UNIVERSITI PUTRA MALAYSIA

DESIGN AND CONSTRUCTION OF A DC·TO·DC CONVERTER FOR ELECTRIC VEHICLE APPLICATION

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DESIGN AND CONSTRUCTION OF A DC-TO-DC CONVERTER FOR ELECTRIC VEHICLE APPLICATION

By

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LIST OF ABBREVIATIONS

A	Ambient atmosphere
BDC	Brush type DC motor
BDCM	Brushless DC motor
BJT	Bipolar junction transistor
B_m	Motor viscous friction constant N.m./rad/s
B_L	Load viscous friction constant N.m./rad/s
C	Collector
C_T	Oscillator capacitor (Farad)
D	Duty cycle, or diode general symbol
E	Emitter
E_a	Armature induced Emf. (Volt)
Emf	Electromotive force (Volt)
EV	Electric vehicle
f	Frequency (H_Z)
f_c	Corner frequency (H_Z)
f_s	Switching frequency (H_Z)
FWD	Free wheeling diode
G	Gate
GTO	Gate turn-OFF thyristor

I	Current flow in Ampere
I_a	Armature current (A)
I_c	Collector current (A)
I_f	Field current (A)
I_g	Gate charging current (A)
I_p	Peak current (A)
I_{pp}	Peak-to-Peak current (A)
I_v	Valley current (A)
IGBT	Insulated gate bipolar transistor
ICE	Internal combustion engine
J	Junction area
J	Rotational inertia ($Kg.m^2$)
J_c	Dissipated conduction energy (Joules)
J_L	Load rotational inertia ($Kg.m^2$)
J_c	Motor rotational inertia ($Kg.m^2$)
K_f	Generated volts per field ampere
K_ϕ	The generated volts per radian/sec or torque per ampere
l	Conductor length
L	General inductance symbol (Henry)
MCT	MOS controlled thyristor
MOSFET	Metal-oxide silicon field effect transistor.

Ni-Cd	Nickel-Cadmium
Ni-Fe	Nickel-Iron
Ni-MH	Nickel-Metal Hybrid
P_a	Armature generated electric power (W)
P_c	Conduction power loss (W)
P_m	Shaft mechanical power (W)
P_s	Switching power loss (W)
P_t	Total power dissipation (W)
PCB	Printed circuit board
Q	Charge (coulomb)
R	General symbol for the electrical resistance (ohms)
R_{sh}	Current shunt resistance (ohms)
R_θ	Thermal resistance (^{o} C/W)
S	Heat sink
SDC	Step down converter
SITH	Static-Induction thyristor
T	General symbol for the temperature (^{o} C) , thyristor symbol
T_{em}	Motor electromagnetic torque (N.m)
T_j	Junction temperature (^{o} C)
T_{WL}	Load working torque (N.m)
V	General symbol for the Voltage measured in (Volts)
ZCS	Zero current switching

ZVS	Zero voltage switching
ϕ	Flux per pole , in webers
τ	Time constant
ω_m	Mechanical angular rotational velocity radians/sec.

Abstract of Thesis Submitted to the Senate of Universiti Putra Malaysia in Fulfillment of the Requirements for the Degree of Master of Science.

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October 1998

Chairman: Dr. Ir. Norman Mariun

Faculty: Engineering

A DC-to-DC converter has been designed to control the speed of a DC motor for electric vehicle application. The power circuit of the converter consists of transistorised power switches (IGBTs) to step-down the voltage to the level required by the speed and load demand. The series shunt resistor method is used to control the current and keep it below the maximum rate of the power transistors and the motor especially at the starting point. The transistor gate drive circuit was designed to provide the maximum isolation between the power and the control circuits.

A controller chip originally used to control a three phase brushless DC motor is programmed and modified to control a brushed DC motor. This

controller chip provides the pulse width modulation (PWM) control signal in order to drive the power switches at fixed frequency and variable duty cycle. Moreover using this chip a control over the current flow through the power circuit could be achieved, this will protect the circuit from any faulty conditions taking the benefit of Cycle-by-Cycle current detection.

Abstrak bagi tesis yang diserahkan kepada Senat Universiti Putra Malaysia bagi memenuhi Syarat Penganugerahan Ijazah Sarjana Sains.

