMARAGURU COLLEGE OF TECHNOLOGY
COIMBATORE

A PROJECT REPORT
Submitted to the

FACULTY OF ELECTRICAL & ELECTRONICS ENGINEERING

In partial fulfillment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

IN

POWER ELECTRONICS & DRIVES

JUNE 2005

BONAFIDE CERTIFICATE

Certified that this project report titled **DSP BASED SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR** is the bonafide work of **Ms.P.S.MAHESWARI** who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

2.6.05

PROJECT GUIDE

HEAD OF THE DEPARTMENT

The Candidate with University Register No: 71203415008 was examined by us in the project Viva-Voce examination held on 23-06-2005

INTERNAL EXAMINER

26/06/05

EXTERNAL EXAMINER

(DR S.Subha Rani)

ABSTRACT

Now a days Switched Reluctance Motors (SRMs) attract more and more attention. The construction of switched reluctance motor is very simple. Simplicity makes the SRM inexpensive and reliable and together with its high speed capacity and high torque to inertia ratio, makes it a superior choice in different application. The control of SRM is not an easy task. The motor flux linkage appear to be a non linear function of stator current as well as rotor position, as does the generated electric torque. Apart from the complexity of the model, the SRM should be operated in a continuous phase to phase switching mode for proper control. This project focuses on speed control of SRM using Digital Signal Processor (DSP) based on simplified model. This simplified model limits the operation of the motor complexity into its linear flux region. By optimizing the average power of the whole system, the motor's transient as well as steady state performance for speed tracking can be improved simultaneously.

ACKNOWLEDGEMENT

I would like to express my deep gratitude and thanks to our beloved Principal of Kumaraguru College of Technology, **Dr.K.K.PPADMANABHAN** without whom I would not have been studying in this institution.

I am also grateful to our H.O.D **Prof. REGUPATHY SUPRAMANIAM.** for providing valuable comments that improved the presentation of this dissertation.

This work wouldn't have been possible without the constant support of **Dr.T .M .KAMESHWARAN** and I am greatly indebted to him.

I would like to express my sincere gratitude and appreciation to my Project guide, **Mr.P.THIRUMOORTHI** for his support, patience, and encouragement throughout my project work. I thank **Mrs. K.PREMLATHA** for giving me valuable suggestions during various stages of my thesis and helping me finish my work on time.

My thanks also go to the other members **Mrs. R.MAHALAKSHMI** our project coordinator and our advisor **Mrs. N.KALAIARASI** for their valuable comments and suggestions.

I wouldn't have been in this position if I hadn't had the support and best wishes from my family, especially my **PARENTS** I would like to thank all my **FRIENDS** for contributing tom such an inspiring and pleasant atmosphere.

TABLE OF CONTENTS

Chapter	Title	Page No
	ABSTRACT	iii
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
1.	INTRODCUCTION	1
	1.1. OBJECTIVE OF THE PROJECT	1
	1.2. GENERAL	1
	1.3. SRM CONTROL	2
	1.4. THE DSP IN MOTOR CONTROL	2
	1.5. ADVANTAGES AND APPLICATIONS OF SRM	2
	1.6. OUTLINE OF THE PROJECT	3
2.	THE DSP IN MOTOR CONTROL	5
	2.1 TRENDS IN SWITCHED RELUCTANCE MOTOR CONTROL	5
	2.2 BENEFITS OF THE DSP CONTROLLERS	6
	2.3 A LARGE RANGE OF APPLICATIONS	7
3.	SRM OPERATION	8
	3.1. MACHINE TOPOLOGIES	8
	3.1.1. Single Phase Motor	8
	3.1.2. Two Phase Motor	9
	3.1.3. Three Phase Motor	9
	3.1.4. Four Phase Motor	9
	3.2. SWITCHED RELUCTANCE MOTOR	9
	3.3. MATHEMATICAL MODEL OF THE SRM	11
	3.4. SRM OPERATION	13
	3.5. SPEED TORQUE CHARACTERISTICS OF SRM	17
	3.6. FLUX LINKAGE CHARACTERISTICS OF THE SRM	18
4.	CLOSED LOOP CONTROL OF DRIVES	20
	4.1. SPEED CONTROL OF DRIVES	20

4.2.1. Current controller 22

4.2.2 Speed controller 23

5. CONVERTER TOPOLOGY 25

5.1. PULSE WIDTH MODULATION TECHNIQUE 26

5.1.1. PWM Generator 26

5.1.2. Different PWM Techniques 27

5.1.3. PWM Objective 28

5.2. SINUSOIDAL PULSE MODULATION 29

5.3. PWM INVERTER 30

6. DIGITAL CONTROL OF SRM 33

6.1. DIGITAL SIGNAL PROCESSOR 34

6.2. COMPLETE DRIVE SYSTEM 36

6.2.1. DSP Controller 37

7. SIMULATION RESULTS 38

7.1. MODEL OF THE WHOLE SYSTEM 38

7.1.1. SRM Model 39

7.1.2. Current Controller and DSP Controller 39

7.2. SIMULATION RESULTS 40

8. HARDWARE IMPLEMENTATION 43

8.1. POWER SUPPLY UNIT 44

8.2. DSP CIRCUIT 45

8.2.1. DSP Architecture Overview 45

8.2.2. DSP Output 47

8.3. HIGH VOLTAGE RECTIFIER 47

8.4. MOSFET INVERTER 47

8.4.1. Power MOSFET 47

8.4.2. MOSFET Inverter 48

9. CONCLUSION 50

9.1. FEATURES OF THE PROJECT 51

9.2. FURTHER WORK 51

APPENDIX 1-DSP Schematics
APPENDIX 2-DSP Functional Block Diagram
APPENDIX 3-DSP Controller Coding
REFERENCES

LIST OF TABLES

No	Title	Page No
Table 6.1.	Input Port Map with Wait-States	35
Table 6.2.	Output Port Map with Wait-States	35

LIST OF FIGURES

No	Title	Page No
Figure 2.1.	Control system using a DSP controller	6
Figure 3.1.	Switched Reluctance Motor	10
Figure 3.2.	Single phase SRM	11
Figure 3.3.	Flux linkage chart	12
Figure 3.4.	Energy Exchange	12
Figure 3.5.	3-phase SRM	13
Figure 3.6.	Phase energizing	14
Figure 3.7.	Inductance profile of one phase SRM	16
Figure 3.8.	Speed Torque Characteristics of SRM	17
Figure 3.9.	Flux linkage chart of SRM	19
Figure 4.1.	Closed loop system	22
Figure 5.1.	PWM Generator	27
Figure 5.2.	Output of PWM Generator	27
Figure 5.3.	Upper Lower output	29
Figure 5.4.	PWM signals	30
Figure 5.5.	PWM inverter	31
Figure 6.1.	System Block Diagram	34
Figure 6.2.	The Switched Reluctance Motor Driver	36
Figure 6.3.	SRM Drive Feedback	37
Figure 7.1.	SRM Drive Model	38
Figure 7.2.	Switched Reluctance Motor Model	39

Figure 7.3.	Simulation model of the SRM Drive with Feedback	40
Figure 7.4.	Three phase current Wave form	41
Figure 7.5.	Speed curve	41
Figure 7.6.	Torque Wave form	42
Figure 8.1.	Hardware Block Diagram	43
Figure 8.2.	Power Supply Unit	44
Figure 8.3.	TMSC320C25 Simplified Block Diagram	45
Figure 8.4.	Single phase MOSFET inverter	48
Figure 8.5.	Hardware Design	50

CHAPTER 1

1. INTRODUCTION

1.1. OBJECTIVE OF THE PROJECT

The objective of the project is to control the speed of the switched reluctance motor using Digital Signal Processor. Here the motor speed is controlled based on a closed loop system.

1.2. GENERAL

The general trend in motor control is to design low cost, highly energy efficient and high time reliability control systems. Therefore low production cost and very high efficient motors such as Switched Reluctance Motors are naturally involved in these designs. It also creates a need to implement more effective and efficient control strategies in order to increase the over all electrical input and system power efficiencies by decreasing the size and cost of drive components. DSP technology allows to achieve both a high level performance as well as system cost reduction. The name "Switched Reluctance", describes the two features of the machine configuration: (a) Switched – the machine should be operated in a continuous switching mode, which is the main reason the machine developed only after good power semiconductors became available ;(b) Reluctance – it is the true reluctance machine in the sense that both rotor and stator have variable reluctance magnetic circuits, or more properly it is a double salient machine. Switched Reluctance Motor drives are simpler in construction compared to induction and synchronous machines.Thier combination with power electronic controllers may yield an economical solution. The Switched Reluctance Motor drives present several advantages as high efficiency, maximum operating speed ,good response of the in terms of torque/inertia ratio together with four quadrant operation, making it an attractive solution for variable speed applications.

1.3. SRM CONTROL

The present interest in the switched reluctance machine has been enabled by the significant advances that have occurred in power electronics and electronic controls because the switched reluctance machine has very limited functionally without external controls of its winding currents. This control, in turn, is not practical without power electronics and electronic controls. Examples of the enabling advances in power electronics and electronic controls include the insulated gate bipolar transistor (IGBT) and the Digital Signal Processor (DSP). In this project a simple method is proposed to control the speed model for the SRM closed loop system was a suitable tool for control design and system simulation. The control of SRM is not an easy task. The motors double salient structure makes its magnetic characteristics highly non linear. The motor flux linkage appears to be a nonlinear function of the Switched Reluctance Motor using Digital Signal Processor. The new simple of stator current as well as rotor position, as does the generated torque. Apart from the complexity of the model, the SRM should be operated in a continuous phase to phase switching mode for proper motor control. The performance of Switched Reluctance Motors strongly depends on the applied motor control. The drive system comprising signal processing, power converter and motor must be designed as a whole for specific application.

1.4. THE DSP IN MOTOR CONTROL

Texas Instruments launches a new DSP, referenced TMS320C250, specifically designed for the Digital Motor Control segment. This device combining a fixed point DSP core with microcontroller peripherals in a single chip solution is a part of a new generation of DSPs called the DSP controllers.

1.5. ADVANTAGES AND APPLICATIONS OF SRM

SR motors offer numerous benefits, such as:

- Performance - much greater torque output and with the same (or slightly higher) efficiencies than "premium efficiency" induction motors. Efficiency is flat over a wider speed range;

- Small unit size - makes efficient use of materials and low inertia;
- Low cost - low manufacturing cost, low material cost and low maintains cost. It does not use magnets;
- High speed and acceleration capability -100,000RPM (Rotation Per Minute), with the proper drive;
- Cooling - most of the heat is generated in stationary stator which is relatively easy to cool;
- Rugged construction suitable for harsh environments such as high temperature and vibration.

SRM controllers add to the benefits. Since they do not need bipolar (reversed) currents, the number of power-switching devices can be reduced by 50%, compared to bridge-type inverters of adjustable-speed drives. An SRM drive has inherent reliability and fault tolerance, it can run in a "limp-home" mode with diminished performance with one failed transistor in a phase, unlike standard motor drives.

As control techniques developed, applications of SRMs include:

(a). general purpose industrial drives;

(b). application-specific drives: compressors, fans, pumps, centrifuges;

(c). domestic drives: food processors, washing machines, vacuum cleaners;

(d). electric vehicle application;

(e). aircraft applications;

(f). servo-drives.

1.6. OUTLINE OF THE PROJECT

Chapter 1 gives a general introduction of switched reluctance motors: its Construction and the objective of the project. The control of switched reluctance motor, advantage and applications of SRM and the DSP in motor control are discussed.

Chapter 2 briefly describes the DSP in motor control includes trends in switched reluctance motor control, benefits of the DSP controllers and the applications of the DSP controller.

In Chapter 3, the principle of the SRM motor is discussed in detail from the physical point of view. The speed torque characteristics also discussed.

In Chapter 4, the control of SRM discussed in detail. In section 4.1 gives a speed control of drives. The closed loop speed control described in section 4.2.

In Chapter 5, describes power converter topologies for the SRM. The section 5.1 gives a pulse width modulation technique and different types of PWM techniques. Sections 5.2 discuss the single pulse width modulation technique in detail. The section 5.3 gives the operation of PWM inverters in detail.

Chapter 6 describes digital control of SRM, Digital Signal Processor (TMS320C25), and the complete drive system.

Simulation model and results are demonstrated in Chapter 7.

Chapter 8 deals with the experimental setup hardware, such as controllers, and power converter.

Chapter 9 concludes the project and proposes further work.

CHAPTER 2

THE DSP IN MOTOR CONTROL

2.1 TRENDS IN SWITCHED RELUCTANCE MOTOR CONTROL

In the context of electrical drives the Switched Reluctance motor shows significant advantages. Because of its simple mechanical construction (and thus its low production cost), its efficiency, its torque/speed characteristic and its very low requirement for maintenance, the Switched Reluctance motor is set to become one of the most widely used low-cost electromechanical energy converters.

Traditionally, SR motor control was designed with relative inexpensive analog components. Several inconveniences appeared with analog systems.

The first drawback is inherent to any analog component: aging and temperature variations cause the system to need regular adjustment, furthermore the reliability of the system decreases as the component count increases and, finally, any system upgrade would be difficult as the design is hardwired.

The second drawback resides in the limitations in the effectiveness of analog control structures (no system adaptive control algorithms or time constrained control structures).These problems are solved by making the control structure digital. In fact, digital systems offer many improvements over analog design. Drift is eliminated since most functions are performed digitally, upgrades can easily be made in software and part count is also reduced since digital systems can handle several functions by integrating them into an one chip solution.

The TMS320C250 Digital Signal Processor goes still further by providing high speed, high resolution and sensor less algorithms in order to reduce system costs.

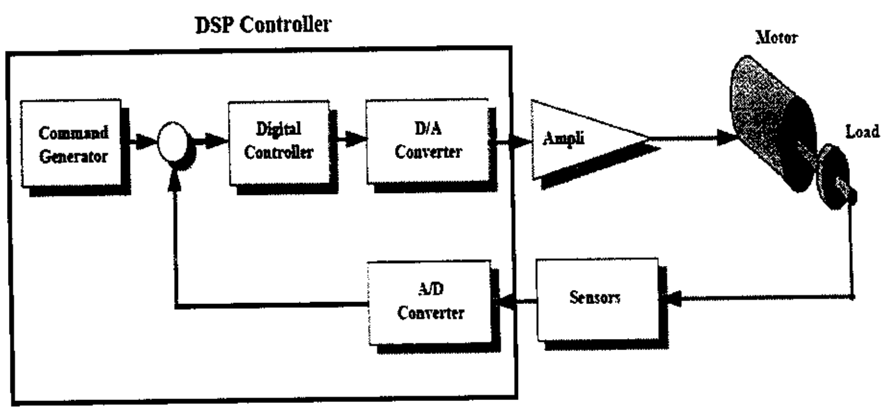
performances often means performing more calculations, the use of some 1-cycle multiplication & addition instructions included in a DSP speeds-up calculations.

2.2 BENEFITS OF THE DSP CONTROLLERS

The performances of a Switched Reluctance Motor are strongly dependent on its control. DSP controllers enable enhanced real time algorithms as well as sensor less control. The combination of both makes it possible to reduce the number of components and to optimize the design of silicon to achieve a system cost reduction.

