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SELÇUK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

DOĞRUSAL VE DÖNER HAREKETLİ
ANAHTARLAMALI RELÜKTANS MOTOR
KONTROL TEKNİKLERİNİN
KARŞILAŞTIRILMASI

MOHAMED SH- OMER MOHAMED

YÜKSEK LİSANS

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**COMPARISON OF LINEAR AND ROTARY MOTION CONTROL TECHNIQUES
OF SWITCHED RELUCTANCE MOTOR**

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MOTOR KONTROL TEKNİKLERİNİN KARŞILAŞTIRILMASI"**

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ÖZET (ABSTRACT)

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Abstract: The SR motor is a type of synchronous machine. Switched RM is new generation motor style that brings positive sides of induction and direct current motors. Direct current motors have high starting torque and easy speed controllable. Induction motors have no maintenance through the life span except rollers. Switched reluctance motor tries to merge positive sides of AC and DC motors. Reluctance 3 or 4 phase switched reluctance motor (6/4, 8/6 SRM) which means 4, 6 rotor poles and 6, 8 stator although these SRM model can provide a rough estimation on how the system will perform, a few shortcomings that will make more accurate analysis. In this master project is designed by MotorSolve, Matlab/Simulink and performance of them is analyzed. In this study submersible pump type Switched Reluctance Motor (SRM). SRM from the finite element method for obtaining a non-linear structure (FEM) calculated inductance curve were included in the model. The data of the inductance curve has been obtained from the Motor solve program. The main objective of this thesis is to build and test a drive system to provide a research platform for having more investigations in this field. The first part of this master project report is the literature review of the SRM which includes the basic principle of the switched reluctance motor, motor topologies, mathematical approach, torque production, electromagnetic, drives, converters and its applications. This part means to help to understand the working principle and properties of SRM. The second part of the report describes the work of modeling and simulating of SRM and its control drives. This model is based on the mathematical equations of SRM. All simulation results are shown in this part. The simulation results for different turn-off angle are discussed, and then the current control and speed control are applied. Finally,

added to hysteresis current control with closed loop speed control model and the results are discussed in the unloaded and laden conditions. In the last part, some conclusion has been discussed.

Key Words: Five Phase, Four Phase, Linear Reluctance Motor, MotorSolve, Phase switched, Rotary Reluctance Motor,

DEDICATION

We dedicate this project first of all to our parents who rose up from difficulties, and show us the way to school till today we are here, Secondly to all our Teachers who used most of their time with us teaching us a good mode and basic way of life.

Lastly to all Dear Brothers and Sisters wherever they are.

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All Brothers and Sisters who participated in any way during our difficulties of preparing
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TEZ KABUL VE ONAYI

Mohamed Sh-Omar MOHAMED tarafından hazırlanan “**DOĞRUSAL VE DÖNER HAREKETLİ ANAHTARLAMALI RELÜKTANS MOTOR KONTROL TEKNİKLERİNİN KARŞILAŞTIRILMASI**” adlı tez çalışması 25/11/2016 tarihinde aşağıdaki jüri üyeleri tarafından oy birliği ile Selçuk Üniversitesi Fen Bilimleri Enstitüsü Elektrik-Elektronik Mühendisliği Anabilim Dalı’nda YÜKSEK LİSANS TEZİ olarak kabul edilmiştir.

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TEZ BİLDİRİMİ

Bu tezdeki bütün bilgilerin etik davranış ve akademik kurallar çerçevesinde elde edildiğini ve tez yazım kurallarına uygun olarak hazırlanan bu çalışmada bana ait olmayan her türlü ifade ve bilginin kaynağına eksiksiz atıf yapıldığını bildiririm.

DECLARATION PAGE

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

İmza

Mohamed Sh- Omar MOHAMED

Tarih: 28.11.2016



LIST OF SYMBOLS, ABBREVIATIONS

(A) Abbreviations

SRM	: Switched Reluctance Motor
VSC	: Voltage Source Control
CSC	: Current Source Control
CCT	: Current Control Technique
SCT	: Speed Control Technique
PCB	: Printed Circuit Board
HCC	: Hysteresis Current Control
EMF	: electromagnetic field(s)
CCM	: continuous conduction mode
DCM	: discontinuous conduction mode
DC	: Direct current
AC	: alternating current.
EMF	: Electromotive force
PWM	: Pulse Width Modulation

(B) Symbols

B	: Friction Coefficient
Δw_{elec}	: Incremental Energy Delivered
$\Delta w_{storage}$	: Incremental Energy Stored
Δw_{mech}	: Mechanical Work
N_r	: Number of Rotor Poles
N_s	: Number of Stator Poles
β_s	: Stator Pole Angle
β_r	: Rotor Pole Angle
ϕ	: Flux (Weber)
a	: Slope of relative permeability
A	: Area of the stator pole (Meter ²)
B	: Flux-density (Weber/meter ²)
e	: Speed error (Rad/Sec)
I_{ph}	: Phase current (Amperes)
I_{ref}	: Desired current (Amperes)
J	: Moment of inertia (Kg-meter ²)
J_s	: Saturation magnetization (Tesla)
K_d	: Differential constant
K_i	: Integral constant
K_p	: Proportional constant
K_v	: Current dependent back-emf coefficient (V-sec/rad)
L_a	: Aligned inductance (Henry)
L_{inc}	: Incremental inductance (Henry)
L_u	: Unaligned inductance (Henry)
N	: Number of turns on stator pole
R_m	: Current sensor resistance (Ohms)
R_{ph}	: Phase resistance (Ohms)
t	: Time (Seconds)
T_e	: Electro-magnetic torque (Newton-meter)

T_L	: Load torque (Newton-meter)
V_{dc}	: DC-bus voltage (Volts)
V_{ph}	: Phase voltage (Volts)
θ_{ovr}	: Phase overlapping angle (Degrees)
θ_{adv}	: Phase advancing angle (Degrees)
τ_{RC}	: time constant (Seconds)
V_{ADC}	: Maximum possible voltage at ADC pin (Volts)
I_{max_sensed}	: Maximum sensed current out of sensor (Amperes)
d_i/d_t	: Rate of change of phase current (Amperes/Second)
d_L/d_θ	: Rate of change of inductance w.r.t position (Henry/Radian)
θ_{old}	: Old rotor position (Degrees)
θ_{new}	: New rotor position (Degrees)
Δ_t	: Change in time interval (Seconds)
θ_{adv}	: Phase advancing angle (Degrees)
I_a, I_b, I_c	: Phase currents (Amperes)
I_{dc}	: DC-link current (Amperes)
I_{dc_ripple}	: DC-link ripple current (Amperes)
I_{dc_avg}	: DC-link average current (Amperes)
I_{ratio}	: Ratio of DC-link currents
$I_{ratio(k)}$	: Present ratio of DC-link currents
$I_{ratio(k-1)}$	: Previous ratio of DC-link currents
I_{max}	: Maximum DC-link current (Amperes)
I_{min}	: Minimum DC-link current (Amperes)
Δ	: Change in turn-off angle (Degrees)

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1. INTRODUCTION

Switched Reluctance Machines was introduced by Wheatstone and Davidson first in 1840. But the motor needs to be heard and to be returned to power electronic elements of the semiconductor and control technology developed in those years has caused this motor not received much attention. As a result of rapid advances in semiconductor technology Switched Reluctance design combined with power electronics for the first time in the second half of the 1970s it was carried Machine. The machine was invented by Davidson and was used to propel a locomotive on the Glasgow-Edinburgh railway (Miller, 1993b). Switched Reluctance Machines first produced for commercial purposes, Oilton Drives Ltd. Drives with license Tascam by Britain were also conducted before 1980. These machines, due to the varying inductance of the phase due to the structure of the machine Variable Reluctance Machine (VRM) was called. Machine power semiconductor phase windings after combining with electronics Due to the removal of elements taken into operation by Switched Reluctance (Miller, 2001). Machine 'Switched Reluctance Machine (SRM) "name more widely; It began to be used, Switched Reluctance Machines and motors, as well as. It can operate as a generator. Efforts to use as machine motor is more common. Power drive systems for industrial applications, SRM has made between 4kW and 80kW. Today, of being simple and inexpensive to manufacture and inverter power electronic circuits switching elements need less equipment than other collector less with advantages such as heard in variable speed drive systems it has become a shareholder.

Fig. 1-1 shows an SRM 6/4 pole section. And three-phase motor is wound on opposite stator poles in each phase, flux has two coils connected in a manner to support each other. This connection can be made in series or in parallel. SRM also has a specific description of some rotor position. Below are the basic position and the necessary explanations (Paramasivam ve ark., 2007).

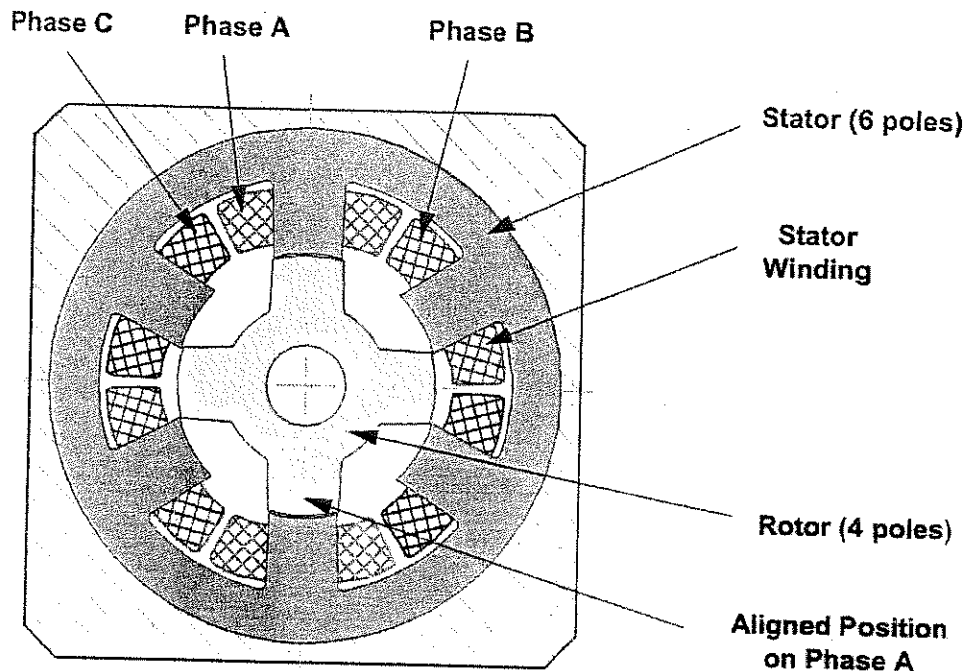


Figure 1.1 3 Phase 6/4 SRM

Each phase of the SRM motor from each other physically, they are pendent from the magnetic induction and maintenance of electrical equipment be reliable and are based on current machines.

Because they do not contain SRMs or permanent magnet windings it can be quite high speed. Switched reluctance to a continuous torque of the properly working operations should be produced. This position sensors monitored by the position of the rotor poles, respectively, according to the stator pole to feed the appropriate phase winding it depends. To accomplish this, the need for appropriate power electronics circuits that drive. The disadvantage of this motor torque it is greater fluctuation. The SRM plays an important role between the variables of speed motors. SRMs is one that has salient rotor and stator pole structure and in which rotary motion occurs due to reluctance torque only from stator winding excitations. SRMs have the low-cost, of any industrial electric motor due to its simple structure. SRMs do not have the magnet and the rotor rolling, high level of rendering on a wide range of speeds, and histrionic design of error. Tolerant to this dominion (Krishnan, 2001). The switched reluctance motors (SRMs) is the three types of switched reluctance machine models are provided:

- 1) Three phase SR MOTOR with 4 rotor poles and 6 stator poles.
- 2) Four phase SR MOTOR with 6 rotor poles and 8 stator poles.
- 3) Five phase SR MOTOR with 8 rotor poles and 10 stator poles.

The reluctance motor is an electric motor in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized. The switched reluctance motor (SRM) which includes the basic principle of the switched reluctance motor, motor topologies, mathematical approach, torque production, electromagnetic, drives, converters and its applications. This part means to help to understand the working principle and properties of SRM.

2. HISTORY AND LITERATURE REVIEW OF THE SWITCHED RELUCTANCE MOTOR

2.1 Switched Reluctance Motors (SRMs)

Switched reluctance motors (SRMs) are a form of stepper motor, but are usually much larger and have fewer poles than the traditional stepper motor. The key to these motors is that the rotor is made of only ferromagnetic material and has no windings. It is a very reliable, low-maintenance motor with high power density at low cost, all of which come at the expense of more complex electronic controls. Opposing stator poles are energized in sequence and the rotor poles closest to the energized stator poles become magnetized and are attracted to them, reducing magnetic reluctance when brought into alignment. Before full alignment is achieved, the next phase is energized to keep the motor turning. There is no need for any transfer of electrical power to the rotor so there are no brushes, commutators, or slip rings. With electrical commutation there are no sparks so these motors can be used in explosive environments. They are also good for holding a load in a stationary position for long periods of time (Mecrow, 1993).

Switched Reluctance Motor, without winding rotor stator and the rotor salient pole from regenerated and made a simple electrical machines. SRMs convert mechanical energy to electrical energy with reluctance force. These forces constitute the torque that performs the rotation. To produce a constant torque, position relative to the stator pole of the rotor pole, respectively, monitoring and feeding of the appropriate phase winding (Taylor, 1991). To achieve this, a power electronics and control mechanisms are required.

The cause of addressing SRM In recent years, software, parallel to the developments in design and technology, simple structure of this motor is reliable and stable, to be almost independent of the working environment, low and high speeds operated can be, less the cost of production of low maintenance and repair costs can be sorted. There are basically two issues in the arm. Provincial when working on SRM fluctuations in torque and noise arising due to centrifugal force. The other is the determination of the motor position. If we have to go to the source of the noise; SRM stator and the rotor has salient pole structure. Stator pole rotor pole by the current flowed through the coils on the stator poles of an electromagnet principle (Tuovinen ve ark., 2013). It will pull itself. The gap between the rotor poles, which causes no change in the air gap distance between the rotor and the stator. Therefore, the rotor rotates the

rotor pole radial and axial forces that will impact continuous change. At the beginning of the rotor magnetic effect caused by radial forces that create noises. Composed in a radial direction and the forces acting on the rotor poles to cause vibrations bearings. This acoustic vibrations in the stator Perceived as noise. After a period of time that vibrations from bearings may have a fault (Takiguchi ve ark., 2015). Noise and resonance of the innovations to be made in motor design and control system it is possible to reduce. Figure 2-2 shows a Switched Reluctance Machine.

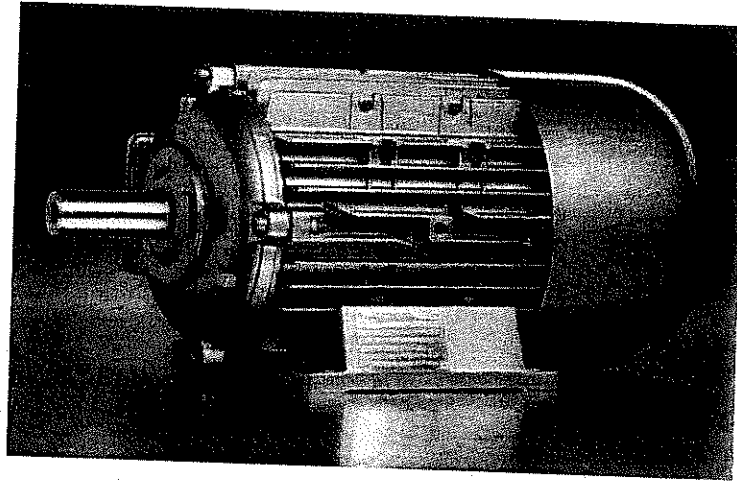


Figure 2-2 Switched Reluctance Machine

2.2 History of the SRM

Switched reluctance machine (SRM) for the first time in Scotland in 1838 to move a locomotive used by the Davidson. 1920 In this days C walk by SRM's name has been invented an motor bearing properties. In 1971 and 1972 by switching Bedford Haft rotor position and stator currents have to simultaneously provide the shaping of today's modern armor. It is also on the rotor and stator pole geometry and power electronic converter structures have been found in research. Commercial importance in Europe to win the switched reluctance motors is provided by Byrne and Lawperson. Also SRDL (Switched Reluctance Drives Ltd.), various studies carried out by the early '80s has increased the interest in this machine. Drives srdl'n Tascam is one of the first licensed manufacturer (this day has taken its name Oilton Drives), 4kW and 80kW of power for industrial applications has made SRM drive system. Today, the power converter is simple and inexpensive to manufacture and has become a shareholder in the variable-speed drive systems thanks to advantages such as the need to be less than the other switching elements in electronic circuit's collector less machine (Berdoyes, 2006).

3. DESCRIPTION SWITCHED RELUCTANCE MOTOR

3.1. Classic Switched Reluctance Motor

SRM and step motors in the motor structure and salient pole synchronous motors are similar. SRM has a simpler structure than the other motor, and both rotor and both dislocation of the stator poles are located. Both the stator and rotor core, to reduce the manufacturing suitability and iron loss, the made of laminated thin sheets. They are on the salient pole in the stator phase winding thin wire and heavily wrapped. In the rotor winding short circuit ring or magnet available. Windings on the opposite pole of the stator phase windings connected in series or parallel form (Boldea ve Tutelea, 2009). SRMs stator / rotor poles are classified according to their rates. Three-phase found a lot of applications in figure 3 - 3 are given the cross-section of industry 6/4 pole SRM. As the motor size is reduced.

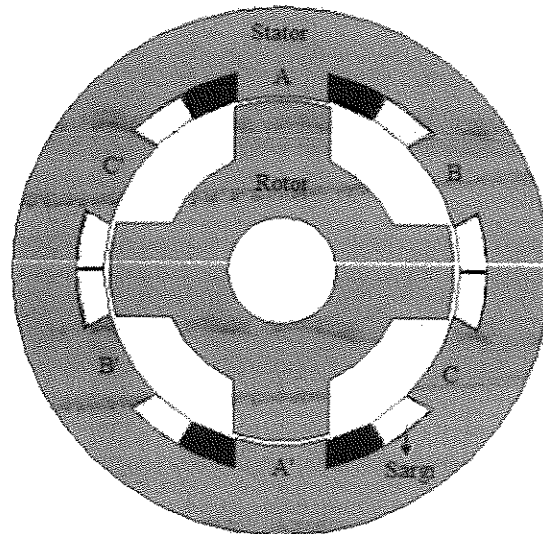


Figure 3-3 Three-phase 6/4 pole SRM section.

Fig. 3-3 in the three-phase stator arm 6 is 4 rotor pole, three phase windings in the stator coil is formed by six. Phase SRM in order to make a full rotation of the rotor excitation of the windings must be more than once. Each Induced when a phase winding, a rotor pitch angle (θ) Up to a rotational motion, m phase number, N_r being the number of rotor pole rotor is $m * N_r$ step completes a full rotation and can be determined by mechanical step angle.

$$\varepsilon = \frac{2\pi}{mN_r} \dots\dots\dots \text{EQ (3 .1)}$$

In the SRM rotor inertia to prevent vibration during takeoff beat a lot more change of formation and change, as in flux induction motor, the rotor are manufactured in the light

axial offsets In the SRMs Number of stator and rotor poles to the formation of a continuous rotary movement are not identical and it will be more than the number of rotor pole number of the stator poles embodiment. It is constructed in such a way. There are the number of poles in the stator when the rotor poles to be closer or to be a smaller number depends on the application purpose (Lawrenson ve ark., 1980). The number of rotor poles in high torque applications requiring close by when selecting the number of stator poles, less high speed is selected according to the desired number of rotor poles and stator poles if the number of applications. In addition, the stator poles are made narrower than the rotor poles to provide more benefits from the magnetic field that occurs when stimulated phase windings and the winding space to be larger (Yamai ve ark., 2000).

3. 2. The couple of Switched Reluctance Motor

The Couple Switched Reluctance Motor is an motor appeared to change the shape of the coil windings of the classical SRM. Changes made in this winding, largely changing the structural advantages of a conventional SRM. Due to the change in the structure of the excitation winding structure changes also occur

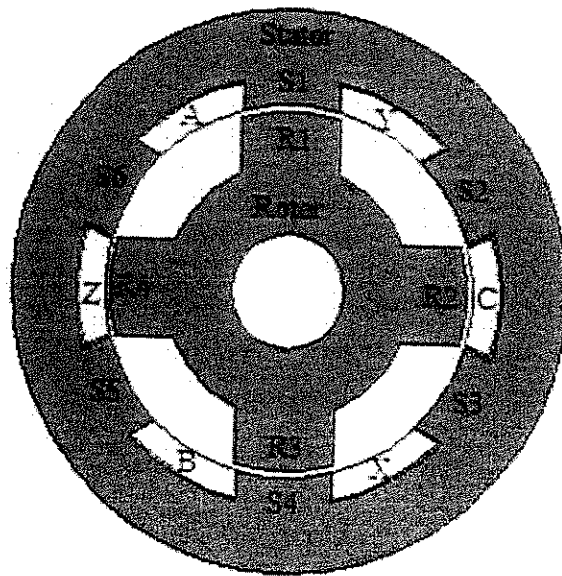


Figure 3-4 Opponents coupled general structure of the SRM

Also winding structure and significant changes in the working principle with changes in the structure of excitation occurs accordingly. The newly formed windings on this machine has a full-pitched winding pole and covers all the grooves (Muntean, 2007). The reciprocal of the coil covering the groove as shown in Fig. 3-4 constitute a phase of

the machine. Any "t" is the machine at the time of transmission at least two phases. This winding structure 6/4 stator and rotor pole structure has been applied in motor winding shape, though the same can also be applied to the motor with other number of stator and rotor poles.

3.3. Choose the geometrical parameters

Air gap of 6/4 SRM in this study (g), the effects on the working curve of variation of stator and rotor pole angle value is examined. In this context only the SRM air gap, the stator and rotor pole angle values determining the change intervals are discussed separately.

3.3.1. Determination of Air Range Value Change Intervals

Air gap in the switched reluctance motor operation is an important parameter in terms of impact on the characteristics. Therefore SRM is required to be small in value as possible of the air gap. Air gap exchange with air gap reluctance value varies in direct proportion (Inderka ve ark., 2002). Equation 3-2 shows the relationship between the air gap reluctance of the air gap. Air gap the relationship between reluctance and inductance is given in equation 3-3. It is apparent from equations air gap inductance value varies inversely with the value of reluctance. Therefore, this change leads to the change of torque value of the inductance value. Hence the air gap changes, which alter the torque value of the most important operating characteristics of SRM.

$$R_h = \frac{g}{\mu_o A} \dots\dots\dots \text{EQ (3. 2)}$$

$$L = \frac{N^2}{R_h} \dots\dots\dots \text{EQ (3.3)}$$

Increasing the maximum value of the torque is small and the current value of the air gap used in the driver circuit and a minimum voltage sufficient it is to ensure that. Furthermore, the fact remains balanced phase currents and acoustic noise of a uniform air gap needs to be kept to a minimum (Lawrenson ve ark., 1980). However, during design, the shaft deflection due to temperature expansion and the material used should be considered. Therefore, considering the selection of a tolerant manner in all operating conditions it must be performed.

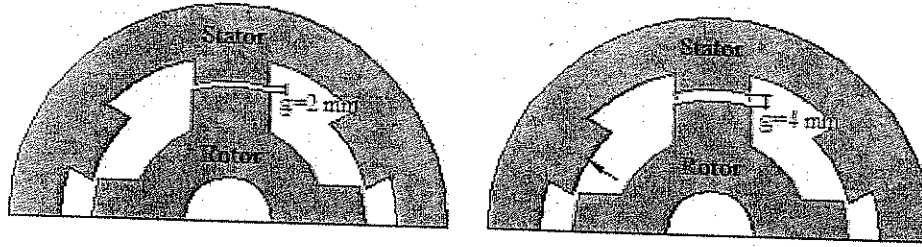


Figure 3-5. 6/4 SRM change in the air gap

This work is changed by narrowing the direction of arrow stator poles as shown in Fig. 3-5. The air gap. Thus the motor without changing other geometrical dimensions of the stator poles, so the air gap changes with the narrowing of the field winding is performed. In this context the value of the air gap 2mm, 3mm and 4mm are to be examined.

3.3.2. Determination of the stator and rotor Polar Angle Value

The selection of the stator and rotor pole angle of the SRM design is an important part. While this selection process, to overcome the moment of inertia is taken into consideration many aspects such as rotor position and shape of the static torque characteristics. The stator and rotor pole angle possible to overcome the moment of inertia during departure as it is desired to be small (Drury, 2001). Let's examine the three items to determine the stator and rotor pole angles.

