DESIGN AND CONTROL OF ELECTRIC VEHICLE CHARGER

ZULAILAH BINTI ZAKARIA

UNIVERSITI TEKNOLOGI MALAYSIA

DESIGN AND CONTROL OF ELECTRIC VEHICLE
CHARGER

ZULAILAH BINTI ZAKARIA

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical – Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2015

Dedicated to my beloved husband

Mohd Dhiauddin bin Abu Samah

Son

Muhammad Ammar Danish bin Mohd Dhiauddin

Parents

Zakaria bin Mohd

Zainab binti Yahya

Siblings

Zubaidah binti Zakaria

Nor Asiah binti Zakaria

Mohd Zalani bin Zakaria

Nurul Aina Rashada binti Zakaria

Aini Sufiah binti Zakaria

Abdul Wahid Qamarussalam bin Zakaria

Muhammad Amirul Syakirin bin Zakaria

and

All my friends in MEP programme

for their support and encouragement

ACKNOWLEDGEMENT

My greatest gratitude and appreciation to my supervisor Dr Tan Chee Wei for his patience, knowledge, guidance and encouragement throughout the duration of completement for this project.

My sincere appreciation also goes to my family especially my dearest husband, Mohd Dhiauddin bin Abu Samah and my lovely son, Muhammad Ammar Danish bin Mohd Dhiauddin, who has been so tolerant and supportive in all years either morally or financially. Special thanks also give to my parents, siblings and family in law for their continuous encouragement, love and emotional supports that they had given to me all this while.

I would also like to extend my appreciation to all my lecturers and all my friends from Universiti Teknologi Malaysia for their constructive criticism, ideas and support in completing this dissertation.

Thank You.
Wassalam

ABSTRACT

Nowadays, the demand for electric vehicle (EV) production increases because this type of transportation provides an alternative to the conventional vehicle that uses power by fossil fuels and reducing the dependence on use of gasoline. Moreover, EV also is introduced in car sharing and mobility concept to overcome traffic congestion problem in the urban area. In order to familiarize with the process of the EV charger, an on-board EV charger is designed with introduction of some controllers for controlling charging process. The topology consist of two stages of conversion, which the first part for AC/DC conversion and power factor correction (PFC) while the second part for DC/DC conversion and galvanic isolation. In order to control the first part, a small signal model for PFC boost is introduced to control the output voltage and input current. This PFC boost controller is designed using PI control and designed to control two loops. The loops are voltage control loop (known as outer loop) and current control loop (known as inner loop). For the second stage, the constant current charging method is introduced to control the charging process of an on-board EV charger within its specification limit. The simulation is done with the help of MATLAB software and the result from Simulink will demonstrate the effectiveness of the design and its implementation. Furthermore, the proposed design of the EV charger reduces the percentage of THD and produce unity power factor that contributes in the stability for the EV charger.