A powerful processor such as a DSP controller does the following:

- it enables system cost reduction by efficient control in all speed ranges, allowing correct dimensioning of power device circuits;
- it performs high level algorithms due to reduce torque ripple, resulting in lower vibration and longer life time;
- it enables a reduction of harmonics using enhanced algorithms, to meet easier requirements and to reduce filter cost;
- it removes speed or position sensors by the implementation of sensor less algorithms;
- it reduces the number of look-up tables which, in turn, reduces the amount of memory needed;
- it controls power switching inverters and generates high-resolution PWM outputs;
- and it provides a single chip control system



For advanced controls, DSPs controllers may also do the following:

- enable control of multi-variable and complex systems using modern intelligent methods such as neural networks and fuzzy logic;
- perform adaptive control. DSPs have the speed capabilities to concurrently monitor the system and control it. A dynamic control algorithm adapts itself in real time to variations in system behavior;
- provide diagnostic monitoring. Diagnostic monitoring is achieved with FFT of spectrum analysis. By observing the frequency spectrum of mechanical vibrations, failure modes can be predicted in early stages;
- produce sharp-cut-off notch filters that eliminate narrow-band mechanical resonance. Notch filters remove energy that would otherwise excite resonant modes and possibly make the system unstable.

2.3 A LARGE RANGE OF APPLICATIONS

The target applications for a fixed point DSP having the necessary features may be anywhere where the above mentioned advantages meet the customer's needs. Typical end equipment applications with an advanced control are:

- automotive control (electronic power steering, anti-lock brakes);
- HVAC (heating, ventilation and air conditioning);
- blowers and compressors;
- factory automation;
- major appliances (direct-drive horizontal-axis clothes washers);
- office products (printers, copiers, tape drivers).

CHAPTER 3

SRM OPERATION

3.1. MACHINE TOPOLOGIES

As any other motor, the structure of the Switched Reluctance Motor consists of a stator and a rotor. Both stator and rotor are laminated. Stacking the laminations punched from steel lamination with high magnetic quality yields the rotor cores. The stator is formed from punched laminations too bonded into a core, and the coils are placed on each of the stator poles. Each stator pole carries an excitation coil, and opposite coils are connected to form one "phase". There are no windings on the rotor.

The numbers of stator and rotor poles are generally different ($N_s \neq N_r$). Some possible combinations are: $N_s = 6$, $N_r = 4$; $N_s = 8$, $N_r = 6$; $N_s = 12$, $N_r = 10$, etc. These combinations ensure that the rotor is never in a position where the summation of the electromagnetic torque generated by each phase is zero. The larger the stator and rotor poles number, the less the torque ripple. By choosing a combination where there are two more stator poles than rotor poles, high torque and low switching frequency of the power converter can be achieved.

3.1.1. Single Phase Motor

These are the simplest SR motors having the advantage of fewest connections between machine and power electronics. However, the very high torque ripple and inability to start at all angular positions represents a drawback. They can present interest only for very high-speed applications.

3.1.2. Two Phase Motor

The use of a stepping the air-gap can avoid the starting problems. For a two phase SRM the high torque ripple is an important drawback.

3.1.3. Three Phase Motor

The most popular topology of a three-phase SRM is the 6/4 form (Ns = 6and Nr = 4). It represents a good compromise between starting and torque ripple problems and number of phases. Alternative three-phase machines with doubled-up pole numbers can offer a better solution for lower speed applications.

3.1.4. Four Phase Motor

The four-phase motor is known for reducing torque ripple. The large number of power electronic devices and connections is a major drawback, limiting four phase motors to a specific application field. A practical limitation to consider larger phase numbers is the increase of the converter phase units, hence of the total cost.

3.2. SWITCHED RELUCTANCE MOTOR

The Switched Reluctance Motor (SRM) has both salient pole stator and rotor, like variable reluctance motor, but they designed for different applications, and therefore, with different performance requirements. A stepper motor is designed to make it suitable for open loop position and speed control in lower applications, where efficiency is not an important factor. On the other hand a switched reluctance motor is used in variable speed drives and naturally designed to operate efficiently for wide range of speed and torque and requires rotor position sensing.

A Switched Reluctance Motor (SRM) is an electric motor in which torque is produced by the tendency of its moveable part to move to a position of least reluctance, which corresponds to the position of maximum inductance. It is a doubly salient, singly excited motor. That is, the SRM has salient poles on both the rotor and a rotating magnetic field, the rotor tries to rotate along with the rotating magnetic field to always be in a position of minimum reluctance. Thus, exciting the stator phase windings of the motor in a particular sequence and consequently, controlling the rotating magnetic field, we can control the movement of the rotor

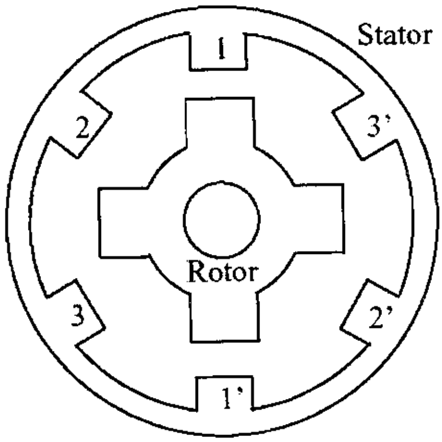


Figure 3.1. Switched Reluctance Motor

Figure 3.1 shows a typical 6/4 SRM. It is a three-phase machine and has 6 poles on the stator and 4 poles on the rotor. The number of poles on the stator and on the rotor is usually not equal. This is to avoid the eventuality of the rotor being in a state of producing no initial torque, which occurs when all the rotor poles are locked in with the stator poles. Here, the diametrically opposite stator pole windings are connected in series and they form one phase. Thus, the six stator poles constitute three phases. When the rotor poles are aligned with the stator poles of a particular phase, the phase is said to be in an aligned position. Similarly, if the inter-polar axis of the rotor is aligned with the stator poles of a particular phase, the phase is said to be in an unaligned position.

In a three-phase SRM, the direction of rotation of the rotor is opposite to the direction of the switching sequence of stator poles. A unique feature of SRM is that it can be operated, albeit with reduced power output, even when there is a loss of one of the phases.

3.3. MATHEMATICAL MODEL OF THE SRM

To derive the basic torque equation of the SRM, let us consider an elementary reluctance machine as shown in Figure 3.2. The machine is single phase exited; that is, it carries only one winding on the stator. The excited winding is wound on the stator and the rotor is free to rotate.

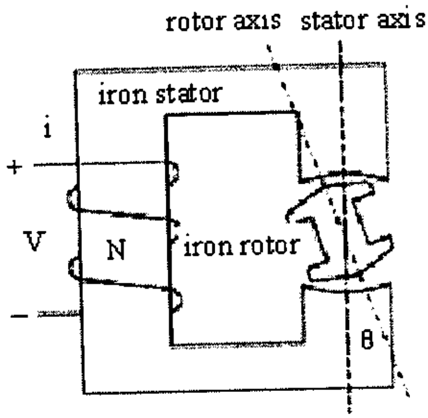


Figure 3.2. Single phase SRM

The flux linkage is

$$\lambda(\theta) = L(\theta) i \qquad (3.1)$$

where i is the independent input variable,i.e. the current flow through the stator.

The general torque expression is given by

$$T_e = \left[\frac{\partial W'}{\partial \theta}\right]_{i=constant} \qquad (3.2)$$

Where W' is the coenergy.At any position the co energy is the area below the magnetization curve as shown in the figure3.3 and figure 3.4 in other words, the definite integral

$$W' = \int_0^i \lambda(\theta, i)\, di \qquad (3.3)$$

So the torque equation becomes

$$T_e = \int_0^i \frac{\partial \lambda(\theta, i)}{\partial \theta}\, di \qquad (3.4)$$

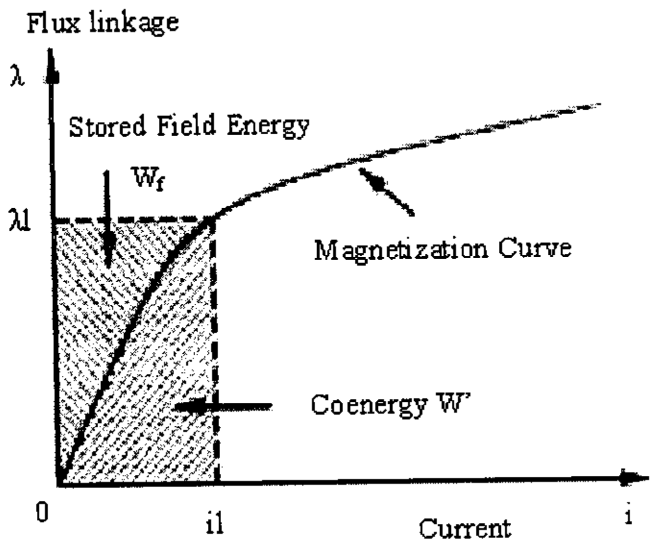


Figure 3.3. Flux linkage chart

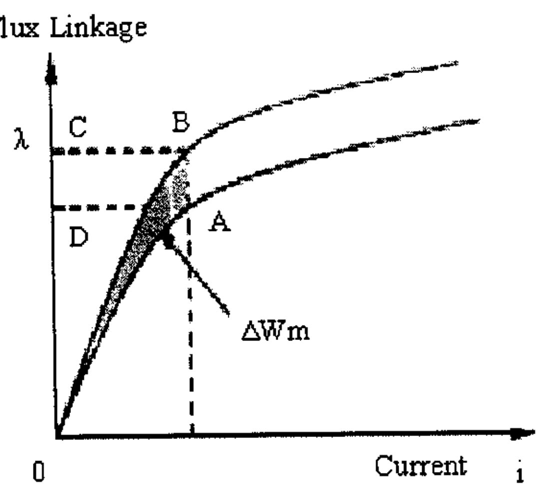


Figure 3.4. Energy Exchange

The mathematical work done

$$\Delta Wm = \Delta W^2 \tag{3.5}$$

At any rotor position θ, the co energy and the stored magnetic energy are

$$W_f = W' = \frac{1}{2}L(\theta)i^2 \qquad (3.6)$$

The instantaneous torque reduces to

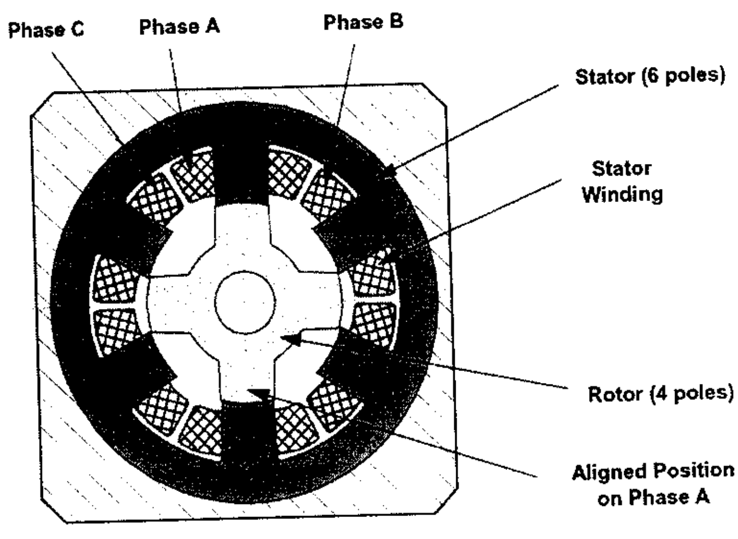
$$T_e = \frac{1}{2}i^2\frac{\partial L}{\partial \theta} \qquad (3.7)$$

Therefore the most SRM are multiphase. In multiphase case, the torque equation becomes a summation.

$$T_e = \sum_{j=1}^{m} T_{ej} \qquad (3.8)$$

3.4. SRM OPERATION

SR motors differ in the number of phases wound on the stator. Each of them has a certain number of suitable combinations of stator and rotor poles. Figure 3.5 illustrates a typical 3-Phase SR motor with a six stator / four rotor pole configuration.



The rotor of an SRM is said to be at the Aligned Position with respect to a fixed phase if the current reluctance has the minimum value; and the rotor is said to be at the Unaligned Position with respect to a fixed phase if the current reluctance reaches its maximum value; otherwise the rotor is said be at the Misaligned Position

The motor is excited by a sequence of current pulses applied at each phase. The individual phases are consequently excited, forcing the motor to rotate. The current pulses must be applied to the respective phase at the exact rotor position relative to the excited phase. When any pair of rotor poles is exactly in line with the stator poles of the selected phase, the phase is said to be in an aligned position; i.e., the rotor is in the position of maximum stator inductance (figure 3.5). If the interpolar axis of the rotor is in line with the stator poles of the selected phase, the phase is said to be in an unaligned position; i.e., the rotor is in a position of minimal stator inductance.

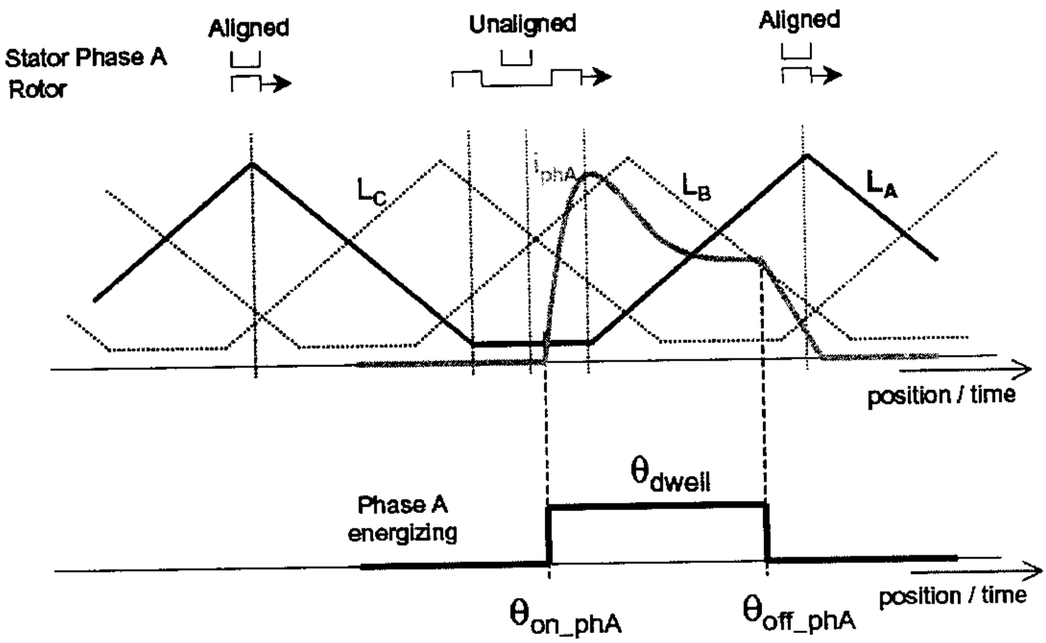


Figure 3.6. Phase energizing

The inductance profile of SR motors is triangular, with maximum inductance when it is in an aligned position and minimum inductance when unaligned.

SR motor, with Phase A high lighted. The individual Phases A, B, and C are shifted electrically by 120^{θ} relative to each other. When the respective phase is powered, the interval is called the dwell angle, (θ dwell). It is defined by the turn-on (θ on) and the turn-off (θ off) angles. When the voltage is applied to the stator phase, the motor creates torque in the direction of increasing inductance. When the phase is energized in its minimum inductance position, the rotor moves to the forthcoming position of maximum inductance. The movement is defined by the magnetization characteristics of the motor.

A typical current profile for a constant phase voltage is shown in figure 3.6. For a constant phase voltage, the phase current has its maximum value in the position when the inductance begins to increase. This corresponds to the position where the rotor and the stator poles start to overlap. When the phase is turned off, the phase current falls to zero. The phase current present in the region of decreasing inductance generates negative torque. The torque generated by the motor is controlled by the applied phase voltage and by the appropriate definition of switching turn-on and turn-off angles. As is apparent from the description, the SR motor requires position feedback for motor phase commutation. In many cases, this requirement is addressed by using position sensors, such as encoders or Hall sensors, etc. The result is that the implementation of mechanical sensors increases costs and decreases system reliability.

