UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AC VOLTAGE CONTROLLER FOR ENERGY SAVING OF INDUCTION MOTOR

ZAINAB AHMAD

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ZAINAB AHMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Partial Fulfillment of Requirement for the Degree of Master of Science

August 2002

Dedicated to

My husband and
my beloved children,
Mardhiyah, Sumaiyah, Nafiysah and Hidayah

Abstract of thesis presented to the senate of Universiti Putra Malaysia in partial fulfillment of requirement for the degree of Master of Science

DEVELOPMENT OF AC VOLTAGE CONTROLLER FOR ENERGY SAVING OF INDUCTION MOTOR

By

ZAINAB AHMAD

August 2002

Chairman : Associate Professor Ir. Dr. Norman Mariun, Ph.D.

Faculty : Engineering

Energy saving can be defined as the ability to reduce the electricity consumption when using an electrical machine. The most common electrical machine is the induction motor. Although it is the workhorse of the industry because of its ruggedness, low cost, low maintenance and versatility, it suffers from considerable inefficiencies and losses.

The induction motor operates most efficiently at full load. However, in many instances, it runs on full load for only part of the time. At light loads, induction motors are approximately inductive and have poor power factor. This leads to high power consumption, thus reduces the motor efficiency.

Modulating the power flow from the supply to the load is the task of a power controller. This thesis presents the power controller called the pulse width modulated (PWM) ac chopper voltage controller. The PWM and chopping technique is predominantly used in dc applications. However, in this thesis, these two techniques will be implemented for the ac application.

AC voltage controller is a single stage power converter that enables voltage variation by varying the duty cycle of its switching devices. Reduction in voltage can be made to suit the power demand of induction motor running at light loads.

The advantages of this voltage controller includes: elimination of lower-order harmonics, improvement of input power factor, nearly sinusoidal input and output current and voltage waveforms, better transient response due to soft-starting and reduced number of control switches.

This voltage controller was simulated using the Pspice software and then assembled in the laboratory. A good agreement has been obtained between the simulation results and the experimental results.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBINAAN SEBUAH PENGAWAL VOLTAN AU BAGI PENJIMATAN TENAGA SEBUAH MOTOR ARUHAN

Oleh

ZAINAB AHMAD

Ogos 2002

Pengerusi : Profesor Madya Ir. Dr. Norman Mariun, Ph.D.

Fakulti : Kejuruteraan

Penjimatan tenaga boleh didefinisikan sebagai keupayaan mengurangkan penggunaan elektrik ketika menggunakan sebuah mesin elektrik. Mesin elektrik yang lazim digunakan ialah motor aruhan. Walaupun ia sangat berguna di dalam industri kerana bentuknya yang tahan lasak, harga yang murah dan kos penyelenggaraan yang rendah, ia seringkali mengalami masalah kecekapan dan kesusutan tenaga.

Motor aruhan beroperasi paling cekap ketika mengendalikan beban penuh. Walau bagaimanapun, ia mengendalikan beban penuh pada sebahagian daripada masa sahaja. Pada beban ringan, motor aruhan menghampiri keadaan teraruh dan mempunyai faktor kuasa yang rendah. Ini membawa kepada penggunaan kuasa yang tinggi dan seterusnya mengurangkan kecekapan motor tersebut.

Pengawalan pengaliran kuasa daripada bekalan ke beban adalah tugas sesebuah pengawal kuasa. Tesis ini mengemukakan sebuah pengawal voltan pemenggal AU jenis pengmodulatan lebar denyut. Pengawal voltan ini menggunakan teknik memodulasikan lebar denyut dan pemenggalan yang lazim digunakan dalam aplikasi (arus terus)AT. Walaubagaimanapun, tesis ini mengemukakan penggunaan kedua-dua teknik tersebut ke dalam aplikasi (arus ulang-alik)AU.

