ELECTRIC VEHICLE POWER OPTIMIZATION STRATEGIES

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ELECTRIC VEHICLE (EV) POWER OPTIMIZATION STRATEGIES

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A report submitted in partial fulfillment of the requirement for the degree

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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I declare that this report entitle “Electric Vehicle (EV) Power Optimization Strategies” is the result of my own research except as cited in the references. The report has not been accepted any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

The rising concern about the global warming, emission of the hazardous gases and limited sources of the fossil fuel has made an electric vehicle one of the most topics that catch the attention of the researchers and automotive companies. However, as everyone concern, electric vehicle is driven or powered by the rechargeable battery that can only withstand certain period of time and the time taken for battery to be fully charged will take quite a long time. Therefore, in this project, the power consumption of the electric vehicle will be calculated and predicted. This will assist the driver to predict how long the vehicle can travel before the battery needs to be charged again. There are two variables that are manipulated in the calculation, the speed of the vehicle and also the gear used. Based on the two parameters, the driver can devise a strategy to optimize the power consumption of the vehicle by selecting the most suitable speed and gear when driving. Besides, this project is focusing on the algorithm development and there will be no simulation or hardware implementation involved. The calculation involves several types of the forces which includes the rolling resistance force, aerodynamic drag resistance force, climbing and downgrade resistance force and also the acceleration force. Beside the forces, the slopes of the roadway are also taken into consideration since the angle of elevation of the roadway is significantly affect the accuracy of the calculation. As a result, the power consumption of the vehicle can be predicted and therefore, the driver can estimate how far the vehicle can travel with fully charged battery. In additions, the driver also can choose the right strategy in order to optimize the power consumption.

ABSTRAK

Kesedaran yang semakin meningkat terhadap isu pemanasan global, pembebasan gas merbahaya dan sumber bahan api yang terhad telah menyebabkan kenderaan elektrik menjadi salah satu topik yang berjaya menarik perhatian para penyelidik dan juga syarikat-syarikat automotif. Walau bagaimanapun, seperti yang semua sedia maklum, kenderaan elektrik dikuasakan oleh bateri yang perlu dicas dan hanya mampu bertahan dalam tempoh masa yang tertentu sahaja serta mengambil masa yang agak lama untuk dicas sepenuhnya. Oleh itu, projek ini memfokuskan kepada pengiraan penggunaan kuasa oleh kenderaan elektrik dan pengiraan ini akan membantu para pemandu untuk meramal berapa lama dan jarak kenderaan itu boleh bergerak sebelum ianya kehabisan tenaga dan perlu dicas semula. Terdapat dua pemboleh ubah yang dimanipulasikan dalam pengiraan penggunaan kuasa kenderaan elektrik ini. Pemboleh ubah tersebut ialah kelajuan kenderaan dan juga pemilihan gear yang digunakan semasa memandu. Berdasarkan kedua-dua parameter tersebut, pemandu dapat membuat strategi pemanduan bagi mengoptimumkan penggunaan kuasa kenderaan dengan memilih kelajuan yang sesuai dan membuat pemilihan gear yang betul ketika memandu. Selain itu, projek ini memberi tumpuan kepada pembangunan algoritma sahaja di mana simulasi serta pelaksanaan prototaip tidak diambil kira. Pengiraan penggunaan kuasa kenderaan elektrik ini membabitkan beberapa jenis daya termasuklah daya rintangan putaran, daya rintangan aerodinamik, daya rintangan memanjat dan menurun serta kuasa pecutan. Selain daripada daya-daya yang dinyatakan, tahap kecerunan jalan juga diambil kira. Hal ini kerana sudut jalan juga memberi kesan kepada ketepatan pengiraan yang dilakukan. Hasilnya, penggunaan kuasa kenderaan tersebut dapat diramalkan dan oleh itu, para pemandu dapat mengagak berapa lama kenderaan tersebut mampu bergerak sebelum perlu dicas semula. Selain itu, pemandu juga dapat menggunakan strategi yang sesuai untuk menjimatkan penggunaan kuasa bateri kenderaan. Strategi yang dimaksudkan ialah pemandu memilih penggunaan gear yang yang bersesuaian dengan kelajuan yang dibawa.