1. In practice, the stator pole angle value (β_s), the rotor pole angle (β_r) should be equal to or less than ($\beta_s \leq \beta_r$).
2. The stator pole angle (β_s), pitch angle (ϵ) should be equal to or greater ($\beta_s \geq \epsilon$). The stator pole angle has been selected for the small step achieved the first movement of the motor rotor to some locations. Pitch angle is given in equation 3-4.
3. Maximum values of polar angle is calculated in cases where overlap of stator and rotor poles. Equation 3-4 'can be calculated as indicated.

$$\beta_s < \frac{2\pi}{N_r} - \beta_r \dots\dots\dots \text{EQ (3 - 4)}$$

The above-mentioned stator and rotor poles selection ranges can be stated in terms of value on the way. In this context, 6/4 SRM stator and rotor poles to open. The selection ranges of values are given in Fig. 3-6. Figure carefully examined when the lower region of the curve OA, Article 1 and Article 2 in the area under the curve DF, GH curve 3 shows the top of the article. The intersection of these areas represent the range of the stator and rotor pole angles (Ayaz ve Yilmaz, 2008).

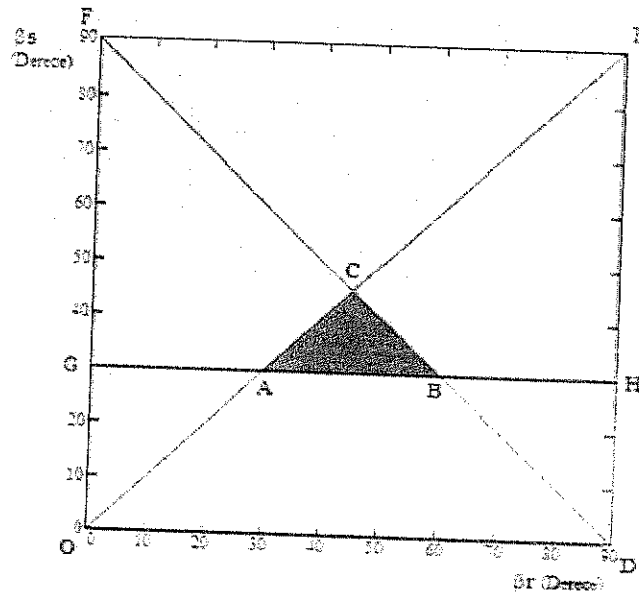


Figure 3-6. 6/4 polar angle range of values for SRM.

In this study, the stator pole angle is 30° and the rotor pole angle of 31° , 32° , 33° analysis will be chosen to be.

4. THE SRM TYPES FOR PHASES

Electrical equipment should understand what is mentioned? If the electric motor or generator machine, known are alive in our minds if something comes to mind. Electric motor; applied mechanical energy into electrical energy is produced (it be) can be explained as a system. The mechanical energy applied in the same way as the generator of electrical energy which can be defined as a structure. So, what is the rationale of this system? Theory is not very popular, but we have to revive our eyes to understand the practice. 1,2,3,4 phases and 5-phase to examine the structure of these systems together.

4.1 Single Phase Motor

These are the simplest SRMs having the advantage of fewest connections between motor and power electronics. For the single phase motor, the quantity of the rotor poles are the same as the stator poles. Figure 4-7 shows the geometries of single phase motor with 4 rotor poles and 4 stator poles.

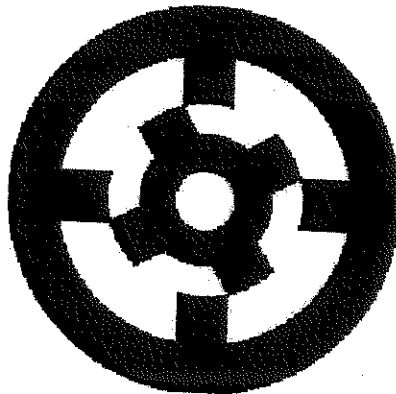


Figure 4-7. Single phase with 4 rotor poles and 4 stator poles

The design of single SRM. 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. In order to solve this problem, A single phase SRM drive with saturation-based starting method (Hennen ve ark., 2011). Also, a presents a new single phase, hybrid SRM for low-cost, low-power, pump or fan drive systems.

The structure of 1-phase motor which is simple, but in many areas of theoretical investigation is very difficult. Motor should return to work. It is easy to provide this third phase of three phases. We came to this thread. So, this is how events are provided in a phase. Need to be in a phase rotation of the motor system in our hands and we cannot do it. So any tool that we will turn the shaft of the vacuum cleaner or your

washing machine motor to consider returning home and it should be spontaneous. Here it windings used here and help our rotary motor as if He was 2-phase and provides magnetic field. As a result; we have produced moments. Motor development has been holding k auxiliary winding, disable the motor is a key reaches 75% of normal speed. It is carried out by utilizing centrifugal force. Formed from two portions of the fixed portion of the cover into the centrifugal switch, the moving part is mounted on the rotor shaft. Two contacts on the fixed part of the motor is not running off and activates the auxiliary winding. When the motor speed reaches to 75% of normal moving parts, with the effect of centrifugal force releases the pressure on outwardly pulling contact.

Meanwhile, the auxiliary winding is switched off by opening the contact. When the motor is stopped again came close to the original position by a spring contact.

4.2. Two Phase Moto

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. Figure 4-8 shows the geometries of 2 phase motor with 2 rotor poles and 4 stator poles.

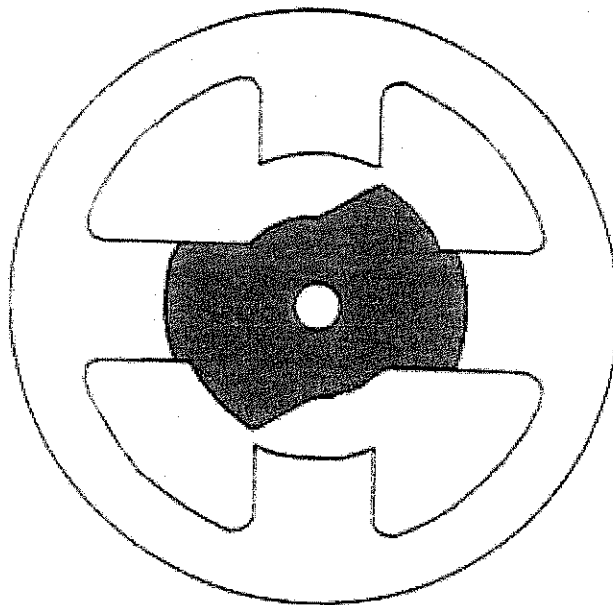


Figure 4-8. Two phase with 2 rotor poles and 4 stator poles

Any First Circle efficient high performance to the starting position and phase SRM novel is seen to handle the full load. Recommended motor and unique features of the pro-free flow in the opposite kind, principles fundamental to limit losses and each

process step to exploit them in one-third of the stator core. A novel two phase SRM with a stator composed of E-core structure having minimum stator core iron.

The E-core stator has three poles with two poles at the ends having windings and a center pole containing no copper windings.

4.3. Three Phase Motor

The most popular topology of a three phase is the 6/4 form (stator poles = 6 and rotor poles = 4). It represents a good compromise between starting and torque ripple problems and number of phases.

Alternative three phase motors with doubled-up pole numbers can offer a better solution for lower speed applications. Fig. 4-9 shows the geometries of 3 phase motor with 4 rotor poles and 6 stator poles.

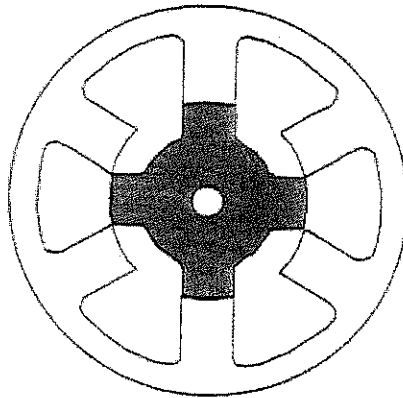


Figure 4-9. Three phase with 4 rotor poles and 6 stator poles

First of all we need to know first information; should return to operation of the motor and the induced voltage means that the rotation means to bring about a moment of tension. This also occurs with the rotating magnetic field. We handle a phase of above and now let us consider the formation of a third phase of the rotating magnetic field. 3-phase system has a 120-degree angle between each phase. Phases differ in the distance of this angle. In three phase systems also need to operate the motor such as rotation of a phase. So, this is how to create rotating field. Together, let's examine. If you pay attention to the following figures of our voltage of 3-phase to the implementation phase is formed by sliding a rotating magnetic field. This information can tell you that under the net of returns, no matter where it is applied to the 3-phase, three-phase system consists of a self-magnetic field. The supporting materials such as a motor is rotated without the need for a number of phase winding.

4.4. 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. Fig. 4 -10 shows the geometries of 4 phase motor with 6 rotor poles and 8 stator poles.

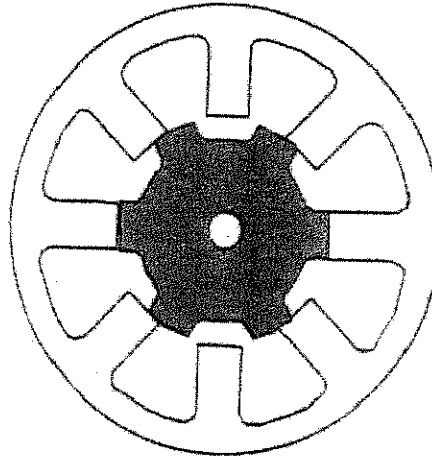


Figure 4-10. Four phase with 6 rotor poles and 8 stator poles

The thorough time-stepping limited-element behavioral paradigm is advanced and used for in detail analysis and design improvement of the prototype 8 / 4 SRM.

4.5. Five and More Phase Motor

10/8 SRM has a different structure from conventional rotor arm. The rotor as well as the package that was created from a block of aluminum and silicon steel consists of the placement of this package. We can list the reasons for using aluminum block as follows:

Magnetic field formed by the magnetic property because aluminum metal has a non-limiting feature. The preferred flux barrier in conventional switched reluctance machine with this feature can perform the task with success (Rallabandi ve Fernandes, 2014). Other metals used in aluminum motor components (such as stainless steel, etc.). According to a much lighter metal. Thus, taken into account in the motor Nm/kg torque value produced per unit weight will be automatically increased. In addition, aluminum is a metal still cheaper than other metals.

This situation is another criteria to be taken into consideration during prototype production. Single phase motor used in the classical SRM method instead of the two-phase energizing method is used. Reasons for using such a method include:

When the bandage properly installed and energized at the same time SRM two phases of the motor's magnetic pole (on machine design) has been shown to follow the short path flux. In this case (Reduction of flux path) loss of both bands will cause a reduction in temperature for the motor coil. The two-phase energizing is a consequence of the value generated in the motor torque has been increased by up to 2.10 times the optimizations. In addition, the motor's stator structure is made small changes. With the use of a similar trapezoid shape pole magnetic saturation it is intended to reduce the power drop in the motor magneto to be concentrated near the air gap and the pole (Wang, 2013).

Fig. 4 -11 shows the geometries of 5 phase motor with 8 rotor poles and 10 stator poles.

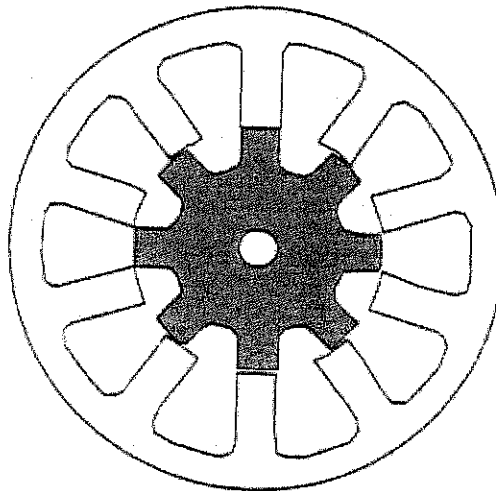


Figure 4-11. Five phase with 8 rotor poles and 10 stator poles

5. OTHER NOVEL MOTOR

Reluctance motor comprising magnetic poles in the ferromagnetic rotor unstable they are synchronous motors. Figure 5- 12 shows a synchronous motors.

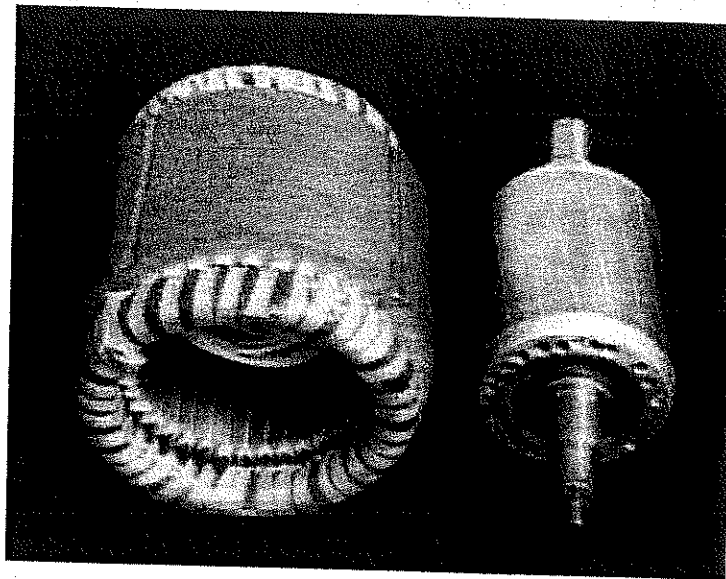


Figure 5-12. A synchronous motors.

Types of reluctance motors are known,

- ☐ Asynchronous reluctance motors
- ☐ Change the reluctance motors
- ☐ Switched Reluctance Motor

Today reluctance motor manufacturing simple and cheap to be and be able to produce very high torque in small volume, power superiority as needed to lower switching elements compared to other collector less motor electronic circuits are commonly used in the industry due. This motor is one of the biggest disadvantages that occur in low speed (torque pulses) and acoustic noise occurring due to this disorder. This disadvantage is very advanced computer aided design and low cost practical reluctance motor power circuit to minimize is used. The power electronics system as the basis of the rotor position, motor current and voltage values are based on calculations made by the aim to create the most appropriate output waveform (Vagati ve ark., 1997).

5.1. Structure and Operation of Reluctance Motor

The structure is very close to the reluctance motor shade pole motor instead of a portion of the surface of the copper ring on the pole shade pole motor with the only difference will be a little more air gap.

It is mounted so. Air gap between one side of the pole with the middle pole rotor is very small in the other part is great (Ilic ve ark., 1987). Magnetic resistance value in the small air gap is large with large portions small. Windshields using the rotor as short-circuited rotor of the three-phase asynchronous motor. When alternating current is applied to the stator windings a sinusoidal current flows through the coil and a changing magnetic flux occurs. When passing from the outgoing lines of force from the N pole to the S pole in the stator where the largest of the small air gap where a large magnetic resistance they encounter a smaller magnetic resistance. This section scrolls showing less resistance in the magnetic flux of the pole surface of the pole regarding impairment. So change the polarity of the magnetic flux in each half periods. The rotor turns with the effect by the movement of the magnetic flux in the pole surface. Shift of the magnetic flux within the air gap portion, which is smaller than the largest air gap portion in the rotor is rotating in the correct direction.

5.2. Reluctance Motor Types

5.2.1. Synchronous Reluctance Motors

Synchronous reluctance motor includes an equal number of stator and rotor poles. Typically 4 or 6 poles are made. Rotor synchronous speed rotating rotor current does not occur in the conductive portion of the rotor losses are extremely low compared to standard AC motors.

Standard mains sinusoidal voltage with synchronous reluctance motors are controlled, but speed electronic speed control device for setting (VFD) is required (Sakuma ve Fukushima, 2006). Figure 5- 13 shows a Synchronous reluctance motor.

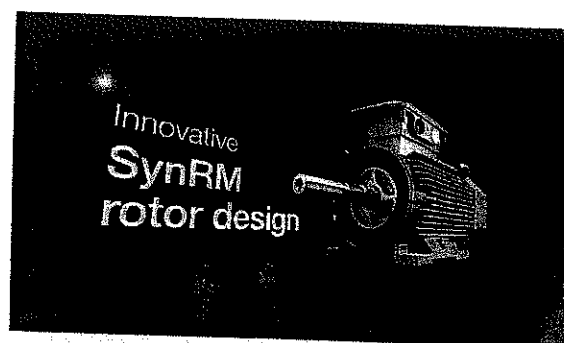


Figure 5-13. Synchronous reluctance motor.

5.2.2. Switched Reluctance Motors

This motor is a special case of the stepper motor. They are made as a three-phase stator poles in each phase and wrapped in mutual flux has two coils connected in a manner to support each other. This connection can be made in series or in parallel. SRM 'depending on the rotor position in the motor torque / current values varies. It shows the motor current changes according to the position of rotor poles below (Miller, 1993a). Figure 5- 14 Switched Reluctance Motors.

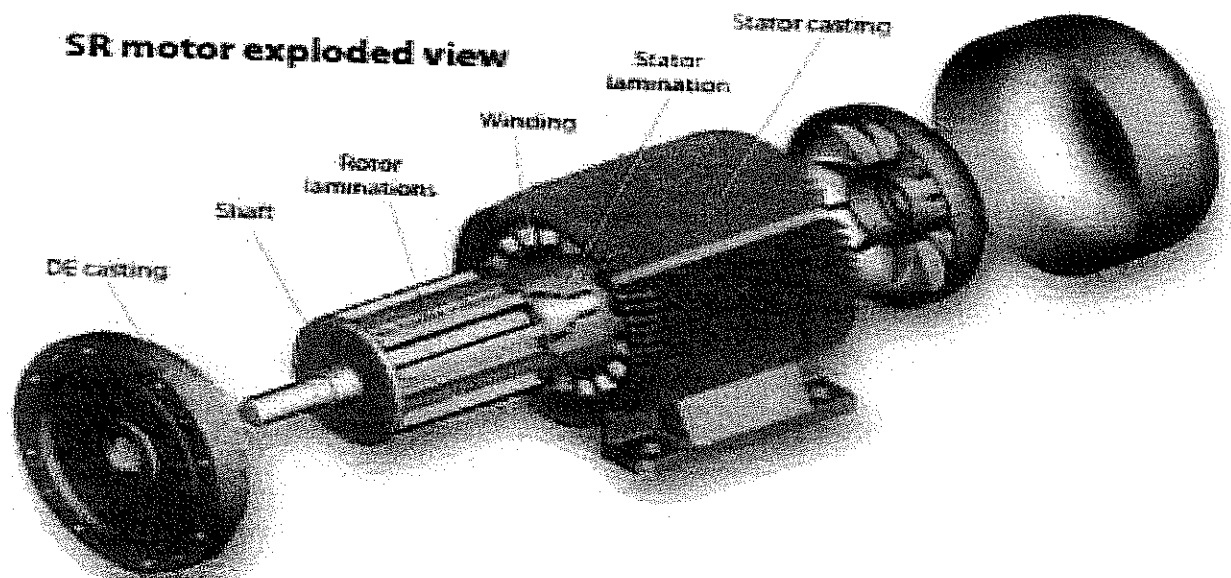


Figure 5-14. Switched Reluctance Motors

6. LINEAR MOTION OF SWITCHED RELUCTANCE MOTOR

SRM to drive the linear motion of the elevator which made a circular motion with an induction motor, reducer, the need for a machine room consisting of pulleys and control panels. Also outside of the nacelle guide rails, pads and ropes are necessary to move the cabin. Which is necessary to obtain a linear movement of a rotating motor cabin each of these units has led to a reduction in both the cost and increases the efficiency and reliability. It also reduces the maintenance time and service life. Therefore, in recent years, or without stitch wire for the solution of this problem and elevators without machine designs are prevalent. The design of the direct drive linear to linear motion system is a breakthrough for the industry. Direct-drive linear motion systems such that the elevator car to be driven by linear motors will bring significant improvements in the elevator industry (Gieras ve ark., 2016). Therefore, it is important original design of linear motor drive on an elevator. With or without stitch wire and machine-less electric motor driven lift linear motors are used. The choice of varieties of these motors, working principles, many factors affect the type of energy used by the elevator as efficiency and reliability. Asynchronous motor type alternating current (AC) linear motors requires working with very high costs, caused by expectations for practical applications such as the low productivity of labor was difficult and welcome. Simple structure, high efficiency and variable speed side of the low order failure rate, due to the precise position control and low cost of linear switched reluctance motors (LSRM) other AC and direct current (DC) has found many applications as an alternative to the motor. These motors are different from the number of rotor pole number of stator poles in terms of structure and they are without any brushless motor windings in the rotor. LSRM especially rail transportation systems and their use where linear movement such as looms, providing advantages over conventional rotary system. Other linear motors which have the advantages that they have a lot of SRM when compared with the potential LSRM are able to offer more efficient solutions.

Excitation will have saved quite a rapid development with the development of semiconductor technology. Due to the wide range of speed control are finding widespread use of these motors in recent years. Simple of construction, maintenance and due to its low production costs and ever increasing consumer interest in applications for industry. Due to the advantages provided by the motion control system as an alternative to other AC and DC motors have many applications.

