



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF A SINGLE-PHASE PWM-BASED  
DC-TO-DC CONVERTER FOR ELECTRIC BICYCLE**

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DC-TO-DC CONVERTER FOR ELECTRIC BICYCLE**

**By**

**ALI OMAR AHMAD ALMATHNANI**

**Thesis submitted in Fulfilment of the Requirements for the  
Degree of Master of Science in the Faculty of Engineering  
Universiti Putra Malaysia**

**April 2000**



**Dedicated**

**To my Parents, Wife, Daughters, Brothers and Sisters**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

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**Chairman: Dr. Ishak Bin Aris**

**Faculty: Engineering**

An electric bicycle is a bicycle that can be operated automatically or manually. The main difference between an electric bicycle and a normal bicycle is that the speed controller of the DC motor attached to the electric bicycle can control the speed of the electric bicycle.

It is suitable for a short distance transportation mode. The advantages of the electric bicycle include better speed performance, no pollution, convenient to use, inexpensive and require less maintenance.

The objective of this project was to develop a single-phase PWM-based DC-to-DC converter for an electric bicycle. The electric bicycle consisted of a lead-acid battery, a DC-to-DC converter, a permanent magnet DC motors and the bicycle itself.



The single-phase converter used pulse width modulation (PWM) switching with an *Insulated Gate Bipolar Transistor (IGBT)* as power device. The speed of the motors was controlled through the duty cycle of the PWM signal.

A protection circuit for the converter was also included in the design. A voltage level monitoring system was developed for the electric bicycle to monitor its lead-acid battery voltage level.

A new bicycle pulley system was designed and constructed to integrate mechanical and electrical parts of the bicycle.

Results of the experimental and simulation showed that there was a good agreement between the hardware and the software. This indicates that the single-phase PWM based DC-to-DC converter was successfully developed.



Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

**PEMBANGUNAN PENUKAR ARUS TERUS KE ARUS TERUS  
BERASASKAN FASA TUNGGAL PWM UNTUK BASIKAL ELEKTRIK**

Oleh

**ALI OMAR AHMAD ALMATHNANI**

**April 2000**

**Pengerusi: Dr. Ishak bin Aris**

**Fakulti: Kejuruteraan**

Basikal elektrik ialah sebuah basikal yang boleh beroperasi secara automatik atau manual. Perbezaan yang utama yang terdapat pada basikal elektrik ialah kelajuan basikal elektrik dikawal dengan menggunakan sebuah alat pengawal kelajuan motor arus terus yang berada pada basikal tersebut.

Ianya sesuai digunakan sebagai pengangkutan jarak dekat. Kelebihan basikal elektrik ini ialah ianya mempunyai tahap kelajuan yang baik, tiada pencemaran, senang digunakan, tidak mahal dan kos penyelenggaraan yang murah.

Tujuan utama projek ini adalah untuk membangunkan sebuah penukar arus terus ke arus terus berasaskan fasa tunggal PWM untuk basikal elektrik. Basikal elektrik ini terdiri dari bateri sel basah, penukar arus terus ke arus terus, motor arus terus magnet kekal dan basikal ini sendiri.

Penukar arus terus ke arus terus satu fasa dikawal dengan menggunakan skema pensuisan PWM. *Insulated Gate Bipolar Transistor (IGBT)* digunakan di dalam litar ini. Kelajuan motor yang digunakan boleh dikawal dengan melaraskan kitar masa isyarat PWM.

Ciri-ciri perlindungan dimasukkan juga di dalam litar penukar ini. Sistem pemantau paras voltan dibangunkan bagi basikal ini untuk memantau paras voltan bateri sel basah basikal ini.

Sebuah sistem takal baru telah direka dan dibina untuk menghubungkan bahagian mekanikal dan bahagian elektrial basikal ini. Keputusan ujikaji dan simulasi dari projek ini menunjukkan persamaan yaag baik di antara mereka. Hasil dari ujikaji ini, ianya boleh disimpulkan bahawa penukar arus terus ke arus terus bagi basikal elektrik telah berjaya dibangunkan.

