



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF SINGLE PHASE INDUCATION MOTOR
ADJUSTABLE SPEED CONTROL USING M68HC11E9
MICROCONTROLLER**

HAMAD SAAD HUSSIEN.

FK 2004 48



**DEVELOPMENT OF SINGLE PHASE INDUCTION MOTOR
ADJUSTABLE SPEED CONTROL USING M68HC11E9
MICROCONTROLLER**

By

HAMAD SAAD HUSSIEN

**This Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the partial Requirements for the Degree of Master of Science.**

July 2004



DEDICATION

To my

Parents, wife, children, brothers and sisters



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the partial requirements of the degree of Master of Science

DEVELOPMENT OF SINGLE PHASE INDUCTION MOTOR ADJUSTABLE SPEED CONTROL USING M68HC11E9 MICRO-CONTROLLER

By

HAMAD SAAD HUSSIEN

JULY 2004

Chairman: Associate Professor. Senan Mahmod Bashi, Ph.D.

Faculty: Engineering

Variable speed control of a single-phase induction motor could be obtained through voltage control method using semiconductor power devices. These methods suffer from the large harmonics that result from the switching operation. Besides that it has a limited speed control range. Pulse Width Modulation (PWM) technique is considered as one solution for harmonic reduction and increasing the motor efficiency.

The advances in domestic and commercial applications in modern life raised the urgent needs to use low power single-phase induction motor. As a consequence, the single-phase induction motor has become the most widely used type of low power ac motors for those applications where regulating speed is of essence and three-phase power source are not available.

This work investigates the performance of a closed-loop adjustable speed drive for single-phase induction motor using voltage amplitude control. A microcontroller

M68HC11E-9 has been used to implement such techniques. The microcontroller senses the speed's feedback signal and consequently provides the (PWM) signal that sets the gate voltage of the chopper, which in turn provides the required voltage for the desired speed. A Buck type chopper has been used to control the input voltage of a fully controlled single phase Isolated Gate Bipolar Transistor (IGBT) bridge inverter.

The proposed drive system is simulated using Matlab / Simulink, its results were compared with the hardware experimental results. The simulation and laboratory results proved that the drive system could be used for the speed control of a single-phase induction motor with wide speed range.

Abstrak tesis yang dikemukakan kepada Senat Unjiversiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

**PEMBANGUNAN KAWALAN KELAJUAN BOLEH-UBAH BAGI MOTOR
ARUHAN SATU FASA MENGGUNAKAN PENGAWALMIKRO MC68HC11**

Oleh

HAMAD SAAD HUSSIEN

Julai 2004

Pengerusi: Profesor Madya. Senan Mahmud Bashi, Ph.D.

Fakulti: Kejuruteraan

Kawalan kelajuan boleh laras motor aruhan satu fasa boleh dilakukan melalui kaedah kawalan voltan menggunakan peranti kuasa semikonduktor. Kaedah ini mengalami gangguan harmonik yang tinggi berpunca daripada operasi pensuisan. Selain dari itu, ianya mempunyai julat kawalan kelajuan yang terhad. Kaedah *PWM* adalah salah satu cara penyelesaian yang boleh mengurangkan harmonik dan meningkatkan kecekapan motor.

Kemajuan dalam aplikasi domestik dan komersil dalam kehidupan moden telah meningkatkan keperluan segera untuk menggunakan SPIM berkuasa rendah. Akibatnya, SPIM telah menjadi jenis yang digunakan secara meluas bagi motor-motor kuasa ac untuk aplikasi-aplikasi tertentu di mana halaju mengatur adalah penting dan sumber kuasa tiga fasa tidak boleh didapati.

Penyelidikan ini mengkaji prestasi kawalan kelajuan boleh laras gelung tertutup untuk motor aruhan satu fasa menggunakan kaedah kawalan amplitud voltan. Pengawalmikro M68HC11E-9 telah digunakan untuk melaksanakan kaedah tersebut.

Pengawalmikro mengesan suapbalik isyarat kelajuan dan kemudian memberikan isyarat *PWM* yang menentukan voltan get pada pemenggal. Isyarat ini akan membekalkan voltan yang diperlukan untuk kelajuan yang diinginkan. Pemenggal jenis *BUCK* telah digunakan untuk mengawal voltan masukan bagi satu penyongsang jejambat *IGBT* satu fasa yang dikawal sepenuhnya oleh pengawal mikro.

