MODELLING OF A DC FAST CHARGING STATION FOR ELECTRIC VEHICLES

ABDELRAHMAN MAGED MOHAMMED
HASSABALLAH

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

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2021

DEDICATION

This thesis is dedicated to my father, who is the reason I was able to persue my Master's degree and who supported me through my journey thus far. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Norzanah Bt Rosman, for encouragement, guidance, critics and friendship. Without the continued support and interest from Dr,Norzanah, this thesis would not have been the same as presented here.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

The trend of the energy sectors around the globe is to lean more towards alternative and renewable sources of energy due to the increase in carbon emissions and inevitable shortage of fossil fuel-based sources. Among those technologies are Electric Vehicles (EVs), which are a green emission free replacement for the traditional Internal Combustion Engine (ICE) vehicle. The charging infrastructure is a major concern among potential EV customers, with emphasis on fast charging ability, especially for highways and long-distance commutations. In this project, modelling of a DC Fast Charging (DCFC) EV Station is designed and modelled using Matlab/Simulink software. The developed DCFC model comprises 2 main conversion stages which are the AC/DC stage as well as the DC/DC stage for regulating and charging the EVs. The control method used for the AC/DC convertor is the synchronous frame reference voltage & reactive current control, while the charging control is a Constant Current/Constant Voltage (CCCV) control. An LCL filter was designed for the harmonic mitigation as it shows superior performance to traditional L and LC filters. The DCFC station was simulated for the case of 2 EVs charging and 4 EVs charging. The results obtained show the state of charge (SoC) of the EV battery has been successfully charged from 35% to 85% SoC in 16.6 minutes, in which considered as an acceptable fast charging time according to the market standards. Also, the AC grid current in both cases of simulation had a THD of lower then 8%. Finally, the DC bus voltage was successfully maintained at a constant voltage level, 600V. The presented simulation results proved that the developed model with its applied control strategies demonstrated the principle work of a DCFC EV system.

ABSTRAK

Trend sektor tenaga di seluruh dunia adalah lebih cenderung ke arah sumber tenaga alternatif dan boleh diperbaharui kerana peningkatan pelepasan karbon dan kekurangan sumber bahan bakar fosil yang tidak dapat dielakkan. Di antara teknologi tersebut adalah Kenderaan Elektrik (EV), yang merupakan pengganti bebas pelepasan hijau untuk kenderaan Mesin Pembakaran Dalaman (ICE) tradisional. Infrastruktur pengecasan yang menjadi perhatian utama di kalangan calon pengguna EV adalah penekanan terhadap kemampuan pengecasan pantas, terutama untuk lebuh raya dan perjalanan jarak jauh. Dalam projek ini, pemodelan Stesen EV Pengecasan Pantas DC (DCFC) dirancang dan dimodelkan menggunakan perisian Matlab/Simulink. Model DCFC yang dimodelkan merangkumi 2 peringkat penukaran utama iaitu penukar AC/DC dan penukar DC/DC untuk mengawal dan mengecas EV. Kaedah kawalan yang digunakan untuk penukar AC/DC adalah voltan rujukan kerangka segerak & kawalan arus reaktif, sementara pengawal pengecasan adalah kawalan Arus Tetap/Voltan Tetap (CCCV). Penapis LCL direka untuk mengurangkan kesan harmonik kerana ia menunjukkan prestasi lebih baik berbanding penapis tradisional L dan LC. Stesen DCFC disimulasikan untuk kes pengisian 2 EV dan pengecasan 4 EV. Hasil yang diperoleh menunjukkan keadaan pengecasan (SoC) bateri EV telah berjaya dicas dari SoC 35% hingga 85% dalam masa 16.6 minit, di mana ia boleh dianggap sebagai masa pengecasan pantas yang dapat diterima sesuai dengan standard pasaran. Juga, arus grid AC dalam kedua-dua kes simulasi mempunyai THD yang lebih rendah daripada 8%. Akhirnya, voltan bas DC berjaya dikekalkan pada tahap voltan malar, 600V. Hasil simulasi yang dibentangkan membuktikan bahawa model yang dibina dengan strategi pengawal yang digunakan telah menunjukkan prinsip kerja sistem DCFC EV yang sebenar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background Study