A suitable converter circuit and drive system controlled by the circular arm can be obtained higher yields than other electric motors. These motors are any dressing without brushless DC motor at different rotors and the number of rotor pole number of stator poles in terms of structure. Besides offsetting the lift system is also reliable, fast, comfortable, durable, and inexpensive, requires little maintenance, and are required to be stable and efficient. Although there is a type of electric motor driven hydraulic elevators, which are used more. Although there are close to almost all of the three-phase brushless DC motors used are also in the final year of the electric motor asynchronous motor is used. These asynchronous motors can make a circular rotary motion as if known (Dursun ve Ateşoğlu, 2014). Flat LSRMs (Longitudinal) shown in Fig. 6 -15. 1. Longitudinal 8 /6 single sided LSRM

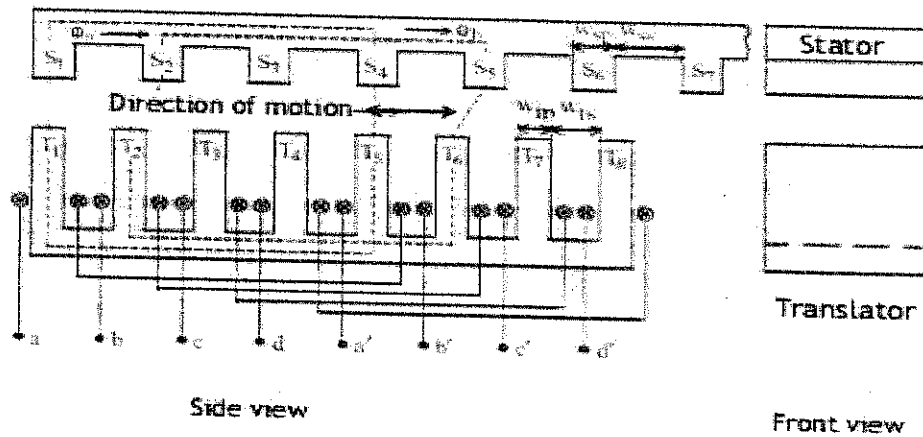


Figure. 6-15 1. Longitudinal 8 /6 single sided LSRM

And shown in Fig. 6 -16 Flat LSRMs (Longitudinal) 2. Longitudinal 8 /6 single sided LSRM

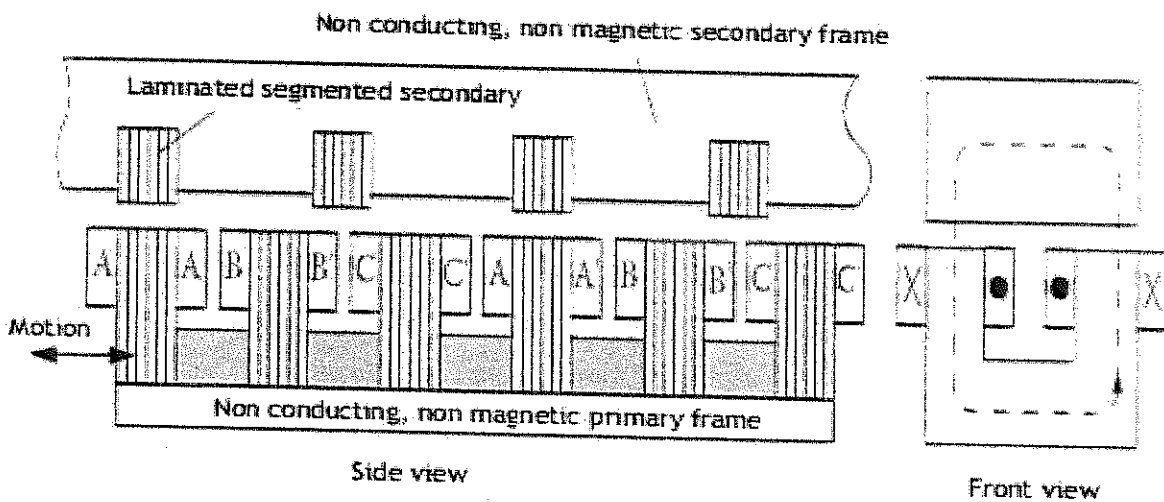


Figure 6-16 2. Longitudinal 8 /6 single sided LSRM

6.1. LSRM FOR ANALYSIS SYSTEM

Linear motor inductance in the rotor position varies depending on the translator and the current through the coil. Figure 6-17 shows a linear motor equivalent circuit for one phase removed

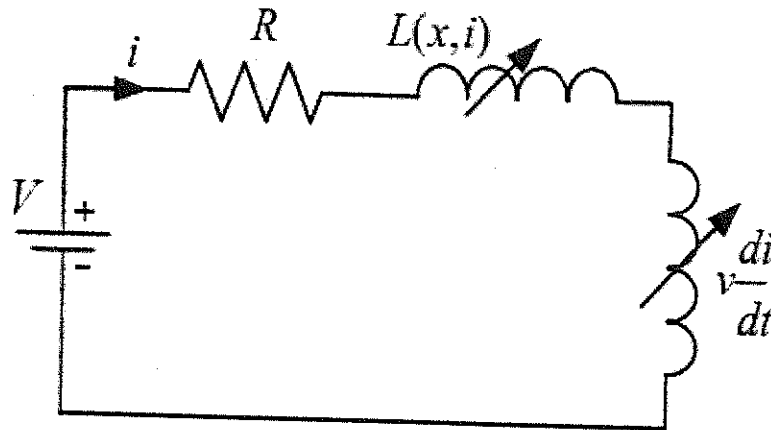


Figure 6-17. LSRM equivalent circuit for one phase

Phase stator voltage equations

$$V = Ri + \frac{d\psi(X, t)}{dt} M(X) \frac{di'}{dt} \dots\dots\dots \text{EQ (6. 5)}$$

Electrical equivalent of the circuit, V source (bar) voltage, i the phase winding current, R stator phase resistance, $M(X)$ mutual inductance, X rotor position, i' refers to the current coil induced before the phase concerned. When saturation is negligible magnetic flux $\Psi = L(X).I$ Because of rearranging.

$$V = Ri + \frac{d(L(X), i)}{dt} - M(X) \frac{di'}{dt} \dots\dots\dots \text{EQ (6.6)}$$

Where $L(X, i)$ indicates the execution inductance. Differential expression neglecting mutual inductance;

$$V = Ri + L(X) \frac{di}{dt} + i \frac{d(X)}{dt} \dots\dots\dots \text{EQ (6.7)}$$

Shape means. When the mutual inductance is negligible;

$$\frac{dL(X,i)}{dt} = \frac{dL(X,i)}{dX} v \dots\dots\dots \text{EQ (6. 8)}$$

$$\frac{di}{dt} = \frac{di}{dX} v \dots\dots\dots \text{EQ (6. 9)}$$

$$V = Ri + L(X) \frac{di}{dx} v + i \frac{dL(X)}{dX} v \dots\dots\dots \text{EQ (6.10)}$$

It is where v represents the linear velocity. Motor phase current of the circuit varies according to the position equation is rearranged K_a , K_b , and K_c are to be fixed to the motor phases;

$$K_a = R + v \left(\frac{dL_a}{dX} \right) \dots\dots\dots \text{EQ (6. 11)}$$

$$K_b = R + v \left(\frac{dL_b}{dX} \right) \dots\dots\dots \text{EQ (6. 12)}$$

$$K_c = R + v \left(\frac{dL_c}{dX} \right) \dots\dots\dots \text{EQ (6. 13)}$$

It happens. All the motor components in the form of state space $\dot{X} = Ax + B$ if indicated by the following written Matrix form.

$$\begin{bmatrix} \dot{i}_a' \\ \dot{i}_b' \\ \dot{i}_c' \end{bmatrix} = \begin{bmatrix} -\frac{K_a}{vL_a} & 0 & 0 \\ a & \frac{K_b}{vL_b} & 0 \\ 0 & 0 & \frac{K_c}{vL_c} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} -\frac{1}{vL} \\ 0 \\ 0 \end{bmatrix} [V] \dots\dots\dots \text{EQ (6.14)}$$

LSRM sided thrust forward or pulling force (F_x), the drag force (F_y) and lateral force (F_z), including a 3-axis force is induced. The direction of this force is given in Figure 6-18. The power components F_x , F_y calculated by Equation 6-15 and Equation 6-16.

$$F_x = \frac{B_g^2}{2\mu_0} YZ = \frac{B_g^2}{2\mu_0} I_{sl} I_g \dots\dots\dots \text{EQ (6. 15)}$$

$$F_y = \frac{B_g^2}{2\mu_0} YZ = \frac{B_g^2}{2\mu_0} I_{sl} I_{tp} \dots\dots\dots \text{EQ (6.16)}$$

Linear speed of movement and force that SRM is F_x (Polat ve ark., 2011).

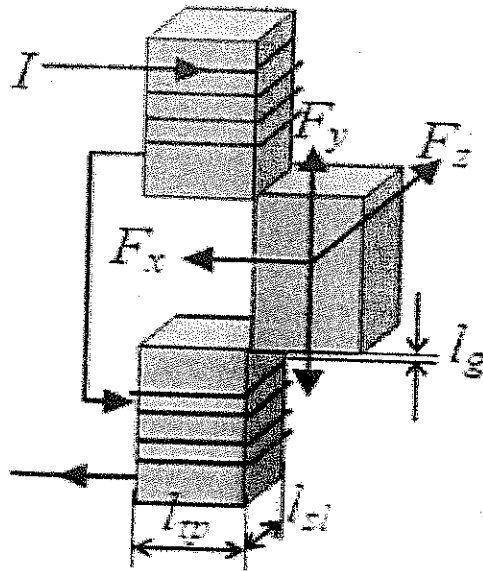


Figure 6-18. Linear SRM in strength and direction of components

6.2. LSRM for Control Circuit and Driver

When the motor is energized motor suitable phase change occurs with the inductance of the motor movement. The closest non-aligned rotor pole position (the position where you least reluctance is) taken by the translator pole. As well as motor traction force increases, the magnetic circuit reluctance is reduced. Here passing aligned position of the motor produced torque ranging inductance. So inductance difference occurs aligned position when passing from the discrete position influences the torque of the motor. Another parameter is the square of the current. Is the current frame of the direction of the resulting torque is the current independent frame. The direction of the motor torque to be changed if desired to change the switching sequence is sufficient.

The performance and the positive torque converter feature also affect the production motor. Figure 6- 19 is given a three-phase LSRM controller block diagram. System operation supplied from a direct current source three-phase and two in phase two switch positions in the conventional converter based on the principle of triggering. If one or both of the motor phase currents exceed the reference value if the relative phase switch from one sector to taken current slaughter is performed. If the current reference range switch maintains the status quo. In this way, it moves around the cabin with the motor fed by converters with switching. Linear encoder position during movement of the car is detected and sent to the microcontroller. The microcontroller used in this study 2 Capture / Compare and PWM channel has. Therefore, using the read position as one Capture of these channels, the other channel it was used as a PWM

output. Therefore, it was necessary to control the three different phases with PWM. It contains an integrated process for passing through gates 3 and applying the same in all three phases are used as PWM 3 (Dursun ve Saygin, 2006).

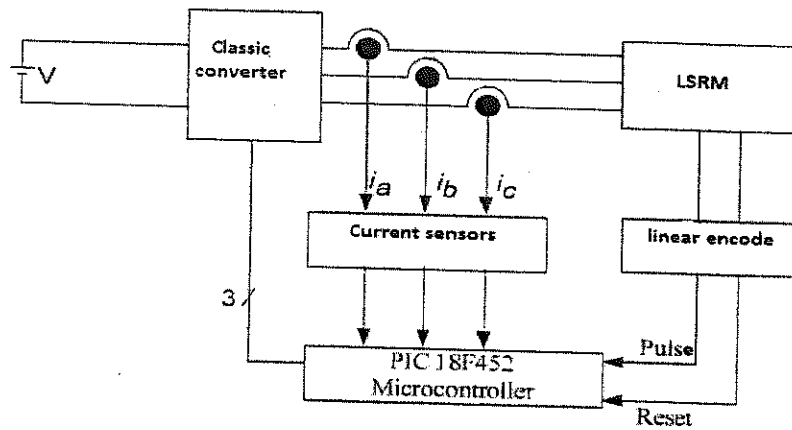


Figure 6-19. Three-phase block diagram of a controller LSRM

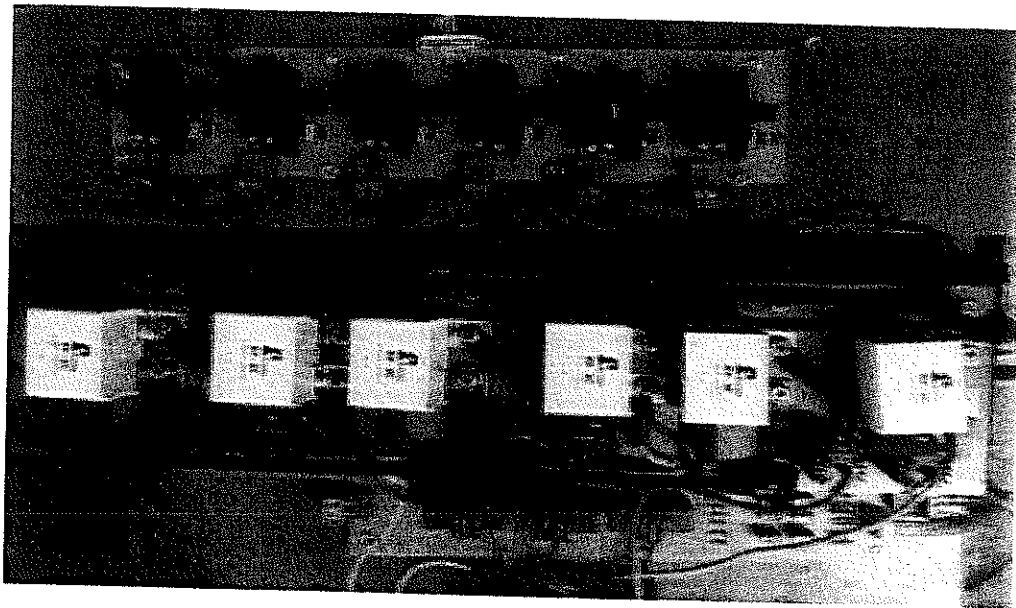


Figure 6-20. Three-phase classic LSRM (Dursun ve Ateşoğlu, 2014)

7. ROTARY MOTION OF SWITCHED RELUCTANCE MOTOR

Switched reluctance motors (SRM) is an electrical machine having a rather simple structure compared to other electrical machines. Does not contain any coil or magnet on the rotor arm has previously called a variable reluctance motor. The literature in this connection the first variable reluctance motor was proposed in 1969. SRM actually having a synchronous machine structure, as well as any stator windings and rotor absence in that a rotor having protruding structures Teams that are separated from other features in terms of electrical machines and operating principles also vary according to other machines in this regard In general, according to the stator and rotor poles that they have named the number one arm of the main characteristics of the magnetic circuit to have inductance values of the motor rotor position and phase current is changed in a nonlinear way. In addition, due to the instability of the stator flux is not applied directly to the dc or ac current, it is operated by applying appropriate current pulses to the stator phase. Therefore, they need a power and control unit. However, the rotor position must be known in order that the current pulse of information. Studies on the sensor or through the use of rotor position sensor less techniques in the literature was performed. In Figure 7 -21, a sectional shape of 6/4 SRM having a double salient structure is shown.

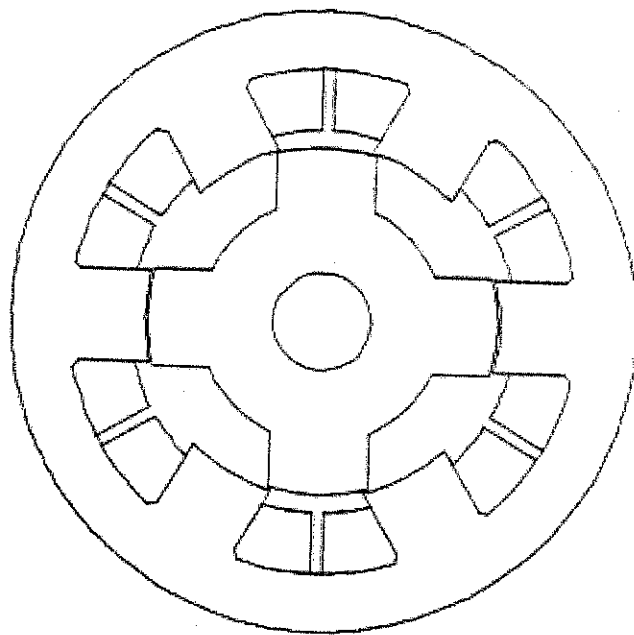


Figure 7-21. Dual-sectional shape having a protruding structure SRM 6/4.

Switched reluctance motors, in 1838 to move a locomotive by Davidson has been used in Scotland. At that time, the use of control due to the difficulty of this motor, though less armor increased interest in the development of motor and drive technology today. Switched reluctance motors, permanent magnet or coil does not just contain the rotor windings of the motor stator are made simple. They reach very high speeds because they do not have windings or permanent magnets on the rotor. There are some exceptions to the switched reluctance motor position of the rotor. In this case, one of the face (Aligned) status, the pole of the rotor with a stator pole is not fully faced. If you can be drained from the motor face current position stator torque is produced. The rotor in this position the minimum air gap magnetic permeability will be the maximum value for minimum reluctance. Finally, it will be seen that I maximum of inductance values.

Switched reluctance motors, with an extremely simple structure and installation are electrical machines compared to other multi-phase electric motor. Since both the stator salient-pole rotor having a structure as well as the motor is referred to as double dislocation reluctance motors. A constant torque to the motor to work properly must be produced. Continuous torque producing position sensors monitored with the pole position of the rotor and the stator pole phase depends on the proper nutrition, respectively. For this, the need for power electronics components. Working Principle and Characteristics its alternating current, sinusoidal current flows when applied to the stator windings in the stator windings and a changing magnetic flux occurs. The rotor turns with the effect by the movement of the magnetic flux in the pole surface.

Switched reluctance machines are protruding from the name of the rotor to be understood the employees are due to the effects caused by the pole reluctance machines. There is no windings in the rotor. Supply and audits are carried out of the stator winding. Because of their protruding poles of the rotor magnetic circuit varies depending on the position. Accordingly, the flux and inductance profile also changes depending on the position. This is necessary in order to produce natural characteristic moment of reluctance machines. Besides, the magnetic circuit particularly noticeable change again by saturation effects at high current values. Position changes occurring due to flux changes with an incessant saturation effects should be in this type of machine is a major problem in terms of both modeling control. Consequently such machines flux and inductance profile is nonlinear relative to current and rotor position indicates a change.

7.1. ROTARY MOTION OF SRM MODELING

In Figure 7-22 SRM in the flux in a case where consideration has been involved in the relationship between the saturation current. In this way the relationship between the fluxes formed by current flow through the phase polarity based on the phase windings can be written as follows;

$$\lambda = L(\theta).i \dots\dots\dots \text{EQ (7.17)}$$

Here; λ motor flux, $L(\theta)$ it is the winding inductance as a function of rotor position and phase current I . The slope of Figure 7-22 gives the inductance value. In the linear operation of winding inductance L , θ is the rotor position or a function of time but it is not the current function. Figure 7-22 due to a linear change in the magnetic k-energy converted to mechanical power, energy stored in the magnetic field are equal. The energy supplied to the system is the sum of these energies (Vasquez ve Parker, 2004).

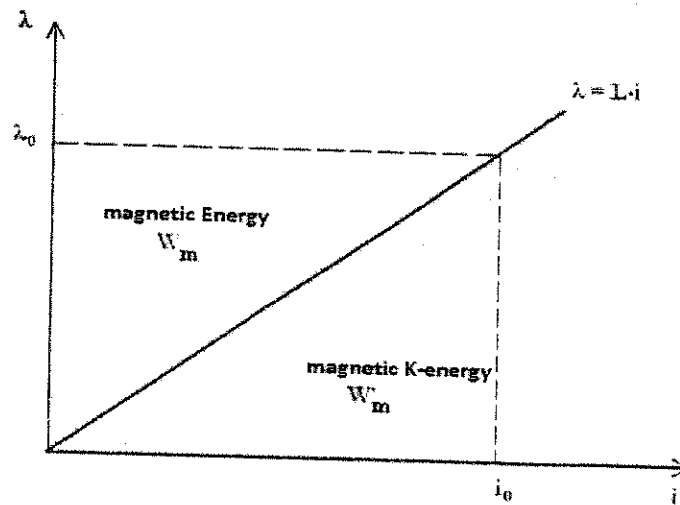


Figure 7-22. SRM flux-current change in the linear case

K-energy magnetic energy stored in the magnetic field equal to each other and can be written as follows;

$$W_m = W'_m = \frac{1}{2} L(\theta).i^2 \dots\dots\dots \text{EQ (7.18)}$$

Equation (7-18) to move by SRM moment expression;

$$T = \frac{1}{2} \frac{\partial L(\theta)}{\partial \theta} .i^2 \dots\dots\dots \text{EQ (7.19)}$$

While SRM is fixed in linear region $\frac{dL}{d\theta}$. The value of the flow in this region will be constant if the torque produced is kept constant. If these conditions also reduced acoustic noise of the motor will be created.

If separate statements for more torque is written

$$T_a(\theta, i_a) = \frac{1}{2} i_a^2 \frac{\partial L_a(\theta)}{\partial \theta} \dots\dots\dots EQ (7.20)$$

$$T_b(\theta, i_b) = \frac{1}{2} i_b^2 \frac{\partial L_b(\theta)}{\partial \theta} \dots\dots\dots EQ (7.21)$$

$$T_c(\theta, i_c) = \frac{1}{2} i_c^2 \frac{\partial L_c(\theta)}{\partial \theta} \dots\dots\dots EQ (7.22)$$

$$T_d(\theta, i_d) = \frac{1}{2} i_d^2 \frac{\partial L_d(\theta)}{\partial \theta} \dots\dots\dots EQ (7.23)$$

Equations are obtained. The total torque generated is equal to the torque produced by independent phases:

$$T_e(\theta, i_a, i_b, i_c, i_d) = T_a(\theta, i_a) + T_b(\theta, i_b) + T_c(\theta, i_c) + T_d(\theta, i_d) \dots EQ (7.24)$$

SRM mechanical equations of motion

$$T_e = J \frac{\partial^2 \theta}{\partial t^2} + B \frac{\partial \theta}{\partial t} + T_L \dots\dots\dots EQ (7.25)$$

- It shaped. Here; T_e SRM produced torque, the load torque T_L B friction coefficient, J represents the moment of inertia.

The relationship between angular velocity ω to position θ

$$\omega = \frac{\partial \theta}{\partial t} \dots\dots\dots EQ (7.26)$$

Equation (7-26), equation (7-25) 'is written instead,

$$T_e = J \frac{\partial \omega}{\partial t} + B \omega + T_L \dots\dots\dots EQ (7.27)$$

Obtained. SRM system of state variables build phase current I and rotor speed ω . state variables are obtained when the voltage equation and the torque equations held. The equivalent circuit of Fig. 7-23 is used to obtain electrical correlations SRM. Where tension phrase;

$$V = Ri + \frac{\partial \lambda(\theta, I)}{\partial t} \dots\dots\dots EQ (7.28)$$

It can be written. Here; V phase voltage, phase current I phase resistance R , λ is the phase current and rotor position θ .

$$V = Ri + \frac{\partial \lambda}{\partial i} \frac{\partial i}{\partial t} + \frac{\partial \lambda}{\partial \theta} \frac{\partial \theta}{\partial t} \dots\dots\dots EQ (7.29)$$

SRM phase flux, θ is a function of rotor position and phase current. Given the partial derivatives according to current and position

Equation is obtained.

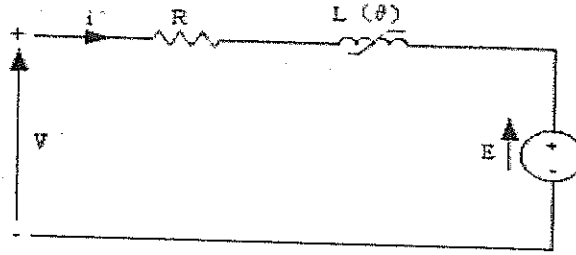


Figure 7-23. The equivalent circuit for one phase of the SRM.

For inductance equation

$$L = \frac{\partial \lambda}{\partial i} \dots\dots\dots EQ (7.30)$$

It can be written. From here, Equation (7-17) and (7-26), (7-27), (7-28), (7-29), (7-30) expressed in Equation (13) instead of written

$$V = Ri + L \frac{\partial i}{\partial t} + i \frac{\partial L}{\partial \theta} \omega \dots\dots\dots EQ (7.31)$$

Obtained. Equation (31) electromotor force (emf) induced in the coil in the third term on the right side of the equation in the equation data.

$$e = i \frac{\partial L}{\partial \theta} \omega \dots\dots\dots EQ (7.32)$$

e gives the counter-emf induced in the phase windings.

SRM four-phase voltage relationships for each phase Equations (33-36) and is expressed.

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + i_a \frac{\partial L_a}{\partial \theta} \omega \dots\dots\dots EQ (7.33)$$

$$V_b = R_b i_b + L_b \frac{di_b}{dt} + i_b \frac{\partial L_b}{\partial \theta} \omega \dots\dots\dots EQ (7.34)$$

$$V_c = R_c i_c + L_c \frac{di_c}{dt} + i_c \frac{\partial L_c}{\partial \theta} \omega \dots\dots\dots EQ (7.35)$$

$$V_d = R_d i_d + L_d \frac{di_d}{dt} + i_d \frac{\partial L_d}{\partial \theta} \omega \dots\dots\dots EQ (7.36)$$

- It happens. Indices indicate phases here. SRM state equations,

$$\frac{\partial i_a}{\partial t} = \frac{1}{L_a} \left[V_a - \left(R_a i_a + i_a \frac{\partial L_a}{\partial \theta} \omega \right) \right] \dots\dots\dots EQ (7.37)$$

$$\frac{\partial i_b}{\partial t} = \frac{1}{L_b} \left[V_b - \left(R_b i_b + i_b \frac{\partial L_b}{\partial \theta} \omega \right) \right] \dots\dots\dots EQ (7.38)$$

$$\frac{\partial i_c}{\partial t} = \frac{1}{L_c} \left[V_c - \left(R_c i_c + i_c \frac{\partial L_c}{\partial \theta} \omega \right) \right] \dots\dots\dots EQ (7.39)$$

$$\frac{\partial i_d}{\partial t} = \frac{1}{L_d} \left[V_d - \left(R_d i_d + i_d \frac{\partial L_d}{\partial \theta} \omega \right) \right] \dots\dots\dots EQ (7.40)$$

$$\frac{\partial \omega}{\partial t} = \frac{1}{J} [T_e - (B\omega + T_L)] \dots\dots\dots EQ (7.41)$$

$$\frac{\partial \theta}{\partial t} = \omega \dots\dots\dots EQ (7.42)$$

It happens.

7.2. Closed Loop Speed Control for SRM

Pump type an SRM rate control strategy consists of two simultaneous actions. The first action by adjusting the duty cycle pulse width modulation according to stabilize the motor speed is performed by the numerical controller. For this, the phase-lead form of regulatory sequences are used. Where needed to eliminate the steady state speed error PI regulator. The phase-lead editor of both the overflow is selected to reduce the rise time on both. To increase motor performance and efficiency of the second action is to adjust the angle as a function of motor speed trigger. Needed to perform the experimental results of this case. Closed loop speed control of SRM, SRM drive is carried out by the built in one phase of the speed control switch located in the opening period D obtained from block-off task. Duty cycle D in Equation (7-43), where in

As it defined.

$$D = t_{on} \cdot f_{chopper} = \frac{t_{on}}{T_{chopper}} \dots\dots\dots EQ (7.43)$$

The frequencies $f_{Chopper}$ and $T_{Chopper}$ in Equation. (7-43) are the period of the chopper respectively.

$$U_m = U * D \dots\dots\dots EQ (7.44)$$

Voltage supply can be vary changing D from U . U is bus voltage that occurs on driving circuit and U_m is adjusted voltage by D . (Polat, 2011). Equ. 7.44 shows that variable voltage can be generated changing D rate.

The figure 7-24 SRM closed loop speed control scheme is provided.