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Date: **8 JUN 2000**



## TABLE OF CONTENTS

	Page
<b>DEDICATION.....</b>	<b>ii</b>
<b>ABSTRACT.....</b>	<b>iii</b>
<b>ABSTRAK.....</b>	<b>v</b>
<b>ACKNOWLEDGMENTS.....</b>	<b>vii</b>
<b>APPROVAL SHEETS.....</b>	<b>viii</b>
<b>DECLARATION FORM.....</b>	<b>x</b>
<b>LIST OF TABLE.....</b>	<b>xiv</b>
<b>LIST OF FIGURES.....</b>	<b>xv</b>
<b>LIST OF ABBREVIATIONS.....</b>	<b>xviii</b>

### CHAPTER

<b>I</b>	<b>INTRODUCTION.....</b>	<b>1</b>
	Why is an Electric Bicycle Important.....	1
	The Objective of the Project.....	2
	Thesis Layout.....	2
<b>II</b>	<b>LITERATURE REVIEW.....</b>	<b>3</b>
	The Electric Bicycle.....	3
	Lead-Acid Battery.....	4
	Electric Motor.....	5
	DC Motors.....	5
	Principle of the DC Motor.....	7
	Speed of Rotation.....	9
	Methods of Speed Control.....	9
	Armature Speed Control.....	10
	Field Speed Control.....	11
	Steady-State Speed Torque Relation.....	12
	The Basic Equation of a DC Motor.....	13
	The Permanent Magnet Motor.....	18
	DC-to-DC Converter.....	19
	Performance of DC-to-DC Converter.....	20
	Step-Down (Buck) Converters.....	20
	Step-Down Chopper with Load.....	22
	Chopper Drives.....	26
	Basic Circuit Operation.....	35
	Insulated Gate Bipolar Transistor.....	40
	Review of IGBT.....	42
	Chopper Control of PM DC Motors.....	43
	Effect of Filter on the Input and Output on the DC-to-DC Converter.....	45
	Snubber Circuit.....	47
	Conclusion.....	49



<b>III</b>	<b>DESIGN AND METHODOLOGY.....</b>	<b>50</b>
	Introduction.....	50
	DC-to-DC Converter.....	52
	PWM Controller.....	52
	Oscillator.....	55
	Current Limit Controller.....	56
	Selection of Power Device.....	58
	Design the Gate Drive for the IGBT.....	59
	Operation of the Switch.....	63
	Voltage Regulator.....	64
	Input Filter.....	65
	Power Diode.....	66
	Protection Schemes.....	67
	Input Protection Fuse.....	67
	Heat Sink.....	68
	Snubber Circuit.....	69
	Printed Circuit Board.....	71
	Design of Voltage Level Monitoring System.....	73
	Permanent Magnet DC Motors.....	74
	Lead-Acid Battery (drifit 4500).....	75
	Bicycle Pulley System.....	76
	Tests.....	78
	On-Road Test of the Electric Bicycle.....	79
	Pspice Simulation .....	80
<b>IV</b>	<b>RESULTS AND DISCUSSION.....</b>	<b>83</b>
	DC-to-DC Converter (buck) Design.....	83
	DC Motor Controller Circuit.....	83
	Gate Drive Circuit.....	84
	Effect of Load on the IGBT and Controller Signal.....	85
	The Effect of Duty Cycle on the Gate, Collector, and Emitter Voltage.....	90
	Protection Circuit.....	92
	Input Filter.....	92
	Snubber Circuit.....	93
	Voltage Level Monitoring System.....	94
	PM DC Motor Test.....	95
	Lead-Acid battery.....	96
	On-Road Test of the Electric Bicycle.....	96
	Simulation Result of the DC-to-DC Converter.....	96
	Effect of Gate Resistor ( $R_G$ ) on the Switch.....	99