The trend of the energy sectors around the globe is to lean more towards alternative and renewable sources of energy due to the increase in carbon emissions and inevitable shortage of fossil fuel-based sources. Among those technologies are electric vehicles (EVs), which are a green emission free replacement for the traditional internal combustion engine (ICE) vehicle. EVs are either battery electric vehicles (BEV), plug in electric vehicles (PHEV) and hybrid electric cehicles (HEV). HEV and PHEV are both hybrid electric vehicles, which reduce the carbon emissions of traditional ICE vehicles by decreasing the Ice vehicle fuel consumption and hence desreasing its emissions. The main difference between PHEV's and HEV's is the ability to externally charge the EV battery which is available in PHEV's. HEV's however, cannot be charged externally, Instead, the battery is charged through regenerative braking and by the internal combustion engine. Both PHEV and HEV are not emission free vehicles but an improvement to the ICE vehicle. BEV's however or pure electricle vehicles as they are also known are sololy dependant on the EV battery with no combustion engine, hence achieveing zero emissions [1].

With the increase in EV demands, there are still several obstacles against EV adoption, for instance high in cost, mileage coverage, and also charging station infrastructures. Charging stations can be a home charger for single EV use or a public station.

1.2 Problem Statement

The electric vehicles (EVs) revolution has become a popular empowering subject in recent years as many believe it will transform the imminent of transportation market. However, there are still several barriers to the widespread adoption of EVs. For instance, as claimed in [2], 56% of EVs' customers placed high importance on fast charging ability, while 62% has stated that the availability of charging infrastructure was their primary concern regarding EVs. According to the three main Fast Charging Standards: Combined Charging System (CCS), CHAdeMO, and Tesla Supercharger, the charging time for fast DC chargers is anywhere from 15 to 45 minutes depending on the charger output and vehicle voltage capacity [3]. To solve these issues, DC fast charging (DCFC) has been introduced by EV manufacturers. More EV stations also have been developed from time to time. Thus, more capacity of EVs can be fueled faster. However, DCFC has poses a burden on the grid when bulky and unpredict charging occurs in simultaneous time. The high loading of the DCFC station on the grid may cause negative impacts on the grid as it will be described in detail in **Chapter-2**. Mitigating these effects requires the suitable control and filter implementation to maintain system stability between the DCFC station and the utility grid.

1.3 Research Objectives

The objectives of this research are:

1. Designing and modelling the EV Charging station with 4 EV slots.
2. Modelling a fast battery charging which SoC of 80% can be achieved around 20 minutes.
3. Controlling the DC bus voltage with low THD level of the grid AC current using DQ-Frame Reference Control with implementing an LCL Filter.

1.4 Scope of the Project

A. Only DC Bus Architecture for the DCFC is considered.
B. IEEE 519-2014 standard for DC Fast charging is the standard considered. 5% voltage harmonic distortion limit and an 8% THD limit should be maintained
C. Converter control will be implementing DQ-reference frame voltage and current control.
D. Charging Control is using a constant current constant voltage (CCCV) control.
E. Simulation will be done in MATLAB/Simulink.

1.5 Report Outline

The work begins with a brief introduction on Fast Charging necessity the challenges facing such implementation. Then, **Chapter-2** will disuss a few elements from the literature regarding charging levels and standards, implications on the grid due to the DCFC station as well as the archetictures. **Chapter-3** describes the various components as well as control methods uses in designing the station. Each power conversion stage is described with its dedicated converter control. The simulation results will be analysed and discussed in **Chapter-4.** The report ends with some conclusions and recommendation for future works in **Chapter-5**

REFERENCES

[1] Z. Li, A. Khajepour, and J. Song, “A comprehensive review of the key technologies for pure electric vehicles,” *Energy*, vol. 182, pp. 824–839, 2019, doi: 10.1016/j.energy.2019.06.077.