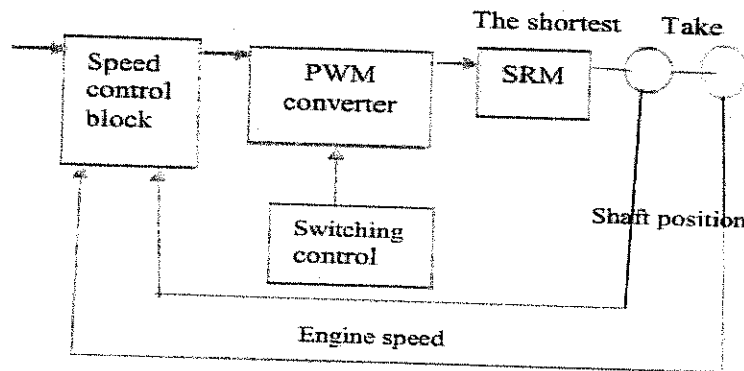


Figure 7-24. SRM closed loop speed control scheme.

The above figure shows the closed loop control implementation of SRM drive system. The actual speed of the motor is compared with the reference speed give the speed error. The speed error is applied to PI controller generates the reference current

which generates the required gate pulses for driving the motor.

SRM has a nonlinear relation. This situation makes it difficult for the controller design. If the system can be applied to linear control theory linearized controller design. The operating point of the variable speed drive an SRM constantly changing. A nonlinear controller designed for a certain operating point, the current cycle and meet the effect of mutual inductance with linear operating conditions and also provides better performance as a result. There are three different approaches to current controller design:

- 1- Linearized current controller design,
- 2- Linearized nonlinear feedback controller design flow,
- 3- Nonlinear current controller design with shared inductance effects.

All these methods are used to produce the desired voltage and current hysteresis current controller. The realization of the need for hysteresis controller PI current controller.

Because not only cannot achieve the desired results can be seen more practical at high speeds. The voltage controller, the voltage rises as long as you create a negative slope of inductance before the point where the torque applied in the form of reduced inductance slope PWM she will be terminated. This method can be applied in high-speed applications it is available here because emf significantly limiting the phase currents. A hysteresis current controller, the current acting in a defined band is based on the method. Depending on the current error is applied to voltage converter. Low speed applications, is much smaller than the current through the stator winding emf source voltage and current regulated by the chopper. Therefore current control method is applied at low and medium speeds (Polat ve ark., 2011). Figure 7-25 illustrates a block diagram of hysteresis current control are provided.

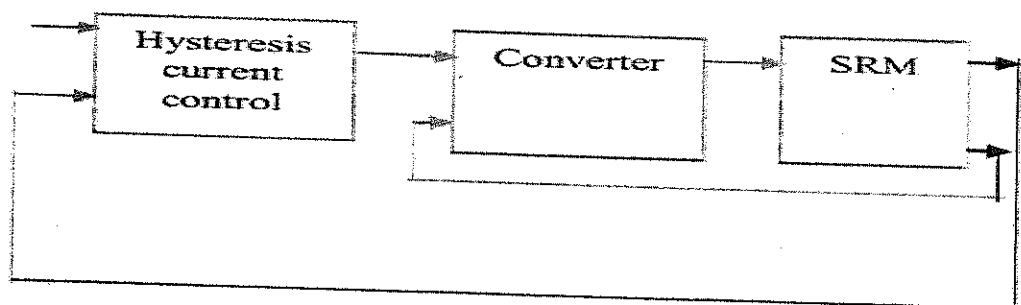


Figure 7-25. Block diagram of the hysteresis current control used in SRM

8. SRM DRIVE SYSTEM SIMULINK MODEL (comparison for Matlab/Simulink and MotorSolve program)

In order to predict the performance of the highly non-linear SRM drive and motor system, a physics-based model has been implemented in Matlab/Simulink using the SimPowerSystems software toolset.

8.1. MATLAB/SIMULINK Simulation

Model the dynamics of the switched reluctance motor

- Library
- Machines
- Description

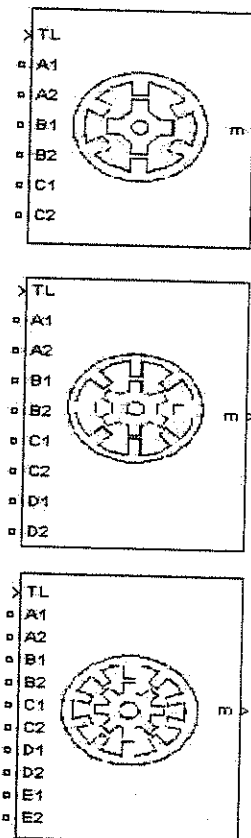


Figure 8-26. Model the dynamics of the switched reluctance motor

Represents a block frequency switched Motor (SRM), the three most common turning motor frequency: three phase SRM 6/4, four phase SRM 6/8, and 10/8 SRM five steps as shown in the figure 8-27.

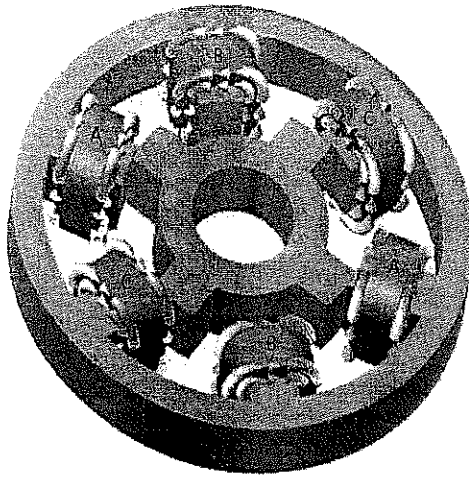


Figure 8-27a. Three-phase 6/4 SRM,

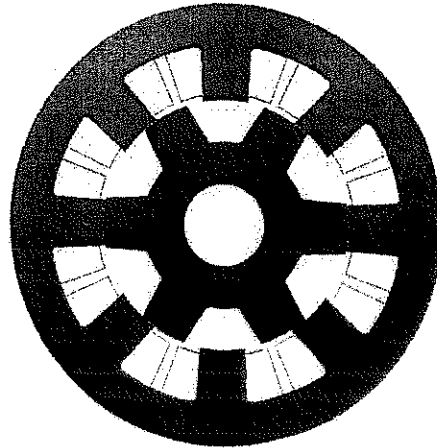


Figure 8-27b. Four-phase 8/6 SRM

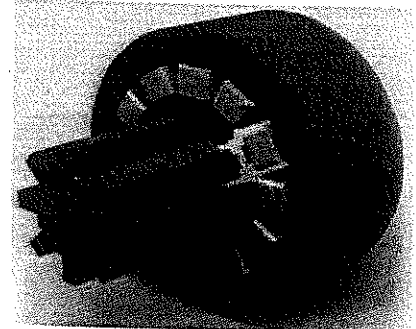
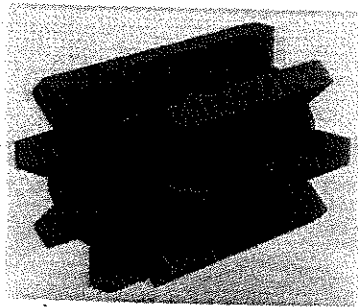
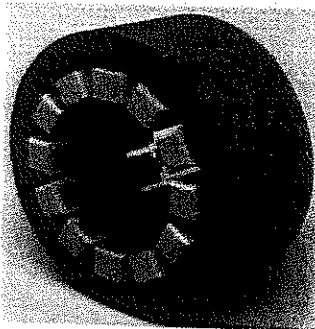


Figure 8-27c. Five-phase 10/8 SRM

- Non-linear model based on the magnetization characteristics, the electrical component characterized in that the motor consists of the several magnetization curve and the calculated torque magnetization curves. Moment of inertia and viscous friction coefficient based on the state-space model of the mechanical parts.
- General and special models: be flexible, mass applied as a model for SRM. Certain models of the SRM, the motor magnetization is ensured by a lookup table. Values obtained by finite element analysis by experimental measurement or calculation.
- In the model, this is calculated using magnetization property and nonlinear functions and parameters was readily available.

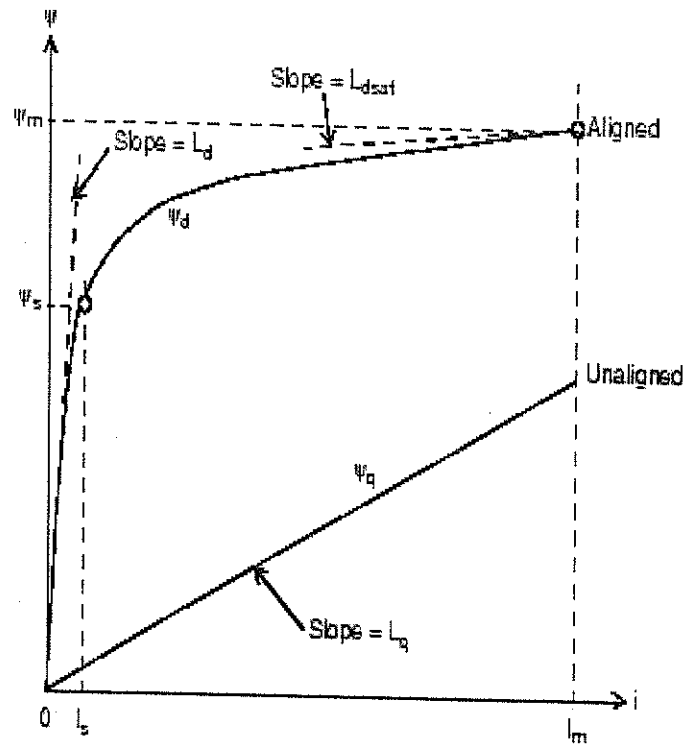


Figure 8-28. The magnetization characteristic of the motor

. Dialog Box and Parameters

Table: 1 Configuration Tab

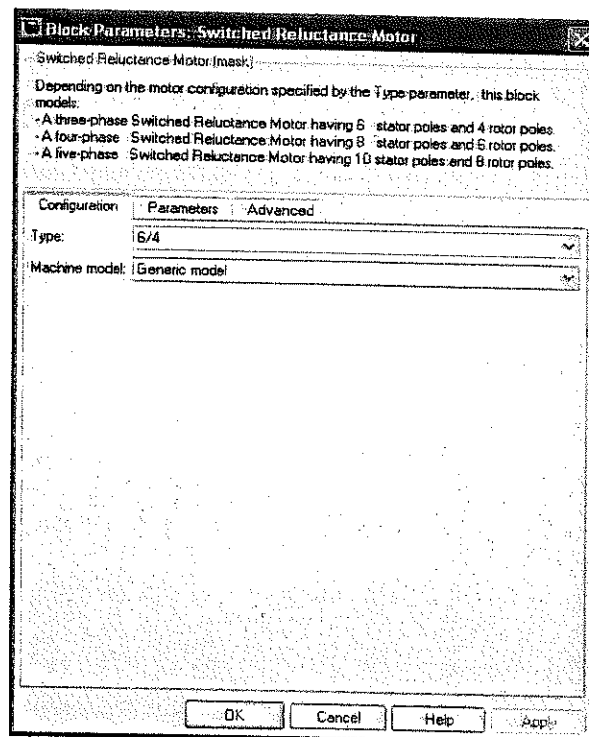


Table: 2 Parameters Tab: Generic Model

Block Parameters: Switched Reluctance Motor

Switched Reluctance Motor (mask)

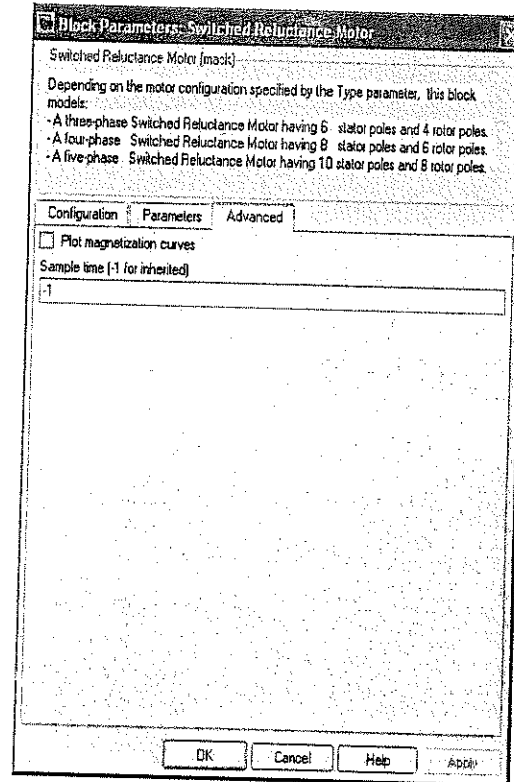
Depending on the motor configuration specified by the Type parameter, this block models:

- A three-phase Switched Reluctance Motor having 6 stator poles and 4 rotor poles.
- A four-phase Switched Reluctance Motor having 8 stator poles and 6 rotor poles.
- A five-phase Switched Reluctance Motor having 10 stator poles and 8 rotor poles.

Configuration	Parameters	Advanced
Stator resistance (Ohm)		
0.01		
Inertia (kg.m.m)		
0.0082		
Friction (N.m.s)		
0.01		
Initial speed and position (wo (rad/s) Theta0 (rad))		
[0 0]		
Unaligned inductance (H)		
0.67e-3		
Aligned inductance (H)		
23.6e-3		
Saturated aligned inductance (H)		
0.15e-3		
Maximum current (A)		
450		
Maximum flux linkage (V.s)		
0.486		

OK Cancel Help Apply

Table: 3 Advanced Tab



- **Plot magnetization curves:** If selected, the table will draw corresponding magnetization curve provided search mask. Flow machine represents the connection to the current position of the rotor and stator as a teacher magnetization curves.
- **Inputs and Outputs**
 - TL: (in N.m) contribute to the determination of the mass of the mechanical load torque. TL is positive and negative processes in the kinetic process of birth.
 - M: mass m output vector that contains many references. You can DE multiplex these signals using a specific bus SIMULINK block library.

Table: 4 Inputs and Output

Signal	Definition	Units
V	Stator voltages	V
flux	Flux linkage	V.s
I	Stator currents	A
Te	Electromagnetic torque	N.m
w	Rotor speed	rad/s
teta	Rotor position	rad

Example

- The power Switched Reluctance Motor demo illustrates the simulation of the Switched Reluctance Motor.

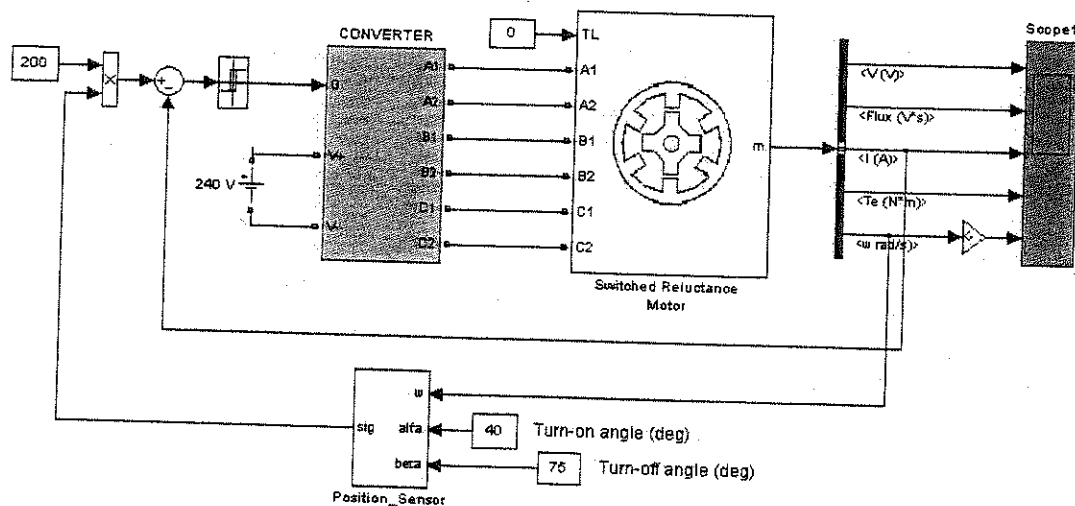


Figure 8-29. Complete block diagram of the three phase SRM drives

➤ Phase Inductance and Current Ideal Waveforms

For the development of a positive determination, the currents in the phases must be synchronized to the rotor position of SRM. The figure below 6/4 SRM perfect waveforms (phase an induction and current).

Power switch is turned on and turned off, respectively.

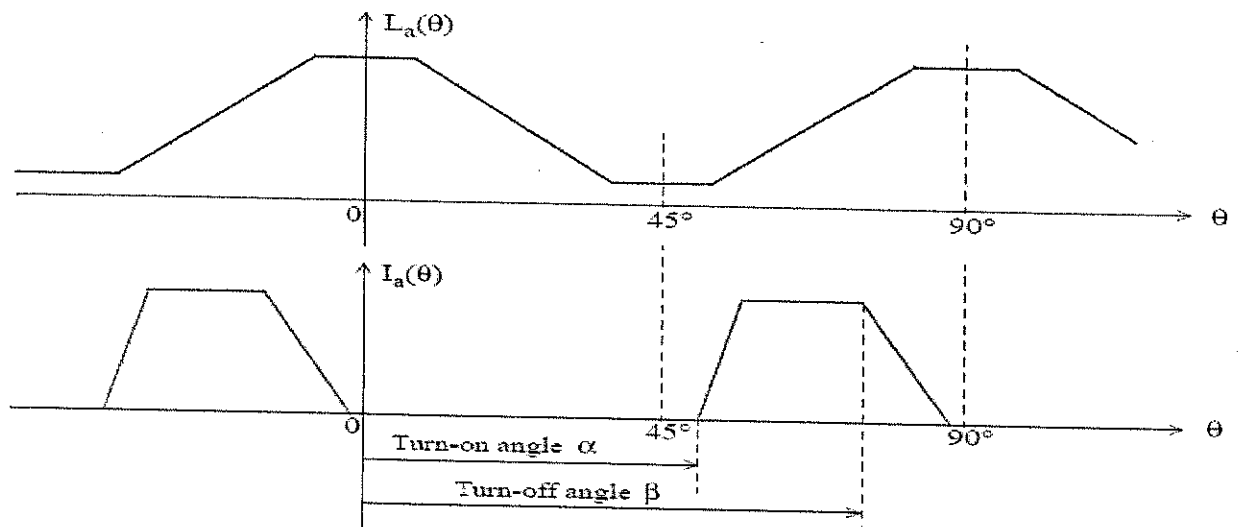


Figure 8-30. Wave forms of 6/4 SRM. Turn-on and turn-off angles

- Power simulation of the Switched Reluctance Motor Analysis:
- Three phase for the Switched Reluctance Motor analysis