ABSTRAK

Pada masa kini, permintaan bagi pengeluaran kenderaan elektrik (EV) meningkat kerana pengangkutan jenis ini menyediakan alternatif kepada kenderaan konvensional yang menggunakan bahan api fosil dan mengurangkan kebergantungan kepada pengunaan petrol. Tambahan lagi, EV juga diperkenalkan dalam konsep mobiliti dan perkongsian kereta bagi menyelesaikan masalah kesesakan lalu lintas di kawasan bandar. Bagi menyesuaikan dengan proses pengecasan EV, pengecasan EV bawaan direkabentuk dengan memperkenalkan beberapa pengawal bagi mengawal proses pengecasan. Topologi ini terdiri daripada dua peringkat penukaran, yang mana bahagian pertama adalah penukaran AC/DC dan pembetulan faktor kuasa (PFC) manakala bahagian kedua adalah penukaran DC/DC dan pengasingan galvani. Bagi mengawal bahagian pertama, satu model isyarat kecil untuk peningkatan PFC diperkenalkan bagi mengawal voltan output dan arus input. Pengawal peningkatan PFC ini direka bentuk menggunakan pengawal PI dan direka bentuk bagi mengawal dua gelung. Gelung-gelung ini adalah gelung kawalan voltan (dikenali sebagai gelung luaran) dan gelung kawalan arus (dikenali sebagai gelung dalaman). Bagi peringkat kedua, arus tetap diperkenalkan untuk mengawal proses pengecasan EV bawaan dalam had spesifikasi yang dibenarkan. Simulasi ini dibuat dengan bantuan perisian MATLAB dan hasil keputusan dari Simulink akan menunjukkan keberkesanan rekabentuk dan pelaksanaannya. Sebagai tambahan, rekabentuk pengecasan EV yang dicadangkan mengurangkan peratusan THD dan menghasilkan faktor kuasa satu lalu menyumbang kepada kestabilan pengecasan EV terbabit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ICE	-	Internal Combustion Engine
GHG	-	Green House Gas
HEV	-	Hybrid Electric Vehicle
PHEV	-	Plug-In Hybrid Electric Vehicle
EV	-	Electric Vehicle
IEC	-	International Electro technical Commission
SAE	-	Society of Automative Engineers
SOC	-	State of Charge
BEV	-	Battery Electric Vehicle
FCEV	-	Fuel Cell Electric Vehicle
EM	-	Electric Motor
AC	-	Alternating Current
DC	-	Direct Current
EVSE	-	Electric Vehicle Supply Equipment
TBD	-	To Be Define
BSI	-	British Specific Institution
CHAdeMO	-	Charge De Move
V2G	-	Vehicle to Grid
WPT	-	Wireless Power Transfer
OLEV	-	On-Line Electric Vehicle
PI	-	hysteresis controller
PWM	-	Pulse Width Modulation
I	-	Current
V	-	Voltage
P	-	Power

WPS	-	Wireless Power System
EMF	-	Electric Magnetic Field
EVCC	-	Electric Vehicle Charging Controller
EVCMS	-	Electric Vehicle Charging System Management
Ha:mo	-	Harmonious Mobility Network
RFID	-	Radio frequency Identification.
PFC	-	Power Factor Correction
SEPIC	-	Single-Ended Primary-Inductor Converter
THD	-	Total Harmonic Distortion
BMS	-	Battery Management System

LIST OF SYMBOLS

V_s	-	supply voltage
V_o	-	output voltage
f_s	-	switching frequency
Vin	-	input voltage
rms	-	root mean square
f	-	frequency
D	-	duty ratio
L	-	inductance
C	-	capacitance
R	-	resistance
L_{min}	-	minimum inductance
r	-	output voltage ripple

CHAPTER 1

INTRODUCTION

1.1 Background

The conventional transportation that used fossil fuel as internal combustion engine (ICE) was a major contributor to air pollution issues where it's produced around 40% of Green House Gas (GHG) emission [1]. In order to reduce the air pollution percentage and decreased the oil dependence, here comes research in electric vehicle, where this type of transportation provides an alternative to vehicle power by fossil fuels and decrease the dependence on gasoline. Electric vehicle, usually are referred to usage of batteries to power up either its motor, auxiliary devices or both conditions.

The types of vehicles using electric vehicle technology were divided into three main categories: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and all electric vehicles (EVs) [2,3]. The HEVs used both gasoline engine and an electric motor to power up the vehicles. Through gasoline engine, the ICE drives an electric generator that produces power for charging the batteries and driving the electric motor. The plug-in electric vehicles were an essential of HEV where it's also provided with a gasoline engine and electric motor.

However the PHEVs have optional to recharge its energy storage system with electricity from the grid. The all electric vehicles were relying mainly on external charge from the utility power grid and did not have an ICE to supply additional power [4]. This all EVs produced zero GHG emission (eco-friendly) and also provide a cleaner environment to the world atmosphere.

Since the EVs were the new invention in the transportation sector, of course, there are some challenge to face through, such as battery cost, interoperability of the charging station, charging strategies and the impact to the grid [5]. These problems need to encounter by a researcher and manufacturer in order to worldwide these kind of new invention for the transportation sector.