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LIST OF ABBREVIATIONS

UTeM	Universiti Teknikal Malaysia Melaka
EV	Electric Vehicle
ICE	Internal Combustion Engine
PM	particulate matter
HC	hydrocarbons
NO_X	nitrogen oxides
CO	carbon monoxide
SO_2	sulphur dioxide
EVs	Electric Vehicles
BMS	battery management system
kW	kilowatt
hp	horsepower
IC	internal combustion
DC	direct current
PLUS	Projek Lebuhraya Utara Selatan
JKR	Jabatan Kerja Raya

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BAKGROUND

The environmental concerns, energy challenges and the economical issues have urged the automotive industry to develop a clean and efficient as well as sustainable vehicle for urban transportation. Since then, the automotive industry becomes very proactive in the production of vehicles with an alternative energy to replace the conventional types of vehicles which mostly were driven by the gasoline. As a result, the alternative vehicles like electric vehicle (EV) and hybrid vehicles have been introduced and keep on evolving every day [1].

Recently, EVs have become the focus in research compared to all types of the vehicles. This is because EVs provide the means for a clean, efficient and environmentally friendly urban transportation system since it is powered by alternative energy sources and enabled by high-efficiency electric motor and controller.

Even though EVs are capable of curbing the pollution problem in a very efficient way, it does have its own disadvantages. It cannot travel in a long distances on one full charge of the battery-pack. In addition, the battery-pack itself is very expensive and the time required to recharge the battery is longer compared to filling up a tank gas. Besides EVs also have low energy density.

1.2 PROBLEM STATEMENT

Nowadays, people are more concern about the environment. The usage of fuel such as petrol and diesel to drive the vehicles is not a good choice since the combustion of the fuel produce a lot of pollutant. These pollutants then lead to the greenhouse effect and cause the increase in the temperature of the earth. Besides, fuel can be categorized as a non-renewable energy and will extinct in the future. Therefore, in order to overcome those problems, EV have been invented as an alternative and attractive solution. However, the EV depends solely on the battery as the main source to drive the vehicle and this battery require much longer time for recharge if compared to filling up a gas tank. Besides, the driver also need an additional way to assist and alert them on how longer does the battery can withstand before it needed to be recharged. Therefore, in this study, the power consumption of the electric car are be calculated and the strategy to optimize the power consumption of the EV are proposed based on the analysis of the factors that affect the power consumption of EV.

1.3 **OBJECTIVES**

The objectives of this project are:

1. To calculate the power consumption of the EV with given roadway profile
2. To analyze the strategy that can optimize the power consumption of EV

1.4 **SCOPE OF PROJECT**

This project will focus on the calculation of the power consumption of the EV based on the algorithm only. The prediction of the power consumption is essential in order to know how long the battery of the vehicle can withstand and through that, the strategies to optimize the power consumption of the batteries can be done. The parameters involved in the calculation are the rolling resistance force, aerodynamic drag resistance force, climbing and downgrade resistance force and also the acceleration force. There are three factors that are taken into consideration during the calculation which are the acceleration of the vehicle, the slope of the roadway and also the changes of the gear throughout the driving. The journey for the calculation starts from Universiti Teknikal Malaysia Melaka (UTeM) to Petronas Twin Tower and the total journey roughly about 136km. However, the simulation and hardware implementation of the EV will not be covered in this project.

1.5 REPORT OUTLINE

This report consists of five chapters. Chapter one is "Introduction" part. This chapter discuss about the project background, problem statement, objectives and lastly the scope of the project.

Chapter two is about the "Literature Review". This chapter describe about the theory of the EV and also the past research or study that have been carried out and published. Besides, this chapter also summarizes the ideas of others that are related to this project.

Chapter three is the "Methodology" section. It includes about the calculation of the power consumption of the EV by using the algorithm only. There is no simulation or hardware implementation involves.

"Results and Discussion" is in chapter four. In this chapter, the results from the calculation are analyzed to know the power consumption of the EV.

