

---

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

---

**Ain Shams University**  
**Faculty of Engineering**  
**Electrical power and Machine Dept.**

## **Speed Control of Switched Reluctance Motor**

**M.Sc. Thesis**

**By**

**Eng. Rania Abd El Rashid Ahmed Turkey**

Submitted in partial fulfillment of the Requirements for  
the M.Sc. Degree in Electrical Engineering

Supervised By

**Prof. Dr. Mohamed Abd Latif Badr**

Professor –Electrical Power and Machines Department  
Faculty of Engineering, Ain Shams University

**Prof. Dr. Mahmoud Abd El Hamid Mostfa**

Professor –Electrical Power and Machines Department  
Faculty of Engineering, Ain Shams University

Cairo  
2010

---

---

## **APPROVAL SHEET**

For The thesis:

### **SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR**

Presented by

**Eng. Rania Abd El Rashid Ahmed Turkey**

Submitted in partial fulfillment of the requirements for the  
M.Sc. degree in electrical engineering

Approved by

Name

Signature

Prof. Dr. Mohamed Abd Latif Badr

Prof. Dr. Mahmoud Abd El Hamid Mostfa

Date:     /     / 2010

---

## **Examiners Committee**

The thesis:

### **SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR**

Presented by

**Eng. Rania Abd El Rashid Ahmed Turkey**

Submitted in partial fulfillment of the requirements for the  
M.Sc. degree in electrical engineering

Name, title and affiliation

Signature

- 1. Prof. Dr. Essam Mohamed Abo El Zahab**  
Electrical Power and Machines Department  
Faculty of Engineering  
Cairo University
- 2. Prof. Dr. Adel Yousef Hanallah**  
Electrical Power and Machines Department  
Faculty of Engineering  
Ain Shams University
- 3. Prof. Dr. Mohamad Abd Latif Badr**  
Electrical Power and Machines Department  
Faculty of Engineering  
Ain Shams University
- 4. Prof. Dr. Mahmoud Abd El Hamid Mostfa**  
Electrical Power and Machines Department  
Faculty of Engineering  
Ain Shams University

---

## **Statement**

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for M.Sc. degree in Electrical Engineering.

The included work in this thesis has carried out by the author at the Electrical Power and Machines Department, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

**Name** : Rania Abd El Rashid Ahmed Turkey

**Signature:**

**Date** : 23 / 6 /2010

---

**To**

**My husband, My daughter, My  
parents, and my sister.**

---

## **Acknowledgements**

The author would like to express his sincerest gratitude to **Prof. Dr. Mohamed Abd Latif Badr, and Prof. Dr. Mahmoud Abd El Hamid Mostfa** for the great support, excellent supervision and encouragement shown during the period of this study.

Special thanks to the Electrical Power and Machines Department, Faculty of Engineering; Ain shams University, for the great support and encouragement.

---

## ABSTRACT

The switched reluctance motor (SRM) drive is nowadays one of the most considerable electric drives due to its good features that made it comparable with induction motor drives.

In this thesis, The dynamic response of an SRM has been obtained using information derived from static measurements, which give the exciting coil flux-linkages as a function of both the coil current and the angular position of the rotor. This has been achieved through a digital simulation of the mathematical model of the motor.

This model comprises a set of phase circuit equations in addition to the mechanical differential equations of motion. These equations are then solved using numerical integration of the nonlinear differential equations of the motor with the magnetization data in the form of a look-up table  $\Psi(\theta, i)$ . The cubic spline interpolation is used to determine the intermediate values of the variables given by the look-up table, which gives more accurate representation than other methods. This method is applied to compute the instantaneous values of current and torque for each phase, total torque and speed under different modes of operation; low speed with current control (chopped mode) and high speed with angle control (single pulse mode), and the required switching-on and off angles.

Early “traditional” controllers for SRM have a simple control technique. This control technique results in ripples in the torque and speed profiles, since the torque developed by an SRM is a nonlinear function of phase currents and rotor position. These ripples represent one of the main disadvantages of this type of motors.

---



---

The main contribution of This thesis is the presentation of a digital observer controller for switched reluctance motors for the purpose of enhancing the speed regulation of this type of motors. The dynamic response of the SRM with the proposed controller is studied during starting and under different load disturbances. The effectiveness of the proposed digital observer controller is then compared with that of both the conventional PI controller and the artificial neural network (ANN) controller. The dynamic response of the SRM with this proposed controller is found to be a fast and better-damped response.

## LIST OF CONTENTS

Abstract	VIII
List of contents	X
List of figures	XIII
List of symbols	XVI

### Chapter 1: Introduction

1.1	General	1
1.2	Over-view of the switched reluctance motors	2
1.3	The advantages of SRM	3
1.4	The disadvantages of SRM	4
1.5	Applications of SRM	4
1.5.1	Low power drives	5
1.5.2	Medium power drives	6
1.5.3	High power drives	7
1.5.4	High speed drives	7
1.5.5	Emerging applications	9
1.6	Thesis objectives and layout	11

### Chapter 2: SWITCHED RELUCTANCE MOTOR CONSTRUCTION AND OPERATION

2.1	General	14
2.2	Motor construction	16
2.3	Torque Production	18
2.3.1	· Principle of operation	18
2.3.2	· Magnetization Curves	19
2.3.3	· Static Torque Curves	23
2.4	Switched reluctance motor operation	24
2.5	Inverter circuits for SRM	28
2.5.1	· Power inverter with asymmetric half bridge	28

2.5.2	· Power inverter with split dc supply	30
2.5.3	· Power inverter for SRM with bifilar windings	31