When current flows in a phase, the resulting torque tends to move the rotor in a direction that leads to an increase in the inductance. Provided that there is no residual magnetization of steel, the direction of current flow is immaterial and the torque always tries to move the rotor to the position of highest inductance. Positive torque is produced when the phase is switched on while the rotor is moving from the unaligned position to the aligned position as shown in figure 3.7.

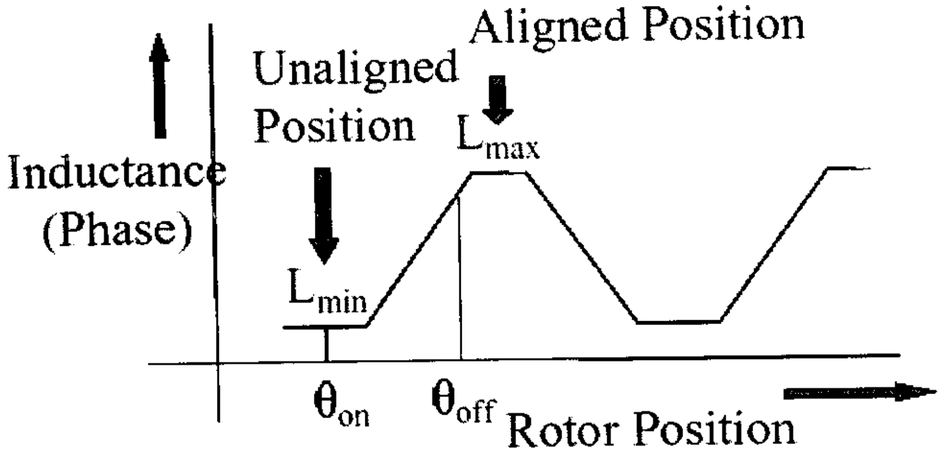


Figure 3.7. Inductance profile of one phase SRM

The phase voltage of the switched reluctance motor can be written as

$$V = iR + \frac{d\lambda}{dt} \tag{3.9}$$

Where V is the bus voltage,'i' is the instantaneous phase current, R is the phase winding resistance and λ flux linking of the coil. Ignoring stator résistance, the above equation can be written as

$$V = L(\theta)\frac{di}{dt} + i\frac{dL(\theta)}{d\theta} * \omega \tag{3.10}$$

Where ω is the rotor speed and L (θ) is the instantaneous phase résistance. The rate of flow of energy can be obtained by multiplying the voltage with can be written as

$$Vi = Li\frac{di}{dt} + i^2 \frac{dl}{d\theta} * \omega \tag{3.11}$$

The equation given above can also be given in the form as follows

$$P = \frac{d}{dt}(\frac{1}{2}Li^2) + \frac{1}{2}i^2 \frac{dl}{d\theta} * \omega \tag{3.12}$$

Where the first term of the above equation represents the rate of increase in the stored magnetic field energy while the second term is the mechanical output. Thus, the instantaneous torque can be written as

$$T(\theta,i) = \frac{1}{2}i^2 \frac{dL}{d\theta} \tag{3.13}$$

Thus positive torque is produced when the phase is switched on during the rising inductance. Consequently, if the phase is switched on during the period of falling inductance, negative torque will be produced

3.5. SPEED TORQUE CHARACTERISTICS OF SRM

The control scheme is based on the torque-speed characteristic (Figure 3.8) describes three basic modes of operation of switched reluctance motor based on the torque speed characteristic. Currents in the stator circuits are switched on and off in accordance to the rotor position. With this simplest form of control, the switched reluctance motor inherently develops the torque speed characteristics typical of d.c. machine.

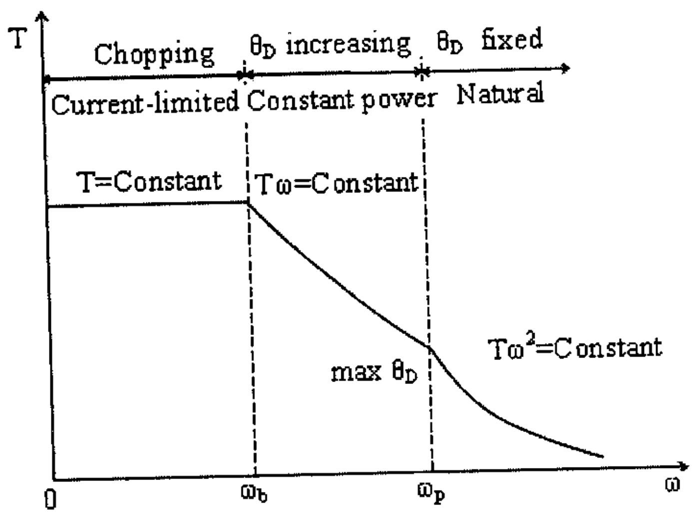


Figure 3.8. Speed Torque Characteristics of SRM

This first mode is the natural one with fixed supply voltage and fixed switching angles. The operating region is the constant torque region, below rated speed. Base speed (ωb) is defined as the highest speed at which maximum current can be supplied to the motor (Imax) at rated voltage, with fixed switching angles. There is, of course, a family of characteristics for varying supply voltages. At given speed the flux is proportional to the voltage V, and the torque varies with the current squared. The chopping voltage control is able to control an SRM drive only in the mode below rated

If fixed switching angles are maintained at speeds above ω_b, the torque falls as $1/\omega$. This is the second important mode of operation, when the machine speed is above base speed (ω_b). A control alternative for the switched reluctance motor is to reduce the conduction angle $\theta c = \theta off - \theta on$ at constant voltage. In this mode, the voltage generator is fully applied across the phase till θoff and the current decreases. There is a practical limitation of increasing the conduction angle. If it were increased so that the turn-off angle corresponds to the next cycle turn-on angle, then the flux level would not return to zero at the end of each pulse. In this case, the net flux in the phase winding would increase until the machine became continuously saturated. This corresponds to a rotor speed ω_p. Running above this sped implies a fall of the torque production as $1/\omega^2$.

3.6. FLUX LINKAGE CHARACTERISTICS OF THE SRM

The double saliency structure of the SRM causes its highly nonlinear motor characteristics of the motor. Compared with other type of motor, the relationship between the electrical torque and stator current of the SRM appears to be more complex. Generally the generated electric torque can be approximated by a high order polynomial of the stator current with an order equal to or larger than two. Even for the simplest case in the linear flux region, the electrical torque is not a linear function of the stator current. That is one main reason why the control of the SRM is so challenging.

The flux linkage λ of a SRM (Figure 3.9) is a function of both Xi and the rotor position Qi. For fixed rotor position Qi, the flux linkage λ is a purely a linear function of the stator current Xi only under the case when there is no saturation effect. Generally, when the stator current is under certain value, the relationship between λ and Xi appear to be linear.

For fixed stator current Xi, λ is a periodic function of rotor position with

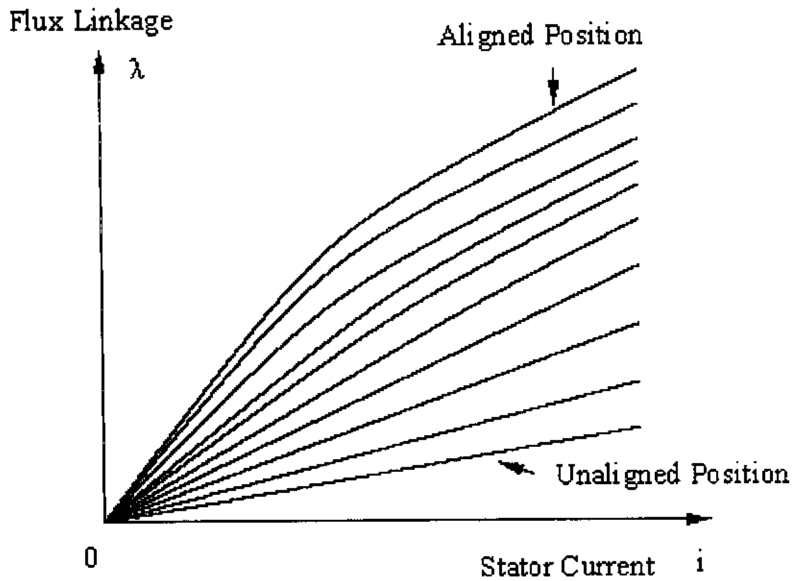


Figure 3.9. Flux linkage chart of SRM

The flux linkage λ is always bounded between the aligned and unaligned position. The SRM should be operated in the linear flux region.

CHAPTER 4

CLOSED LOOP CONTROL OF DRIVES

Feedback loops in an electrical drive may be provided to satisfy one or more of the following requirements.

(i) Protection
(ii) Inhancement of speed of response
(iii) To improve steady state accuracy

4.1. SPEED CONTROL OF DRIVES

Drives where the driving motor runs at nearly fixed speed are known as constant speed or single speed drives.Multi speed drives are those which operate at discrete speed settings. Drives needing stepless change in speed and multispeed drives called variable speed drives. When a number of motors are fed from a common converter, or when a load is driven by more than one motor, the drive is termed as multi motor drive.

Speed range of variable speed drive depends on the application. In some applications it can be from rated speed, to10% of rated speed. In some other applications, speed control above rated speed also desired, and there ratio of maximum to minimum speed can be high as 200.There also applications where the speed range is also low as from rated speed to 80% of rated speed.

A variable speed drive is called constant torque drive if the drives maximum torque capability does not change with change in speed setting. The corresponding mode of operation is called constant torque mode. It must be noted that the term 'constant torque' refers to maximum torque capability of the drive and not to the actual output torque, which may vary from no load to full load torque.

Ideally it is desired that for a given speed setting, the motor speed should remain constant as load torque as changed from no load to full load. In practice, speed drops with an increase in the load torque. Quality of speed control system is measured in terms of speed regulation which is defined as

$$\text{Speed regulation} = \frac{\text{No load speed} - \text{full load speed}}{\text{Full load speed}} \text{ X } 100\%$$

If open loop control fails to provide the desired speed regulation, drive is operated as a closed loop speed control system.

4.2. CLOSED LOOP SPEED CONTROL

The switched reluctance drive is an electro-mechanical unit, composed of an SRM, a power electronic converter and a controller, all components being coupled. A specific power electronic converter supplies the switched reluctance motor. The converter's turn-on and turn-off conditions can follow different schemes in order to control the motor speed.

Closed loop speed control scheme which is widely used in electrical drives. It employs an inner current loop with an outer speed loop. Inner current control loop is provided to limit the converter and motor current or motor torque below a safe limit. In some schemes the current is controlled directly .In others it may be controlled indirectly.

Figure 4.1 is the general diagram of the SRM with closed loop speed control. The core loop is the torque controller. In position or speed control application an outer loop is added to the torque controller, with a fast inner current loop that can be regarded as creating impressed currents to the stator windings necessary to achieve the desired torque specified by the outer loops.

The speed closed-loop control is characterized by the measurement of the actual motor speed. This information is compared with the reference speed while the

the difference between the actual and required speed. Based on the speed error, the PI controller generates the corrected motor stator frequency to compensate for the error.

An increase in reference speed ω* produce a positive error Δω. Speed error is processed through a speed controller. Consequently, limits sets current reference for inner current control loop at a value corresponding to the maximum allowable current. Drives accelerates at the maximum allowable current .Steady state reached at the desired speed and at current for which motor torque is equal to load torque. A increase in reference speed produces a negative speed error. Current and speed controllers consists of proportional and integral (PI), proportional and derivative (PD) or proportional ,integral and derivative (PID) controller , depending on steady state accuracy and transient response requirements.

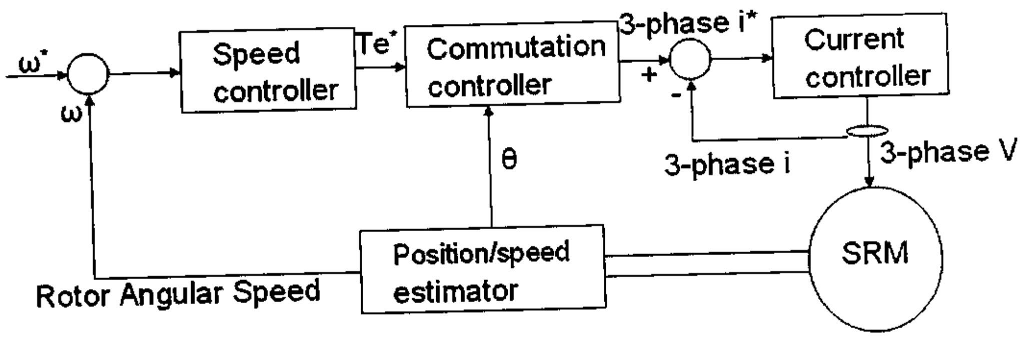


Figure 4.1. Closed loop system

4.2.1. Current controller

Adjusting the SRM torque to obtain constant speed under different load condition is the objective of the SRM controller. The innermost current loop is implemented by a current tracker, which consists of current controller, power converter, the stator windings of the SRM and current sensoring devices for feedback control. The function of the current controller is to adjust the shape of the current waveform as well as the magnitude in order to maintain the desired torque under different load condition. The input signal of the speed controller is the error between the reference speed and the architecture of the current controller proposed in his thesis. It is composed of four parts: power stage, DSP controller, gate drive, and interface.

The performance of this loop has a critical influence on the whole system, especially for the current model discussed in this chapter. Usually, there are three kinds of current controllers: PI controller, hysteresis controller and a hybrid structure by the combination of the first two. In this control method the magnitude of the current flowing into windings is controlled using a control loop with a current feed back. The current in a motor phase winding is directly measured with a current/voltage converter or a current sensor resistor connected in series with a phase. The current is compared with a desired value of current forming an error signal. The current and position feedback are needed for controlling the SR motor. Position feedback is needed to synchronize the current flow with respect to the rotor position, in order to generate the desired, motoring torque. Position feed back is also needed to compute the rotor mechanical speed which is compared with desired value of speed.

4.2.2 Speed controller

The commutation controller and speed controller are realized by the DSP controller. These loops are the core of the control algorithm. There are many choices for this controller, such as PI controller, two degree of freedom controller, robust controller, fuzzy controller, adaptive controller, artificial neutral network controller and so on. The speed or position of the rotor needs feedback for proper control. This can be done by sensoring device or estimation. The position sensor less technology uses such estimators for speed and position feedback.

The PI controller is chosen for the switched reluctance motor speed loop regulation. Tuning of PI controller can be realized by using various methods. The standard proportional integrator (PI) controllers ensure the regulation of the torque and the flux to their constant reference values and provide the synchronous reference currents. The PI parameters are selected by trial and error in order to achieve the torque within pre determined boundaries is achieved by limiting the output of the speed controller. The most commonly used speed controller for drives contains two separate control loops. The inner loop is responsible for current control and incorporates a PWM hysteresis controller, activated by the error between set and measured motor current. The torque/current reference is generated by the outer control loop in which the error between and actual speed activates the proportional integral speed controller. The reference speed is compared with machine speed, and the error is transformed through a current controller into a torque reference.

At lower speeds, the current is regulated either by PWM voltage or direct instantaneous current regulation (e.g. hysteresis band current control). The turn-on angle must be advanced to be able to build up the flux from zero to the desired value before the inductance starts rising. Similarly, the turn-off angle must be advanced to be able to reduce the flux to zero before the inductance starts diminishing.