REKABENTUK DAN PEMBINAAN PENUKAR ARUS TERUS KE ARUS TERUS UNTUK APLIKASI KENDERAAN ELEKTRIK

Oleh

EYAD MOH'D RADWAN

Oktober 1998

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Sebuah penukar arus terus ke arus terus telah direka untuk mengawal kelajuan sebuah motor arus terus untuk aplikasi kenderaan elektrik. Litar bekalan kuasa bagi penukar tersebut terdiri daripada beberapa suis kuasa bertransistor (Transistor Dwikutub Get Tertebat – *IGBT*) untuk merendahkan voltan kepada suatu peringkat yang diperlukan oleh kelajuan dan beban. Kaedah perintang pirau siri digunakan untuk mengawal arus dan untuk mengekalkannya supaya berada di bawah kadar maksimum bagi transistor kuasa dan motor terutama sekali pada peringkat permulaan. Litar pemacu get transistor telah direka untuk menghasilkan pemencilan yang maksimum antara litar bekalan kuasa dan litar kawalan.

Pada asalnya, cip pengawal digunakan untuk mengawal satu motor tiga fasa tanpa berus tapi kemudiannya diprogramkan dan diubah suai untuk mengawal satu motor arus terus yang mempunyai berus. Cip pengawal ini menghasilkan isyarat kawalan lebar denyut pemodulat (PWM) untuk memacu suis-suis kuasa pada frekuensi yang tetap dan kitar kerja boleh ubah. Selain daripada itu, pengawalan arus menerusi litar bekalan kuasa juga boleh dicapai dengan penggunaan cip tersebut. Oleh itu, ia dapat melindungi litar daripada sebarang keadaan kerosakan dangan menggunakan kaedah pengesanan arus secara kitar demi kitar.

CHAPTER I

INTRODUCTION

There have been growing interests in electric vehicles (EV) in the past 15 years particularly since 1985. The recent EV developments were mainly simulated by the environmental concerns (Chang, 1993). Because of the up coming shortage of gasoline products, the cost, and supply of them have encouraged the people to look at the EV as a possible alternative mode of transportation.

As electricity can be generated from many alternate energy resources EVs are the ultimate flexible fuel vehicle, more over they are generally recharged when the power utilities have excess energy available.

Basically an electric vehicle consists of (1) a battery pack that provides the power, (2) an electric motor, and (3) a controller unit that regulates the energy flow to the motor per instruction provided by the driver. The controller and the motor will be the main two parts discussed and analysed in this dissertation.

The demand for control of the electric power for the electric motor drive system and industrial controls exists for many years, and this led to the early development of the Ward-Leonard system to obtain a variable DC voltage for control of DC motor drives. Power electronics have revolutionised the concept of power control for power conversion and for control of electrical drives.

DC motors have variable speed characteristics and are used extensively in variable-speed control over a wide range. The methods of speed control are normally simpler and less expensive than that of AC drives. Both series and separately excited DC motors are normally used in variable-speed drives. However series motors are traditionally employed for traction applications. Due to the commutator, DC motors are not suitable for very high-speed application and require more maintenance than the AC motors do, however from this point of view DC motors are common for the EV applications a speed about up to 7000 rpm could be obtained from some DC motor types.

DC drives can be classified in general into three types,

(1) Single phase drives.

(2) Three phase drives.

(3) Chopper drives.

Single phase and three phase drives are based on converting (rectifying) the AC voltage into DC voltage using either single phase or three phase rectification circuits. However choppers are used to control unregulated DC input and supply regulated DC output.

The step-down chopper (converter) topology would be used to provide a regulated output voltage to control the speed of the DC motor. The average output voltage would be controlled using the pulse width modulation (PWM) techniques; at a fixed frequency and variable duty cycle.

This dissertation presents the initial work of providing the required facilities for a DC-to-DC converter for commutator series excitation DC motor control. In addition a scheme of open loop speed control of the series DC motor is presented. The design of the control circuit using the MC33033p controller produced by Motorola, and the power circuit using the IGBTs produced by IRF are provided. The dissertation is organised in the following manner.

In chapter Two, a literature review of the importance of the electric vehicle and the recent developments, the electric vehicle drive train types, and the main components are discussed in brief. A general study for the DC-to-DC converter including, the low power control circuit, and the basic power circuit configuration is also presented. In chapter Three, the materials and methods used in the control circuit design is provided and analysed, including the gate drive technique, the monitoring and the protection circuits. The high power circuit design and analysis is provided as well.