### **Chapter 3: STEADY STATE PERFORMANCE OF SRM**

3.1	General	33
3.2	Static Characteristics	33
3.3	Representation of the magnetic curves of SRM	34
3.4	Computation of the static characteristics	37
3.4.1	· The flux linkage-current curves	37
3.4.2	· Computation of the static torque curves	38
3.5	SRM Performance under constant speed operation	41

### **Chapter 4: SPEED CONTROL OF SRM USING THE DIGITAL OBSERVER CONTROLLER**

4.1	General	56
4.2	Dynamic model of SRM	56
4.3	The Conventional PI Controller	57
4.3.1	· Basic principles	57
4.3.2	· Simulation results for speed control using a PI controller	60
4.4	The ANN controller	65
4.5	The digital observer controller	69
4.6	Performance Evaluation	72
4.6.1	· Dynamic response during starting (first zone)	72
4.6.2	· Dynamic response during a step down load torque disturbance (second zone)	74
4.6.3	· Dynamic response during a step up load	76

torque disturbance (third zone)

## **Chapter 5: Conclusion**

<b>CONCLUSION</b>	79
<b>REFERENCES</b>	80
<b>APPENDIX(A)</b>	83

## LIST OF FIGURES

2.1	The phase inductance related to the motor Poles	15
2.2	A cross section of a 3 phase, 6/4 SRM	17
2.3	A cross section of a 4 phase, 8/6 SRM	18
2.4	The magnetization curves of SRM.	20
2.5	The inductance curves of SRM.	21
2.6	The inductance of three phase 6/4 SRM.	21
2.7	The idealized phase inductance of a 4 phase SRM	23
2.8	The static torque curves of SRM	24
2.9	The variation of phase inductance and current profile.	26
2.10	An asymmetric half bridge inverter for a 3-ph SRM	29
2.11	Four phase power inverter with a split Dc supply	31
2.12	Three phase power inverter with bifilar winding	32
3.1	The measured flux linkage-current curves using cubic spline interpolation.	38
3.2	Co-energy curves against:	
	a) current for different rotor positions	40
	b) rotor angle for different values of phase current	40
3.3	The static torque curves of SRM	41
3.4	The motor performance at speed 500rpm, $\theta_{on} = 40^\circ$ and $\theta_{off} = 50^\circ$ .	44
3.5	The motor performance at speed 500rpm, $\theta_{on} = 40^\circ$ and $\theta_{off} = 50^\circ$ . $T_{av}=1.14$ p.u.	45
3.6	The motor performance at speed 500rpm, $\theta_{on} = 42^\circ$ and $\theta_{off} = 52^\circ$ . $T_{av}=0.8$ p.u.	46
3.7	The motor performance at speed 500rpm, $\theta_{on} = 45^\circ$ and $\theta_{off} = 55^\circ$ . $T_{av}=0.4$ p.u.	47
3.8	The motor performance at speed 500rpm, $\theta_{on} = 45^\circ$ and $\theta_{off} = 58^\circ$ . $T_{av}=0.4$ p.u.	48

3.9	The motor performance at speed 500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 45^\circ$ . $T_{av}=1.18p.u.$	49
3.10	The motor performance at speed 500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 47^\circ$ . $T_{av}=1.5p.u.$	50
3.11	The motor performance at speed 500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 50^\circ$ . $T_{av}=2p.u.$	51
3.12	The motor performance at speed 1500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 40^\circ$ . $T_{av}=0.4p.u.$	52
3.13	The motor performance at speed 1500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 44^\circ$ . $T_{av}=0.85p.u.$	53
3.14	The motor performance at speed 1500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 48^\circ$ . $T_{av}=1.3p.u.$	54
3.15	The motor performance at speed 1500rpm, $\theta_{on} = 30^\circ$ and $\theta_{off} = 50^\circ$ . $T_{av}=1.45p.u.$	55
4.1	The SRM control model.	59
4.2	The variation of load torque (p.u) ,with time (sec).	61
4.3.a	The dynamic response of the SRM driven by a PI controller during the starting period (first zone) with $k_i = 0.5$ , and variable gain $k_p$ .	62
4.3.b	The dynamic response of the SRM driven by a PI controller during sudden decrease of the load by 50% (second zone) with $k_i = 0.5$ , and variable gain $k_p$ .	63
4.3.c	The dynamic response of the SRM driven by a PI controller during sudden increase of the load by 50% (third zone) with $k_i = 0.5$ , and variable gain $k_p$ .	64
4.4.a	The dynamic response of the motor during starting provided with the ANN controller as compared with the PI controller of gains $k_p = 0.01$ and $k_i = 0.5$ .	66
4.4.b	The dynamic response of the motor during the second zone, using the ANN controller as compared with the PI controller of gains	67

	$k_p = 0.01$ and $k_i = 0.5$ .	
4.4.c	The dynamic response of the motor during the third zone, using the ANN controller as compared with the PI controller of gains $k_p = 0.01$ and $k_i = 0.5$ .	68
4.5	Block diagram for speed control of SRM using digital observer controller.	72
4.6.a	The dynamic response of the motor during starting provided with the digital observer controller as compared with the PI controller of gains $k_p = 0.01$ and $k_i = 0.5$ and the ANN controller.	74
4.6.b	The dynamic response of the motor during the second zone, using the digital observer controller as compared with the ANN controller and the PI controller of gains $k_p = 0.01$ and $k_i = 0.5$ .	76
4.6.c	The dynamic response of the motor during the third zone, using the digital observer controller as compared with the ANN controller and the PI controller of gains $k_p = 0.01$ and $k_i = 0.5$ .	78