1.2 Problem Statement

As there are relatively few electric vehicle chargers in use today, the issues and application of this equipment has yet to discover. The successful development of EVs over the next decade is linked to the introduction of international standards and codes, a universal infrastructure, and associated peripherals and user friendly software for public and private property. The identification of standards for each type of designing EV and the EV charging stations are differes and had been controlled by industry standards. This standard had been classed by their operational characteristics. In order to select the best choice for a given application, the various aspects of electric vehicle charging systems, including its requirement and standard need to understand and deeply clarify to prevent from mischosen condition.

Another critical condition to take into account in development of EVs is the battery charger since the charging time and battery life are linked to the characteristics of the battery charger. A battery charger must be efficient and reliable, with high power density, low cost, and low volume and weight. Its operation depends on components, control, and switching strategies. Charger control algorithms are implemented through analog controllers, microcontrollers, digital signal processors, and specific integrated circuits depending upon the rating, cost, and types of converters. An EV charger must ensure that the utility current is drawn with low distortion to minimize power quality impact and at high power factor to maximize the real power available from a utility outlet [6].

1.3 Objectives of Project

The aim of this research is to design of EV charger based on Malaysia power supply and user profile. This design must follow EVs charging system standard. In order to realize the aim, several objectives are planned to be pursued and executed:

a) To study about the EV charger standards which include plugs, socket outlets, vehicle connectors and vehicle inlets
b) To design the charging requirements based on Malaysia power supply and user profile
c) To simulate the designed of EV charger using constant current charging method

1.4 Scope of Study

In order to achieve the objectives of this project, further studies and research had been done to clarify each type of an EV charging station and its standard (IEC 61851-1/SAE J7172). This understanding of codes and standards for various aspects of electric vehicle charging was the important step in order to select the right EVcharger for a specific type of EV.

The classification of EV battery charger also needs to consider and this EV battery charger can be categorized either on-board or off-board charger with unidirectional or bi-directional power flow. The on-board charger refers to level 1 and level 2 charging system. Meanwhile the off-board charger refers to a level 3 charging system with can be designed for high charging rates and less constrained by size and weight. The on-board charger can be either conductive or inductive mode of charging while off-board charger only conduct in conductive mode. The conductive charging mode uses direct contact between the connector and the charger inlet while an inductive charger transfers power magnetically [7].

The study of design topologies for a standard EV charger also is covered. This design topology includes the usage level of supply connection, type of converters and type of battery for an EV charger. Moreover, the process for charging an EV car also is an important aspect to review in order to get efficient charging for an EV car. This process of charging is divided into two parts of converters with their controller. Part one is to convert from AC supply to DC supply regarding to the source is taken from the grid which is in AC supply. This converter is presented by fullwave rectifier and boost converter. In order to maintain the stability of the grid supply, a controller is designed and apply to the part one design converter. The higher frequency applies from the converter in part one will influence the process of an EV charger regarding to the frequency of battery charger must be equal to the line frequency which is 50 Hz. Therefore, to overcome this problem, part two of design an EV charger which is DC to DC converter is introduced. At this part, the DC input with high frequency is converted to DC output with output frequency of 50 Hz. Then, in order to ensure the design EV charger performs the charging process, the charging method is applied to the design circuit and the performance of the charging is investigated,

Another consideration that must be included in EVs development are discharge and state of charge (SOC) processed [8]. However, these processes do not cover in the circuit simulation of this thesis, but this process is an important step for further development in an EV charger. The battery pack cut-off point is normally determined by a predefined total pack voltage. This pack voltage is with respect to a particular current. As the battery pack undergoes discharge, the coolest cells with less available capacity are discharged further to a lower state of charge than their hotter counterparts. During the discharge, the capacity of the coolest batteries may be reduced enough to force them into a reversal of polarity (i.e., the batteries are reverse charged while the other batteries in the pack are discharged normally). Gradually these repeated over-discharges reduce the battery life. Equalization charges applied to the battery pack balance the batteries. However, the variations in temperature bring back the same discharge and charge limitations as before the equalization.