Chapter five is the "Conclusion and Recommendation". This chapter concludes the outcome of the project and recommendation to improve the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO ELECTRIC VEHICLE

EV is a new technology that has been rapidly developed. This technology gets the attention due to awareness to the environment and the facts that fuel is non-renewable energy and EV is able to curb the pollution problem since it does not have emission of pollutant. Therefore, EV has become the alternative way to overcome those problems.In order to be classified as an EV, the vehicle must have the following features:

1. The energy source is portable and electrochemical or electromechanical in nature
2. Traction effort is supplied only by an electric motor

The block diagram of an EV system driven by a portable energy source is shown in Figure 1. The electrochemical energy conversion linkage system between the vehicle energy source and the wheels is the powertrain of the vehicle. The powertrain has electrical as well as mechanical components [3].

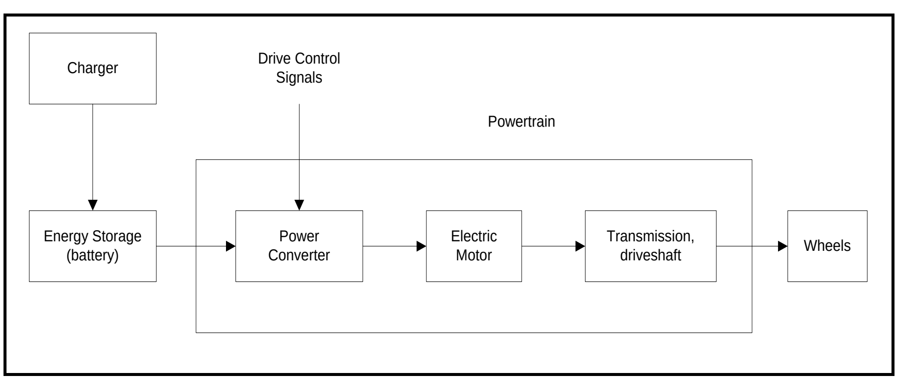

Figure 1: An Electric Vehicle System

The energy storage device like battery –pack stores the fuel for the EV for energy delivery on demand. The primary source of energy for electricity generation for EVs is varied, ranging from fossil fuel to solar-based energy. For the battery-based EV, the electric power transmission system is the system required in order for the fuel to be delivered in the form of electricity to the vehicle. As for solar EVs, the solar panel and a power converter is used to charge the batteries on the vehicle. The special feature of these EVs is that these are zero emission vehicles (ZEVs) as far as pollution within the vehicle is concerned [3].

2.1.1 ELECTRIC VEHICLE COMPONENTS

The system for the automobile is very complex. This is due to numerous hardware component and software algorithms interconnected through mechanical links and electrical communications network. The system level design extends to intricate details of subsystem or component design in the automobile design. The system design fundamental includes the physics of motion, energy, power and the energy conversion principle. The primary hardware components for automobile are the energy conversion and the power transmission devices.

Internal combustion (IC) engine, energy storage device and electric machine are the primary energy conversion devices for EV. IC engine is a heat engine that converts chemical energy to mechanical energy. As for electric machine, it can be used either as motor or generator. The electrical energy will be converted as mechanical energy in a motor state and in contrast, the mechanical energy will be converted to electrical energy once it is used as generator.

The energy storage devices and electrical-to-electrical power or energy conversion is very important in EVs and the most common energy storage device for EV is a high-energy capacity battery pack. In order to control the electric machine and also to deliver the power required and as requested by the demands and feedback signals, electric drive is needed. The drive is electrical to electrical energy conversion devices that convert steady voltages with fixed frequency. The results from the conversion are variable voltage supply for the electric machine.

The drives also can process the electrical power in other way round when the machine operates as generator. In order to convert the high voltage to low voltage levels convert the DC other way round, DC-DC converter is required. This converter can be bidirectional and it is made up from power electronic devices and energy storage inductors. This component is very important and it acts as the key component for the fuel cell interface with electric motor drive.