Sistem pemacu yang telah dicadangkan telah disimulasikan menggunakan Matlab / Simulink. Keputusannya telah dibandingkan dengan hasil yang diperolehi melalui kaedah eksperimen menggunakan perkakasan yang sebenar. Keputusan simulasi dan eksperimen di dalam makmal membuktikan bahawa sistem pemacu tersebut boleh digunakan untuk mengawal kelajuan motor aruhan satu fasa dengan julat kelajuan yang lebih besar.



ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to the Most Gracious and Most Merciful ALLAH S.W.T. for helping me to complete this project.

I would like to express my respect and most sincere gratitude and appreciation to my advisor, Associate Professor Dr. Senan Mahmod Basha, for his continued support and encouragement throughout the course of this work.

I would like to express my appreciation and thanks to Dr. Ishak Aris, Dr.Samsul Bahari Mohd Noor, and Nashiren Farzilah for their valuable discussions and comments on this work.

I would like to express my special thanks to my friend and lab mates Yousef El Tommi, Omar Ben Nanes, Liyth Nissirat, and Abdurrahman Huweg for their support throughout the period of study and the hard times I wish to them all the best.

Finally great thanks to every anybody thought me during my life.

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGMENTS	vii
APPROVAL SHEETS	viii
DECLARATION FORM	x
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF ABBEVIATIONS	xvii
CHAPTERS	
1. INTRODUCTION	1
1.1. Ac-Induction Motor	3
1.1. Single-Phase Induction Motors	3
1.2. Aims and Objective	5
1.3. System Description	5
1.4. Structure of the thesis	6
2. LITERATURE REVIEW	7
2.1. Introduction	7
2.2. Converter Topology	7
2.2.1. AC-dc Converter	8
2.2.2. DC- dc Converter	8
2.2.3. Buck Regulator	9
2.2.4. Inverters	10
2.2.5. Full Bridge Single-Phase Inverter	11
2.3. Induction Motor Drives	12
2.3.1. Current Source Inverter (CSI)	13
2.3.2. Voltage Source Inverter (VSI)	13
2.3.3. Vector Control Drives	14
2.3.4. Direct Torque Control Drives	14
2.3.5. Synchronous Drives	15
2.4. Selecting of Microcontroller	18
2.5. Speed Sensing	19
2.6. Conclusion	20
3. METHODOLOGY	21
3.1. Hardware Design	21

3.1.1.	Full-Wave Bridge Uncontrolled Rectifier	22
3.1.2.	Dc Chopper	22
3.1.3.	Inductor and Capacitor Estimation of the dc chopper	24
3.1.4.	Calculation for Gate Resistance of IGBT dc Chopper	26
3.1.5.	Dc-ac converter (Inverter Circuit)	28
3.1.6.	Pulse Width Modulation (PWM)	29
3.1.7.	Triangle and Sine wave Generation	30
3.1.8.	PWM waveform generation	31
3.1.9.	Inverter Driver	34
3.2.	Software Development	36
3.2.1.	Microcontroller Interface Components	36
3.2.1.1.	Speed Control Module (SCM)	37
3.2.1.2.	User Interface Module (UIM)	38
3.2.1.3.	Pulse Width Modulation Module (PWMM)	39
3.2.2.	Variable frequency and duty cycle PWM	40
3.3.	System Integration	46
3.3.1.	Control algorithm and speed regulation	49
3.3.2.	Proportional Control Algorithm	49
4.	RESULTS AND DISCUSSION	52
4.1.	Introduction	52
4.2.	Simulation Results	52
4.3.	Experimental Results	62
4.3.1.	PWM Output of the chopper	63
4.3.2.	Testing the Optocoupler of the chopper	64
4.3.3.	Dc Chopper Performance	66
4.3.4.	Switching Circuit for dc-to-ac Converter	68
4.3.5.	Output Waveform of the Inverter Drive	70
4.3.6.	Testing the Speed Sensor output	70
4.4.	Motor Speed control Results	72
4.5.	Experiments and Simulation Results analysis	76
4.5.1.	Comparison between simulation and experimental results	77
5.	CONCLUSIONS AND FUTURE WORK	79
5.1.	Conclusion	
5.2.	Future works and Recommendation	79
	REFERENCES	R.1
	APPENDICES	A.1
	BIODATA OF THE AUTHOR	D.1