As speed increases, the back-EMF e increased. At speeds higher than this base speed, there is insufficient voltage available to control the current. The current can then only be controlled by timing of current pulses. This control mode is called 'single-pulse mode'.

CHAPTER 5

CONVERTER TOPOLOGY

The phase-to-phase switching in the SRM drive must be precisely timed with rotor position to obtain smooth rotation and the optimal torque output. Rotor position feedback, or the so-called "senseless" feedback method, is needed for proper control. It is well known that this phase-to-phase switching is realized by power semiconductors. The so-called power converter topology refers to different circuit structures by power semiconductors, which can meet the SRM's switching operation mode requirement. It is well known that the power converter topology has great influence on the SRM's performance. A power converter is required to activate and commutate the SRM phases, and the classic asymmetric half-bridge inverter is in general used, requiring two switching devices and two power diodes per phase.

Inverters are employed to get a variable frequency ac supply from a dc supply. Stepped wave inverters can be designed to behave as voltage source or current source. Accordingly they are known as voltage source inverter or current source inverter. For the control of ac motor, voltage/current should also be controlled along with the frequency. Variable frequency and variable ac voltage is directly obtained from fixed voltage dc when the inverter is controlled by Pulse Width Modulation(PWM).The PWM control also reduces harmonics in the output voltage. Inverters are built using semiconductor devices such as thyristors, power transistors, IGBTs, GTOs, and power MOSFETs. They are controlled by firing pulses obtained from a low power control unit.

5.1. PULSE WIDTH MODULATION TECHNIQUE

A fixed dc input voltage is given to the inverter and a controlled ac voltage obtained by adjusting the on and off periods of the inverter components .This is the most popular method of controlling the output voltage and this method is termed as pulse width modulation control (PWM) .

Pulse Width Modulation technique is used to generate required voltage or current to feed the motor or phase signals. This method is increasingly used for AC drives with the condition that the harmonic current is as small as possible and the maximum output voltage is as large as possible. Generally, the PWM schemes generate the switching positions pattern by comparing 3 phase sinusoidal waveforms with a triangular carrier. The selection of Pulse Width Modulation strategy is an important issue in SR motor control because it dictates how the motor can be controlled. The PWM strategy is also directly related to the power driver topology.

The advantages possessed by PWM technique are as under:

1. The output voltage control with this method can be obtained without any additional components.
2. With this method lower order harmonic can be eliminated or minimized along with its output voltage control. As higher order harmonics can be filtered easily, the filtering requirements are minimized.

5.1.1. PWM Generator

The PWM wave can be generated by comparing an adjustable sine wave voltage with a triangular carrier wave as shown in figure 5.1 .This comparison is done in a comparator. Combining a triangle wave and a sine wave produces the output voltage waveform.

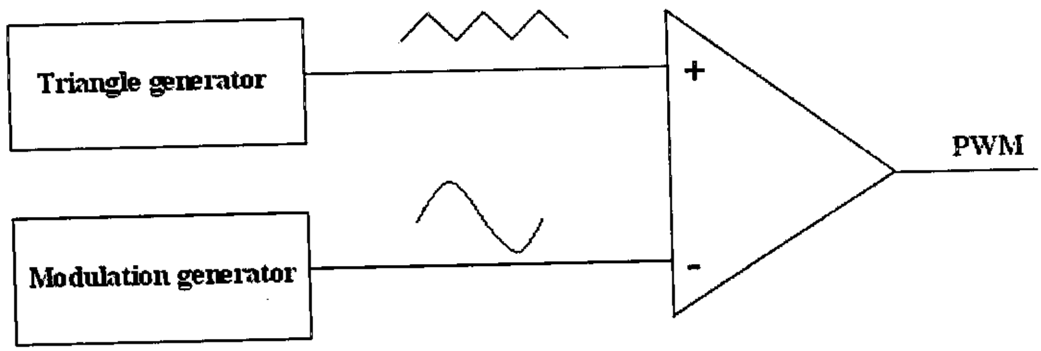


Figure 5.1. PWM Generator

The triangular signal is the carrier or switching frequency of the inverter. The modulation generator produces a sine wave signal that determines the width of the pulses, and therefore the RMS voltage output of the inverter. The output of the PWM generator shown in figure 5.2.

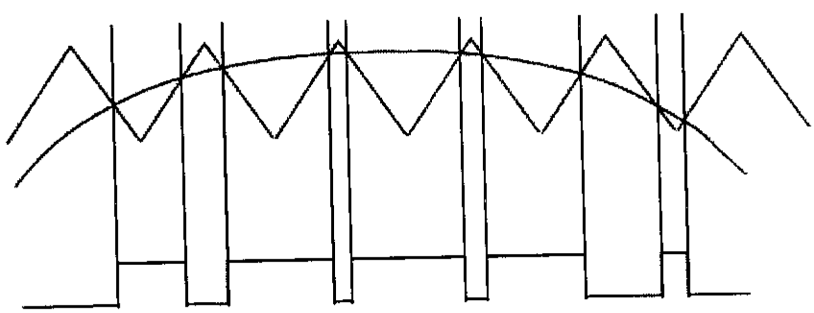


Figure 5.2. Output of PWM Generator

5.1.2. Different PWM Techniques

PWM techniques are characterized by constant amplitude pulses. The width of these pulses is, however, modulated to obtain output voltage control and to

1. Single-pulse modulation
2. Multiple-pulse modulation
3. Sinusoidal-pulse modulation.

The three PWM techniques listed above differ from each other in the harmonic content in their respective output voltages. Thus choice of a particular PWM technique depends upon the permissible harmonic content in the converter output voltage.

5.1.3. PWM Objective

- Maximum Bus voltage Utilization
- Minimum Harmonics
- Less Audible Acoustic Noise
- Less Motor Temperature Rise

The Pulse Width Modulation (PWM) block offers high freedom in its configuration, enabling efficient control of the AC induction motor.
The PWM block has the following features:

- Three complementary PWM signal pairs, or six independent PWM signals
- Features of complementary channel operation
- Dead time insertion
- Separate top and bottom pulse width correction via current status inputs or software
- Separate top and bottom polarity control
- Edge-aligned or center-aligned PWM reference signals
- 15 bits of resolution
- Half-cycle reloads capability
- Integral reloads rates from one to 16
- Individual software-controlled PWM outputs

- Polarity control
- 20-mA current sink capability on PWM pins
- Write-protectable registers

The PWM outputs are configured in the complementary mode in this application.

5.2. SINUSOIDAL PULSE MODULATION

In this method of modulation, several pulses per half cycle are used in the case of multiple pulse modulation. In multiple pulse modulation the pulse width is equal for all the pulses .But in sinusoidal pulse modulation the pulse pulse width is a sinusoidal function of the angular position of the pulse as shown in figure5.3.

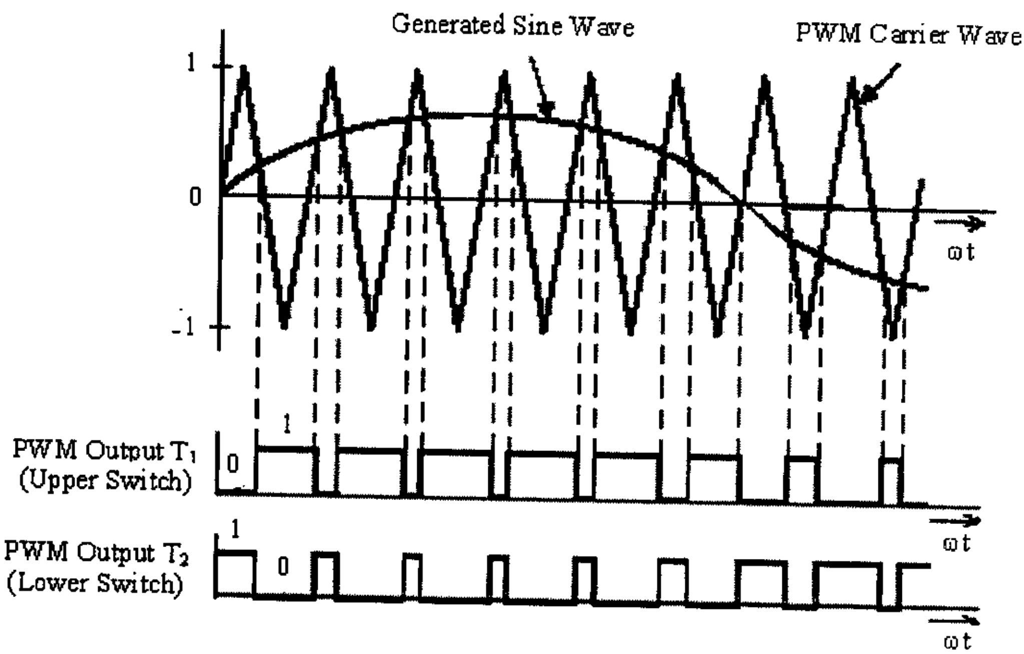


Figure 5.3. Upper Lower output

The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turn off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulating signal.

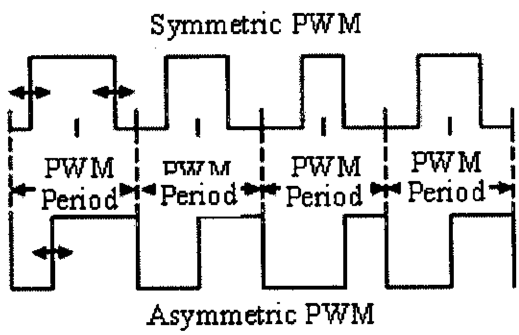


Figure 5.4. PWM signals

Figure 5.4 shows two types of PWM signals, symmetric and asymmetric edge-aligned. The pulses of a symmetric PWM signal are always symmetric with respect to the center of each PWM period. The pulses of an asymmetric edge-aligned PWM signal always have the same side aligned with one end of each PWM period. Both types of PWM signals are used in this application.

5.3. PWM INVERTER

Switched Reluctance Motors do not require bi-directional current like other common ac motors. Therefore, unipolar converters are used as the power converter for SR motor drives. The converter topology for any specific SR motor depends on the motor construction as well as on the application. There are many types of converters available for different types of applications.

The torque is independent of direction of phase current, which can be therefore be unidirectional. This permits the use of unipolar control circuits with a alternating current, unidirectional current has the added advantage of reducing hysterisis losses.

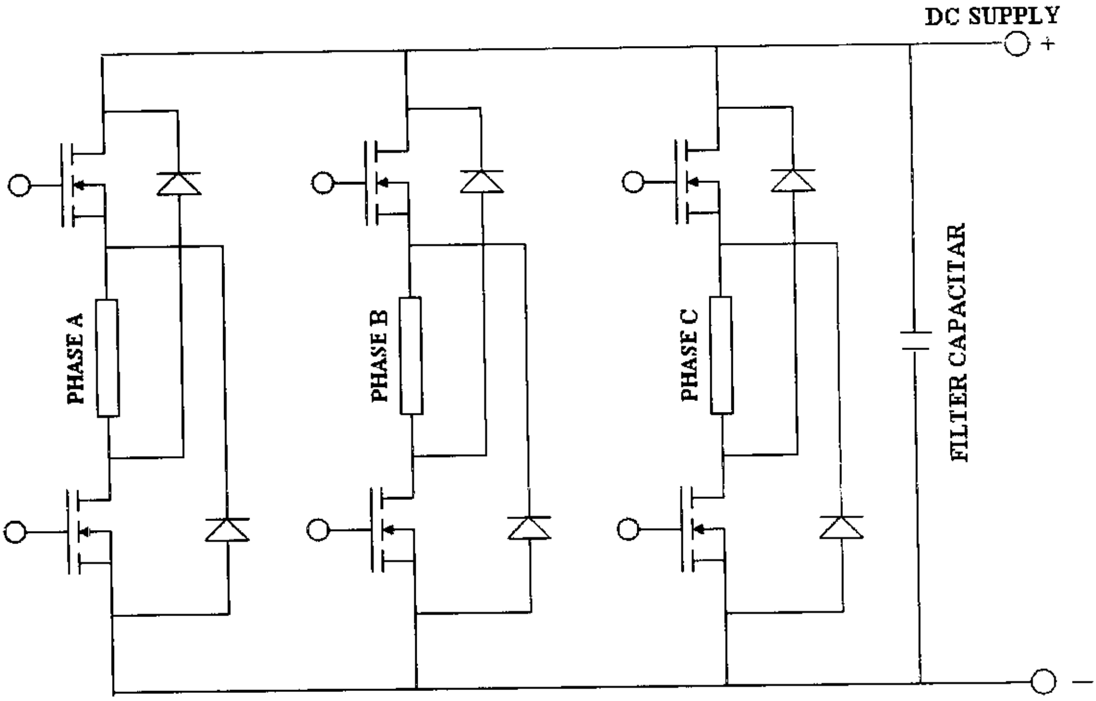


Figure 5.5. PWM inverter

Figure 5.5 shows a circuit well suited for use with transistors. This phase are independent and in this respect the SR controller differs from the ac inverter, in which the motor windings are connected between the midpoints of adjacent inverter phase legs.

The winding is in series with both the switches, providing valuable protection against faults. In ac inverter the upper and lower phaseleg switches must be prevented from switching on simultaneously and shorting the dc supply; this is possible only by means of additional control circuitry, which is unnecessary in the SR controller.

The upper and lower phaseleg switches are switched on together at the both switched off. At high speeds both transistors remain on throughout the conduction period and the current waveforms adopts a 'natural' shape depending on the speed and torque. It is convenient in the logic design to use one transistor primarily for 'commutation' and the other for regulation or chopping. At the conduction period when both switches are turned off, any stored magnetic energy that has not been converted into mechanical work is returned to the supply by the current freewheeling diodes. In a PWM inverter output voltage, since the harmonics are at the high frequency, the ripple in the motor current is usually small due to high leakage reactance at this frequencies.

CHAPTER 6

DIGITAL CONTROL OF SRM

Digital controller systems are used extensively in the field of motion control. High performance digital control systems usually require the fast execution of control algorithms. Some advanced algorithms, such as for sensor-less motor drive control, require a large number of computations. As algorithms become more complex, faster digital controllers are required to execute them within given time limitations. As some applications require motor drives to be controlled at high rotational velocities, the time which is allowable for one iteration of the control loop can be very small.

Many existing controllers are designed around a microprocessor or a microcontroller which typically runs at a moderate clock frequency and uses multiple instruction cycles for each processing step. These systems lack the ability to execute advanced algorithms fast enough for real-time control. Recently the use of a Digital Signal Processor (DSP) as the heart of the controller has been explored. DSPs are designed for signal processing and have hardware optimizations which are directly applicable to digital control. Some of these desirable features are short instruction cycle duration, pipelining to achieve one instruction per cycle, and one cycle hardware multipliers. These systems are an improvement over many existing controllers, but they depend too much on the DSP for data acquisition tasks and do not have the speed performance necessary for demanding high speed or complex algorithm control applications.

The main features of the system design are listed below.

- 50 MHz TMS320C25 Digital Signal Processor with 80 ns instruction cycle
- 64K by 16-bit EPROM, two banks of 16K by 16-bit static RAM
- Full function serial port with 38.4 kBaud maximum rate

- 8 channels of 8-bit PWM output with 49 kHz maximum frequency
- 32 bits digital input, 13 bits digital output

6.1. DIGITAL SIGNAL PROCESSOR

The DSP chip is the central processing unit for the system. The system block diagram shown in figure 6.1. The DSP used is the 50 MHz version of the TMS320C25 by Texas Instruments. The DSP is clocked at exactly 50 MHz and has an instruction cycle time of 80 ns. It has a 16-bit word size with a 32-bit ALU and accumulator. It uses a 16 by 16-bit parallel multiplier with a 32-bit result to perform multiplies in one instruction cycle. It also provides an internal 16-bit timer.