Powertrain is the path for the flow of energy in a vehicle starting from the energy source and ends at the wheels with the deliver propulsion. In EV, the power transmission path is electrical except for the coupling devices between the wheels and electric propulsion motor. This path is known as electric power transmission path as shown in Figure 2. The difference of this path compared to IC energy vehicle is the power and energy flow can be directional. This means that when the vehicle brakes to slow down or stops, the kinetic energy is processed back to energy storage device.

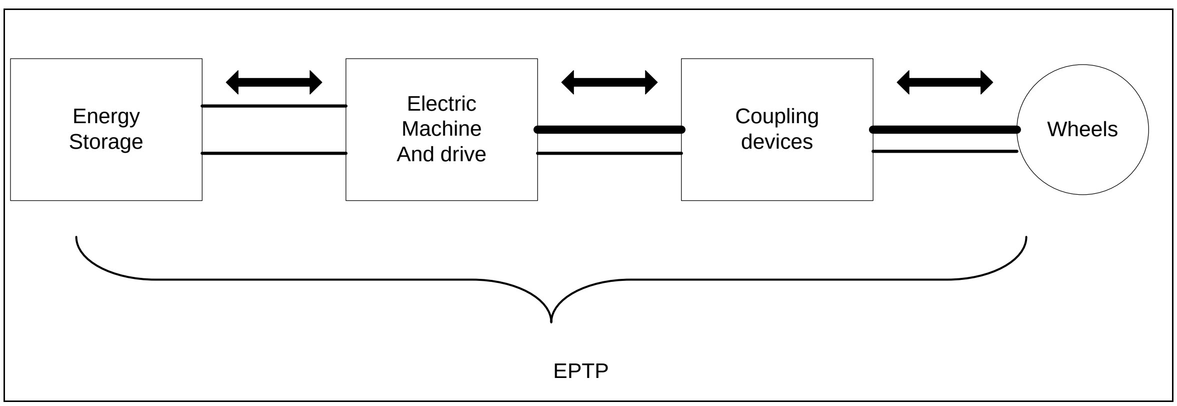

Figure 2: Power transmission path in an EV

2.1.2 **ELECTRIC MOTOR AND RATINGS**

Electric motor capability is described by using kilowatt (kW) or horsepower (hp) ratings. Rated power is the power that an electric motor can continuously deliver without overheating, which is typically a derated figure. The motor can deliver two to three times the rated power within a short period of time. Because of that, higher power and torque is available from an electric motor for acceleration and the torque can be maximum under stall condition which is at zero speed.

The types of the motor determines whether maximum torque is availabe at zero speed or not. High torque is available at The peak or rated power from a motor is obtained at base speed (ω_b) when the motor characteristics enter the constant power region from constant torque region once the voltage limit of the power supply is reached.

The motor rated speed (ω_{rated}) is at the end of the constant power region. High torque is produces by electric motor even at zero speed and typically, it has constant power characteristics over a wide speed range. Because of that, electric motor can be attached directly to the drive wheels to accelerate the vehicle from zero speed to its maximum speed. Therefore, the speed of the vehicle and the motor can be controlled directly through the power electronic converter feeding the current into the motor. Essentially, there is no requirement for a transmission with an electric motor other than a fixed gear for appropriately sizing the motor.

There are several important characteristics of an EV motor. They includes the flexible drive control, fault tolerant, high efficiency and low acoustic noise. Besides, the motor drive also should be able to handle voltage fluctuations from the source.

2.2 RELATED PREVIOUS WORK

The research paper by Haddoun, Benbouzid, Diallo, Abdessemed, Ghouili and Srairi entitle “A Loss Minimization DTC Scheme for EV Induction Motors” proposes a strategy to minimize the losses of an induction motor propelling an EV. The proposed control strategy is based on a direct flux and torque control scheme. The stator flux is utilized as a control variable and the flux level is selected in accordance with the torque demand of the EV to achieve the efficiency-optimized drive performance [2].