LIST OF TABLES

Table	Page
3.1 User Interface Commands on LCD	38



LIST OF FIGURES

Figure	Page	
1.1	Characteristic curves for single-phase induction motor.	4
1.2	Block diagram of single-phase motor control system.	6
2.1	Buck regulator circuit diagram.	9
2.2	Equivalent circuits and waveforms for buck regulator.	10
2.3	Single-phase full-bridge inverter.	11
2.4	Block diagram for current source inverter.	13
3.1	Ac SPIM drive system block diagram.	21
3.2	Uncontrolled rectifier circuit with dc filter.	22
3.3	Buck converter dc chopper.	23
3.4	Chopper circuit with optocoupler.	23
3.5	Single-phase full-bridge inverter.	29
3.6	Generating Pulse Width Modulation.	30
3.7	Block diagram of PWM Generation.	30
3.8	Connection for sinusoidal and triangle wave signal generation.	31
3.9	Pin connection of (ICL 8038) triangle-waveform.	32
3.10	Pin connection of (ICL 8038) sine-waveform.	33
3.11	Inverting and non-inverting comparator circuits.	33
3.12	Overall schematic circuit of control and inverter driver.	35
3.13	PWM module of chopper.	40
3.14	Speed sensor output.	42
3.15	Flowchart for algorithm used in realizing PWM.	45

3.16	Block diagram representation of the software routine and speed measurement.	46
3.17	Schematic diagram for the whole circuit.	51
4.1	Circuit diagram of complete circuit simulation.	53
4.2	Rectifier block diagram.	53
4.3	V_{in}/V_{out} of the rectifier circuit.	54
4.4	Input and Output of the Rectifier separately.	54
4.5	Chopper Block Diagram.	55
4.6	Chopper output voltage.	55
4.7	Block parameter for universal bridge.	56
4.8	PWM generator block.	57
4.9	Modification of PWM generator.	57
4.10	Inverter circuit diagram.	58
4.11	Inverter output during simulation test.	58
4.12	Final circuit performance a) Rectifier output, (b) Chopper output, (c) Load inverter.	59
4.13	Rectifier output.	60
4.14	Chopper output during simulation.	60
4.15	The load voltage during complete circuit simulation.	61
4.16	Photo showing the experiment hardware set up.	63
4.17	PWM waveform at duty cycle of 5%.	64
4.18	Output of Optocoupler at 20%.	65
4.19	Output of Optocoupler at 80% duty cycle.	66
4.20	Block diagram of dc chopper.	66
4.21	Dc chopper output at 12% duty cycle.	67
4.22	Dc chopper output at 92% duty cycle.	68
4.23	Symmetrical triangular carrier waveform for chip ICL-8038.	69

4.24	Output voltage for comparator LM-339.	69
4.25	Firing signal for the bridge inverter.	70
4.26	Speed sensor output.	71
4.27	Motor speed response under normal condition.	73
4.28	System's sudden stop command response.	73
4.29	Drive system speed tracking response.	74
4.30	Speed response during speed change from 2300rpm to 1000rpm.	75
4.31	Motor speed under load condition.	75
4.32	Oscilloscope print out of the load.	76
4.33	Load voltage during experiments and simulation.	77
4.34	Expanding to Figure 4.33-b.	78

LIST OF ABBREVIATIONS

Symbols	Stands for
ac	Alternating current
ADC	A/D Control registers
ALU	Algorithm logic unit
C	Capacitor
CSI	Current source inverter
CPU	Central processor unit
dc	Direct current
Dm	Freewheeling diode
D	Diode
EMF	Electrical magnetic field
EVB	Evaluation board
f	Frequency
FCNT	Frequency count
HCMOS	High density complementary semiconductor
G	gate
IGBT	Insulated Gate Bipolar Transistor
I_a	Average load current
I_1	Rise inductor current
I_2	Fall inductor current
I_c	Capacitor current
$I_{g(erq.)}$	Required gate current
K	Duty cycle