1.5 Methodology

In methodology process, there are two parts involved to accomplish this project which are theoretical part and simulation part . The first part covers the literature review about electric vehicle, including the charging system, power storage and power distribution need to study and gain more information in order to understand the process of the EV charging system.

For the second part, the topologies of EV charger has been study and later on the parameters of EV charger are determined. After that, the simulation of EV topology for level 2 on-board EV charger had been performed by using Matlab/Simulink Software. This simulation had been performed after some consideration such as circuit identification and parameters involved for EV charging station are clarified.

Hence, the controllers for EV charger are designed to ensure the stability of supply grid and also to maintain constant charge for EV battery. Then the simulation results had been analyzed to ensure that the design of EV charger had followed the specification and standard for the selected type of EV car. The work flow for all steps in this project had been concluded as referred to the Figure 1.1 below.

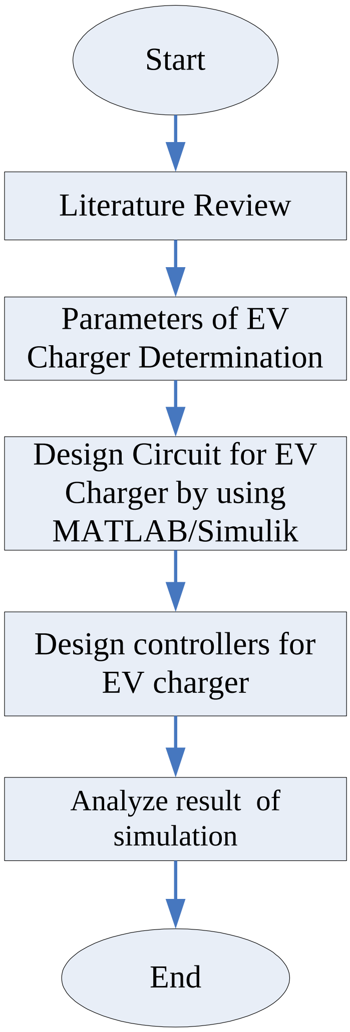

Figure 1.1: The project work flow

1.6 Outline of Thesis

This thesis is divided into five chapters and further explanation of each chapter is outlined for easier review.

- Chapter 1 describes about an introduction. In this chapter, an overview of this project has been discussed which includes background, problem statements, objectives, scopes of work and methodology.

- Chapter 2 explains about the literature review. It presents the EV charging levels and infrastructure, the standard of an EV charger according to the world standard, the topologies of charging system and battery charging strategies.

- Chapter 3 discusses on the chosen topologies for an EV charger of level 2 charging process.

- Chapter 4 explains about results and discussion. In this chapter, the simulation results about the EV charger topologies has been analyzed and discussed.

- Chapter 5 describes the conclusion of the project. The recommendation for future works also suggested in this chapter.

REFERENCES

1. http://kettha.gov.my/portal/index.php
2. Daniel Knutsen and Oscar Willén, "A Study of Electric Vehicle Charging Patterns and Range Anxiety," UPTEC STS13, 2013.
3. Agus Purwadi, Jimmy Dozeno, Nana Heryana, "Simulation and Testing of a Typical On-Board Charger for ITB Electric Vehicle Prototype Application," International Conference on Electrical Engineering and Informatics, ICEEI 2013.
4. Afida Ayob,Wan Mohd Faizal Wan Mahmood, Azah Mohamed, Mohd Zamri Che Wanik, "Review on Electric Vehicle, Battery Charger, Charging Station and Standards," Res. J. Appl. Sci. Eng. Technol., 7(2): 364-373, 2014.
5. Singh M., Kumar P. , Kar I, "A Multi Charging Station for Electric Vehicles and Its Utilization for Load Management and Grid Support," Smart Grid, IEEE Transactions, Vol: 4, Issue: 2, 2013.
6. Arnaldo Arancibia, Kai Strunz, "Modelling of An Electric Vehicle Charging Station for Fast DC Charging," Electric Vehicle Conference (IEVC), 2012.
7. Alireza Khaligh and Serkan Dusmez, "Comprehensive Topological Analysis of Conductive and Inductive Charging Solutions for Plug-In Electric Vehicles," IEEE Transactions on Vehicular Technology, Vol. 61, No. 8, October 2012.
8. G. Joos and M. de Freige Jr, "Design and Simulation of a Fast Charging Station for PHEV/EV Batteries," Electric Power and Energy Conference (EPEC), 2010.
9. Murat Yilmaz and Philip T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles," Power Electronics, IEEE Transactions, Vol: 28, 2013.
10. Siang Fui Tie, Chee Wei Tan, "A Review of Energy Sources and Management System in Electric Vehicles," Elsvier Ltd, 2012.
11. XIE, Wei-dong and LUAN, Wei, "Modelling And Simulation of Public EV Charging Station with Power Storage System," Electric Information and Control Engineering (ICEICE), 2011.

12. SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charger Coupler, SAE J1772.
13. BSI Standars Publication, BS EN 61851 , BS EN 62196.
14. http://www.chademo.com/
15. Chan-Song Lee, Jin-Beom Jeeong, Baek-Haeng Lee, Jin Hur, “Study on 1.5 kW Battery Chargers for Neighborhood Electric Vehicles,” Vehicle Power and Propulsion Conference (VPPC), 2011.
16. I. Stranad, D. Skrlec, T. Tomisa, “A Model for the Efficient Use of Electricity Produced from Renewable Energy Sources for Electric Vehicle Charging,” Energy (IYCE), 2013.
17. Jia Ying Yong, Vigna K.ramachandaramurthy, Kang Miao Tan,Atputharajah Arulampalam, “Modellling of Electric Vehicle Fast Charging Station and Impact on Network Voltage,” Innovative Smart Grid Technologies - Asia (ISGT Asia), 2012.
18. Adam R.Sparacino,Brandon M.Grainger,Robert J.Kerestes, “Design and Simulation of DC Electric Vehicle Charging Station Connected to MVDC Infrastructure,” Energy Conversion Congress and Exposition (ECCE), 2012.
19. Zulhani Rasin and M.F. Rahman, “Grid-connected Quasi-Z-Source PV Inverter for Electric Vehicle Charging Station,” Renewable Energy Research and Applications (ICRERA), 2013.
20. Tianshu Zhang, Wencong Su, Qing Duan, “A Simulation Study of Electric Vehicle Charging in Microgrids,” Power and Energy Engineering Conference (APPEEC), 2013.
21. IEEE Electrification Magazine, Vol 1, Dec 2013.
22. Hideaki Fujibe, Katsumi Kesamaru , “Magnetic Field Analysis of Wireless Power Transfer via Magnetic Resonant Coupling for Electric Vehicle,” International Conference on Electrical Machines and Systems, Oct. 26-29, 20 1 3, Busan, Korea.
23. Sivanand Krishnan et al, “Frequency Agile Resonance-Based Wireless Charging System for Electric Vehicles,” Electric Vehicle Conference (IEVC), 2012.
24. Palakon Kotchapansompote et al, “Electric Vehicle Automatic Stop using Wireless Power Transfer,” IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society, pg 3840 – 3845.