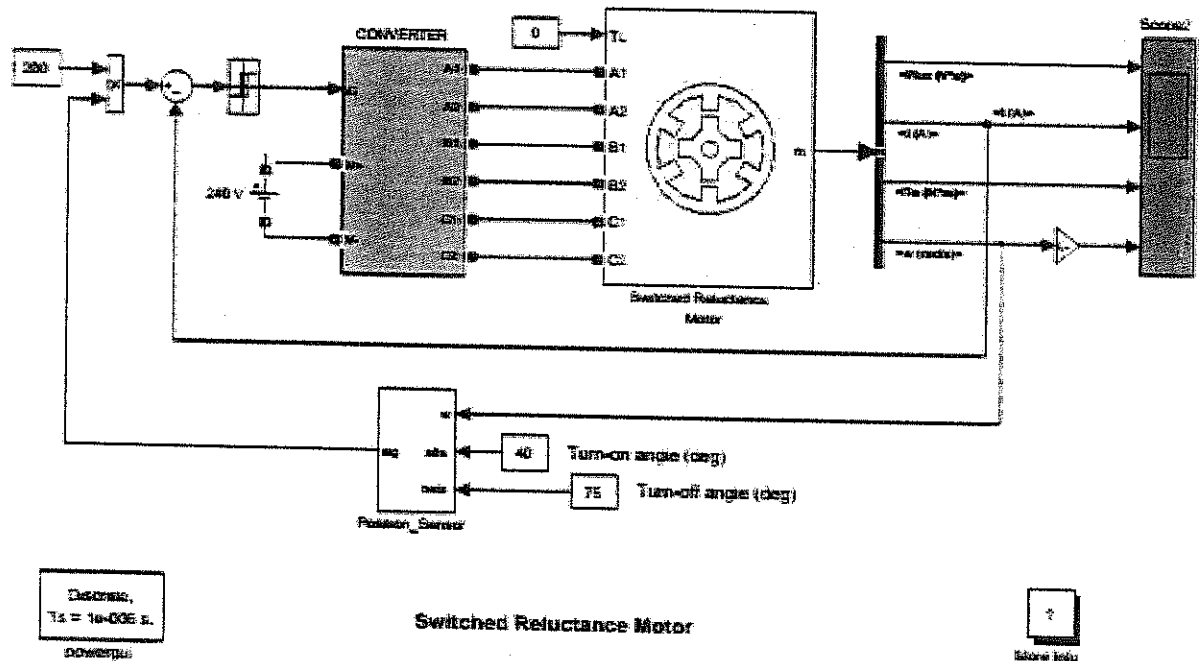


Figure 8-31. Complete block diagram of the three phase SRM drives

- CONVERTER

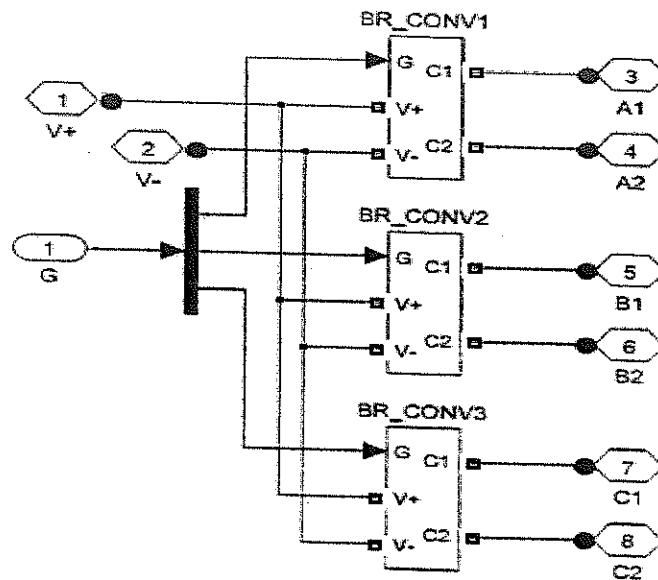


Figure 8-32. CONVERTER blocks diagram

- BR_CONV

BR_CONV1 = BR_CONV2 = BR_CONV3

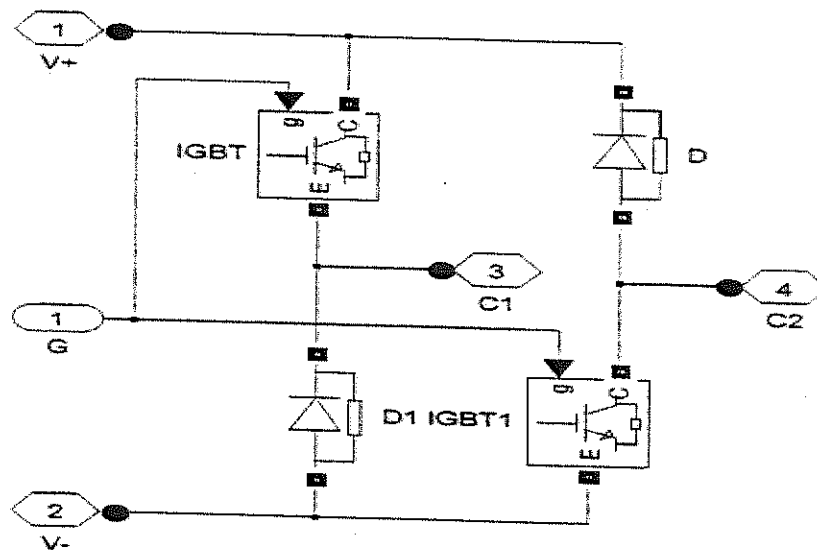


Figure 8-33. BR_CONV blocks diagram

- Position Sensor

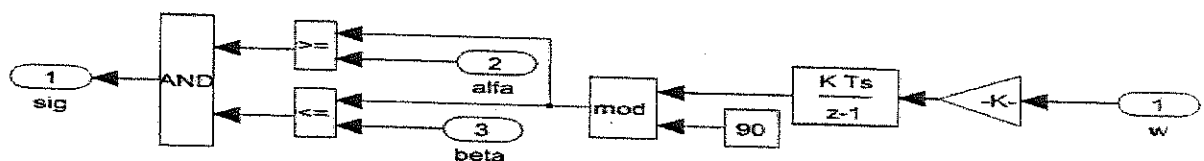


Figure 8-34. Position Sensor blocks diagram

❖ Switched Reluctance Motor

- powersysdomain

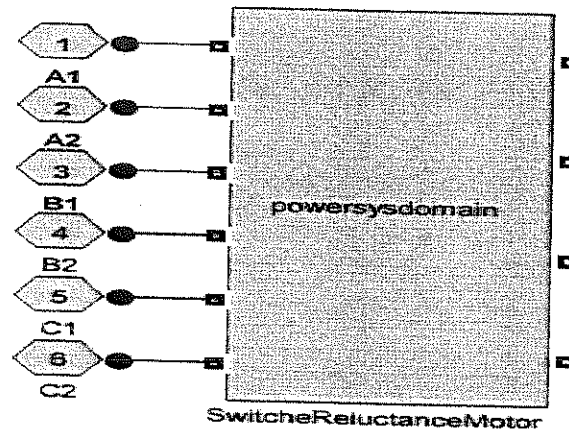


Figure 8-35. Powersysdomain blocks diagram

❖ Model Continuous

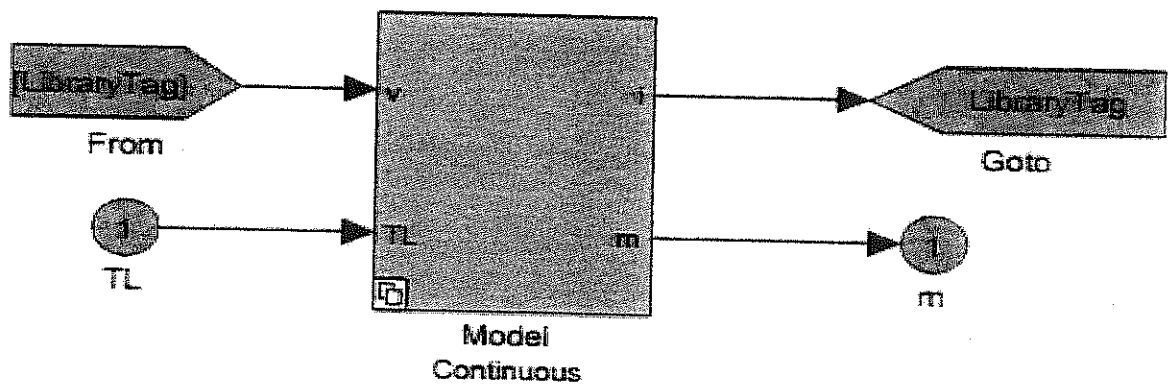


Figure 8-36. Model Continuous blocks diagram

- Model Continuous

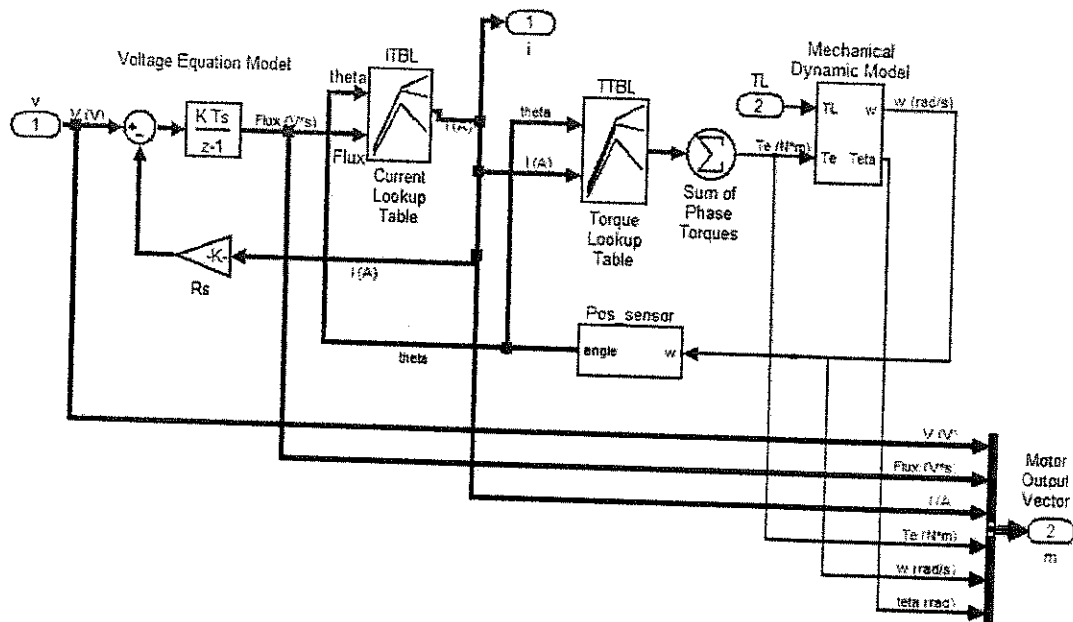


Figure 8-37. Switched Reluctance Motor Simulink SimPowerSystems Model blocks diagram

- Possessor

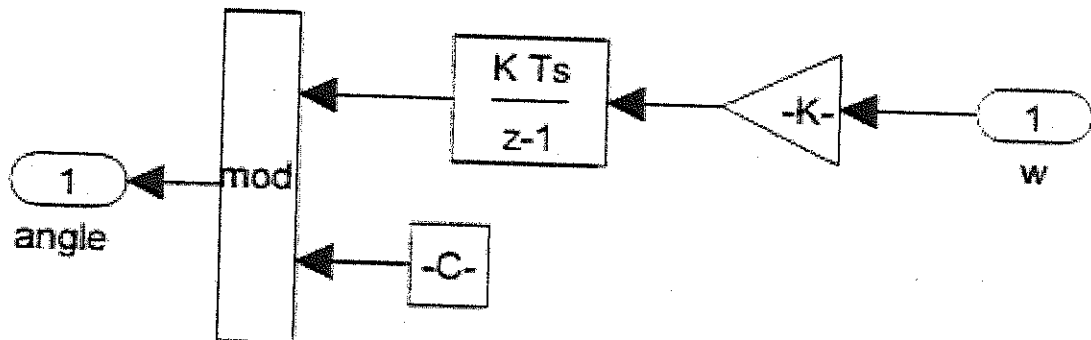


Figure 8-38. Position sensor blocks diagram

- Mechanic

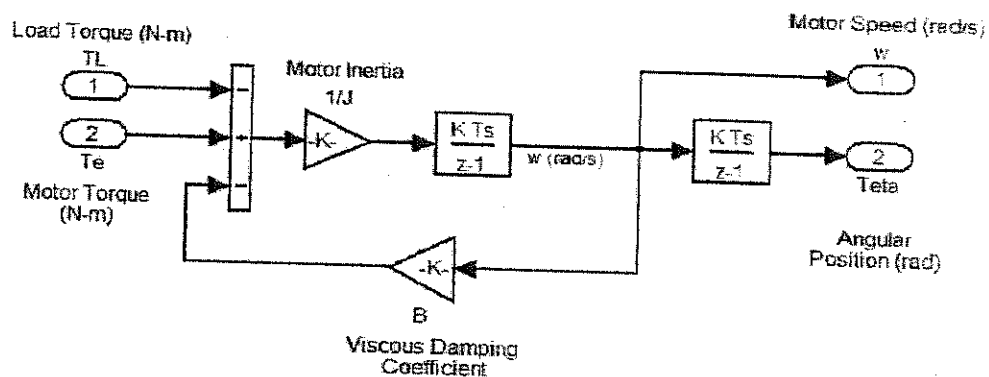


Figure 8-39. Switched Reluctance Motor Dynamic Mechanical System Model blocks diagram

Four phase of the Switched reluctance motor

Switched reluctance motor with four phase and 8/6 poles on both stator and rotor

Table 5. Four phase SRM Specifications.

Number of rotor poles	6
Number of Stator poles	8
Aligned Inductance	23.6e-3 H
Unaligned Inductance	0.67e-3 H
Saturated Aligned Inductance	0.15e-3 H
Stator resistance	0.05 Ohms
Inertia	0.05 Kg.m.m
Friction	0.02 N.m.s
Maximum Current	450 A
Maximum Flux Linkage	0.486 V.s
Power	7.5KW

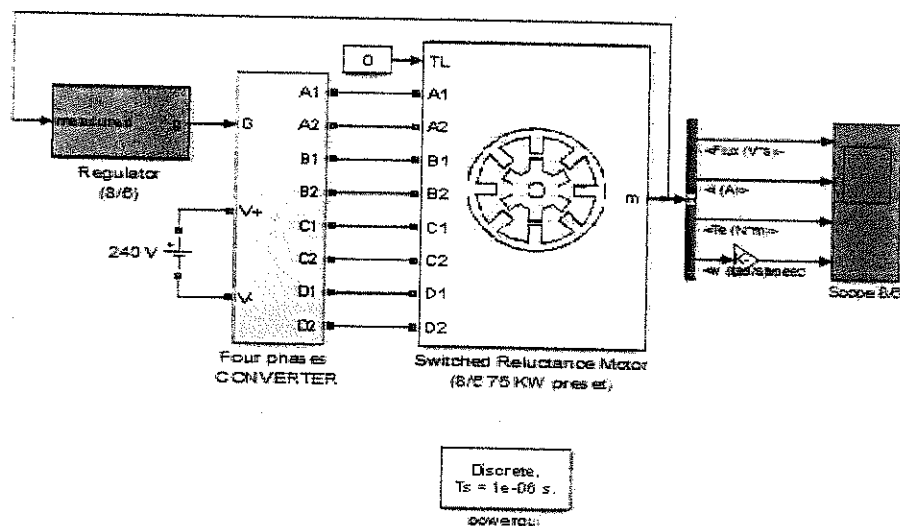


Figure 8-40. Complete block diagram of the four phase SRM drives

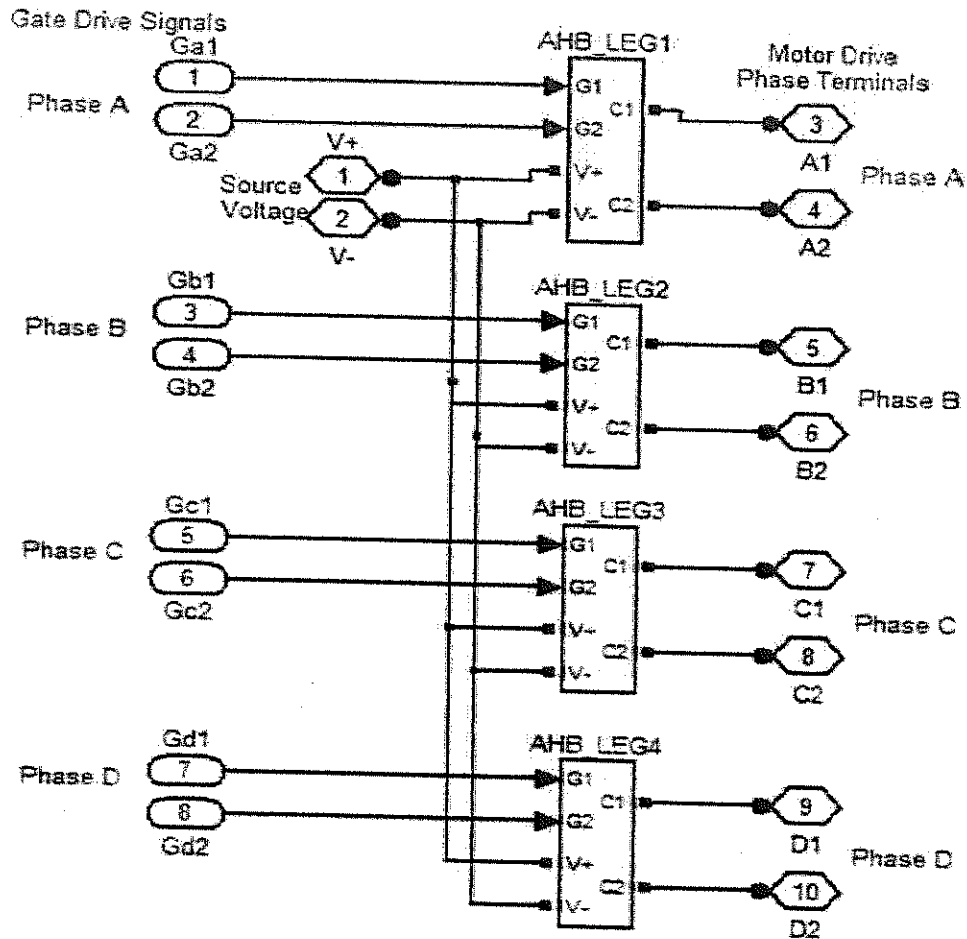


Figure 8-41. Switched Reluctance Motor (8/6 pole, 4-phase) Power Electronic Converter Macro-model

➤ **Five phase of the Switched reluctance motor**

Switched reluctance motor with five phase and 8/6 poles on both stator and rotor

Table 6. Five phase SRM Specifications.

Number of rotor poles	8
Number of Stator poles	10
Aligned Inductance	23.6e-3 H
Unaligned Inductance	0.67e-3 H
Saturated Aligned Inductance	0.15e-3 H
Stator resistance	0.05 Ohms
Inertia	0.05 Kg.m.m
Friction	0.02 N.m.s
Maximum Current	450 A
Maximum Flux Linkage	0.486 V.s
POWER	10KW

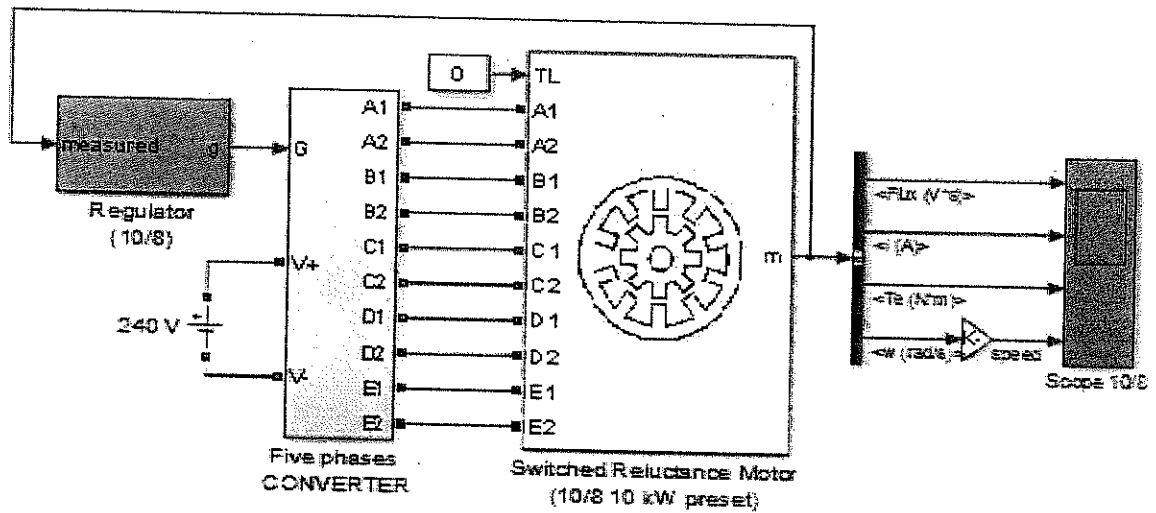


Figure 8-42. Complete block diagram of the five phase SRM drives

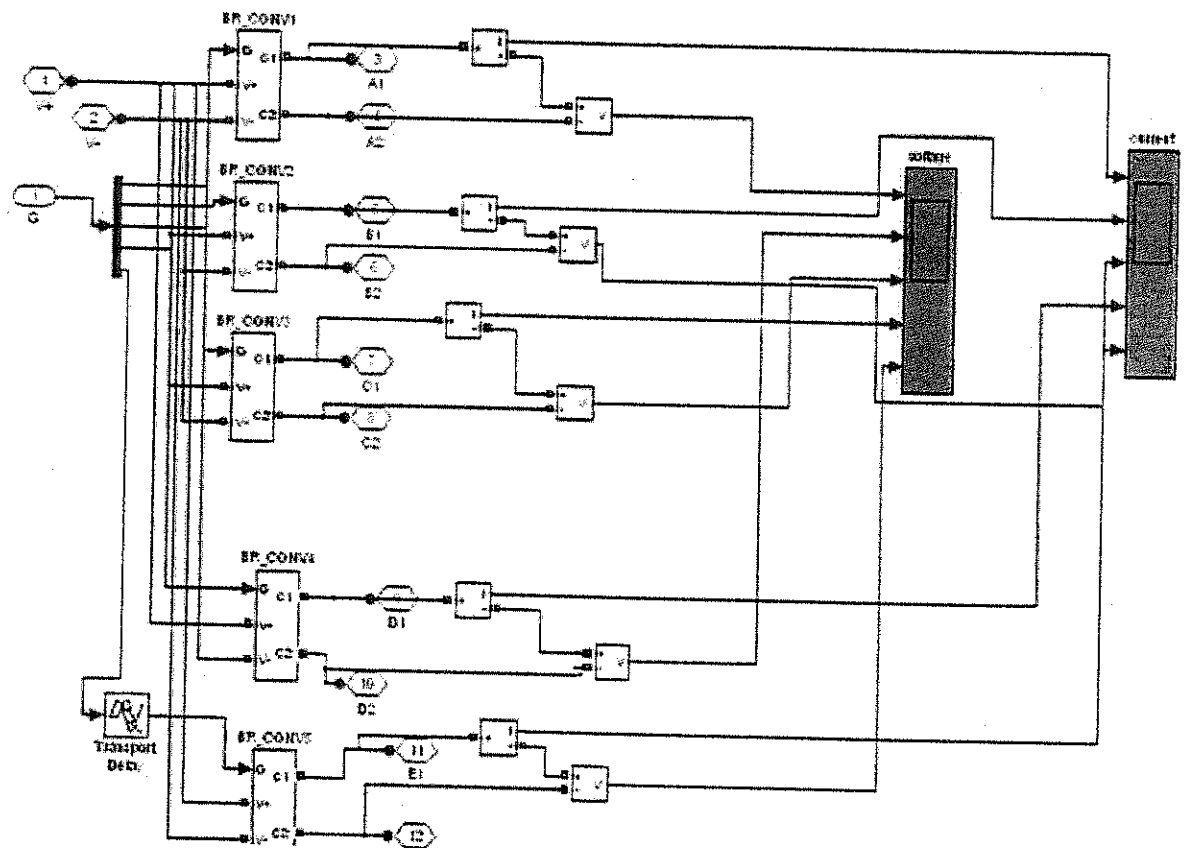


Figure 8-43. Simulation circuit diagram of converter for five phases

8.1.1 Simulation of Results

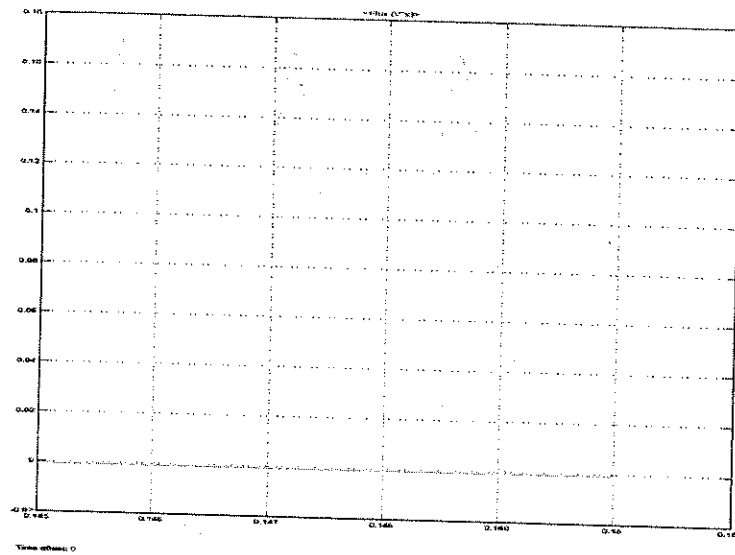


Figure 8-44. Simulation circuit diagram of flux linkage ψ_m (Wb or V.s) for three phases in the turn-on (θ_{on}) angles (0) and the turn-off (θ_{off}) angles (25)

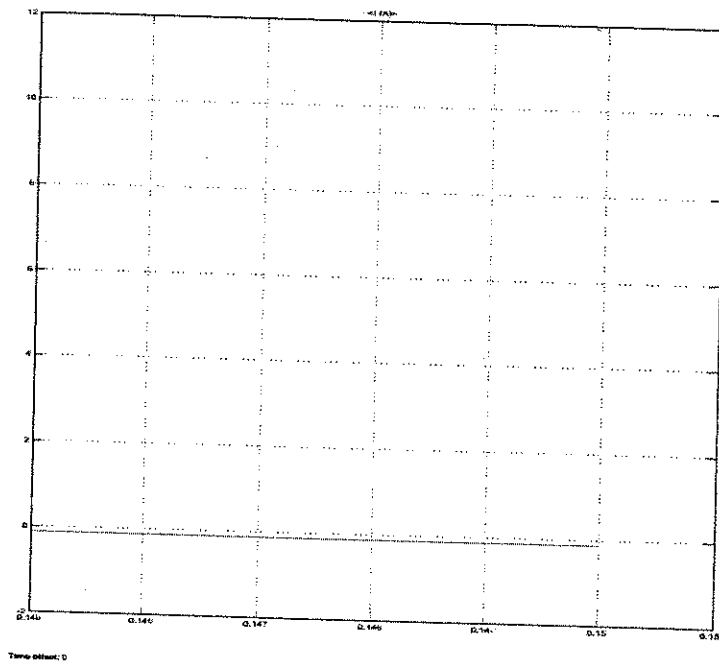


Figure 8-45. Simulation circuit diagram of stator current I (A) for three phases in the turn-on (θ_{on}) angles (0) and the turn-off (θ_{off}) angles (25)

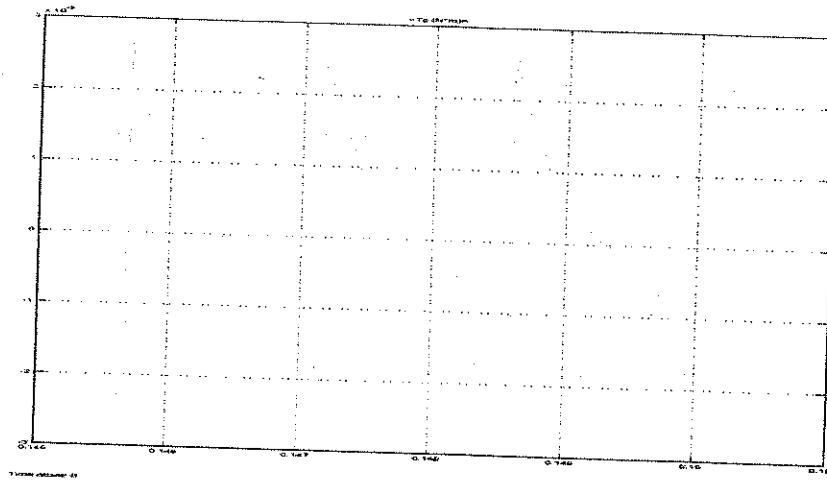


Figure 8-46. Simulation circuit diagram of Electro-magnetic torque T_e (N-m) for three phases in the turn-on (θ_{on}) angles (0) and the turn-off (θ_{off}) angles (25)

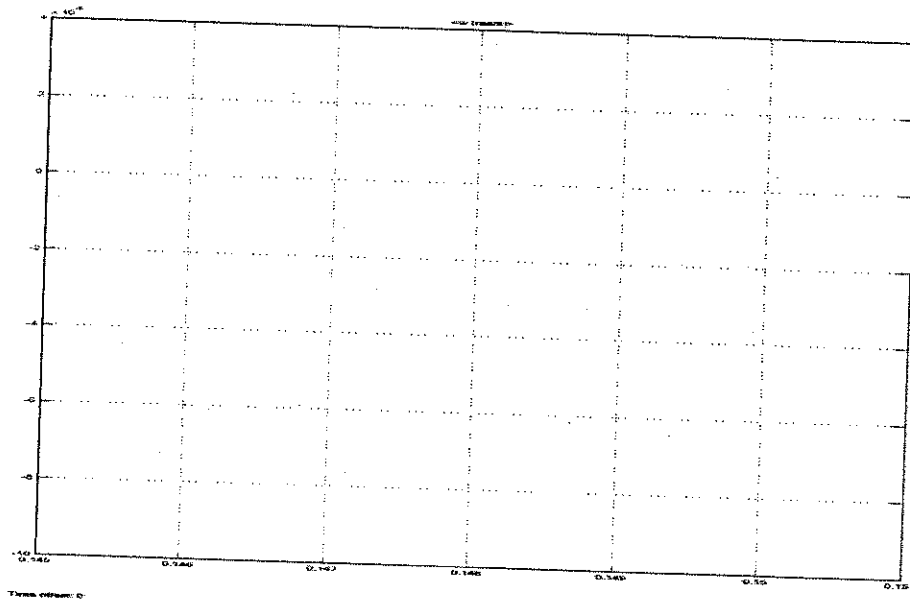


Figure 8-47. Simulation circuit diagram of rotor speed w (rad/s) for three phases in the turn-on (θ_{on}) angles (0) and the turn-off (θ_{off}) angles (25)