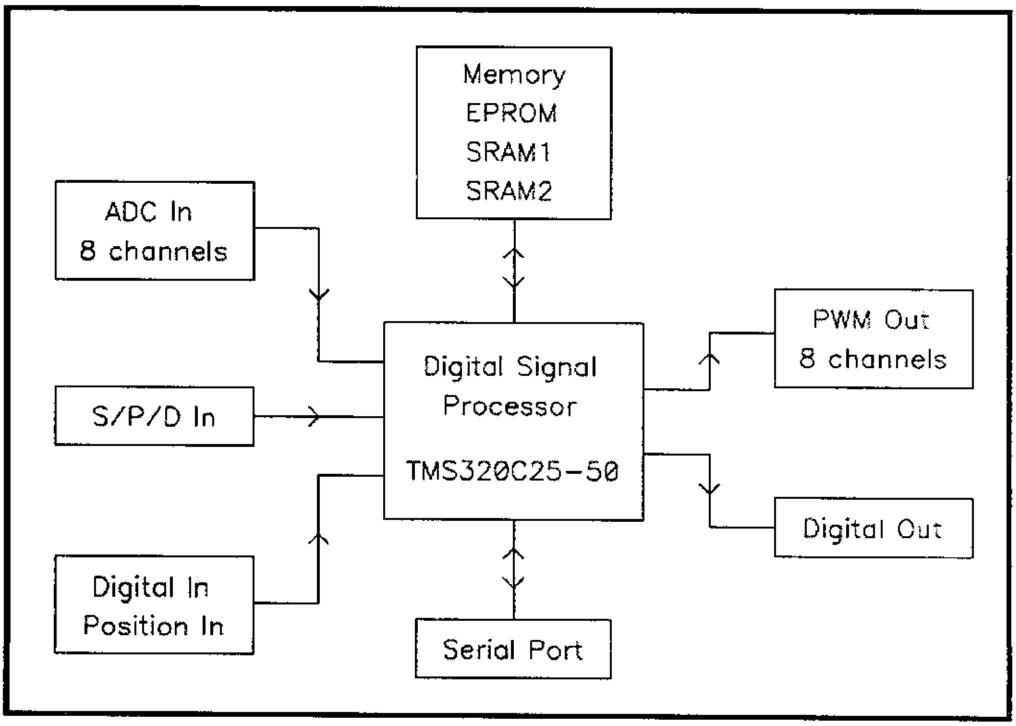


Figure 6.1. System Block Diagram

A 50 MHz clock oscillator with a CMOS level output is used to drive the external clock input of the DSP. This 50 MHz clock is divided by two by a toggle flip-flop to provide a 25 MHz reference for use elsewhere in the system. To cause a reset on reset input of the DSP. On power-up, the RC circuit asserts reset for approximately 400 ms, allowing the clock oscillator to stabilize and the DSP to reset.

The DSP has three interrupt inputs which support either level triggered or edge-triggered interrupts. Two of the interrupt lines are used by the analog-to- digital hardware and the serial port hardware. The third interrupt, XINT, is available for an external interrupt signal. The DSP has an I/O space of 16 words. These are divided into 16 input and 16 output ports. The lower eight input and output ports are decoded by two 3-to-8 line decoders. The upper eight input and output ports are used by the serial port. Input and output port maps are shown in Table 6.1 and Table 6.2.

Input Port	Function	Wait-states
0	Digital In	0
1	S/P/D Speed Time	0
2	S/P/D Pos, Dir	0
3	Digital Position	0
4	Unused	0
5	ADC Data	1
6	Unused	0
7	Unused	0
8 - 15	Serial	5

Table 6.1. Input Port Map with Wait-States

Output Port	Function	Wait-states
0	Digital Out, ADC Select	0
1	PWM1, PWM0	0
2	PWM3, PWM2	0
3	PWM5, PWM4	0
4	PWM7, PWM6	0
5	ADC Start	0
6	S/P/D Divider	0
7	PWM Divider	0
8 - 15	Serial	5

Table 6.2. Output Port Map with Wait-States

6.2. COMPLETE DRIVE SYSTEM

The complete drive system shown in figure6.2. The input filter provides several functions, protection of the hardware (by fuse and voltage transient suppresser) and, to match the EMC standards, an EMI filter and a power factor correction (PFC) are implemented. The PFC may be active or passive; in the active case it is entirely handled by the DSP. This block is directly connected to the voltage supply.

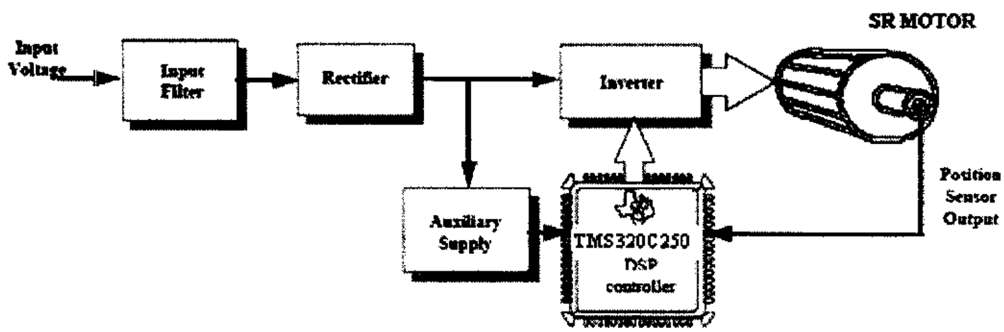


Figure 6.2. The Switched Reluctance Motor Driver

To achieve a continuous voltage from the alternating input signal, a single-phase input bridge with tank capacitor is needed, represented as the rectifier block to generate the phase voltages with variable amplitude and frequency to supply the 3 SR motor phase signals to the motor, a 3-phase inverter is used, based on MOSFET technology.

The system is controlled by the TMS320C250 DSP. The inputs are three Hall effect sensors to detect the shaft position, and a resistor sensor on the line (IBUS) to measure the phase currents. The controller uses a serial link to communicate. The auxiliary supply feeds the inverter driver and the logic circuitry.

6.2.1. DSP Controller

The DSP prototype consists of two parts:

Software prototype

Hardware prototype

For example software prototype used in this project is MATLAB/simulink, while the hardware prototype is TMS320C25 controller board. Design tools such as MATLAB/Simulink enable different users to design their own controllers directly in the block diagram. Real time code is generated from the block diagram and automatically implemented on flexible prototyping hardware. Users program their control algorithms using MATLAB/Simulink. And after compiling, these algorithms will be downloaded to the DSP controller by means of real time workshop.

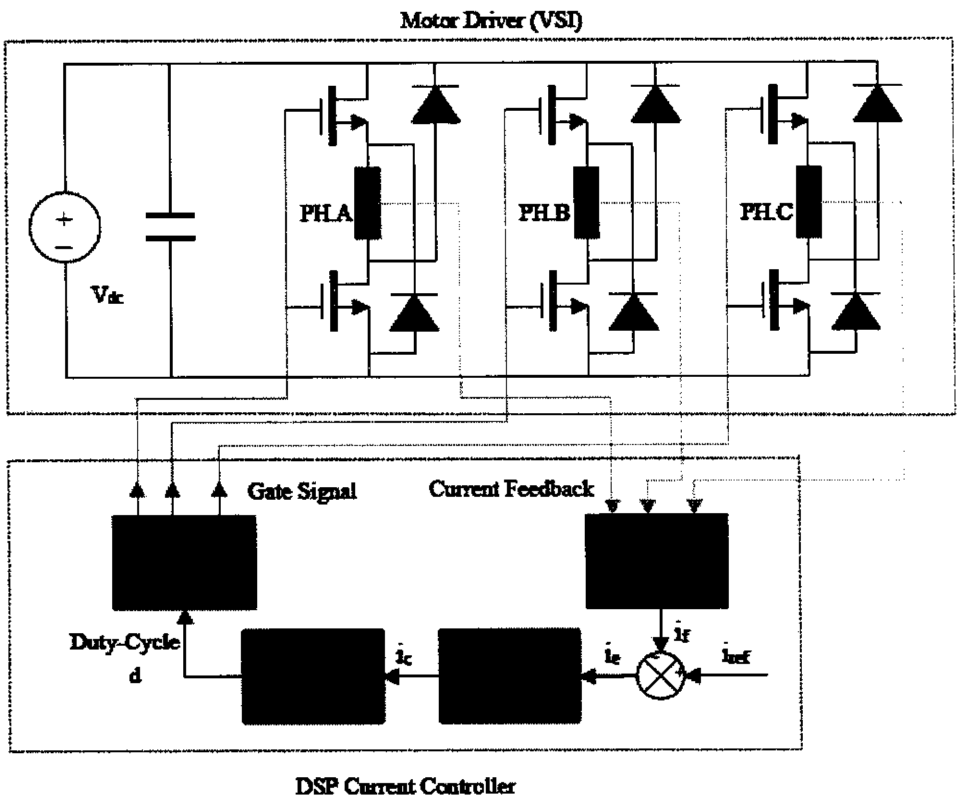


Figure 6.3. SRM Drive Feedback

The DSP controller (figure 6.3), which samples the phase current feedback and the encoded position signal to produce six independent gate signals for

CHAPTER 7

SIMULATION RESULTS

Computer simulation and experimental investigation were conducted on a 3-phase 6/4 SRM 90kw at 25,000rpm in closed loop current control and closed loop speed control. It has 6 stator poles and 4 rotor poles. Some experimental results obtained with the complete three electronic converters, working together, are presented in this chapter. The software written on TMS320C25 implements all the control blocks described in previous chapters.

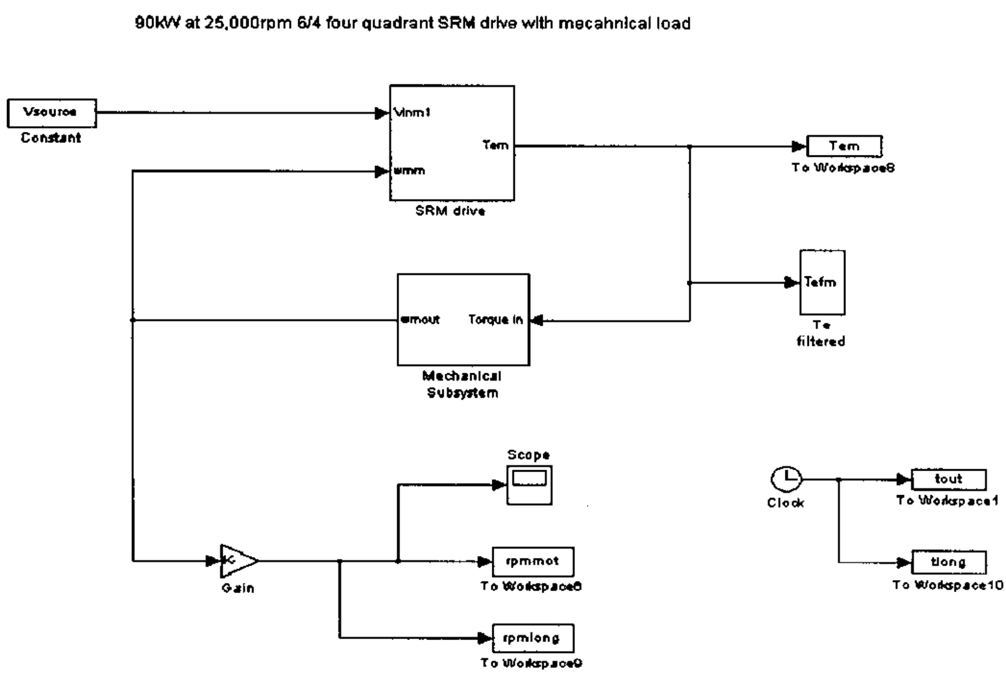
7.1. MODEL OF THE WHOLE SYSTEM

The whole model of the drive system as shown in figure7.1. The SRM drive model consists of

1 SRM

2 Current Controller

3 DSP Controller



7.1.1. SRM Model

Actually there is no direct model for the Switched Reluctance Motor. So the switched reluctance motor model developed in the simulink using MATLAB6.5.The input to the motor is voltage and speed of the motor. The output of the motor is current torque and rotating angle of the rotor.

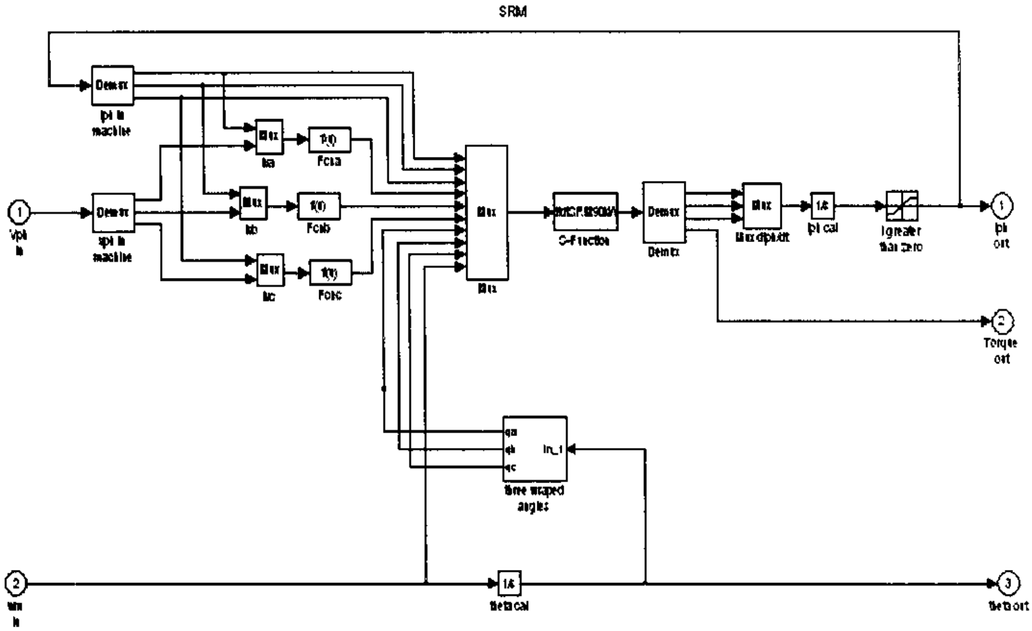


Figure 7.2. Switched Reluctance Motor Model

7.1.2. Current Controller and DSP Controller

The power converter is the core component of the current controller (figure7.3). The input to the current controller is phase current, voltage and pulse signals. The pulse signals used to trigger the power semiconductor devices. The output of the current controller is current and the phase voltage. The current is again fed to drive model circuit and the phase voltage is given to SRM. The input to the DSP controller is voltage, command torque, speed, rotor position, and phase current. And the output of the DSP controller is pulse signals which is fed to the current controller. After compiling these algorithms will be downloaded to the DSP controller in real time workshop. It controls power switching inverters and generates high resolution PWM outputs.