25. Jingook Kim and Franklin Bien, "Electric Field Coupling Technique of Wireless Power Transfer for Electric Vehicles," TENCON Spring Conference, 2013.
26. Hwansoo Moon and Seungyoung Ahn, "Design of a Novel Resonant Reactive Shield for Wireless Charging System in Electric Vehicle," Wireless Power Transfer Conference (WPTC), 2014.
27. Naoki Shinohara, Yuta Kubo, "Wireless Charging for Electric Vehicle with Microwaves," ElectricDrives Production Conference (EDPC), 2013.
28. Seungyoung Ahn and Joungho Kim, "Magnetic Field Design for High Efficient and Low EMF Wireless Power Transfer in On-Line Electric Vehicle," Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on 2011, Pg: 3979 – 3982.
29. Su Y. Choi et al. , "Generalized Active EMF Cancel Methods for Wireless Electric Vehicles," Power Electronics, IEEE Transactions, Vol: 29, 2014.
30. Li-ke Gao, Ke Zhou, Wen-ji Zhu and Zhi-ding Wu, "Design of Energy Feedback Mode Wireless Charging System for Electric Vehicles," Industrial Electronics and Applications (ICIEA), 8th IEEE Conference, 2013.
31. Zengquan Yuan, Haiping Xu, Huachun Han, and Yingjie Zhao, "Research of Smart Charging Management System for Electric Vehicles Based on Wireless Communication Networks," Information and Automation for Sustainability (ICIAfS), IEEE 6th International Conference, 2012.
32. Foo Tuan Seik, "Vehicle Ownership Restraint and Car Sharing in Singapore," Habitat International 24, 2000.
33. Dimitrios Efthymiou, Constantinos Antoniou, Paul Waddell,"Factor Affecting The Adoption Of Vehicle Sharing Systems By Young Drivers," Transport Policy, Volume 29, September 2013, Pages 64-73.
34. Patrícia Baptista, Sandra Melo, Catarina Rolim,"Energy, Environmental and Mobility Impacts of Car-sharing Systems. Empirical Results from Lisbon, Portugal," Procedia - Social and Behavioral Sciences, Volume 111, 5 February 2014, Pages 28-37.
35. Susan A. Shaheen, MarkA.Mallery,Karla J. Kingsley, "Personal vehicle sharing services in North America," Research in Transportation Business & Management, Volume 3, August 2012, Pages 71-8.
36. http://www.toyota-global.com/

37. Alessandro Luè, Alberto Colorni, Roberto Nocerino, Valerio Paruscio,” Green Move: An Innovative Electric Vehicle-Sharing System,” Procedia - Social and Behavioral Sciences, Volume 48, 2012, Pages 2978-2987.

38. Rania Mkahl and Ahmed Nait Sidi Moh, “Modelling of Charging Station Batteries for Electric Vehicle,” Journal of Asian Electric Vehicle, Vol 11, Dec 2013.

39. Daniel W. Hart, “ Power Electronics,” Mc Graw Hill International Edition, 2011.

40. P. Majid et al, “A New Control Approach Based on the Differential Flatness Theory for an AC/DC Converter Used in Electric Vehicle”, IEEE Transactions on Power Electronics, Vol. 27, No. 4, April 2012.

41. Hae-gwang Jeong and Kyo-Beum Lee, “Stability Improvement in an On-Board Battery Charger for Electric Vehicles,” IEEE Vehicle Power and Propulsion Conference, Oct 2012.

42. K. Mahmud and L. Tao, “Power Factor Correction by PFC Boost Topology Using Average Current Control Method,” Global High Tech Congress on Electronics (GHTCE), 2013 IEEE.

43. S. Maulik, P.K. Saha, G.K. Panda, “ Power Factor Correction and THD Minimization by Interleaved Boost Converter in Continuous Conduction Mode”, Int. Journal of Engineering Research and Applications, Feb 2014.

44. Habiballah Rahimi-Eichi, Federico Baronti, Unnati Ojha, and Mo -Yuen Chow, “Battery Management System,” IEEE Industrial Electronics Magazine, June 2013.

45. H.Makkonen, J.Partanen, P.Silventoinen, “Concept of Battery Charging and Discharging in Automotive Applications,” Power Electronics Electrical Drives Automation and Motion (SPEEDAM), 2010.

46. Aaron W. Cousland, Richard J. Ciaravolo, Gary Blieden and Dr. Nasser Hosseinzadeh, “Design of a Battery Charger and Charging Management System for an Electric Vehicle,” Universities Power Engineering Conference (AUPEC), 2010.

47. Jialei Hu, Changhong Liu, Xuguang Li, “Smart Charger Based on Exact Linearization of Boost Converter,” IEEE Vehicle Power and Propulsion .