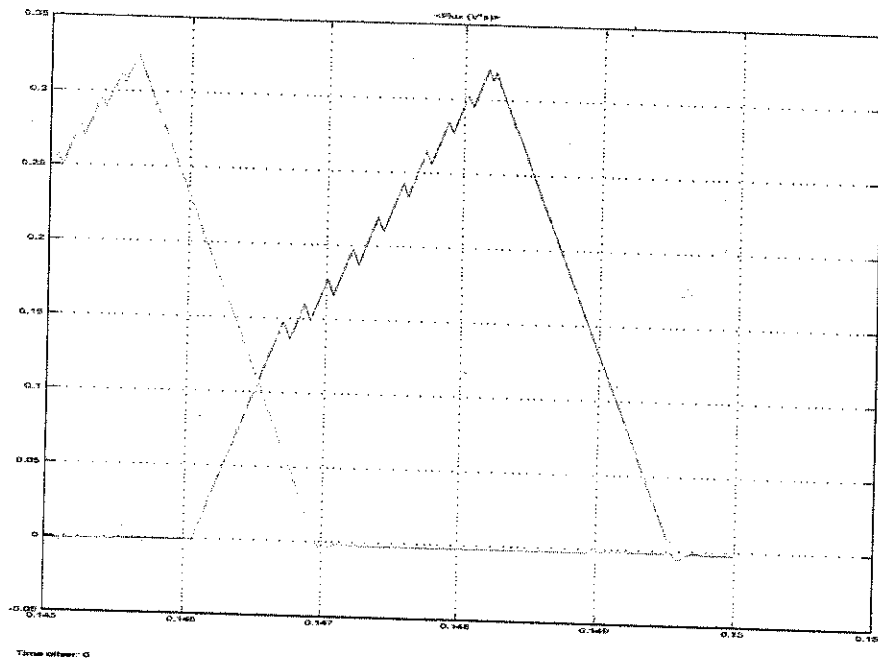


Figure 8-48. Simulation circuit diagram of flux linkage ψ_m (W_b or V.s) for three phases in the turn-on (θ_{on}) angles (25) and the turn-off (θ_{off}) angles (50)

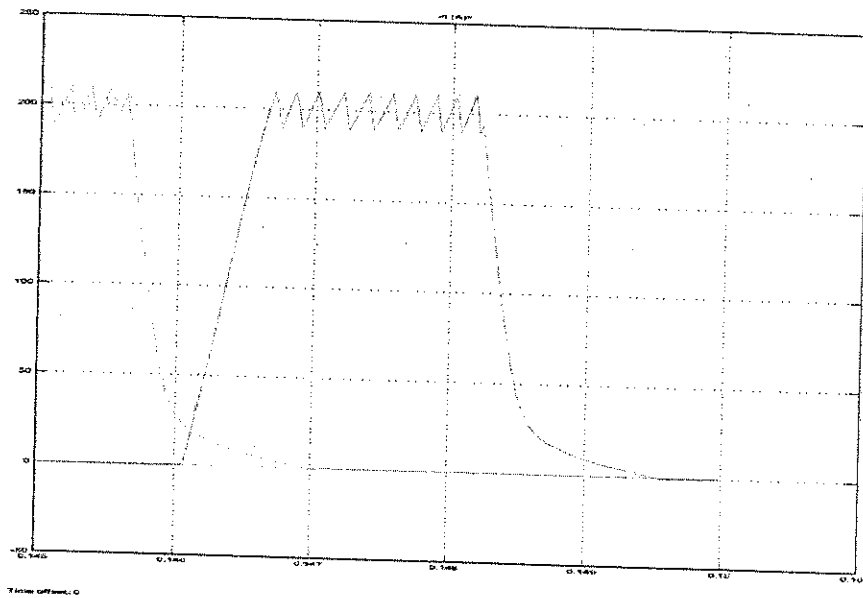


Figure 8-49. Simulation circuit diagram of stator current I (A) for three phases in the turn-on (θ_{on}) angles (25) and the turn-off (θ_{off}) angles (50)

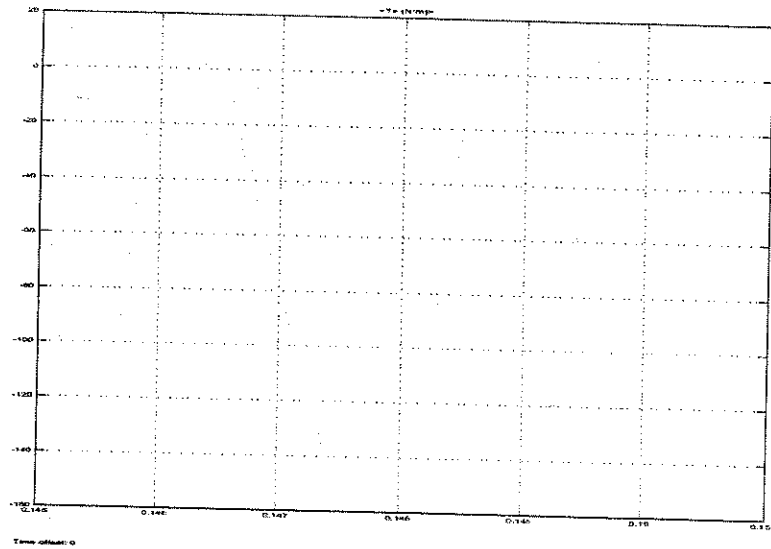


Figure 8-50. Simulation circuit diagram of Electro-magnetic torque T_e (N-m) for three phases in the turn-on (θ_{on}) angles (25) and the turn-off (θ_{off}) angles (50)

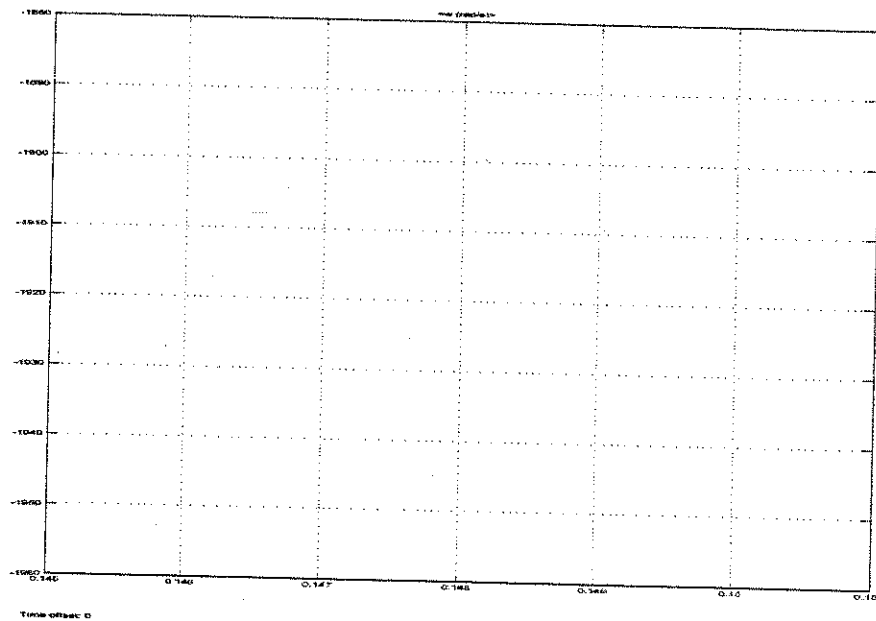


Figure 8-51. Simulation circuit diagram of rotor speed w (rad/s) for three phases in the turn-on (θ_{on}) angles (25) and the turn-off (θ_{off}) angles (50)

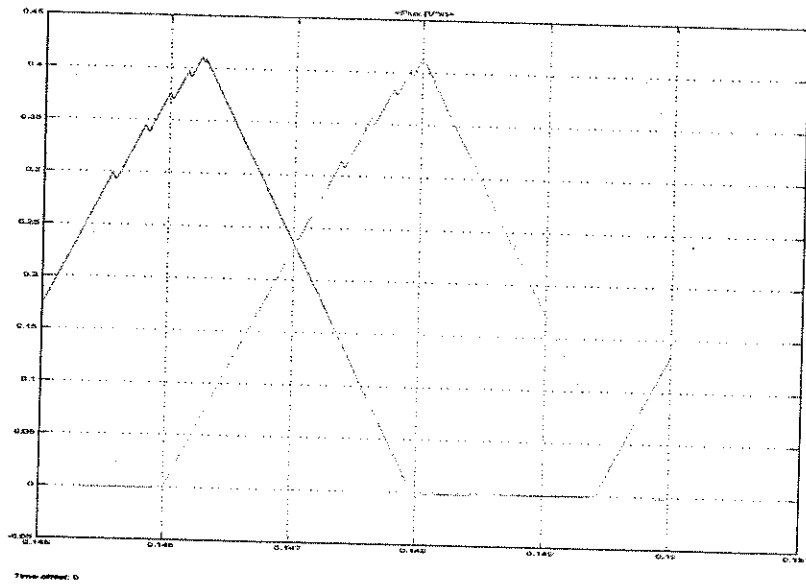


Figure 8-52. Simulation circuit diagram of flux linkage ψ_m (Wb or V.s) for three phases in the turn-on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)

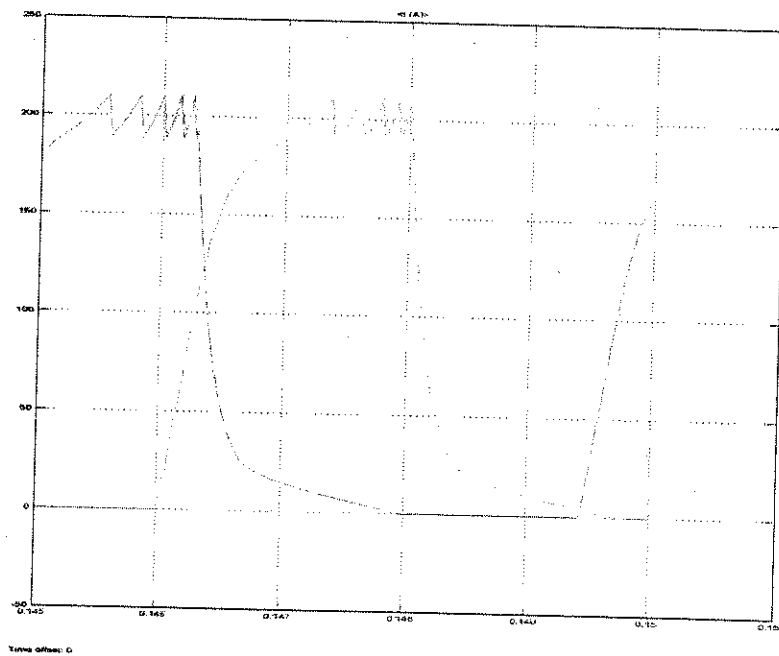


Figure 8-53. Simulation circuit diagram of stator current I (A) for three phases in the turn-on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)

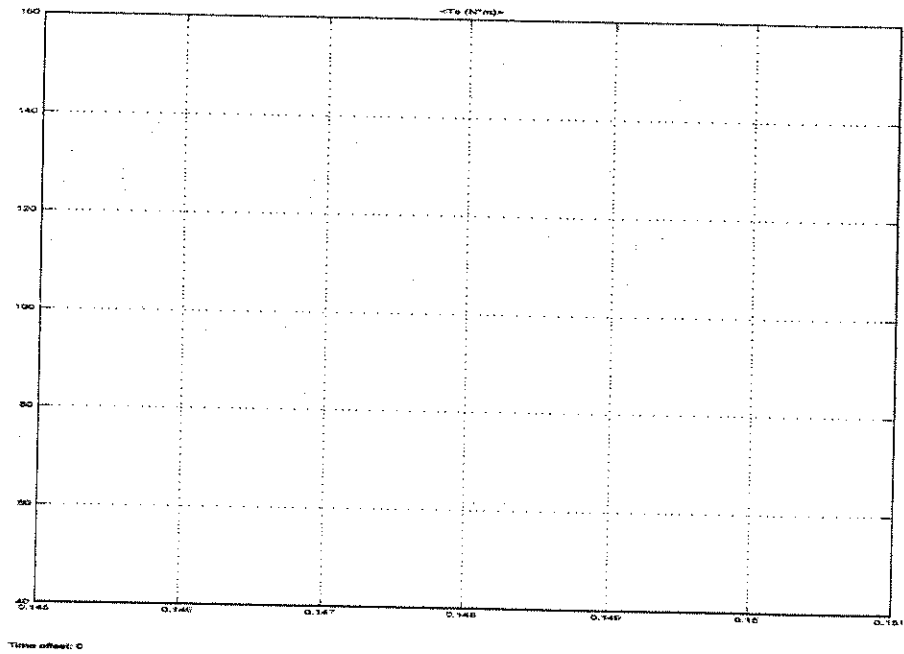


Figure 8-54. Simulation circuit diagram of Electro-magnetic torque T_e (N-m) for three phases in the turn-on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)

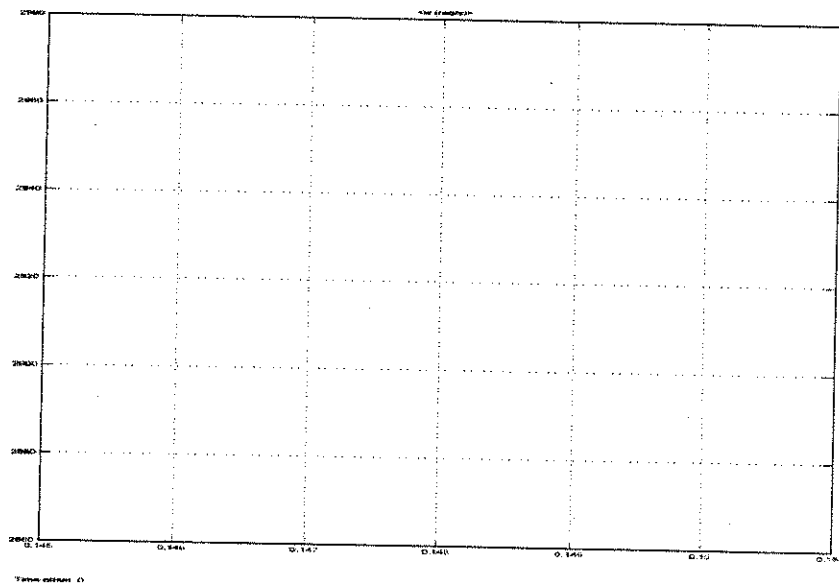


Figure 8-55. Simulation circuit diagram of rotor speed w (rad/s) for three phases in the turn-on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)

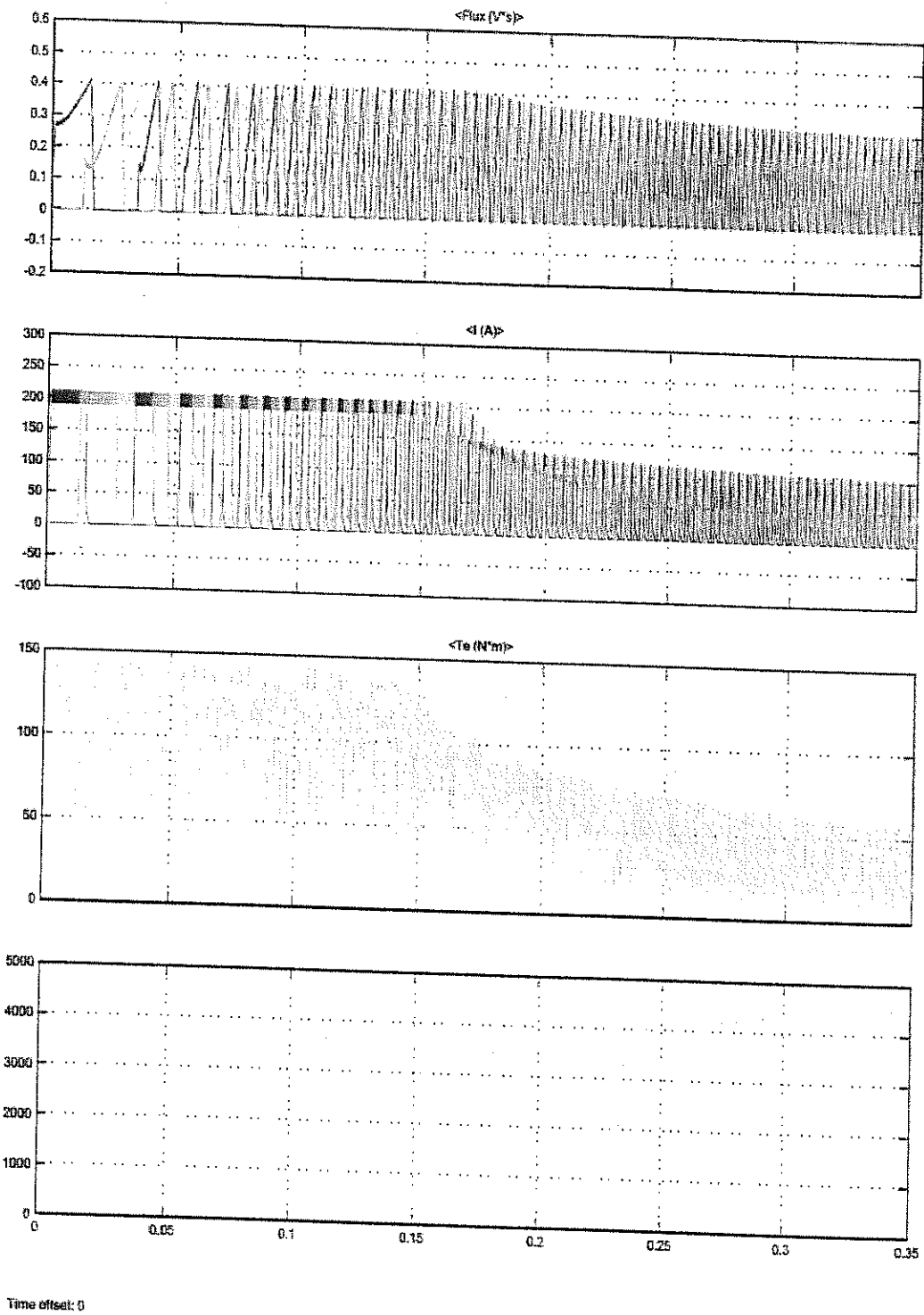
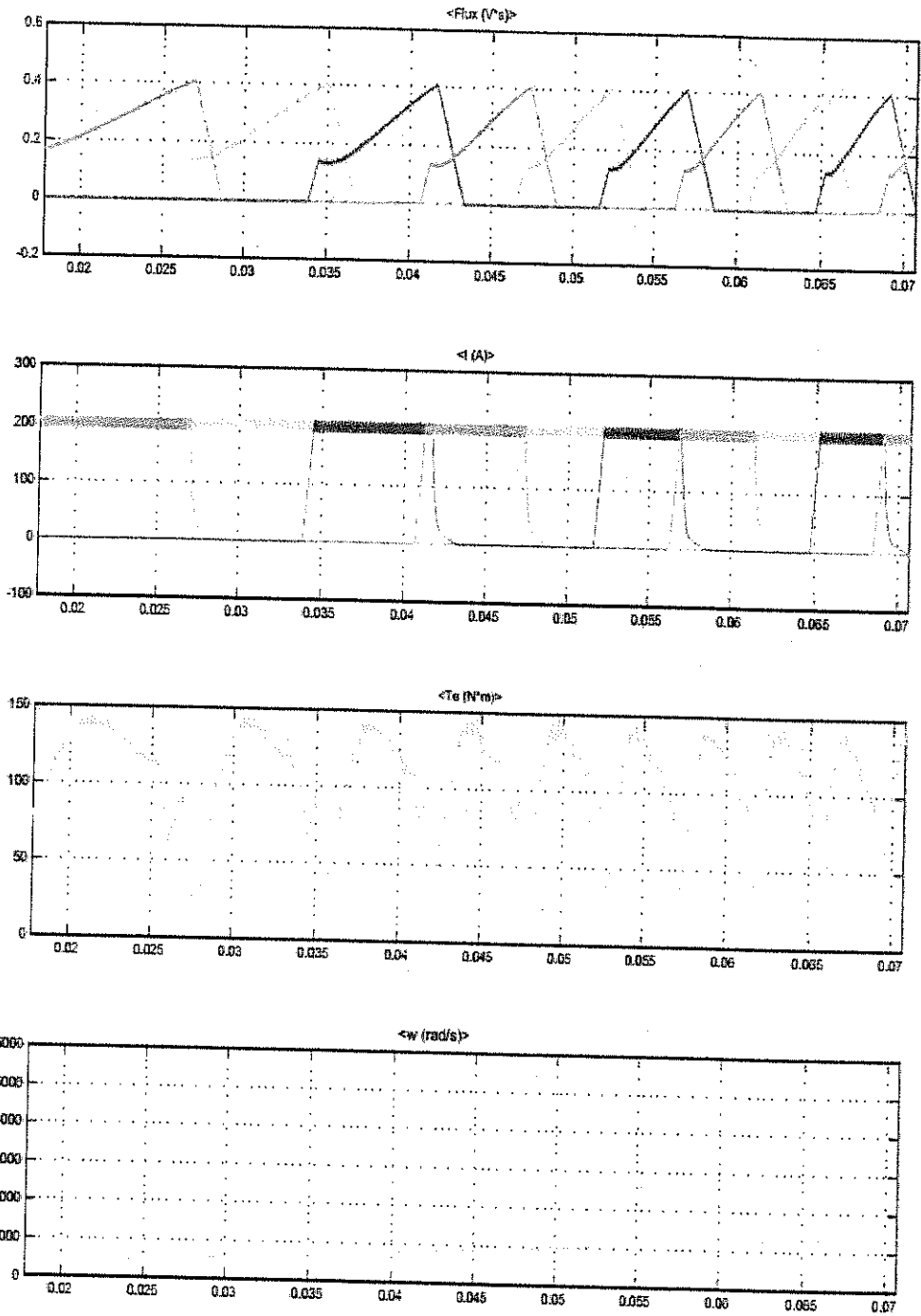


Figure 8-56. Complete circuit diagram of the three phase phases in the turn -on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)



Time offset: 0

Figure 8-57. Complete circuit diagram of the three phase phases in the turn -on (θ_{on}) angles (40) and the turn-off (θ_{off}) angles (75)

8.2. Four-Phase Switched Reluctance Motor for MotorSolve software

motorsolv SRM combines motors- not drawing any manual treatment network and is not required after processing with easy to use templates of the Federal Agency for automated environment to calculate the shifted frequency performance. An interface template, the desired wave, quantity selection or use fails with the specified operating conditions. Characteristic curves to compare multiple designs and / or operating point, "Whatever makes it easy analysis.

- Motorsolv and is available for a test drive their circuit design includes a collection of different types of car designers and models. motorsolv gives accurate results quickly and easily design verification software program. Although it is possible to use motorsolv programs to assist in motor design as a result.

- Motorsolv SRM electric motor is a special limited version of the popular software design. They convenience for machine designers frequency, accuracy and flexibility, offering new levels of electrical devices designed to motorsolv motor or generator exact prediction turned one program is needed to get the full performance. Finite element analysis includes the powerful motor is fully automated tool. Environment and automatically according to the Federal Authority for fast and accurate simulation results. User refinement level (accuracy versus time) lets you control including analysis, there are many methods10/8 SRM Design Modeling and Analysis with Exterior (CR10: cold rolled 1010 steel) for MotorSolve software.

Breaks the MotorSolve tradition and today advanced computing capabilities, taking full advantage of the electric motor design software gives a new look. Modern user interface is intuitive and lets it react and large easy. MotorSolve SRM only the rotor and to specify the number of stator poles effortless- smear new designs to create and then a template-based interface that makes such identifying information uses the GUI- Stack length;

- Basic geometric dimensions of the coils and teeth;
- Lamination and coil material.

Efficiency is key, that is why MotorSolve SRM includes many automated features which reduce the time to perform each design cycle:

- Integrated Results for computing performance data and Feld plots;
- Mechanical Losses: friction, wind age and stray;

- Easy-to-use template interface;
- Full 3D view of the machine;
- Automated winding configuration;
- Detailed end winding geometry;
- Accurate loss calculations.

MotorSolve SRM includes two analysis methods (static and motion analysis), suitable for different phases of the design process. The waveforms, Fields and charts are computed using one of the selected analysis method, allowing users to choose the computation time based on their required degree of accuracy.