[2] M. A. H. Rafi and J. Bauman, “A Comprehensive Review of DC Fast Charging Stations with Energy Storage: Architectures, Power Converters, and Analysis,” *IEEE Trans. Transp. Electrif.*, vol. 7782, no. c, 2020, doi: 10.1109/TTE.2020.3015743.

[3] D. Sbordone, I. Bertini, B. Di Pietra, M. C. Falvo, A. Genovese, and L. Martirano, “EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm,” *Electr. Power Syst. Res.*, vol. 120, pp. 96–108, 2015, doi: 10.1016/j.epsr.2014.07.033.

[4] G. Sharma, V. K. Sood, M. S. Alam, and S. M. Shariff, “Comparison of common DC and AC bus architectures for EV fast charging stations and impact on power quality,” *eTransportation*, vol. 5, p. 100066, 2020, doi: 10.1016/j.etran.2020.100066.

[5] L. Wang, Z. Qin, T. Slangen, P. Bauer, and T. van Wijk, “Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures - An Overview,” *IEEE Open J. Power Electron.*, vol. 2, no. February, pp. 56–74, 2021, doi: 10.1109/ojpel.2021.3054601.

[6] S. Deb, K. Kalita, and P. Mahanta, “Review of impact of electric vehicle charging station on the power grid,” *Proc. 2017 IEEE Int. Conf. Technol. Adv. Power Energy Explor. Energy Solut. an Intell. Power Grid, TAP Energy 2017*, vol. 1, pp. 1–6, 2018, doi: 10.1109/TAPENERGY.2017.8397215.

[7] Q. Wang, N. Zhou, J. Wang, and N. Wei, “Harmonic amplification investigation and calculation of electric vehicle charging stations using three-phase uncontrolled rectification chargers,” *Electr. Power Syst. Res.*, vol. 123, pp. 174–184, 2015, doi: 10.1016/j.epsr.2015.02.010.

[8] M. Wanik, “Harmonic Measurement and Analysis during Electric Vehicle Charging,” *Engineering*, vol. 05, no. 01, pp. 215–220, 2013, doi: 10.4236/eng.2013.51b039.

[9] H. Jouybari-Moghaddam, A. Alimardani, and S. H. Hosseinian, “Influence of

electric vehicle charging rates on transformer derating in harmonic-rich battery charger applications," *Arch. Electr. Eng.*, vol. 61, no. 4, pp. 483–497, 2012, doi: 10.2478/v10171-012-0037-8.

[10] M. R. Khalid, M. S. Alam, A. Sarwar, and M. S. Jamil Asghar, "A Comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid," *eTransportation*, vol. 1, p. 100006, 2019, doi: 10.1016/j.etran.2019.100006.

[11] T. U. Solanke, V. K. Ramachandaramurthy, J. Y. Yong, J. Pasupuleti, P. Kasinathan, and A. Rajagopalan, "A review of strategic charging–discharging control of grid-connected electric vehicles," *J. Energy Storage*, vol. 28, no. September 2019, p. 101193, 2020, doi: 10.1016/j.est.2020.101193.

[12] M. Khonji, S. C. K. Chau, and K. Elbassioni, "Challenges in scheduling electric vehicle charging with discrete charging rates in AC power networks," *e-Energy 2018 - Proc. 9th ACM Int. Conf. Futur. Energy Syst.*, pp. 183–186, 2018, doi: 10.1145/3208903.3208934.

[13] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany, and A. Zidan, "Uncoordinated charging impacts of electric vehicles on electric distribution grids: Normal and fast charging comparison," *IEEE Power Energy Soc. Gen. Meet.*, pp. 1–7, 2012, doi: 10.1109/PESGM.2012.6345583.