<b>V</b>	<b>CONCLUSION AND SUGGESTION FOR FUTURE WORK.....</b>	<b>100</b>
	<b>REFERENCES.....</b>	<b>103</b>
	<b>APPENDIX.</b>	
	<b>A: Simulation Program.....</b>	<b>106</b>
	<b>B: Components Data Sheet.....</b>	<b>110</b>
	<b>BIODATA OF AUTHOR.....</b>	<b>144</b>



## LIST OF TABLE

<b>Table</b>		<b>Page</b>
1	Different Motor Speed Results.....	95



## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
1	Block Diagram of an Electric Bicycle.....	1
2	Circuit Diagram of the Lead-Acid Battery.....	4
3	The Simple PM DC Motor.....	8
4	Ward-Leonard Speed Control System.....	10
5	Schematic Diagram of a Shunt Motor Including the Field Rheostat.....	12
6	Steady-State Equivalent Circuit of the Armature of a DC Motor.....	13
7	Separately-Excited Motor Circuit.....	13
8	Speed Characteristics of a DC Motor.....	15
9	Characteristics of DC Series Motor.....	17
10	Characteristics of a Separately-Excited Motor.....	18
11	Schematic Diagram of a Chopper-Controlled DC Motor.....	20
12	Step-Down Chopper with Resistive Load. (a) Circuit, (b) Waveforms.....	21
13	Chopper With RL (a) Circuit, (b) Waveforms .....	23
14	Chopper-Fed DC Drive in Power Control (a) Circuit, (b) Waveforms...	27
15(a)	Circuit Diagram of Regenerative Braking of a DC Separately-Excited Motor .....	28
15(b)	Waveforms of Regenerative Braking of a DC Separately-Excited Motor.....	29
16	Rheostat Braking by DC Motor (a) Circuit, (b) Waveforms.....	30
17	Circuit Combine Regenerative and Rheostatic Braking.....	31
18	Circuit of a Step-Down Switch Mode Regulator.....	32
19	PWM Control Signal.....	34
20	Waveforms for a Step- Down Switch-Mode Regulator.....	38



21	Capacitor Current.....	40
22	Characteristics of Switching States.....	41
23	Structure of (a) MOSFET, (b) IGBT.....	42
24	Basic IGBT Equivalent Circuit.....	42
25a	The Basic Circuit of Chopper Control, Two-Quadrant Operation, Motoring and Generating.....	44
25b	The Waveforms of Chopper Control, Two-Quadrant Operation, Motoring and Generating.....	45
26	Snubber Circuit.....	48
27	Flowchart Showing the Project Activity .....	51
28	General Block Diagram of the Electric Bicycle.....	52
29	The Complete Circuit Design of DC Motor Controller for the Electric Bicycle.....	53
30	The Chip Pin Connection.....	54
31	Experiment DC-to-DC Converter Circuit.....	58
32	(a) IGBT Equivalent Circuit, (b) IGBT Symbol.....	59
33	Gate Drive Circuit.....	60
34	Typical Gate Charge Vs Gate-to-Emitter Voltage.....	63
35	Current Path Through the Motor.....	64
36	Voltage Regulator Circuit.....	65
37	Input Filter Circuit.....	66
38	Model of Heat Flow under Thermal Equilibrium Condition.....	69
39	Printed Circuit Board Layout for the Circuit Shown in Figure 29.....	72
40	Voltage Level Monitoring System for the Electric Bicycle.....	74
41	Lead-Acid Battery, PMDC Motors and Belt.....	76
42	The Dimension of Pulley Used.....	77
43	The ON/OFF Switch.....	77