Since the vehicle dynamics influenced the energy efficiency, the EV dynamics are taken into account in the research. There are several forces that are included for the vehicle dynamics analysis follows:

Nomenclature:

F_ω	Road Load
F_{ro}	Rolling resistance force
F_{sf}	Stokes' force or viscous friction force
F_{ad}	Aerodynamic drag force
F_{cr}	Climbing and drag force
P_v	Vehicle driving power

Mathematical equation:

$$F_\omega = F_{ro} + F_{sf} + F_{ad} + F_{cr} \tag{2.1}$$

where;

$$F_{ro} = \mu mg \cos \alpha \tag{2.2}$$

$$F_{sf} = k_A \upsilon \tag{2.3}$$

$$F_{ad} = ½\, \xi\, C_\omega A_f (\upsilon+\upsilon_o)^2 \tag{2.4}$$

$$F_{cr} = \pm\, mg \sin \alpha \tag{2.5}$$

Besides, the formula for the power required to drive a vehicle in the motor ratings and transmission also provided as below:

$$P_v = \upsilon F_\omega \tag{2.6}$$

In the paper "High Level Optimization of Electric Vehicle Power-Train with Doehlert Experimental Design" written by Jaber, Fakhfakh and Neji, an optimization is reported for the determination of Time Response (T_r) and Power (P) of EV. Several factors that are able to influence the T_r and P are selected. They are back-electromotive-force, stator d- and q- axes inductances, switching period, battery voltage stator resistance and torque gear ratio [4].

Figure 3 shows the chain of electric traction. The traction chain determines the performance of EV. High level modeling of electric traction chain is described using VHDL – AMS and it is then simulated using Simplorer 7.0 software.

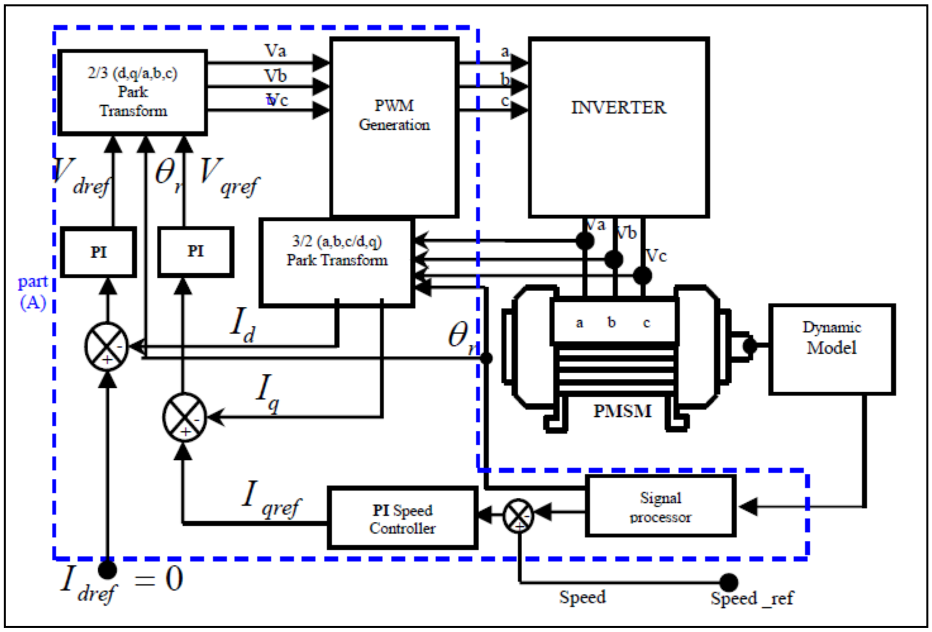

Figure 3: Example model of traction chain

Besides, in this paper, simple motion equation is derived in order to discuss the ecological driving of an electrical vehicle. In order to maintain the simplicity, acceleration resistance is the only resistance that is taken into consideration. Other resisting forces like rolling, aerodynamics and incline force are neglected. Figure 4 illustrates one wheel model used in order to derive the simple mathematical model of the EV.