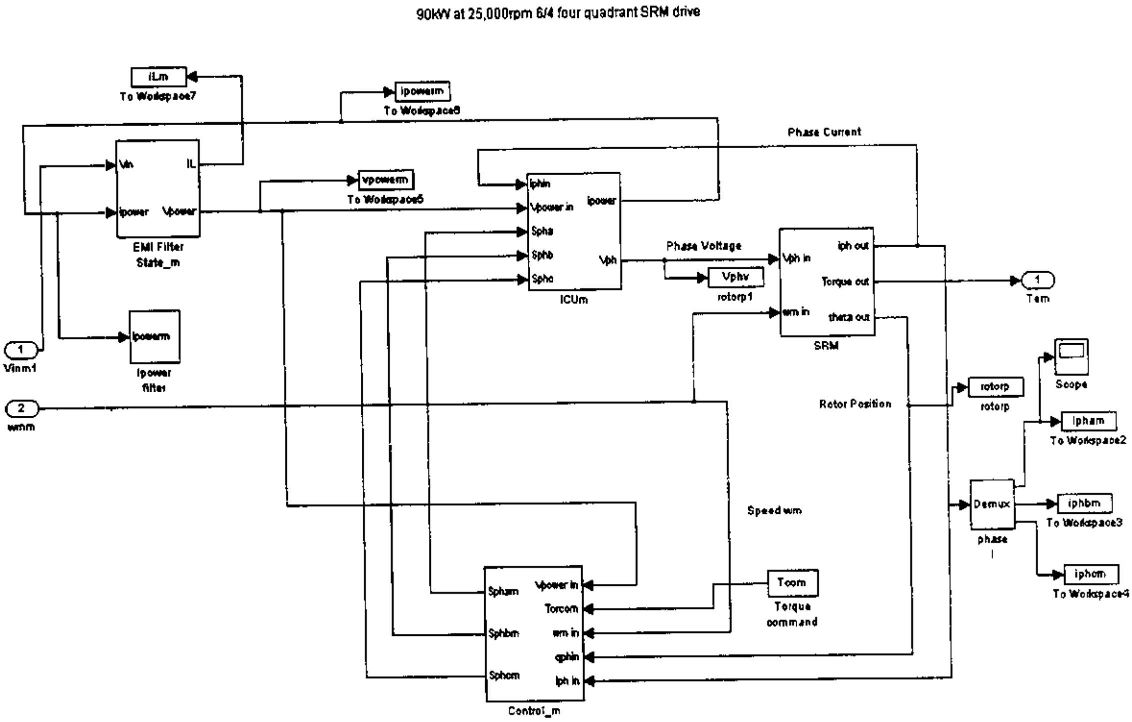


Figure 7.3. Simulation model of the SRM Drive with Feedback

7.2. SIMULATION RESULTS

All experimental results were measured under zero loads for simplicity. The figure 7.4 shows the steady state current waveform for all the phases of 6/4 SRM without any loading using different exciting methods. The SRM drive was operated in a closed loop speed control mode using position and speed information. The figure7.5 shows the speed curve of the SRM. Here the motor speed is controlled upto 25000 rpm. The figure 7.6 shows the torque curves of the system.

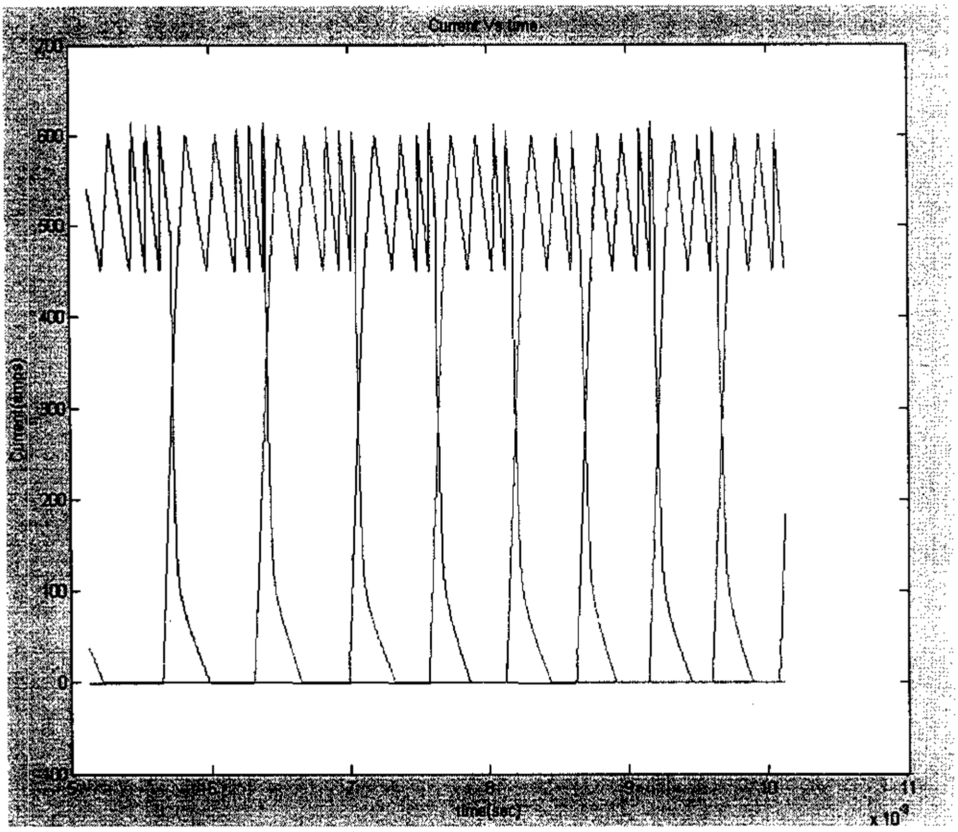


Figure 7.4. Three phase current Wave form

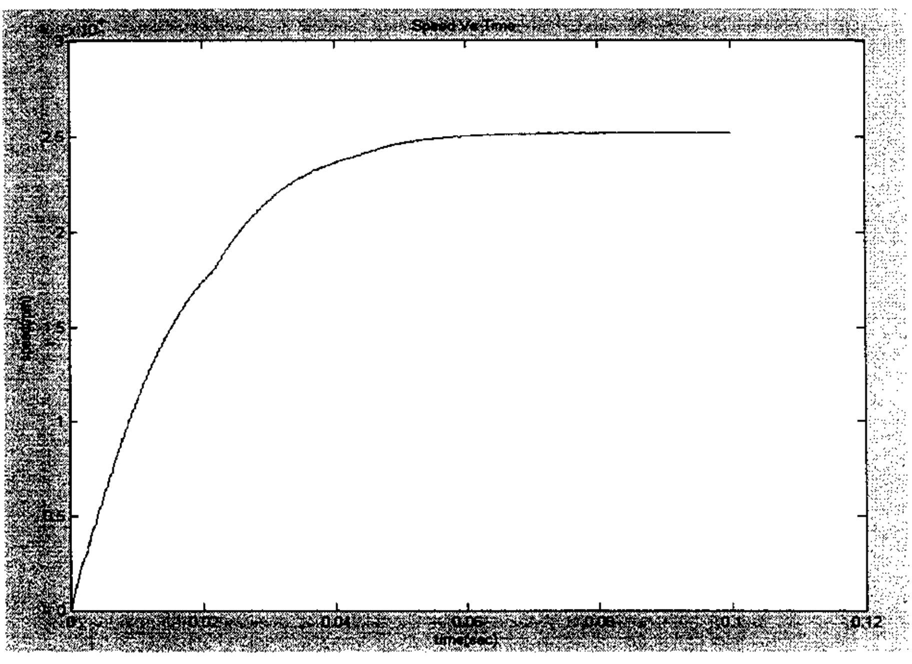


Figure 7.5. Speed curve

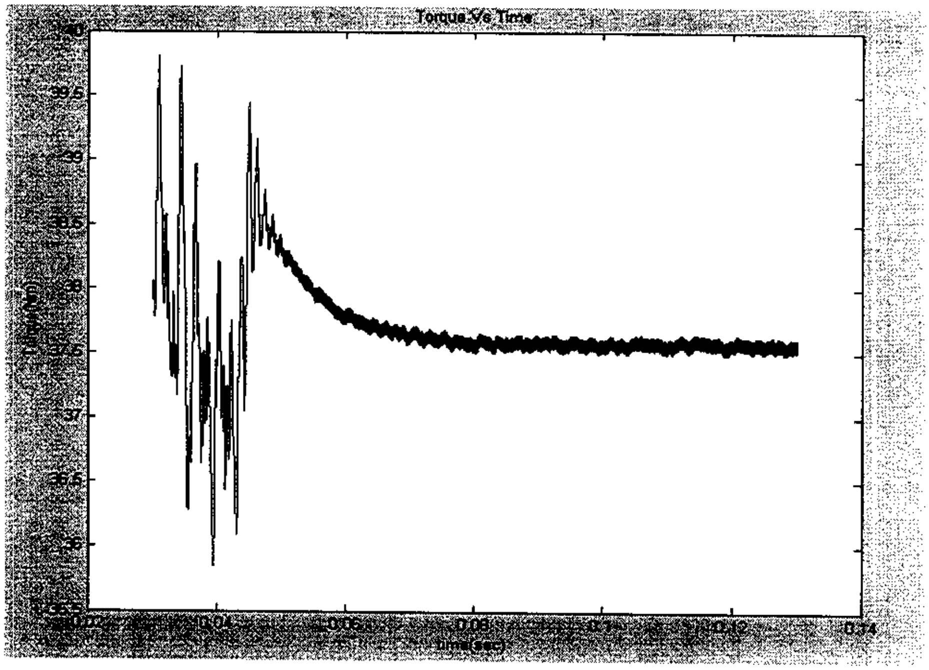


Figure 7.6. Torque Wave form

CHAPTER 8

HARDWARE IMPLEMENTATION

The hardware is implemented by using the Digital Signal Processor. Using Pulse Width Modulation technique the pulses are generated from the digital signal processor. The pulses are used to switch on and off the semiconductor device in the single phase inverter. The digital signal processor used here is TMS320C25.The semiconductor device in the single phase inverter is MOSFET.

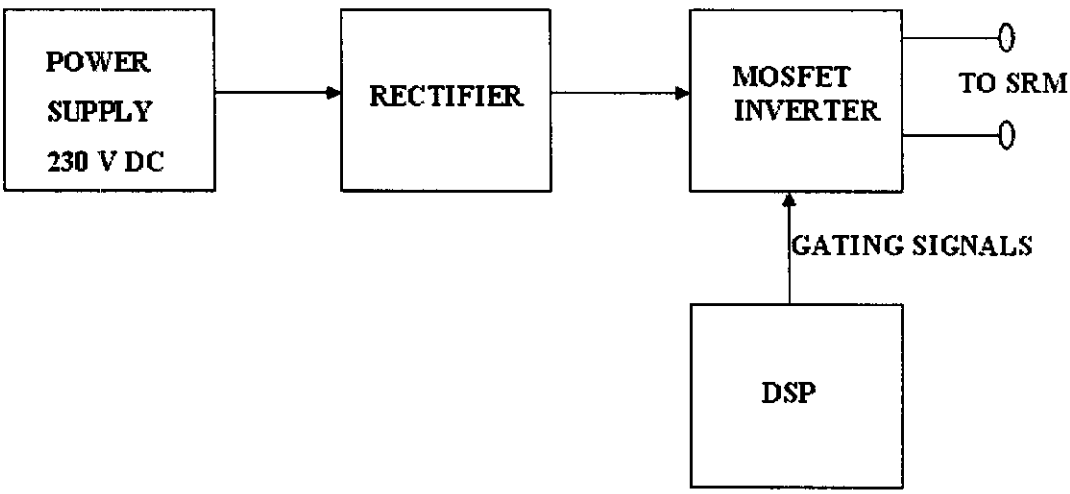


Figure 8.1. Hardware Block Diagram

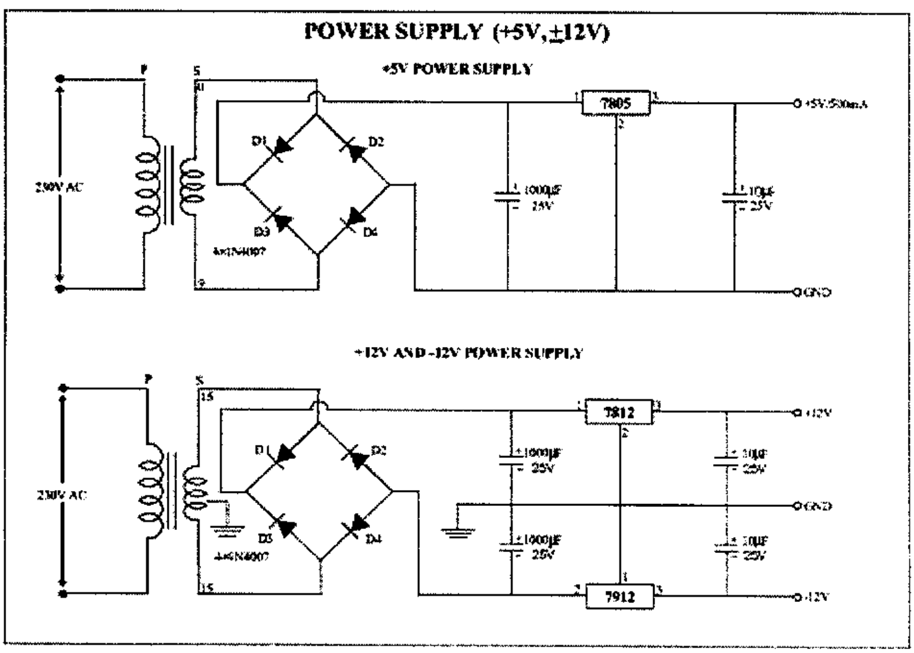
The various blocks in the hardware are

1. Power supply unit
2. DSP circuit
3. High voltage rectifier
4. MOSFET inverter

8.1. POWER SUPPLY UNIT

The operation of power supply (figure8.1) circuits built using filters, rectifiers, and then voltage regulators. Starting with an ac voltage, a steady dc voltage is obtained by rectifying the ac voltage, then filtering to a dc level, and finally, regulating to obtain a desired fixed dc voltage. The regulation is usually obtained from an IC voltage regulator unit, which takes a dc voltage and provides a somewhat lower dc voltage, which remains the same even if the input dc voltage varies, or the output load connected to the dc voltage changes.

The ac voltage is connected to a transformer, which steps that ac voltage down to the level for the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit can use this dc input to provide a dc voltage that not only has much less ripple voltage but also remains the same dc value even if the input dc voltage varies somewhat, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of a number of popular voltage regulator IC units



8.2. DSP CIRCUIT

The TMS320C25, like all members of the TMS320C2x generation, is processed in CMOS technology. The TMS320C25 is capable of executing 10 million instructions per second. Enhanced features such as 24 additional instructions (133 total), eight auxiliary registers, an eight-level hardware stack, 4K words of on-chip program ROM, a bit-reversed indexed addressing mode, and the low power dissipation inherent to the CMOS process contribute to the high performance.

8.2.1. DSP Architecture Overview

Harvard Architecture. The TMS320C25 high-performance digital signal processors, like the TMS320C1x devices, implement a Harvard-type architecture that maximizes processing power by maintaining two separate memory bus structures, program and data, for full-speed execution.