Pengawal voltan ini ialah sejenis penukar kuasa satu peringkat yang boleh mengubah voltan dengan mengubah nilai kitar kerja pada peranti-peranti pengsuisan. Pengurangan voltan boleh dilakukan supaya ia bersesuaian dengan keperluan kuasa yang diperlukan oleh motor aruhan yang beroperasi pada beban rendah.

Kelebihan-kelebihan yang terdapat pada pengawal voltan ini adalah: pengurangan nilai erotan pada harmonik rendah, pembaikan nilai faktor kuasa masukan, gelombang isyarat masukan, voltan dan arus keluaran yang menghampiri bentuk sinus, sambutan transien yang lebih baik kerana pemula-lembut dan pengurangan bilangan suis pengawal.

Rekabentuk pengawal voltan ini telah disimulasi menggunakan perisian Pspice dan kemudian litarnya disambung di makmal. Terdapat persamaan yang hampir di antara keputusan yang dicapai secara simulasi dengan secara ujian.

ACKNOWLEDGMENTS

In the name of Allah, the Most Beneficent, the Most Merciful.

Many people have contributed meaningful knowledge, help and guidance towards the success of this research. The author wishes to express her deepest appreciation especially to: -

Assoc. Prof. Ir. Dr. Norman Mariun; main supervisor, advisor and lecturer for his guidance and support, Dr. Sinan Mahmod and Assoc. Prof Dr. Mohibullah for their technical knowledge and expertise. The author is also grateful to the staffs of Electrical Engineering Department, Universiti Putra Malaysia and fellow post-graduates of room KEE008 for their help and assistance. Finally, the author would like to thank her family for their love, patience, understanding and support.

May Allah bless all of you. Thank you.

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as a partial fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

NORMAN MARIUN, Ph.D., P. Eng.
Associate Professor
Head of the Department
Department of Electrical and Electronic Engineering
Faculty of Engineering
Universiti Putra Malaysia.
(Chairman)

SENAN MAHMUD BASHI, Ph.D.
Lecturer
Department of Electrical and Electronic Engineering
Faculty of Engineering
Universiti Putra Malaysia.
(Member)

MOHIBULLAH, Ph.D.
Associate Professor
Department of Electrical and Electronic Engineering
Faculty of Engineering
Universiti Putra Malaysia.
(Member)

AINI IDERIS, Ph.D.
Professor / Dean,
School of Graduate Studies,
Universiti Putra Malaysia.

Date:

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 PLATES	xvii
LIST OF ABBREVIATIONS	xviii

CHAPTER

1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statements	1
1.3 Aim and Objectives	2
1.4 Proposed Solution	3
1.5 Importance of the Project	5
1.6 Scope of Work	5
2 LITERATURE REVIEW	7
2.1 Energy Saving	7
2.2 The Concept of Loss Minimisation	10
2.3 The Concept of Energy Optimisation	11
2.4 Methods of Speed Control for Induction Motor	12
2.4.1 Variable Frequency Control	13
2.4.2 Stator Voltage Control	14
2.5 Energy Saving Methods	15
2.5.1 Fuzzy Logic in Induction Motor Drives	23
2.5.2 Neural Network in Induction Motor Drives	23
2.5.3 DSP Control in Induction Motor Drives	24
2.5.4 Summary on Energy Saving	25
3 METHODOLOGY	28
3.1 The Energy Saving Scheme	28
3.2 ac Voltage Controller	30
3.3 The Simple ac Chopper Voltage Controller	31
3.4 Harmonic Analysis	35
3.5 Harmonic Filter	36