- An 10/8 SRM is simulated. Presented below are a series of results that are integral to the design and analysis of any SRM. The results presented here are for such a machine operating at 3500 RPM. Some other specifications of this motor are; rated current and voltage: 25A, 600 V.

-shows the fig (69) (four phase SR MOTOR with 10 stator poles and 8 rotor poles):

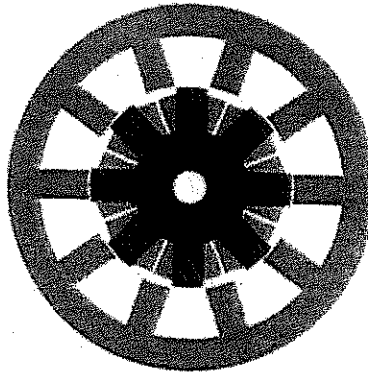
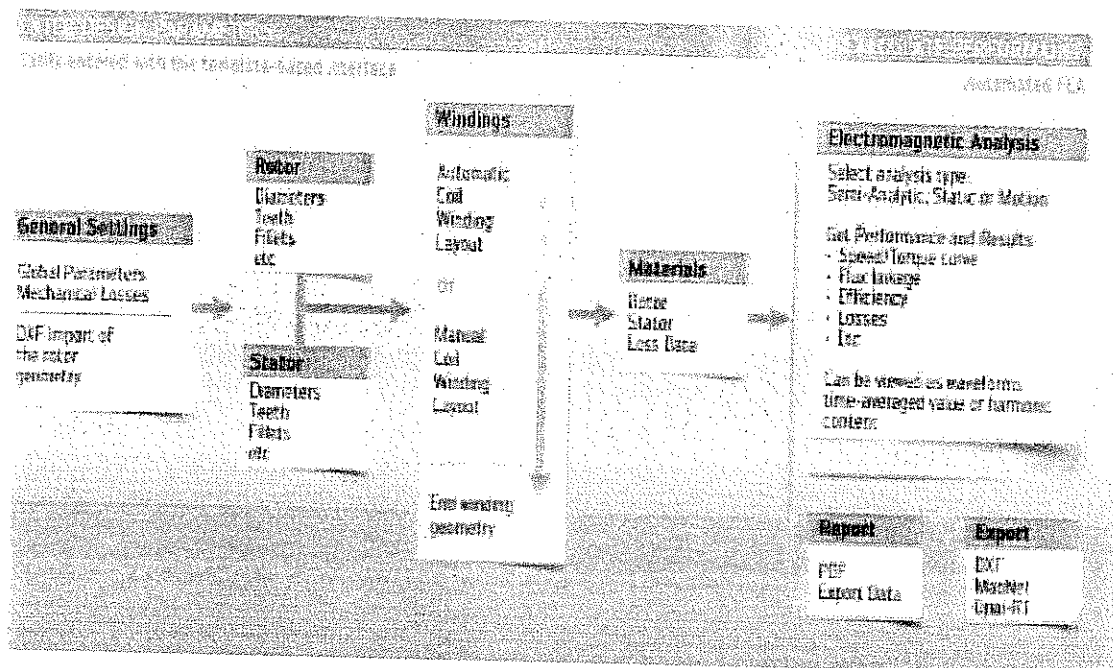


Figure 8-58. SRM with 8 rotor poles and 10 stator poles

- The MotorSolve SRM uses a template-based GUI which makes creating new designs from scratch effortless - specifying the number of rotor and stator poles and then specify information such as:
 - Outer diameter, firing angles and other constraints
 - Stack length
 - Basic geometric dimensions of the coils and teeth
 - Lamination and coil material

Design parameters for SRM



Template Design Parameters

- ☐ Geometric dimensions of the rotor and stator
- ☐ Templates for both interior and exterior types
- ☐ Number of poles and slots can be arbitrarily large
- ☐ Polyphase machines supported
- ☐ Vary fringe angles for continuous conduction mode analysis over a wide range of speeds
- ☐ Select laminations and wire materials from extensive database
- ☐ Import custom rotor and stator geometries

Coil Winding Layout

- ☐ Select from a list of automatic calculated balanced layouts or specify via manual entry
- ☐ Detailed end winding geometry
- ☐ Supports several wire sizing methods
- ☐ Relevant factors (winding factor, full factor, etc.) are automatically calculated

Report and Output

- ☐ Design parameters and performance data can be added to a standard report form which can be printed or saved as a PDF file for distribution.
- ☐ the summary feature compares two or more designs side-by-side and highlights the differences in design or performance data.

Rapid and Accurate Results

- ☐ Static analysis
 - Ideal for obtaining machine characteristics: flux linkage, static torque and inductance profiles etc.
- ☐ Extremely rapid: based on either semi-analytic analysis, or completely FEA solve.
- Motion analysis
 - ☐ Perform a full time-stepping non-linear FEA simulation.
 - ☐ Highly accurate for all types of operating conditions and ideal for final design verification.

Charts, Fields and Motor Performance

- ☐ Performance Calculations
 - Flux Linkage, Inductance, Static torque, Torque vs. Speed, etc.
- ☐ Field Plots
 - Flux function, Flux density, Current density, Winding losses, etc.

Scripting

- ☐ Powerful scripting capability for customization, batching and optimization. Use this feature with any programming language or Active X compliant software (e.g. Microsoft Excel)
- 1) General settings for the 10/8 SRM design (Input panel)
 - Specifications
 - a) Supply voltage (600V)
 - b) Rated current (25A)
 - c) Rated speed (3500 rpm)
 - Global
 - a) Outer diameter (147mm)
 - b) Air gap thickness (0.5mm)
 - c) Stack length (200mm)
 - Rotor
 - a) Rotor location (interior/exterior)
 - b) Rotor type (general)
 - c) Number of rotor poles (10)
 - Stator
 - a) Stator type (general)
 - b) Number of phases (4)

C) Number of stator poles (8)

- Mechanical Losses

a) Friction loss (19)

b) Winding loss (19)

c) Stray loss factor (19)

In fig. 8-59 is Shown general settings for 10/8 SRM design

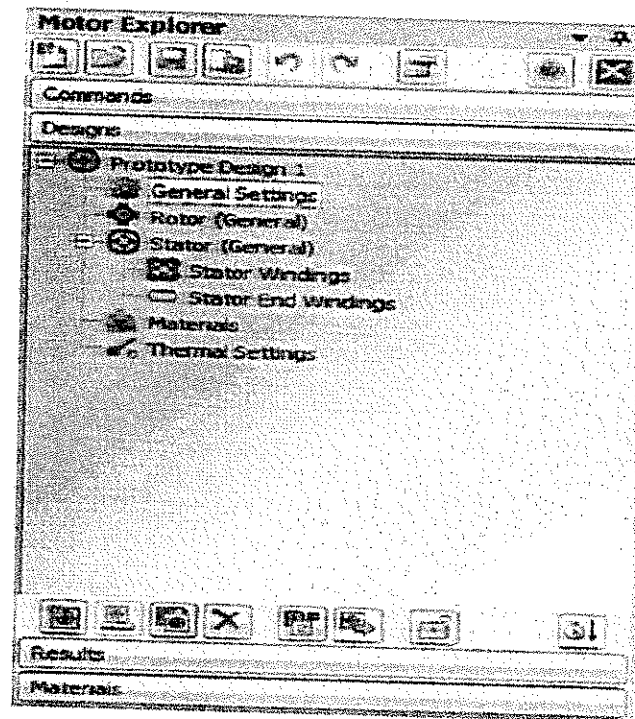


Figure 8-59. General settings for 10/8 SRM design

2) General settings for Rotor (SRM)

- Diameters

a) Inner diameter (28mm)

b) Outer diameter (98mm)

- Core

a) Core thickness (20.4mm)

- Teeth

a) Bifurcation radius (0mm)

b) Rotor pole angle (25.9457560)

c) Tooth angle (77.8055420)

- Fillets

a) Pole bottom radius (0mm)

b) Pole tip radius (0mm)

In fig. 8-60 is shown general settings for Stator (SRM)

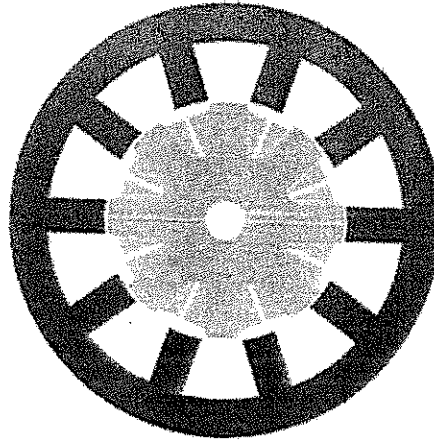


Figure 8-60. General settings for Rotor

3) General settings for Stator (10/8 SRM)

- Diameters

- a) Inner diameter (99mm)
- b) Outer diameter (147mm)

- Coils

- a) Coil angle (90°)
- b) Coil bottom width (8.26mm)
- c) Coil length (14.2mm)

- Teeth

- a) Bifurcation radius (0mm)
- b) Slot depth (15.2mm)
- c) Stator pole angle (23.30°)
- d) Tooth angle (90°)

- Fillets

- a) Bottom fillet radius (0mm)
- b) Tooth tang radius (0mm)

In fig. 8-61 is Shown general settings for Stator SRM

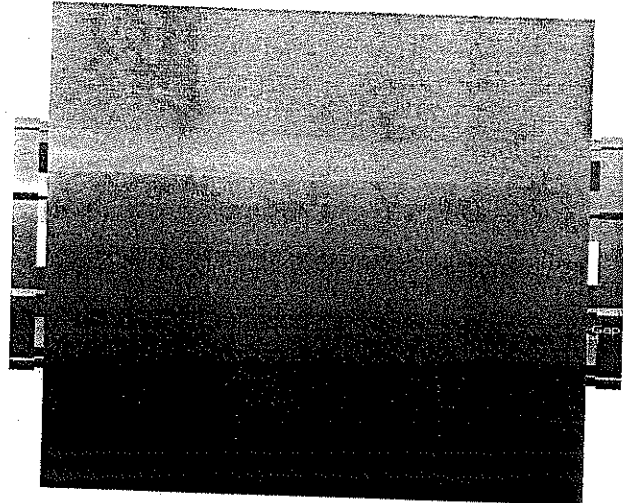


Figure 8-63. Stator the End Windings

6) SRM materials the all parts in the design

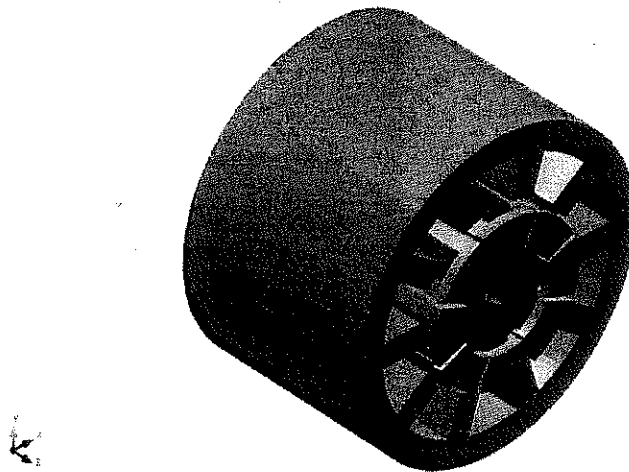


Figure 8-64. 10/8 SRM materials design

8.2.1. Rapid and Accurate Results for 10/8 SRM

- The reluctance motor is an electric motor in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized.
- The Results various it's result quantities for the selected design and provides post-processing capabilities for different analyses, where various results of The selected design can be chosen for generating charts, tables, or field plots.

Rapid and Accurate Results

A- Static analysis

- Ideal for obtaining machine characteristics: flux linkage, static torque and inductance profiles etc.

- Extremely rapid: based on either semi-analytic analysis, or completely FEA solve.

B-Motion analysis

- Perform a full time-stepping non-linear FEA simulation.

- Highly accurate for all types of operating conditions and ideal for final design verification.

Charts, Fields and Motor Performance

- Performance Calculations

- Flux Linkage, Inductance, Static torque, Torque vs. Speed, etc.

- Field Plots

- Flux function, Flux density, Current density, Winding losses, etc.

In fig. 8-65 all Results in the SRM

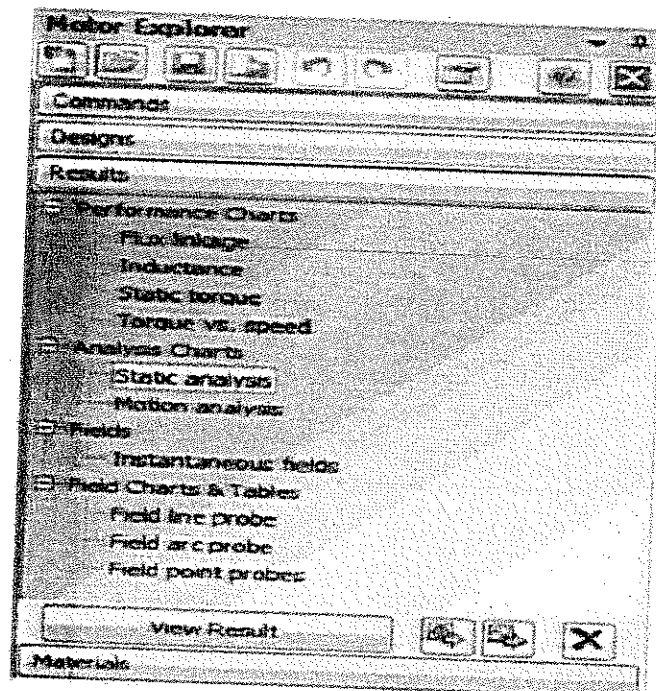


Figure 8-65. All Results in the 10/8 SRM

- The results show that number of poles plays an important role in improving efficiency SRM motor and by changing the configuration of motor line current, total loss, and efficiency will be changed.

1) Performance characteristics

Can be using the results semi-analytic or the Complete FEA based analysis method

A) Flux linkage

The output flux linkage waveform of 10/8 SRM

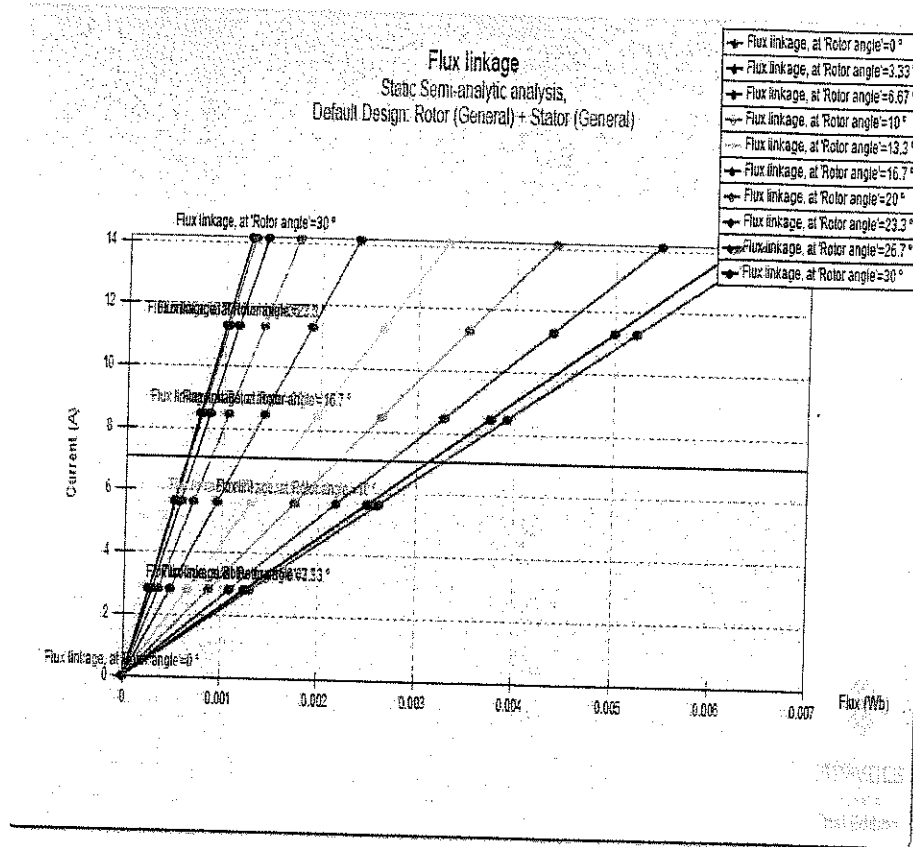


Figure 8-66. Flux linkage waveform at load points of 10/8 SRM in the semi-analytic

Table 7 showing flux linkage characteristics of the 10/8 SRM

Table 7: flux linkage characteristics of the 10/8 SRM

Current (A)	0	2.8284272	5.6568544	8.4852816	11.3137088	14.142136
Flux linkage, at 'Rotor angle'=0 ° (Wb)	0	0.0013057	0.00261142	0.00391713	0.00522284	0.00652854
Flux linkage, at 'Rotor angle'=2.14 ° (Wb)	1.9273E-10	0.00128169	0.00256339	0.00384508	0.00512678	0.00640846
Flux linkage, at 'Rotor angle'=4.29 ° (Wb)	7.4839E-10	0.00121245	0.00242491	0.00363737	0.00484983	0.00606228

B1) Inductance (Inductance, rotor angle)

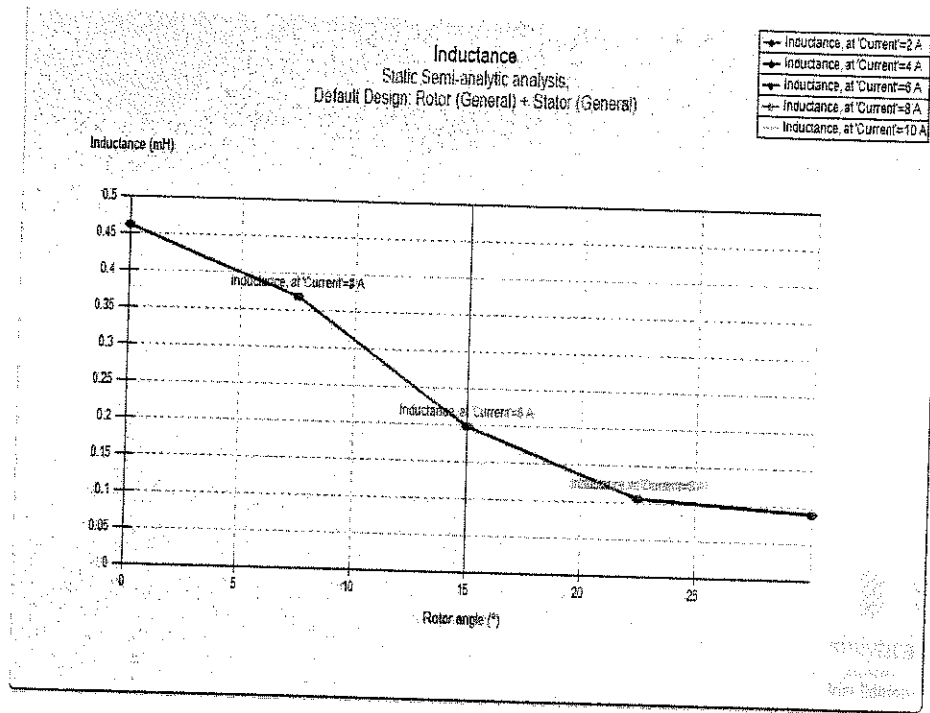


Figure 8-67. Inductance waveform at load points of 10/8 SRM in the semi-analytic

Table 8 showing inductance profile of 10/8 SRM

Table 8. Inductance profile of 10/8 SRM

Rotor angle (°)	0	7.5	15	22.5	30
Inductance, at 'Current'=2 A (mH)	0.46237852	0.36911684	0.1988293	0.10613413	0.09046481
Inductance, at 'Current'=4 A (mH)	0.46237961	0.36911767	0.19882965	0.10613422	0.09046485
Inductance, at 'Current'=6 A (mH)	0.46237997	0.36911794	0.19882977	0.10613425	0.09046486
Inductance, at 'Current'=8 A (mH)	0.46238016	0.36911808	0.19882983	0.10613426	0.09046487
Inductance, at 'Current'=10 A (mH)	0.46238025	0.36911815	0.19882986	0.10613427	0.09046488

B2) Inductance (Inductance, current)

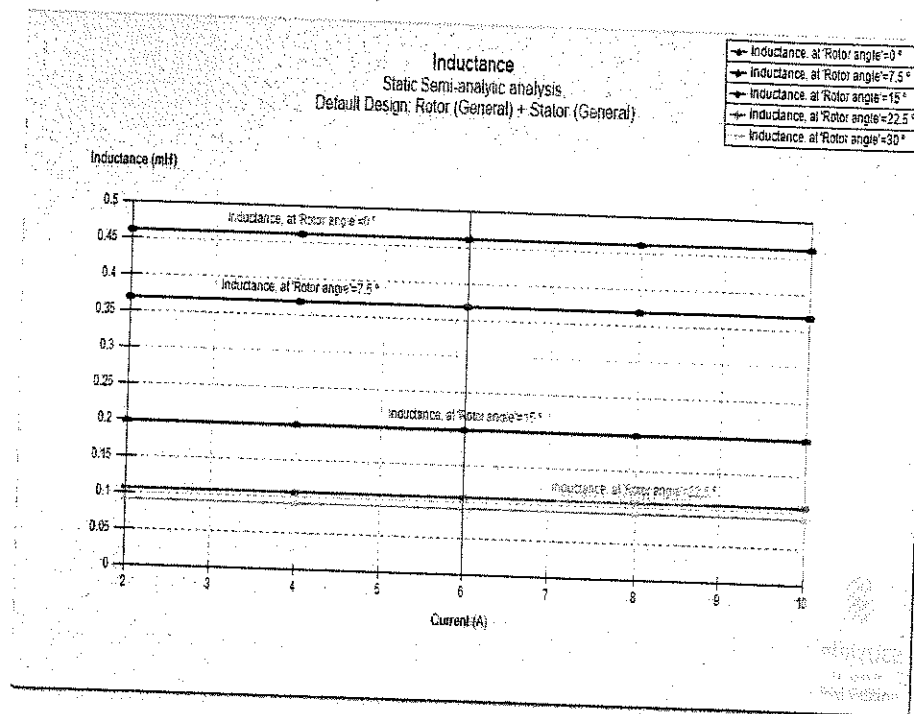


Figure 8-68. Inductance waveform at load points of 10/8 SRM in the semi-analytic

Table 9 showing inductance profile of 10/8 SRM

Table 9. Inductance profile of 10/8 SRM

Current (A)	2	4	6	8	10
Inductance, at 'Rotor angle'=0° (mH)	0.46237852	0.46237961	0.46237997	0.46238016	0.46238025
Inductance, at 'Rotor angle'=7.5° (mH)	0.36911684	0.36911767	0.36911794	0.36911808	0.36911815
Inductance, at 'Rotor angle'=15° (mH)	0.1988293	0.19882965	0.19882977	0.19882983	0.19882986
Inductance, at 'Rotor angle'=22.5° (mH)	0.10613413	0.10613422	0.10613425	0.10613426	0.10613427
Inductance, at 'Rotor angle'=30° (mH)	0.09046481	0.09046485	0.09046486	0.09046487	0.09046488

C1) Static torque (torque, rotor angle)