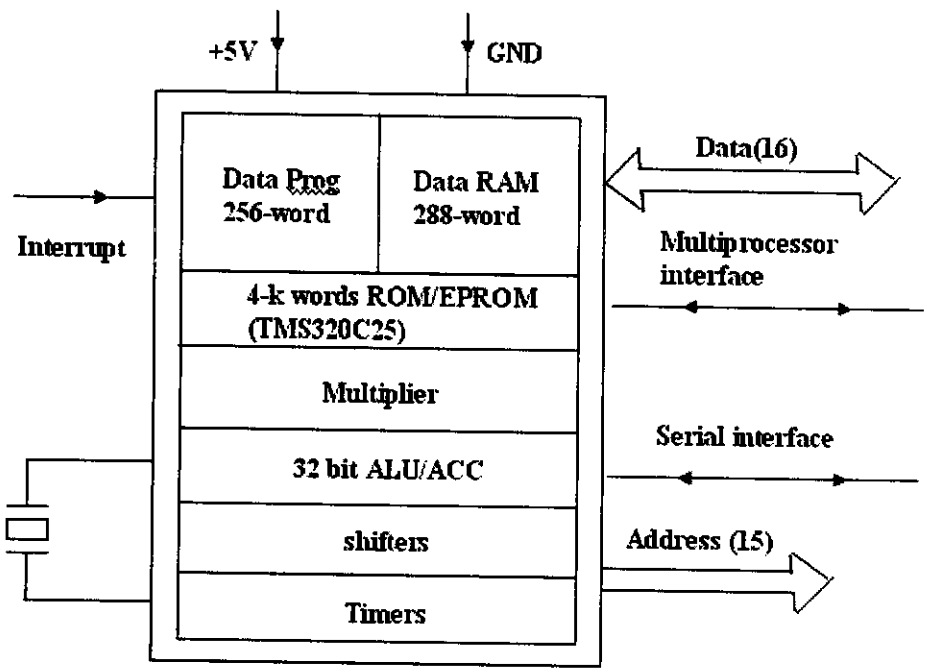


Figure 8.3. TMSC320C25 Simplified Block Diagram

On-Chip Memory. The TMS320C25 provides increased flexibility in system design by two large on-chip data RAM blocks (a total of 544 16-bit words), one of which is configurable either as program or data memory.

Arithmetic Logic Unit. The TMS320C25 performs 2s-complement arithmetic using the 32-bit ALU and accumulator. The ALU is a general-purpose arithmetic unit that operates using 16-bit words taken from data RAM or derived from immediate instructions or using the 32-bit result of the multiplier's product register.

Multiplier. The multiplier performs a 16 × 16-bit 2s-complement multiplication with a 32-bit result in a single instruction cycle. The multiplier consists of three elements: the T register, P register, and multiplier array.

Memory Interface. The TMS320C25 local memory interface consists of a 16-bit parallel data bus (D15–D0), a 16-bit address bus (A15–A0), three pins for data/program memory or I/O space select (DS, PS, and IS), and various system control signals. The R/W signal controls the direction of a data transfer, and the STRB signal provides a timing signal to control the transfer. When using on-chip program RAM, ROM/EPROM, or high-speed external program memory, the TMS320C25 runs at full speed without wait states. The use of a READY signal allows wait-state generation for communicating with slower off chip memories.

Direct Memory Access. The TMS320C2x supports direct memory access (DMA) to its external program/data memory using the HOLD and HOLDA signals. Another processor can take complete control of the TMS320C2x external memory by asserting HOLD low. This causes the TMS320C2x to place its address, data, and control lines in the high-impedance state. Signaling between the external processor and the TMS320C2x can be performed by using interrupts. On the TMS320C2x, two modes are available: a mode in which execution is suspended during assertion of HOLD, and a concurrent DMA mode in which the TMS320C2x continues to execute its program while operating from internal RAM or ROM, thus greatly increasing throughput in

8.2.2. DSP Output

The output of the DSP circuit is PWM signal. The DSP chip read the program from the latch 27C256.The purpose of the ADC is to convert the feedback signal from the motor into digital form.

8.3. HIGH VOLTAGE RECTIFIER

The high voltage rectifier is connected before the power MOSFET inverter. The output of the high voltage rectifier is 230V DC. To achieve a continuous voltage from the alternating input signal, a single-phase input bridge with tank capacitor is needed, represented as the high voltage rectifier block

8.4. MOSFET INVERTER

8.4.1. Power MOSFET

The N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching converters, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power.

FEATURES

- 8A, 500V
- $r_{DS(ON)} = 0.850\Omega$
- Single Pulse Avalanche Energy Rated
- SOA is Power Dissipation Limited
- Nanosecond Switching Speeds

- Linear Transfer Characteristics
- High Input Impedance
- Related Literature

8.4.2. MOSFET Inverter

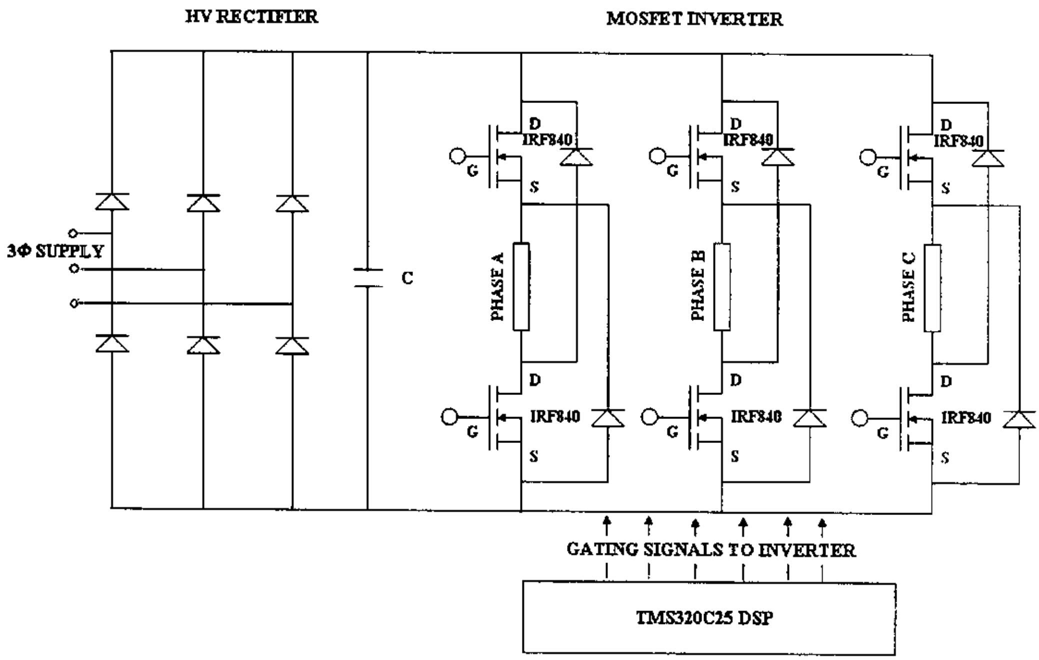


Figure 8.4. MOSFET inverter

Nowadays the most common method to control the inverter is the use of PWM principle. PWM drives are more efficient and typically provide higher levels of performance. A basic PWM drive consists of a converter, DC link, control logic, and an inverter. In this each phase winding is placed between two switches. This technique allows independent control of phase currents irrespective of the duration of phase supplying. The each phase leg circuit shown in figure 8.3 can supply current in only one direction, while it can supply a positive, negative (reversed) or zero voltage at the phase terminals. The converter section consists of a fixed diode bridge rectifier which section consists of six switching devices. Various devices can be used such as thyristors, bipolar transistors, MOSFETS and IGBTs. Here the inverter that utilizes MOSFETS. The control logic uses a Digital Signal Processor to switch the MOSFETS on and off providing a variable voltage and frequency to the motor. The output voltage can now be controlled by pulse width modulation. The control signals for the upper and lower switches are generated from the TMS320C25 DSP controller.

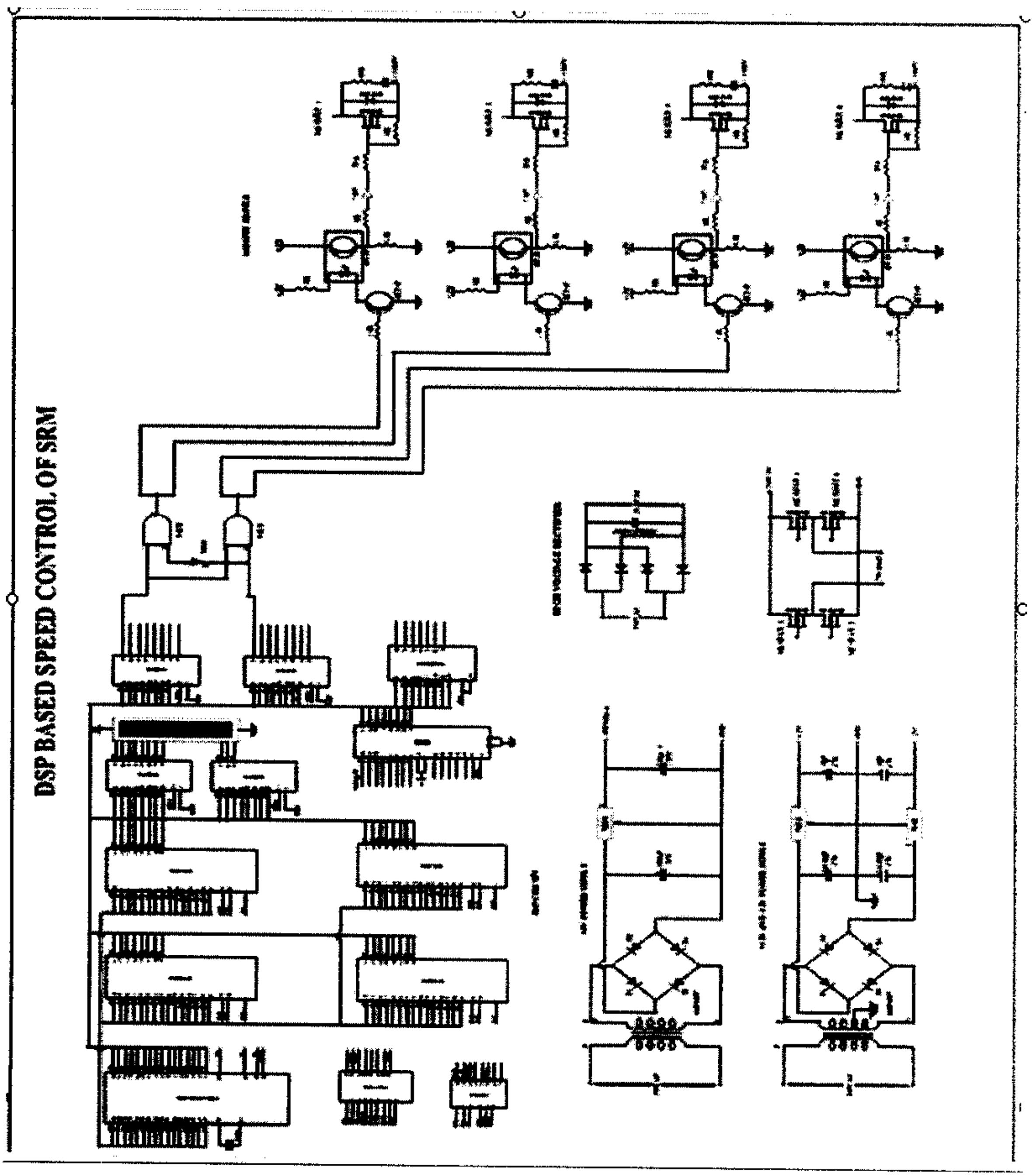


Figure 8.5. Hardware Design

CHAPTER 9

CONCLUSION

This project gave a general introduction to Switched Reluctance Motors control. It introduced the control of switched reluctance motors from the view of control Side. Based on the general control structure (Figure4.1), each part of this structure has been covered by this project. After the introduction the project explains the DSP in motor control and also gave benefits and applications of DSP controller in motor control.

After the DSP in motor control the next chapter was to introduce the basic principles of switched reluctance motor, main machine topologies and motor construction, mathematical approach, switched reluctance motor operation, speed torque characteristics of SRM and flux linkage characteristics of SRM.

Apart from the operation of the project focused on the speed control of an 6/4 SRM based on a simplified model .This simplified model limits the operation of the motor totally into its linear flux region. Next the converter topology described in detailly.Because the converter topology has great influence on the SRM's performance. In this project, a PWM inverter topology was proposed for a switched reluctance motor drive.

Following the description of digital control of SRM. The complete drive system explains the whole project. The simulation results in this project show that with complete drive system in the simulink, individual part of the complete drive system, speed curve current curve and torque curve.

This project presents new controller architecture the DSP controller. The an induction motor. With the DSP controller an intelligent control approach is possible to reduce the overall system costs and to improve the reliability of the drive system.

9.1. FEATURES OF THE PROJECT

The switched reluctance motor has no dq-axis transformation, and no field oriented control principle has been developed for it. Therefore, the requirements of four-quadrant operation and servo performance can only be met by high-speed real-time controllers which operate with phase currents and voltages directly, and not with slow-varying dq-axis quantities. Such high-speed controls are used in advanced DC and AC drives already, in order to achieve the highest dynamic performance. What makes the SRM different is that the relationships between torque, current, speed and firing angles are highly nonlinear and vary as functions of speed and load.

The control system strategy consisted of two simultaneous actions: adjusting the motor speed using voltage Pulse Width Modulation (PWM) and regulating the advanced firing angles as a function of the desired motor speed. The new simplified SRM closed loop model was used to perform simulations of the SRM. In addition, a speed loop can be implemented with digital signal process to keep constant speed under all the load condition.

9.2. FURTHER WORK

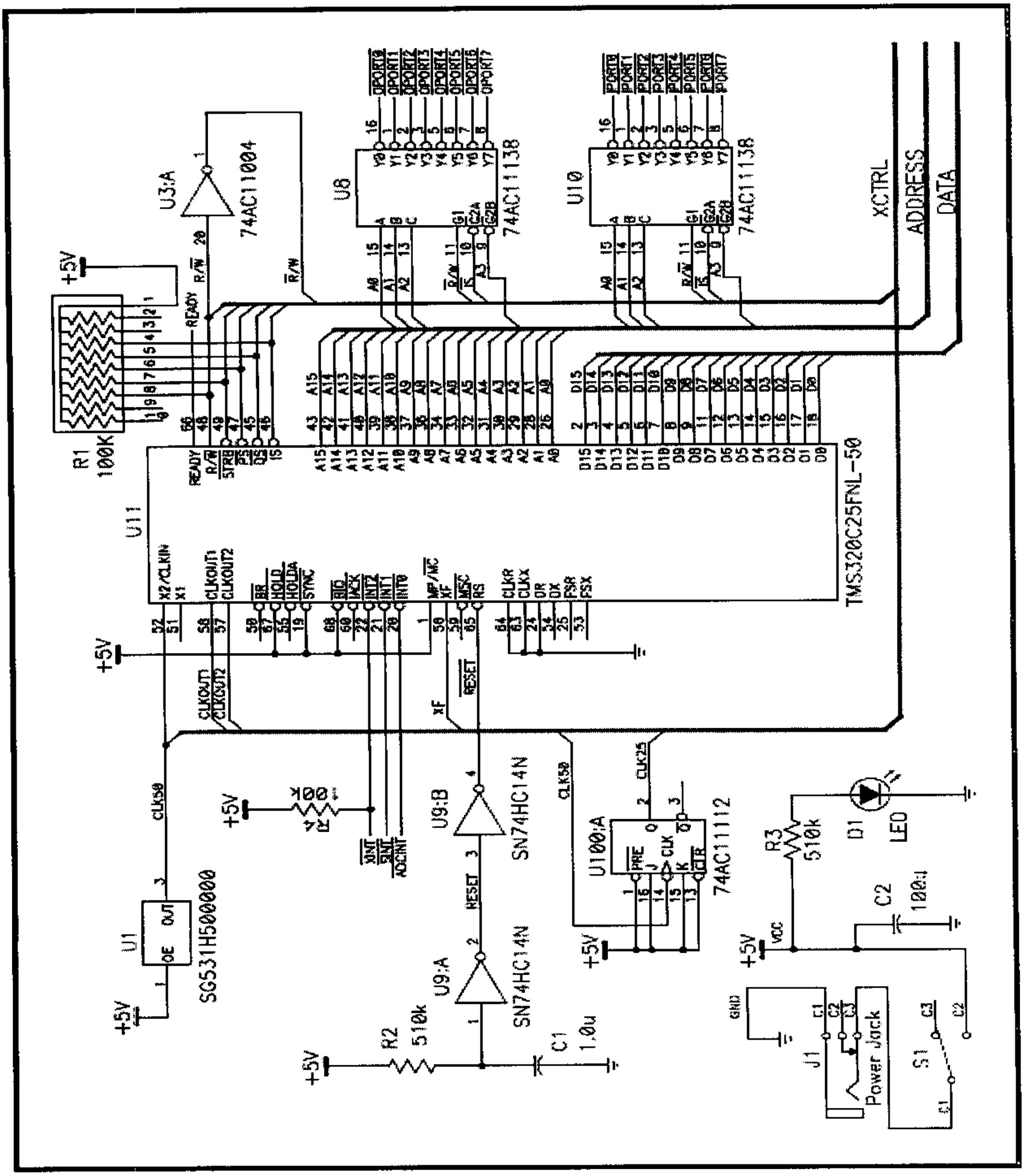
The control of the switched reluctance motor is a very big topic which contains a lot of challenging issues. From the view of the project further work can be performed as the following

1. Use of the designed DSP based system for control of induction and synchronous motor drive systems with position sensor-less algorithms.