Chapter Four demonstrates the test results obtained from the output of the DC-to-DC converter and the control circuit. The discussion of the results is included in the respective chapter.

Conclusions about the research work associated with this dissertation are presented in Chapter Five. Suggestions of further research related to this topic are also included in this chapter.

CHAPTER II

LITRATURE REVIEW

The Electric Vehicle System

The electric vehicle (EV) offers one of the best solutions for improving air quality while reducing the reliance on fossil fuel to power the vehicles. The use of EVs remains limited, because of their driving performance has been very poor and cost has been too high. In order for an EV to be accepted in society, EV design should take advantage of attributes which could only be incorporated into EVs, such as lower maintenance, quieter and easier driving.

Until now most of the electric vehicles have been converted from existing internal combustion engine vehicles. The converted EVs have the characteristics that they are easy to produce, and are less expensive to develop. However, there was a serious problem that it is difficult to make the vehicle performance higher, because it is impossible to design by taking the advantage of the converted electric vehicles (Brant, 1994)

On the other hand some of the grand-up designed EVs have been produced, the IZA, and the general motors IMPACT are examples. These EVs achieved remarkably high performance. For instance, in the IZA the mileage per one charge, on 100 Km/h recorded 270 Km. It accelerates 0-to-400m within 18 seconds and its highest speed is 176Km/h (Chan, 1993).

System Technology

The EV system is an integration of vehicle body (chassis, exterior, interior), drive train (motor, controller's transmission, brakes, sensors), energy storage (battery), safety system and auxiliaries. The technologies involved are diversifi

electrical and electronic engineering, mechanical and automotive engineering, and chemical engineering. The philosophy and architecture of the system are of prime consideration. System integration and optimisation enables perfect matching among subsystems, bearing in mind that the components used in the EV are working in mobile and severe temperature conditions. A thorough study on the degree of significant of interaction among subsystems, components that affect vehicles cost, performance, safety and other objectives should be performed in order to achieve overall optimisation. The energy management in EV systems is of capital importance which controls and regulates the energy flows within the vehicle with aims of using the energy from batteries as economical as possible and recharging the batteries more convenient and efficient.

Based on the concept of multi-energy system, the batteries can be normally charged up at night or quicker charged up in short period using the dedicated super quick charger. During deceleration battery charging can be performed through regenerative braking. They also can be charged by solar energy using the solar cells embedded in the vehicle roof (Chan, 1993).

Because of the energy densities of storage batteries are so much smaller than that of the fuel of the internal combustion engine (ICE), a larger number of batteries should be used to assure a certain level of power performance. However, mounting a vehicle with a larger number of batteries require various types of trade-off. For instance, it reduces the interior space and luggage space; the resulting increase in vehicle weight sacrifices acceleration and other areas of performance; and the cost of the vehicle also rises.

Body Technology

The consistent weight-saving design of EVs is very important, which directly affects the performance of EVs. The EV body is of a hybrid design, possibly consisting of supporting aluminium structure which is light and very rigid, and plastic outer skin. The EV suspension is purposely designed to attain simplicity and very light weight.
Low drag coefficient body design can effectively reduce the aerodynamic resistance of the body. In general it is more difficult to reduce the drag coefficient as the vehicle length is shortened. However the aerodynamic resistance can still be reduced through a good balance among the following features, tapering of the front and the rear ends, fl

under floor design, adoption of an undercover optimisation of air flow around the front and rear windows, and slanted front nose design. The drag coefficient of GM IMPACT reached 0.19, which is among the lowest figure in present EV (Chan, 1993).

Low rolling resistance tyres are particularly effective in reducing running resistance at low and medium driving speeds and play an important role in extending the range of EVs in city driving. This has been achieved through the use of a newly developed blended tyre polymer, together with an increase in tyre pressure. The rolling resistance of GM IMPACT is 0.0048 which is about the half that of conventional tyres.

EV Propulsion Technology

An electric propulsion system is the heart of EVs. Its function is to transfer with high efficiency the electrical power from the battery to the mechanical power of moving elements. From functional point of view, an electric propulsion system can be divided into two parts namely the electrical and mechanical parts. As shown in Figure 2.1 the electrical part consists of the following sub-systems:

(1) Electric motor,

(2) Power electronics, and

(3) Electronic control.

On the other hand, the mechanical part includes these sub-systems:

(1) Transmission device, and

(2) Moving elements.