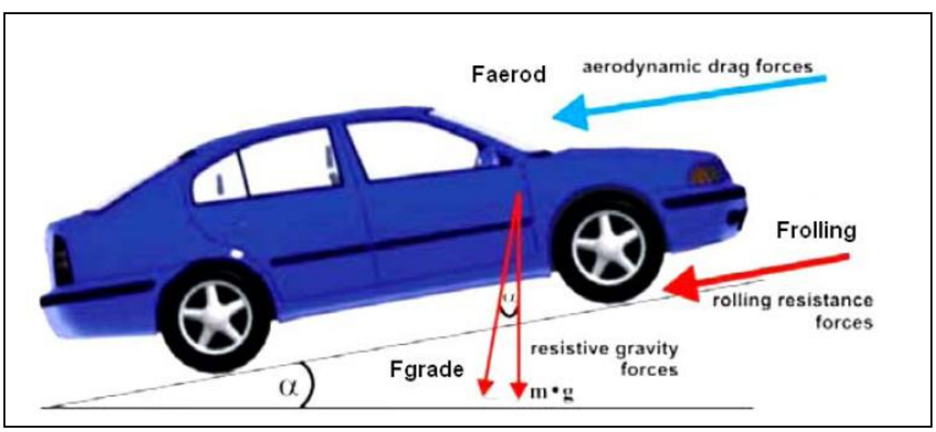

Figure 4: Forces on a Vehicle

Nomenclature:

$F_{rolling}$	Rolling force
F_{aerod}	Aerodynamics force
F_{grade}	Incline force
P_a	Power EV must develop at stabilized speed
P_m	Power available in the wheels
γ	Acceleration of the vehicle (s-2)
T_1	Load torque (N.m)
W_m	Angular speed of the motor (rad/s)
f	Coefficient of rolling friction
Mv	Total mass of the vehicle (kg)
g	Acceleration of terrestrial gravity (m/s^2)
l	Density of the air (kg/m^3)
S	Frontal surface of the vehicle (m^2)
Cx	Drag coefficient of the vehicle
V	Speed of the vehicle (m/s)
α	Angle that make the road with the horizontal (in °)
r_m	Torque gear ratio
R_{wheels}	Wheels radius (m)
T_{em}	Electromagnetic torque of the motor (N.m)
T_l	Load torque (N.m)

Mathematical model:

$$F_{rolling} = f \times M_v \times g \quad (2.7)$$

$$F_{aerod} = ½. l.s.c_x.V^2 \quad (2.8)$$

$$F_{grade} = M_v.g \sin\alpha \quad (2.9)$$

$$P_a = V. (F_{rolling} + F_{aerod} + F_{grade}) \quad (2.10)$$

$$P_m = T_{em}. r_m. (V/R_{wheels}) \quad (2.11)$$

Based on the fundamental principle of dynamics, an acceleration of the vehicle is given by:

$$\gamma = (P_m - P_a / M_v V) \tag{2.12}$$

$$\gamma = [T_{em} . r_m - R_{wheels} . (F_{Rolling} + F_{aerod} + F_{grade}) / M_v . R_{wheels}] \tag{2.13}$$

$$T_1 = R_{wheels} . (F_{Rolling} + F_{aerod} + F_{grade}) \tag{2.14}$$

$$W_m = (r_m / R_{wheels}) . (d\gamma / dt) \tag{2.15}$$

EV with high energy efficiency have been develop since fuel consumption has been a key issue in the performance of cars in recent years. However, EV has small battery energy stored. This caused problems related to the running distance per charging, long charging time and many more.

Therefore, Tanaka, Ashida, and Minami have produced a paper concerning “An Analytical Method of Electric Vehicle Velocity Profile Determination from Power Consumption of Electric Vehicles”. In this paper, a method to obtain the performance of the EV from the equations between the measured acceleration, a and the input or the regenerated electric power, P is described analytically. This method is used because it can demonstrate possibilities to predict the performance of EVs using stored electric energy and the driving root [7].

The equations or the mathematical model involved in this analytical are:

Nomenclature:

F	Force [N]
F_a	Acceleration resistance
F_r	Rolling resistance
F_k	Air resistance
F_t	Inclination resistance
p	Output power
ηP	Input efficiency
η	Efficiency