K_p	Proportional constant
KP	Proportional coefficient in percentage
L	Inductor
LCD	Liquid Crystal Display
MOSFET	Metal-Oxide Silicon Field Effect
MSD	Measured speed
PWM	Pulse width modulation
PWMM	Pulse width modulation module
PPR	Pulse Per Revolution
Q_g	Total gate charge
RPM	Revolution Per Minute
rms	Root mean square
ROM	Read only memory
RAM	Read access memory
R_G	Gate resistance
R_A, R_B	Timing resistance
SC	Start capacitor
SPC	Split phase capacitor
SS	Speed sensor
SMT	Speed measurement time
SPIM	Single-phase induction motor
SME	Speed measurement error
SMAX	Maximum speed
T	Switching period
T_{on}	On time

T_{off}	Off time
T_d	Delay time
TSD	Target speed
T_x	Interval time
UIM	User Interface Module
V	Voltage
V_a	Average output voltage
V_s	Voltage source
V_{in}	Input voltage
V_{out}	Output voltage
V_G	Gate voltage
V_{av}	Voltage available to charge
VSI	Voltage Source Inverter
V_{ref}	Reference voltage
ΔI_{max}	Maximum ripple current
ΔI	Peak -to-Peak ripple current
ΔV	Peak -to-Peak ripple voltage

CHAPTER 1

INTRODUCTION

Loads driven by electrical prime movers often need to run at a speed that varies according to the operation they are performing. The speed in some cases such as pumping may need to be changed dynamically to suit the conditions, and in other cases it may only change as the duty of the load progresses.

In the past, the various techniques for controlling the speed of ac machines are available and often the use of auxiliary rotating machines may be necessary. These auxiliary machines have now been supplanted by static ac drives systems using various types of power semiconductor, operating as electrically controlled switches. High efficiency is attained because of the low “ON-state” conduction losses when the power semiconductor is conducting the load current and the low “OFF-state” leakage losses when the power semiconductor is blocking the source, or load, voltage. The transitions times between blocking and conducting, and vice versa, depend on the type of power semiconductor used. In practice, various types of power semiconductor devices for example, Thyristors, IGBT's, MOSFET's and Diodes are used for the control of ac motors [1].

Nowadays, manufacturers assemble several semiconductor components into a single package, or module. The use of such a module reduces the number of electrical interconnections necessary and heat sinks requirements. Various combinations of devices are assembled into a common package. These common packages are what is widely referred to as an integrated circuits (IC). The selling price of these modules and of the basic power semiconductors themselves has been declining as the market expands [1].

The pulses that a switching power converter delivers to a motor are controlled by means of Pulse Width Modulated (PWM) signals applied to the gates of the power transistors or IGBT's. This technique is employed in electrical circuits to reduce the effect of harmonics. PWM signals are pulse trains with fixed frequency and magnitude, and with variable pulse width. Furthermore, in every PWM period there is one pulse of fixed magnitude. However, the width of these pulses changes from one period to another, according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turns off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load will depend mostly on the modulating signal. The pulses of a symmetric PWM signal are always symmetric with respect to the center of each PWM period, while the pulses of an asymmetric edge-aligned PWM signal are correspondingly asymmetrical with respect to the center of each PWM period.

Another major factor in ac drives technology is the availability of microprocessor / microcontroller for the control of ac drive system. Microprocessor operates at an adequately high clock frequency to complete their calculations in sufficient time to directly control the firing of the power semiconductors circuit operating from the utility supply frequency. In addition to the direct calculation of the power semiconductors firing times, the microprocessor can perform lower priority tasks, such as diagnostics, self-test, start-up and shutdown sequencing, and fault monitoring [1].

1.1 Ac-Induction Motor

AC- induction motors are the most widely used type of electronic motor in the modern world. AC-motors are primarily used as a source of constant-speed mechanical power and they are increasingly being used in variable-speed control applications. They are popular because they can provide rotary power with high efficiency; no commutation is required, lighter in weight, low maintenance, and exceptional reliability, all at relatively low cost.

These desirable qualities are the result of two factors:

- (1) AC motors can use the ac-power.
- (2) Most ac motors do not need brushes as in dc motors.