44	Complete Circuit and DC Motor on a Bicycle.....	78
45	Block Diagram of Pspice.....	81
46	Flowchart of the Pspice.....	81
47	Pspice Schematic Diagram for the DC-to-DC Converter.....	82
48	Voltage Waveform of the Controller Output at 50% Duty Cycle, and 10kHz Frequency.....	84
49	The Turn-On Voltage Waveforms of the IGBT Gate and Controller Output Without Load.....	85
50	The Turn-On Voltage Waveforms With Load at the IGBT Gate and Controller Output.....	86
51	Turn-Off Voltage Waveforms of the IGBT Gate and Collector Output Without Load.....	86
52	Turn-Off Voltage Waveforms of the IGBT Gate and Controller Output With Load.....	87
53	Voltage Waveforms of $V_{cc}$ , $V_m$ and $V_{ce}$ at the DC-to-DC Converter.....	88
54	Filtered, Emitter Current and Gate Signal Waveforms With Load of the DC-to-DC Converter.....	88
55	The Relation Between Duty Cycle and Efficiency.....	90
56	The Relationship Between the IGBT Switch Output Voltage and Collector Output Voltage Waveforms.....	91
57	Relationship Between Duty Cycle, $V_{-IN}$ , $V_G$ , $V_C$ and $V_E$ .....	92
58	Unfiltered Emitter Current and Gate Voltage Waveforms With Load of the DC-to-DC Converter Circuit.....	93
59	Output Voltage Across the Motor at 80% Duty Cycle, 10kHz.....	97
60	Output Current Across the Motor.....	98
61	Average Output Current Across the Motor.....	98
62	The Effect of Gate Resistance on the Output Waveform.....	99





## LIST OF ABBREVIATIONS

AC	Alternative Current (A)
BJT	Bipolar Junction Transistor
CEMF	Counter Electric Motive Force
C	Collector
DC	Direct Current (A)
EB	Electric Bicycle
$E_s$	Supply Voltage (V)
ESR	Effective Series Resistance
E	Emitter
F	Frequency of Chopping (Hz)
$F_c$	Cut Off Frequency (Hz)
FWD	Free Wheeling Diode
G	Gate
hp	Horse Power (W)
IGBT	Insulated Gate Bipolar Transistor
$I_x$	Generation Excitation
I	Total Current Supplied to the Armature (A)
J	Junction ,or Energy Density (Joule)
$I_a$	Armature Current (A)
$I_{a, avg}$	Average Load Current of Step-Down (Buck) Converter (A)
$I_{c, avg}$	Average Capacitor Current (A)
$K_g$	Kilogram
L	Inductance (H)



LED	Light Emitting Diode
MOSFET	Metal-Oxide Silicon Field Effect Transistor
PWMIC	Pulse Width Modulation Integrated Circuit
P <sub>i</sub>	Input Power (Watt)
PM	Permanent Magnet
PCB	Printer Circuit Board
PWM	Pulse Width Modulation
Q <sub>G</sub>	Total Gate Charge.
R	Resistance of Ward-Leonard Speed Control System(Ohm)
R <sub>a</sub>	Resistance of the Armature Circuit (Ohm)
R <sub>G</sub>	Gate Resistance (Ohm)
rms	Root Mean Squared
rpm	Revulsion per Minutes
S	Heat Sink
T	Torque Developed by the Motor (N-M)
T <sub>j</sub>	Junction Temperature (C°/W)
T <sub>JA</sub>	Juncttion to Ambient Temperature (C°)
V <sub>a,avg</sub>	Average Output Voltage (Volt)
V <sub>c</sub>	Control Voltage (Volt)
V <sub>ce</sub>	Collector-Emitter Voltage (Volt)
V <sub>g</sub>	Gate Voltage (Volt)
V <sub>m</sub>	Motor Voltage (Volt)
V <sub>o</sub>	RMS. Value of Output Voltage (Volt)
V <sub>r</sub>	Reference Voltage (Volt)
V <sub>out</sub>	Output Voltage (Volt)

$V_s$	Source Voltage (Volt)
$V_Q$	Transistor Voltage (Volt)
$V_L$	Load Voltage (Volt)
$\omega_m$	Speed of Armature ( rad/sec)
$\Phi$	Flux Pole (Webers)
$\Delta I$	Peak-to- Peak Ripple Current
$\Delta I_{\max}$	Maximum Ripple Current
$\zeta$	Emissivity of the Heat sink
$\theta_{jc}$	Thermal Resistance ( $C^\circ/W$ )
$\eta$	Efficiency

## CHAPTER I

### INTRODUCTION

#### Why is an Electric Bicycle Important?

The electric bicycle is expected to become a very important means for short distance transport because of its convenient use, cheapness and minimal maintenance required. Moreover, it is almost pollution free and operates quietly.