3.6	Power Factor Improvement		37
3.7	MOSFET Drive Requirements		38
	3.7.1	Basic Principles and Characteristics	38
	3.7.2	Methods of Driving the MOSFET	40
	3.7.3	Drive Circuits Not Referenced to Ground	44
	3.7.4	Operation of the Bootstrap Circuit	46
4	**RESULTS AND DISCUSSION**		50
4.1	Resistive Load Simulation		50
4.2	Inductive Load Simulation		55
	4.2.1	Without Filters	55
	4.2.2	With Output Filter	62
4.3	Experimental Results		68
	4.3.1	Resistive Load	68
	4.3.2	The Control Circuit	71
	4.3.2.1	The Pulse Generator	71
	4.3.2.2	The Current Buffer	74
	4.3.2.3	The Opto-coupler	74
	4.3.2.4	The High-Voltage Floating Gate Driver	76
	4.3.2.5	The Performance of ac Chopper on Load	78
4.4	Summary		81
5	**CONCLUSION AND FUTURE WORK**		83
5.1	Conclusion		83
5.2	Future Work		84
	REFERENCES		85
	APPENDICES		89
A1	(i) Harmonic Analysis		89
	(ii) Harmonic Filter		93
	(iii) Power Factor Improvement		96
A2	Fast Fourier Transform Analysis for Inductive load simulation without output filter		97
A3	Fast Fourier Transform Analysis for Inductive load simulation with output filter		98
B	Components Data sheets		99
	BIODATA OF THE AUTHOR		125

LIST OF TABLES

Table		Page
3.1	Switching sequence for MOSFETs S, S1 and S2	34
4.1	FFT analysis for output voltage on resistive load	52
4.2	FFT analysis for output current on resistive load	53
A2.1	Fast Fourier Transform Analysis for inductive load voltage without using output filter	97
A2.2	Fast Fourier Transform Analysis for inductive load current without using output filter	97
A3.1	Fast Fourier Transform Analysis for inductive load voltage with output filter	98
A3.2	Fast Fourier Transform Analysis for inductive load current with output filter	98

LIST OF FIGURES

Figure		Page
2.1	Power Flow Diagram of an Induction Motor	9
2.2	Per-phase equivalent circuit referred to the stator	10
2.3	Reduced voltage operation	10
2.4	Methods of Speed Control (a) Topology for stator voltage control (b) Topology for variable frequency control	13
3.1	Induction motor with close loop control and PWM ac Chopper	29
3.2	Control block diagram of the system	29
3.3	Conventional ac voltage controller	30
3.4	PWM ac chopper voltage controller	31
3.5	The proposed ac chopper voltage controller	32
3.6	The switching patterns of the gating signals	33
3.7	(a) Active mode (b) Free-wheeling mode	34
3.8	Output voltage of the ac chopper voltage controller	35
3.9	An LC filter	37
3.10	Gate drive for MOSFETS	38
3.11	Asymmetric gate drive circuit	40
3.12	Double emitter-follower low-impedance drive circuit	41
3.13	Driving a MOSFET from an operational amplifier	42
3.14	TTL with bootstrap gate drive circuit	43
3.15	Transformer-isolated gate drive	45
3.16	Optically isolated gate driver	45

3.17	Bootstrap circuit for high side switching	46
4.1	Simulation circuit for resistive load of ac voltage controller	50
4.2	(a) Multiple PWM gating signal (b) Voltage across MOSFET (c) Output voltage across resistive load	51
4.3	Harmonic spectra of (a) Output current (b) Output voltage on resistive load	53
4.4	Percentage THD against duty cycle for switching frequency of 1KHz	54
4.5	ac voltage controller on inductive load	56
4.6	(a) Gating signal at main MOSFET, M1 (b) Gating signal at freewheeling MOSFET, M3 (c) Gating signal at freewheeling MOSFET, M2	57
4.7	(a) Inductive load voltage without output filter (b) Inductive load current without output filter	58
4.8	Harmonic spectra of load voltage without using output filter	59
4.9	Harmonic spectra of load current without using output filter	59
4.10	Percentage of voltage THD against duty cycle	60
4.11	Percentage of current THD against duty cycle	61
4.12	Normalised output voltage against duty cycle	61
4.13	Improved ac voltage controller for inductive load	63
4.14	(a) Inductive load voltage with output filter (b) Inductive load current with output filter	64
4.15	Harmonic spectra of load voltage with output filter	65
4.16	Harmonic spectra of load current with output filter	65
4.17	Percentage of output voltage THD against duty cycle	66
4.18	Percentage of output current THD against duty cycle	66
4.19	Normalised output voltage against duty cycle	67