In most cases, the ac power is connected only to motor's stationary field windings. The rotor gets its power by electromagnetic induction; a process that does not require physical contact. Maintenance is reduced because brushes do not have to be periodically replaced. In addition, the motor tends to be more reliable and last longer because parts malfunctioning are minimal and there is no "brush dust" to contaminate the bearings or windings [2].

1.2 Single-Phase Induction Motors.

In domestic applications, single-phase induction motors are commonly used in dishwashers, washing machines, hermetic compressors, fans, pumps, draft inducers, etc. A truly variable speed operation from this motor with a wide range of speed and loads would help applications designers to incorporate many new features in their products. It would also mean operation with high efficiency and better motor utilization. In industrial applications, three-phase induction motors have been used.

However, in residential applications with small power, single-phase induction motors are preferred due to the greater availability of single-phase power [3].

A single-phase motor can only produce an alternating field: one that pulls first in one direction, then in the opposite as the polarity of the field switches. The major distinction between the different types of single-phase ac motors is how they go about starting the rotor in a particular direction such that the alternating field will produce rotary motion in the desired direction. Some device that introduces a phase-shifted magnetic field on one side of the rotor is usually employed for this purpose. The Figure 1.1 shows the performance curves of the four major types of single-phase ac motors [4].

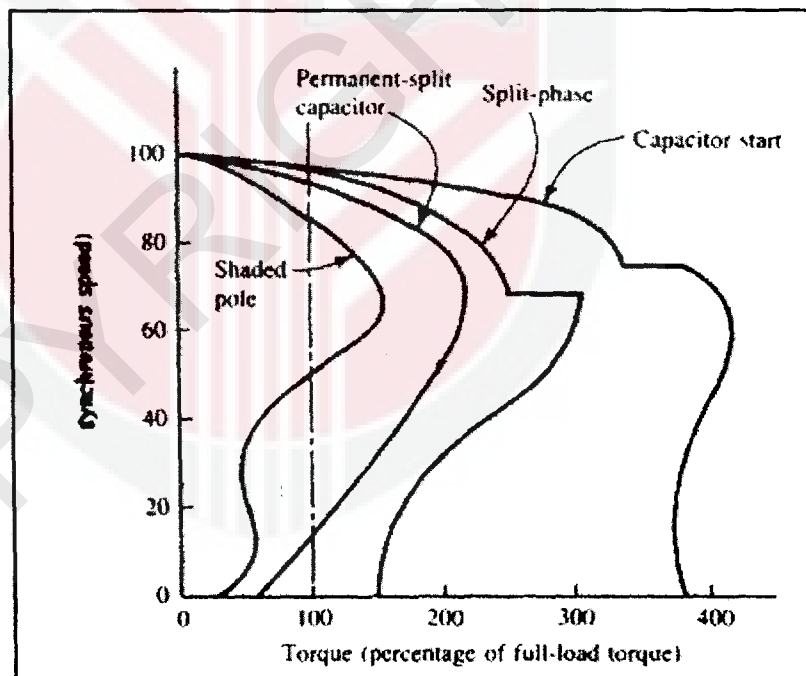


Figure 1.1: Characteristic curves for single-phase induction motor

1.3 Aims and Objectives

The objective of this particular project is to design and build an adjustable speed drive system for a single-phase induction motor, to use M68HC11-microcontroller for closed-loop control system with Voltage amplitude control algorithm, to build a simulink model and simulated using Matlab/Simulink software and compare the results with the experiment results, and to investigate that the elements used in this system can be easily control the motor speed.

1.4 System Description

The experiment has been carried out using many components that made this work possible. The power supply of this circuit was fed via a variable transformer. The full bridge rectifier has been used to convert the ac supply to a dc voltage. The output of the rectifier is the input to the dc chopper which controls the voltage level. The microcontroller-based adjustable closed loop control system hardware has been implemented and tested in the laboratory. The M68HC11E9-microcontroller has been programmed to vary the PWM that controls the duty cycle of the dc chopper. The last component of this set up is the inverter which receives the dc signal from the chopper and converts it to ac power to feed the motor under control. Figure 1.2 shows the block diagram of system used in this work.