[14] Y. Zheng, S. Niu, Y. Shang, Z. Shao, and L. Jian, "Integrating plug-in electric vehicles into power grids: A comprehensive review on power interaction mode, scheduling methodology and mathematical foundation," *Renew. Sustain. Energy Rev.*, vol. 112, no. May, pp. 424–439, 2019, doi: 10.1016/j.rser.2019.05.059.

[15] H. Fathabadi, "Utilizing solar and wind energy in plug-in hybrid electric vehicles," *Energy Convers. Manag.*, vol. 156, no. August 2017, pp. 317–328, 2018, doi: 10.1016/j.enconman.2017.11.015.

[16] L. Pieltain Fernández, T. Gómez San Román, R. Cossent, C. Mateo Domingo, and P. Frías, "Assessment of the impact of plug-in electric vehicles on distribution networks," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 206–213, 2011, doi: 10.1109/TPWRS.2010.2049133.

[17] S. Deilami, A. S. Masoum, P. S. Moses, and M. A. S. Masoum, "Voltage profile and THD distortion of residential network with high penetration of plug-in electrical vehicles," *IEEE PES Innov. Smart Grid Technol. Conf. Eur.*

ISGT Eur., pp. 1–6, 2010, doi: 10.1109/ISGTEUROPE.2010.5638979.

[18] M. T. Hussain, D. N. Bin Sulaiman, M. S. Hussain, and M. Jabir, "Optimal Management strategies to solve issues of grid having Electric Vehicles (EV): A review," *J. Energy Storage*, vol. 33, no. November 2020, p. 102114, 2021, doi: 10.1016/j.est.2020.102114.

[19] H. S. Das, M. M. Rahman, S. Li, and C. W. Tan, "Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review," *Renew. Sustain. Energy Rev.*, vol. 120, no. February 2019, 2020, doi: 10.1016/j.rser.2019.109618.

[20] H. Shareef, M. M. Islam, and A. Mohamed, "A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles," *Renew. Sustain. Energy Rev.*, vol. 64, pp. 403–420, 2016, doi: 10.1016/j.rser.2016.06.033.

[21] T. D. Nguyen, S. Li, W. Li, and C. C. Mi, "Feasibility study on bipolar pads for efficient wireless power chargers," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, pp. 1676–1682, 2014, doi: 10.1109/APEC.2014.6803531.

[22] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, and N. Mithulananthan, "A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects," *Renew. Sustain. Energy Rev.*, vol. 49, pp. 365–385, 2015, doi: 10.1016/j.rser.2015.04.130.

[23] A. Pathak and V. Sahu, "Review & study of bidirectional of DC-DC converter topologies for electric vehicle application," *Int. J. Sci. Technol.*, vol. 3, no. 6, pp. 101–105, 2015.

[24] T. Dragičević and Y. Li, *AC and DC microgrid control*. 2018.

[25] M. Dursun and M. K. Dosoglu, "LCL Filter Design for Grid Connected Three-Phase Inverter," *ISMSIT 2018 - 2nd Int. Symp. Multidiscip. Stud. Innov. Technol. Proc.*, no. 3, pp. 13–16, 2018, doi: 10.1109/ISMSIT.2018.8567054.

[26] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, and J. Selvaraj, "Experimental Validation of a Three-Phase Off-Board Electric Vehicle Charger with New Power Grid Voltage Control," *IEEE Trans. Smart Grid*, vol. 9, no. 4, pp. 2703–2713, 2018, doi: 10.1109/TSG.2016.2617400.

[27] S. Y. Syed Hussien, H. I. Jaafar, R. Ghazali, and N. R. Abdul Razif, "The effects of auto-tuned method in PID and PD control scheme for gantry crane

system," *Int. J. Soft Comput. Eng.*, vol. 4, no. 6, pp. 121–125, 2015, [Online]. Available: http://eprints.utem.edu.my/14047/1/%5B1%5D_F2492014615.pdf.