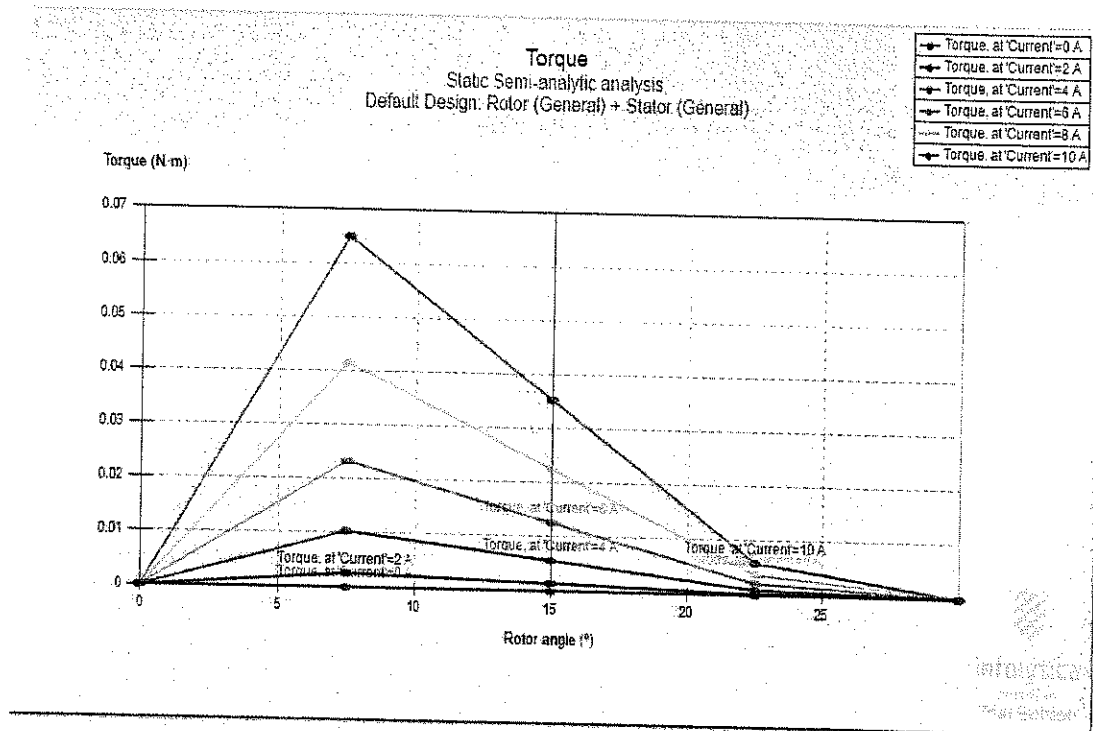


Figure 8-69. Static torque waveform at load points of 10/8 SRM

Table 10 showing static torque of 10/8 SRM

Table 10. Static torque of 10/8 SRM

Rotor angle (°)	0	7.5	15	22.5	30
Torque, at 'Current'=0 A (N·m)	0	0	0	0	0
Torque, at 'Current'=2 A (N·m)	0	0.00260179	0.00141627	0.00023941	0
Torque, at 'Current'=4 A (N·m)	0	0.01040721	0.00566511	0.00095764	0
Torque, at 'Current'=6 A (N·m)	0	0.02341626	0.01274653	0.00215469	0
Torque, at 'Current'=8 A (N·m)	0	0.04162895	0.02266051	0.00383056	0
Torque, at 'Current'=10 A (N·m)	0	0.06504527	0.03540707	0.00598526	0

C2) Static torque (torque, current)

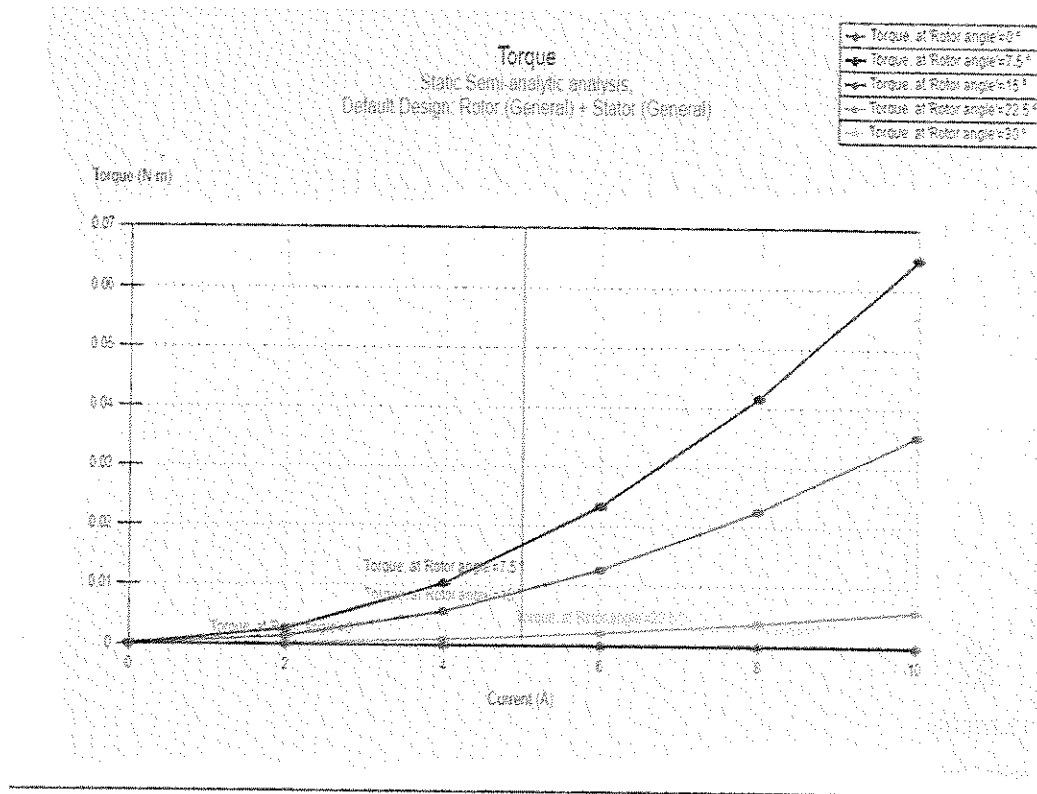


Figure 8-70. Static torque waveform at load points of 10/8 SRM

Table 11 showing Static torque of 10/8 SRM

Table 11. Static torque of 10/8 SRM

Current (A)	0	2	4	6	8	10
Torque, at 'Rotor angle'=0 ° (N·m)	0	0	0	0	0	0
Torque, at 'Rotor angle'=7.5 ° (N·m)	0	0.00260179	0.01040721	0.02341626	0.04162895	0.06504527
Torque, at 'Rotor angle'=15 ° (N·m)	0	0.00141627	0.00566511	0.01274653	0.02266051	0.03540707
Torque, at 'Rotor angle'=22.5 ° (N·m)	0	0.00023941	0.00095764	0.00215469	0.00383056	0.00598526
Torque, at 'Rotor angle'=30 ° (N·m)	0	0	0	0	0	0

D) Torque vs speed

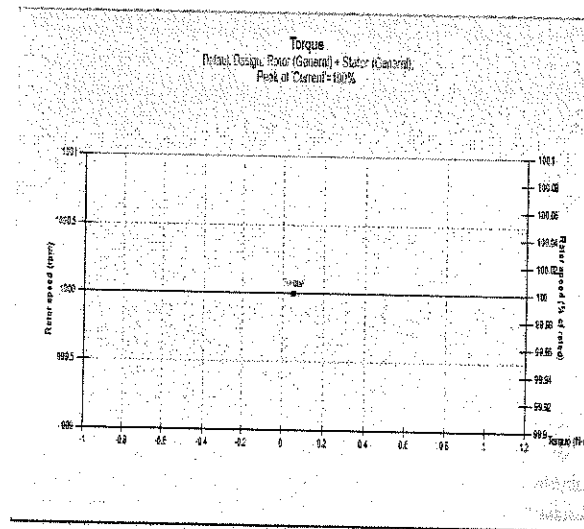


Figure 8-71. Torque-speed characteristics of 810/8 SRM

Table 12 showing Static torque of 10/8 SRM

Table 12. Static torque of 10/8 SRM

Rotor speed (rpm)	1000
Rotor speed (% of rated)	100
Torque (N.m)	0.05048108

E1. Energy-Coenergy

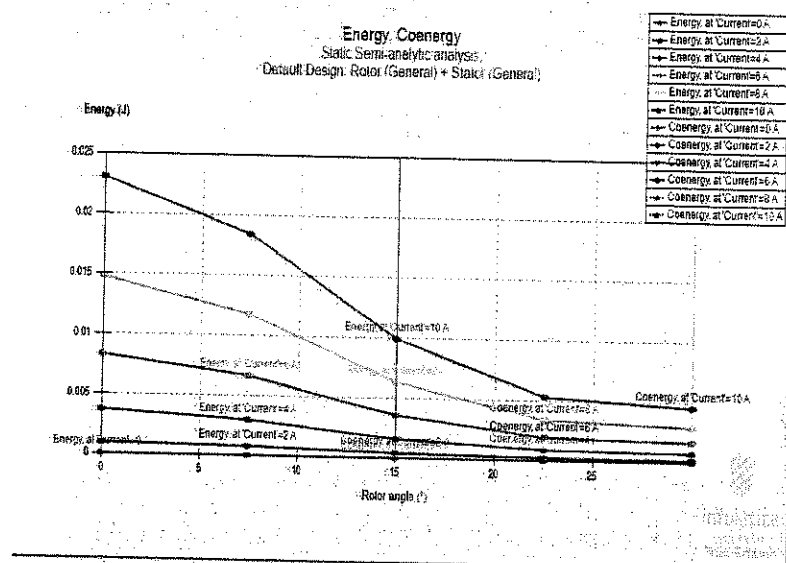


Figure 8-72. Energy-current characteristics of 810/8 SRM

Table 13 showing energy-current of 10/8 SRM

Table 13. Energy -current of 10/8 SRM

Rotor angle (°)	0	7.5	15	22.5	30
Energy, at 'Current'=0 A (J)	0	0	0	0	0
Energy, at 'Current'=2 A (J)	0.00092476	0.00073823	0.00039766	0.00021226	0.00018093
Energy, at 'Current'=4 A (J)	0.00369904	0.00295294	0.00159064	0.00084907	0.00072372
Energy, at 'Current'=6 A (J)	0.00832285	0.00664413	0.00357894	0.00191041	0.00162836
Energy, at 'Current'=8 A (J)	0.01479618	0.01181179	0.00636256	0.00339629	0.00289487
Energy, at 'Current'=10 A(J)	0.02311903	0.01845592	0.0099415	0.00530671	0.00452324
Coenergy, at 'Current'=0 A(J)	0	0	0	0	0
Coenergy, at 'Current'=2 A (J)	0.00092476	0.00073823	0.00039766	0.00021227	0.00018093
Coenergy, at 'Current'=4 A (J)	0.00369903	0.00295294	0.00159064	0.00084908	0.00072372
Coenergy, at 'Current'=6 A (J)	0.00832283	0.00664412	0.00357894	0.00191042	0.00162837
Coenergy, at 'Current'=8 A (J)	0.01479615	0.01181177	0.00636255	0.0033963	0.00289488
Coenergy, at 'Current'=10 A(J)	0.02311899	0.01845589	0.00994149	0.00530672	0.00452325

E2. Energy-Coenergy

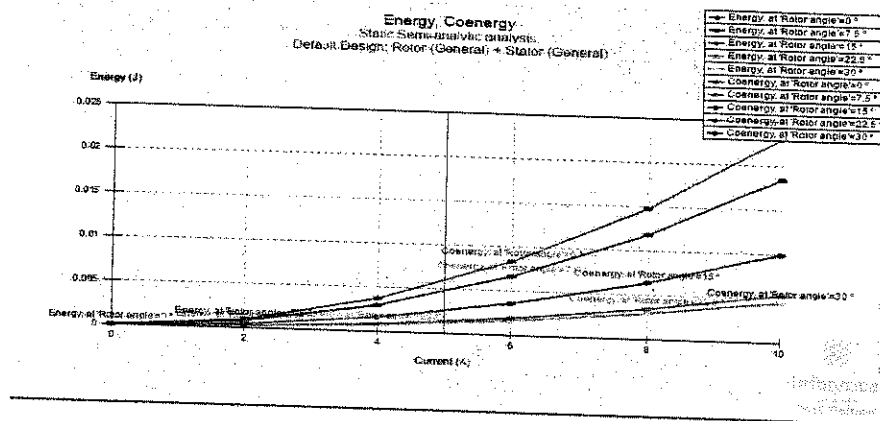


Figure 8-73. Energy-Current characteristics of 810/8 SRM.

Table 14 showing energy-Rotor angle of 10/8 SRM

Table 14. Energy-Rotor angle of 10/8 SRM

	Current (A)					
	0	2	4	6	8	10
Energy, at 'Rotor angle'=0°(J)	0	0.00092476	0.00369904	0.00832285	0.01479618	0.02311903
Energy, at Rotor angle'=7.5°(J)	0	0.00073823	0.00295294	0.00664413	0.01181179	0.01845592
Energy, at Rotor angle'=15°(J)	0	0.00039766	0.00159064	0.00357894	0.00636256	0.0099415
Energy, at Rotor angle'=22.5°(J)	0	0.00021226	0.00084907	0.00191041	0.00339629	0.00530671
Energy, at Rotor angle'=30°(J)	0	0.00018093	0.00072372	0.00162836	0.00289487	0.00452324
Coenergy, at Rotor angle'=0°(J)	0	0.00092476	0.00369903	0.00832283	0.01479615	0.02311899

Coenergy, at Rotor angle'=7.5°(J)	0	0.00073823	0.00295294	0.00664412	0.01181177	0.01845589
Coenergy, at Rotor angle'=15°(J)	0	0.00039766	0.00159064	0.00357894	0.00636255	0.00994149
Coenergy, at RotorAngle'=22.5°(J)	0	0.00021227	0.00084908	0.00191042	0.0033963	0.00530672
Coenergy, at 'Rotor angle'=30°(J)	0	0.00018093	0.00072372	0.00162837	0.00289488	0.00452325

2) Analysis Charts

a) Static analysis

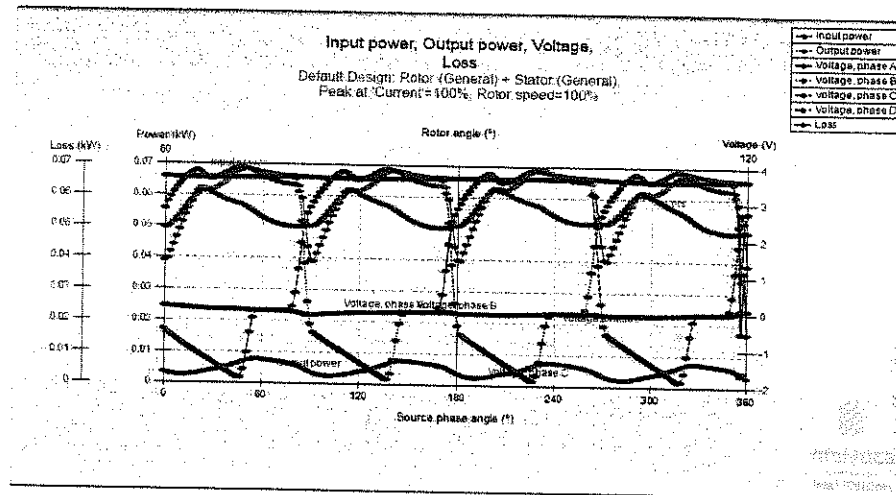


Figure 8-74. Voltage+ loss+ input and output power characteristics of 10/8 SRM

Table 15 showing static torque of 10/8 SRM

Table 15. Static torque of 10/8 SRM

	Source phase angle (°)				
	0	60	120	180	240
Rotor angle (°)	60	70	80	90	100
Input power (kW)	0.039040307	0.066158836	0.061561021	0.039987642	0.067531432
Output power (kW)	0.003578471	0.00774221	0.004138352	0.003941878	0.007496718
Voltage, phase A (V)	-0.517562889	-0.007049915	-0.032507373	2.829037702	3.797184265
Voltage, phase B (V)	3.643342264	3.633083063	-1.397127102	-0.02792634	-0.00131788
Voltage, phase C (V)	2.772337306	3.776582305	3.623877008	-0.357615485	-0.007336738
Voltage, phase D (V)	0.115908995	-0.0011675	3.586972775	3.661143205	3.662733997
Loss (kW)	0.049586167	0.052998623	0.060808127	0.050793709	0.054479208

b) Motion analysis

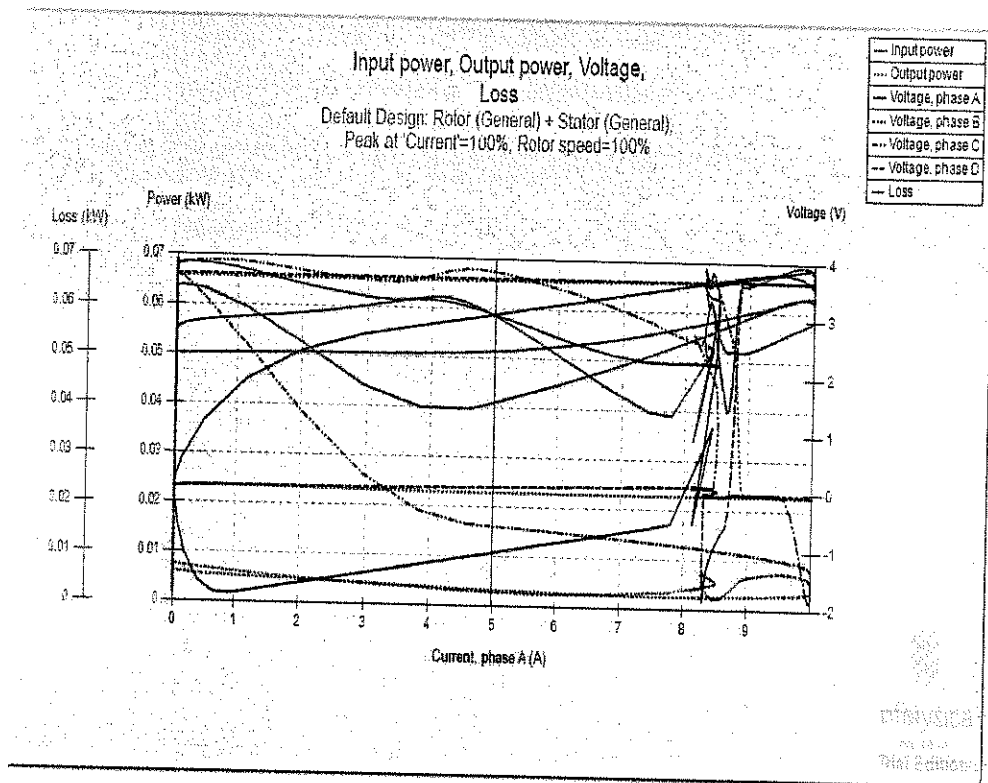


Figure 8-75. Voltage+ loss+ input and output power characteristics of 10/8 SRM.

Table 16 showing Voltage+ loss+ input and output power characteristics of 10/8 SRM

Table 16. Voltage+ loss+ input and output power characteristics of 10/8 SRM.

	Current, phase A (A)				
	7.783261187	2.58478E-05	0.000311485	5.354072964	9.122264671
Input power (kW)	0.039040307	0.066158836	0.062071238	0.042385244	0.066087359
Output power (kW)	0.003578471	0.00774221	0.00433497	0.003235157	0.007064294
Voltage, phase A (V)	-0.517562889	-0.007049915	-0.031348027	3.108350108	3.749163996
Voltage, phase B (V)	3.643342264	3.633083063	-1.450086451	-0.033436671	0.000722272
Voltage, phase C (V)	2.772337306	3.776582305	3.624524032	-0.643647154	-0.010093193
Voltage, phase D (V)	0.115908995	-0.0011675	3.617119889	3.660462566	3.666891022
Loss (kW)	0.049586167	0.052998623	0.060222309	0.051667419	0.052842192

3) Fields (Instantaneous fields)

Default Design: Rotor (General) + Stator (General)

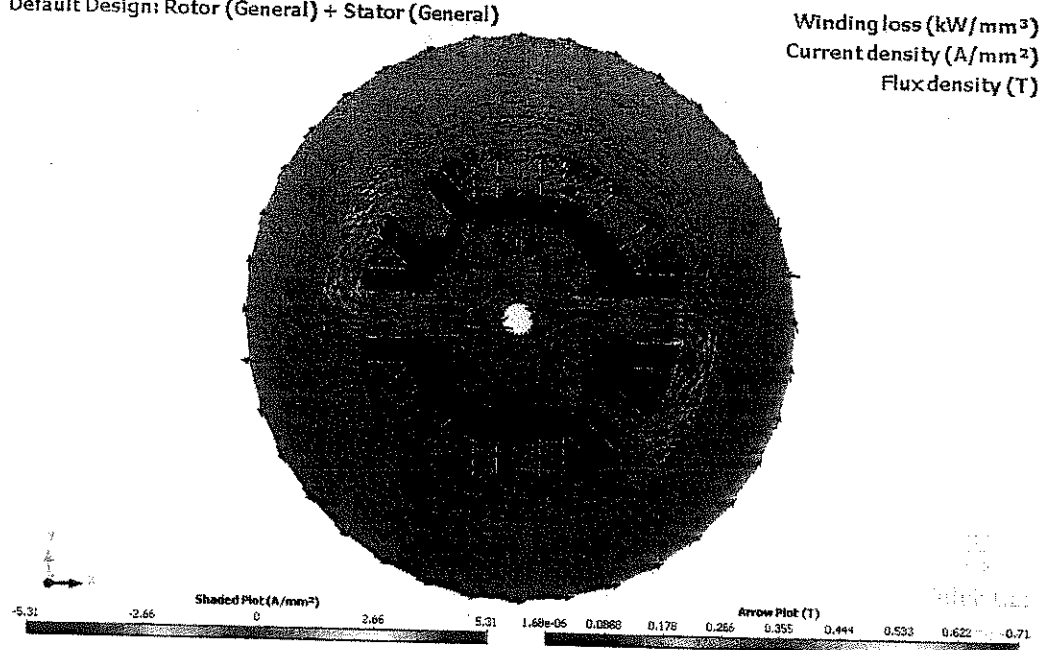


Figure 8-76. (Winding loss +current density flux density) of 10/8 SRM

4) Field characteristics

Default Design: Rotor (General) + Stator (General)

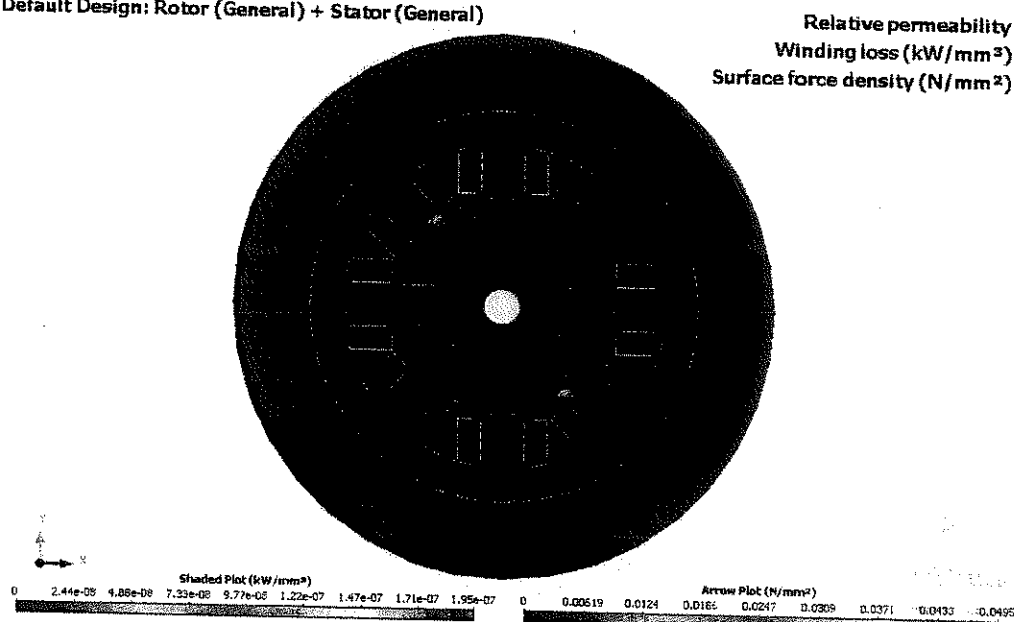


Figure 8-77. Winding loss and surface force density of 10/8 SRM.

9. CONCLUSION & DISCUSSING

For matlab/Simulink

The goal of this report is to introduce the basic principles of switched reluctance motor, main motor, and mathematical approach. A literature study was done about the fundamental SRM operation and then for estimating its parameters such as aligned and unaligned inductances, number of windings and the other specifications of the machine and characteristics of the SRM. Also this report has described and discussed in detail how from MATLAB one can achieve the simulation environment for SRM. Torque or force production in a reluctance motor is developed from the variation of the stored magnetic energy as a function of the rotor position. Torque production, interval control and switching angles have been described. From the simulation results, it can be seen that the switching angle has a significant impact on the SRM output (torque, speed, phase current and back EMF etc.) The current control and speed control works well, but it only works with the low motor speed. By comparing the simulation results based on different simulation environment, it can be seen that the MATLAB environment and Simulink environment will significantly impact the simulation results. For the future studies, how to control this motor more precise can be considered.

- For MotorSolve software

It operates Umea performed after this linear model SRM, closed loop speed control hysteresis current and simulations utilizing the SRM magnetic characteristics obtained by Exterior (CR10:cold rolled 1010 steel) for MotorSolve software is done on computers. Whereby the nonlinear structure of the motor current and speed control is performed in the model.

The MotorSolve software model presented in this thesis can be used to simulate steady state operation of the switched reluctance motor.

The SRM converter is analyzed and waveforms of flux of each phase, phase currents, torque and speed were recorded. It is observed that the motor draws a ripple current and the torque developed by the motor contains the ripples as per current phase. The speed of the motor settles at 3500 rpm.

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