4.20	Experimental circuit of ac voltage controller on resistive load	69
4.21	Block diagram of control circuit	71
4.22	Pulse generator with variable duty cycle	72
4.23	(a) Pulse generator output at duty cycle of 0.12, frequency 1KHz (b)) Pulse generator output at duty cycle of 0.72, frequency 1KHz	73
4.24	Current buffer circuit	74
4.25	Opto-coupler circuit	75
4.26	(a) Input waveform of opto-coupler for duty cycle of 0.32 (b) Output waveform of opto-coupler for duty cycle of 0.32	75 76
4.27	High voltage floating gate driver circuit	77
4.28	(a) Output waveform of gate driver IR2117 (b) Output waveform of opto-coupler	77
4.29	MOSFET switching test circuit	78
4.30	(a) Voltage across gate-source terminal, V_{gs} (b) Voltage across drain-source terminal, V_{ds}	78
4.31	(a) Input pulses to gate-source terminal (b) Voltage across drain-source terminal (probe X10) (c) Voltage across resistive load (probe X10)	79 79 80
4.32	Comparison between practical and theoretical normalised values of output voltage against duty cycle	81
A1.1	Generation of multiple PWM	90
A1.2	Output voltage of the ac chopper voltage controller	92
A1.3	An LC filter	93
A1.4	Equivalent circuit for harmonics	93

LIST OF PLATES

Plate		Page
4.1	The power circuit of the ac chopper voltage controller	70
4.2	The control circuit of the ac chopper voltage controller	70

LIST OF ABBREVIATIONS

α	Delay angle
ac	Alternating Current
A/D	Analog to digital
ASD	Adjustable speed drive
BJT	Bipolar junction transistor
C_1	Input filter capacitor
C_2	Voltage suppressor capacitor
C_{bs}	Bootstrap capacitor
CMOS	Complementary metal oxide semiconductor logic
$\cos\phi_1$	Displacement factor
d	Duty cycle
D	MOSFET drain terminal
D_{bs}	Bootstrap diode
dc	Direct Current
DSP	Digital Signal Processor
emf	Electro-magneto-motive force
f	Frequency
FFT	Fast Fourier Transform
FET	Field Effect Transistor
G	MOSFET gate terminal

GTO	Gate Turn-Off Thyristor
HO	High output terminal of MOSFET gate driver
HV	High voltage
Hz	Hertz
IC	Integrated Circuit
IEEE	Institute Of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
I_D	Drain current
I_F	Forward current
I_m	Magnetising current
I_r	Rotor current
I_{ref}	Reference stator current
I_s	Stator current
I_L	Load current
$I_{o\,(rms)}$	Total rms output current
$I_{1(rms)}$	Fundamental rms load current
$I_{qbs\,(max)}$	Maximum bootstrap charging current
$I_{cbs\,(leak)}$	Bootstrap capacitor leakage current
K	Loss minimisation factor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
n	Speed in revolution per minute
n_{ref}	Reference speed in revolution per minute

pf	Power factor
P_{cu}	Stator copper loss
P_{ro}	Rotor copper loss
P_c	Iron (core) loss
PI	Proportional integral
PID	Proportional integral derivative
PWM	Pulse width modulation
Q_{bs}	Bootstrap charge
Q_g	Gate charge
Q_{ls}	Level shift charge per cycle
R_D	Drain series resistor
R_G	Gate series resistor
rms	Root-mean-square
R_m	Magnetising resistance
R_r	Rotor resistance
R_s	Stator resistance
s	Slip
S	Main MOSFET of ac chopper voltage controller
S_1	Upper freewheeling MOSFET
S_2	Lower freewheeling MOSFET
SCR	Silicon controlled rectifier
THD	Total Harmonic Distortion factor
TTL	Transistor-transistor logic
t_{RR}	Reverse recovery time