2. Implementation of the control algorithms in C language, and implementation of the necessary software to interface with the system.

4. One of the major problems in SRM drives is the high torque ripple. Any work done to minimize this torque ripple would be interesting and challenging.

APPENDIX-1 SCHEMATICS



APPENDIX-2 FUNCTIONAL BLOCK DIAGRAM

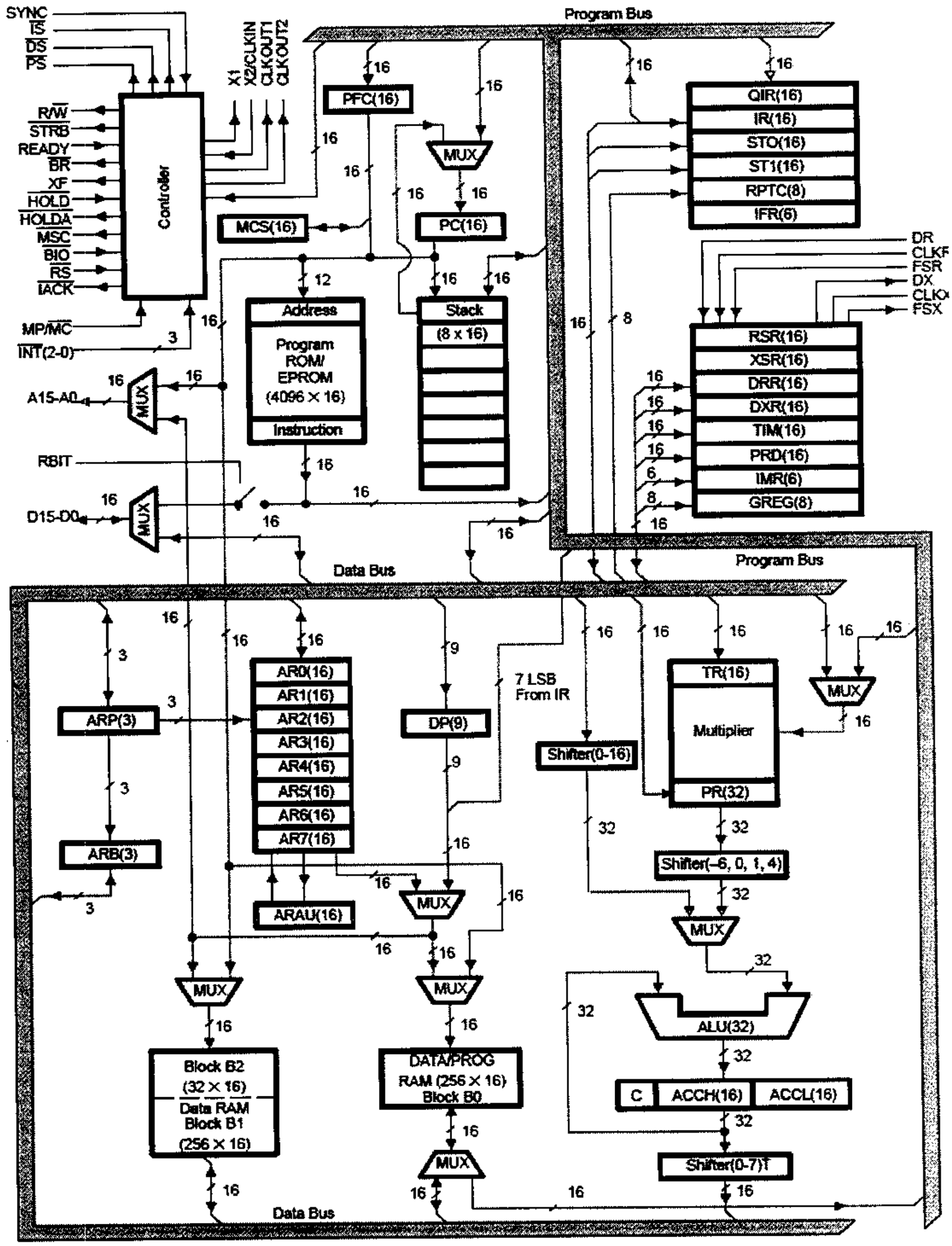


Figure A.2. Functional Diagram

APPENDIX-3 DSP CONTROLLER CODING

```
reset:          b       start
                b       start
                b       start
                b       start
                b       start
                b       start
                b       start
                b       start

start:          ldpk    #100h
                call    lcd_init
                call    delay
                call    pwm ;display pwm
                call    delay

                ldpk    #06h
                lacl    #00h
                sacl    300h
                sacl    301h
                sacl    302h
                sacl    303h
                sacl    304h
                sacl    305h
                sacl    306h
                sacl    307h
                sacl    308h

                ldpk  #100h
                lacl #00h
                sacl 8010h,0
                sacl 8018h,0

main:            call dac_d4
                 call dac_d1
                 call delays
                 call delays

                 call dac_d4
                 call dac_d2
                 call delays

                 call dac_d4
                 call dac_d1
                 call delays
                 call delays
                 call delays
                 call delays

                 call dac_d4
                call dac_d2
                call delays
```

```
call delays
call delays
call delays
call delays
call delays
call delays

call dac_d4
call dac_d2
call delays

call dac_d4
call dac_d1
call delays
call delays
call delays
call delays
call delays
call delays

call dac_d4
call dac_d2
call delays

call dac_d4
call dac_d1
call delays
call delays
call delays
call delays

call dac_d4
call dac_d2
call delays

call dac_d4
call dac_d1
call delays
call delays

call dac_d4
call dac_d2
call delays

;negative
call dac_d3
call dac_d1
call delays
call delays

call dac_d3
call dac_d2
call delays

call dac_d3
call dac_d1
```

```
call delays

call dac_d3
call dac_d2
call delays

call dac_d3
call dac_d1

call delays
call delays
call delays
call delays
call delays
call delays

call dac_d3
call dac_d2
call delays

call dac_d3
call dac_d1
call delays
call delays
call delays
call delays
call delays
call delays

call dac_d3
call dac_d2
call delays

call dac_d3
call dac_d1
call delays
call delays
call delays
call delays

call dac_d3
call dac_d2
call delays

call dac_d3
call dac_d1
call delays
call delays

call dac_d3
call dac_d2
call delays

b main
```

```
                call   small_delay
                ret

dac_d2:         ldpk #100h
                lacc    #0ffh
                sacl    8010h,0
                call   small_delay
                ret


dac_d3:         ldpk    #100h           ; Load data pointer
                lacc    #00
                sacl    8018h,0
                call   small_delay
                ret

dac_d4:         ldpk #100h
                lacc    #0ffh
                sacl    8018h,0
                call   small_delay
                ret




lcd_init:       lacl    #038h
                sacl    8000h,0
                call    lcd_write
                call    delay
                lac     #038h
                sacl    8000h,0
                call    lcd_write
                call    delay
                lac     #038h
                sacl    8000h,0
                call    lcd_write
                call    delay
                lac     #01h
                sacl    8000h,0
                call    lcd_write
                call    delay
                lac     #0ch
                sacl    8000h,0
                call    lcd_write
                call    delay
                ret

pwm:            ldpk    #100h
                lac     #80h
                sacl    8000h,0
                call    lcd_write
                call    delay

                lac     #' '
                sacl    8000h,0
                call    data_write
```

```
call    data_write
call    delay
lac     #'P'
sacl    8000h,0
call    data_write
call    delay
lac     #'U'
sacl    8000h
call    data_write
call    delay
lac     #'L'
sacl    8000h
call    data_write
call    delay
lac     #'S'
sacl    8000h
call    data_write
call    delay
lac     #'E'
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #'W'
sacl    8000h
call    data_write
call    delay
lac     #'I'
sacl    8000h
call    data_write
call    delay
lac     #'D'
sacl    8000h
call    data_write
call    delay
lac     #'T'
sacl    8000h
call    data_write
call    delay
lac     #'H'
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
```

```
ldpk    #100h
lac     #0c0h
sacl    8000h,0
call    lcd_write
call    delay

lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #' '
sacl    8000h
call    data_write
call    delay
lac     #'M'
sacl    8000h
call    data_write
call    delay
lac     #'O'
sacl    8000h
call    data_write
call    delay
lac     #'D'
sacl    8000h
call    data_write
call    delay
lac     #'U'
sacl    8000h
call    data_write
call    delay
lac     #'L'
sacl    8000h
call    data_write
call    delay
lac     #'A'
sacl    8000h
call    data_write
call    delay
lac     #'T'
sacl    8000h
call    data_write
call    delay
lac     #'I'
sacl    8000h
call    data_write
call    delay
lac     #'O'
sacl    8000h
call    data_write
call    delay
lac     #'N'
sacl    8000h
```

```
                sacl    8000h
                call    data_write
                call    delay
                lac     #' '
                sacl    8000h
                call    data_write
                call    delay
                lac     #' '
                sacl    8000h
                call    data_write
                call    delay
                lac     #' '
                sacl    8000h
                call    data_write
                call    delay
                ret

lcd_write:      lacl    #04h
                sacl    8008h
                call    small_delay
                lacl    #00h
                sacl    8008h
                call    small_delay
                ret

data_write:     lacl    #05h
                sacl    8008h
                call    small_delay
                lacl    #01h
                sacl    8008h
                call    small_delay
                ret

delay:          lacc    #01fffh
del:            sblk    #01h
                bnz     del
                ret
delays:          lacc    #030h
delss:          sblk    #01h
                bnz     delss
                ret


small_delay:    lacc    #01fh
sdel:           sblk    #01h
                bnz     sdel
                ret
```

REFERENCES

1. Arthur V.Radun "Design Consideration for the SRM" IEEE trans. Ind. Applic., vol.31 Sep, oct 1995.
2. GAO Yuan "Speed Control of Switched Reluctance Motor" Report August 2000
3. Hossain S.A, Husain I., Klode H, Lequeshe B and omekanda A. "Four quadrant and zero speed sensorless control of a SRM", IEEE trans. Ind. Applic., vol.39 Sep, oct 2003.
4. Hakan akpulat Z, Greg M. Asher and Jon C.Clare " A practical approach to the design of Robust Speed Controller for machine drives. IEEE trans Ind, Elec., Vol 47 April 2000.
5. Miller T.J.E. "Switched Reluctance Motor and their Control" Magna Physics and Clarendon Press, Oxford 1993.
6. Milo D.sprague "A High Performance DSP Based System Architecture for Motor Drive Control",report May 1993.
7. Robert B. Inderka and Rik W.A.A.De Doncker " High Dynamic Direct average Control for Switched Reluctance Drives, IEEE trans Ind, Applns, Vol 39 Jul-Aug 2003
8. Sharma V.K, Moorthy S.S and Bhim Singh " An Improved method for the determination of saturation characteristics of SRM, IEEE trans Measure. And Inst., Vol 48 oct 1999.
9. Texas Instruments Europe." Digital signal processing solutions for the switched reluctance motor".Report: BPRA058, 1997.
10. Xiayun wang "Modelling and Implementation ofController for Switched Reluctance Motor with AC small signal model"Report October 2001.

NATIONAL CONFERENCE
on

CUTTING EDGE TECHNOLOGIES IN POWER CONVERSION AND INDUSTRIAL DRIVES (PCID – 2005)

BANNARI AMMAN
INSTITUTE OF TECHNOLOGY
Stay Ahead

TÜV

RWTÜV

Department of Electrical & Electronics Engineering
Bannari Amman Institute of Technology
Sathyamangalam – 638 401, Tamilnadu

March 25 – 26, 2005

To

Date: 21-02-2005

Ms.P.S.Maheswari
Final M.E. (P.E.&D)
Department of Electrical &Electronics Engg.
Kumaraguru College of Technology
Coimbatore-06
E Mail:mahe_rini@yahoo.co.in

Title of paper :DSP BASED SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR

Dear **Ms.P.S.Maheswari**

Congratulations! Thank you for your interest in PCID 2005.

This is a pro-author Conference and your personal participation is absolutely essential. Kindly confirm your participation for PCID 2005 by return mail

We will provide free boarding and lodging for all the participants within our campus. To serve you better, we would request you to furnish the following details as soon as possible.

We are personally anxious to see you here at Sathyamangalam during the Conference. Please treat this letter as an official document for all conference related activities. The schedule for presentation will be informed at the time of registration. Your presentation would be for 15 minutes. You may present your paper with the help of OHP transparencies or with power point slides. Best paper in each session will be rewarded.
Please feel free to write to us in case you have any query.
Best wishes & Awaiting your active participation in PCID 2005

Dr. A. Nirmal Kumar
Convenor, PCID – 2005,
Bannari Amman Institute of Technology,
Sathyamangalam,
Tamilnadu

* - Details available in website

BANNARI AMMAN INSTITUTE OF TECHNOLOGY

Sathyamangalam - 638 401 Erode Dt. Tamil Nadu

BANNARI AMMAN INSTITUTE OF TECHNOLOGY
Stay Ahead

FIRST NATIONAL CONFERENCE ON
"CUTTING EDGE TECHNOLOGIES IN POWER CONVERSION AND INDUSTRIAL DRIVES"

PCID-2005

Organised by : Department of Electrical & Electronics Engineering
(Accredited by NBA, AICTE New Delhi)

Sponsored by : Council of Scientific and Industrial Research(CSIR), New Delhi

THIS CERTIFIES THAT

Prof./Dr./Mr./Ms. P.S. MAHESWARI

has participated in the NATIONAL CONFERENCE on "POWER CONVERSION AND INDUSTRIAL DRIVES", PCID-2005 held during 25 - 26 March 2005 and has presented a paper titled DSP Based Speed Control of Switched Reluctance Motor.

in the session SD-1 *of the conference.*

Dr. A. Nirmal Kumar	Session Chair	Dr.G.Gurusamy	Dr. A. Shanmugam
Convenor PCID-2005	PCID-2005	Dean EEE	Principal