The general structure of the electric bicycle is shown in Figure 1. Basically it consists of a lead-acid battery, a DC-to-DC converter, a permanent magnet DC motor and the bicycle itself. The speed of the bicycle is controlled by varying the duty cycle of the PWM signal used to operate the DC-to-DC converter.

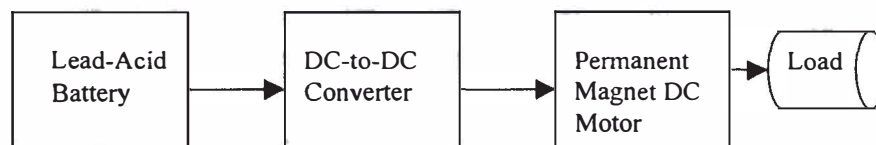


Figure 1: Block Diagram of an Electric Bicycle

## **Objective of the Project**

This project aims to develop an electric bicycle. To achieve this, the following works were carried out.

- Development of a single-phase DC-to-DC converter.
- Development of protection circuits.
- Development of a voltage level monitoring system.
- Development of a bicycle pulley system.

## **Thesis Layout**

This thesis is divided into five chapters. Chapter One gives a short introduction to the work and its objectives. Chapter Two reviews the literature on the electric bicycle, and discusses briefly its importance in modern life. A general study of the DC-to-DC converter, including its control circuit, is also presented.

The work done, including designing the drive circuit of IGBT, control and protection circuits for the DC motor, are presented in Chapter Three. The performances of the DC-to-DC converter and control circuit are discussed in Chapter Four. Finally, Chapter Five presents the conclusions and suggestions for further work.

## CHAPTER II

### LITERATURE REVIEW

#### The Electric Bicycle

With air pollution increasing in severity, especially in urban areas, from the growing use of petrol/diesel vehicles, electric bicycles are being looked at as a better mode of transport (Hsu *et al.*, 1989). They produce considerably less pollution than the nearest comparable mode of transport- the motor cycle.

An electric bicycle for transport would have many advantages. Powered by a small electric motor and sipping electric energy from a battery (rechargeable by solar power or the mains), it produces no pollution. Being light, it is convenient to use and can even be peddled to skimp on or dispense with electricity. Under power, a smooth ride is obtained. It can, of course, also be ridden in hybrid mode using both peddling and electric power.

The manual part of the bicycle is simply a pair of pedals driving the rear wheel through a chain and sprockets (Chou, 1994) although modern bicycles would also have gears and a clutch. The electric power is provided by a DC motor drawing electricity from a battery.



Typically, the bicycle would be able to run two to three hours on a full charge and the depleted battery takes six hours to recharge (Hsu *et al.*, 1989).

### Lead-Acid Battery

Despite its limitations, the lead-acid battery is still the only practical battery for the electric bicycle although the modern version is but only slightly improved from its predecessors at the turn of the century. Most, if not all, of the other rechargeable batteries available commercially today easily outperform the lead-acid battery technically, and nickel batteries are increasingly looked at for possible use. But for the moment, their limitations outweigh their advantages.

The battery, as shown in Figure 2, comprises the following.

- Cathode attached to the negative terminal,
- Anode attached to the positive terminal, and
- Electrolytic solution such as sodium chloride.

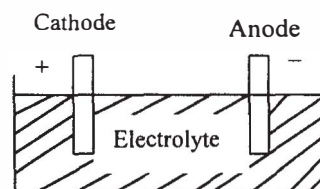


Figure 2: Circuit Diagram of the Lead-Acid Battery

A battery is an electrochemical cell which can be used to deliver current or power to a load. The number of cells are connected in series determines the