$V_{1(rms)}$	Fundamental rms load voltage
V_{bs}	Bootstrap voltage
V_{cc}	Input dc voltage
V_{bsuv}	Undervoltage lockout bootstrap voltage
V_{ds}	Drain-source terminal voltage
V_f	Forward volt-drop across bootstrap diode
V_{gs}	Gate-Source terminal voltage
V_{LS}	Volt-drop across low voltage side of FET
V_{min}	Minimum voltage between V_b and V_s of MOSFET gate driver
V_{RRM}	Power rail voltage
V/f	Volts/ Hertz ratio
VSD	Variable speed drive
VSI	Voltage source inverter
V_m	Peak voltage
$V_{o(rms)}$	Total rms output voltage
V_s	Stator voltage
X_r	Rotor reactance
X_m	Magnetising reactance
Z_1	Zener diode for limiting gate voltage

CHAPTER 1

INTRODUCTION

1.1 Background

Electricity is the most important form of energy. It is generated mainly by non-renewable fossil fuels such as oil, gas and coal. Electrical energy is the backbone of industrialisation and hence indispensable for the progress of a modern society.

High-energy consumption is one of the major problems facing the industry today. In many organizations, it is the next highest cost, after direct labour. Electrical machines are the major consumers of all industrial electricity. Although they play a vital role in our modern life, these machines suffer from inefficiencies and losses.

According to Nelson et. al.[1], currently 50% of electrical energy is consumed by motors. From this value, about 10% are wasted at idle and additional 5% to 10% are wasted when the motor operates at less than full load. This figure is also true for the Malaysian industries. According to M.Y.Hassan et.al [2], more than half of the electricity generated in Malaysia is consumed by electric motor system applications.

1.2 Problem Statements

The most common ac motor is the induction motor. It is the workhorse of the industry because of its ruggedness, low cost, low maintenance and is versatile in its design for a broad range of speed, torque and power ratings. However, according to

K.Sundareswaran and S. Palani [3], induction motors consume about 60% of all industrial electricity.

It is a well-known fact that induction motors operate most efficiently at full load. However, in many cases, a motor runs on full load for only a small fraction of the operating time. Often, motors are so much over-rated with respect to the actual load that they never utilize their full power capability [4].

Induction motors are also considered as problem loads that cause energy wasting through starting and running at no and partial loads. At light loads, they are considered as approximately pure inductive loads that have poor power factor. This leads to high reactive power consumption and results in a reduction in the motor efficiency due to increase in core loss [5]. Coupled with concerns over energy conservation, research on obtaining energy loss reduction and efficiency optimization for motors has gained much attention.

1.3 Aim and Objectives

The main aim of this thesis is to develop a controller that will produce energy saving for the operation of a single-phase induction motor under no load and part load conditions. The motor is to operate at a constant speed. To achieve this aim, several objectives were set forth: -

i. to study the concept of energy saving for induction motors,

ii. to develop an energy saving scheme for the operation of a single-phase induction motor,

iii. to build a power controller that is able to save energy through voltage reduction,

iv. to reduce the harmonics generated to a low permissible value (preferably less than 5% of Total Harmonic Distortion level (THD) for voltage measurements), and

v. to maintain the power factor (p.f.) at a reasonably high value irrespective of the load conditions (p.f. greater than 0.85).

1.4 Proposed Solution

Modulating the power flow from the supply to the load via the motor is the task of a power controller. Controllers are built using power semiconductor devices employing thyristors (also known as SCR), power transistors, diodes, IGBTs, GTOs and MOSFETS. With the advanced development of these devices, it is possible to build a controller so that the motor can be controlled to reduce losses, improve motor performance and hence increase energy efficiency.

According to A. Yong [6], efficient motor controller designs can be chosen from either one of this approaches:-

i. variable speed drive (VSD), if the load and speed should vary together. This method gives longer equipment life, greater reliability and better matching between motor and load,

ii. power factor controller, if operation is at constant speed while load torque varies. This method is able to reduce energy wastage, and