Design and Implementation

of

High Power Factor Battery Charger

By

Ahmed Mahmoud Mohamed Aboelleel

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE
in
Electrical Power and Machines Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

Prof. Osama A. Mahgoub	**Assoc. Prof. Sherif A. Zaid**
Faculty of engineering Cairo University, Egypt	Faculty of engineering Cairo University, Egypt

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Approved By the Examining Committee

Prof. Osama A. Mahgoub — Thesis Main Advisor
Faculty of Engineering - Cairo University

Prof. Mahmoud Ebraheem Gilany — Internal Examiner
Faculty of Engineering - Cairo University

Prof. Mahmoud M. Ahmed Salem — External Examiner
Electronics Research Institute

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017

Engineer's Name: Ahmed Mahmoud Mohamed Aboelleel

Date of Birth: 21/ 9 /1987

Nationality: Egyptian

E-mail: aboelleel_2009@yahoo.com

Phone: 01111951121

Address: 5 st. Nabil Adly, King Faisal st., Giza

Registration Date: 1 / 3 / 2012

Awarding Date: / / 2017

Degree: Master of Science

Department: Electrical Power and Machines Engineering

Supervisors:

Prof. Osama A. Mahgoub

Assoc. Prof. Sherif A. Zaid

Examiners:

Prof. Mahmoud M. Ahmed Salem (External Examiner) (Electronics Research Institute)

Prof. Mahmoud Ebraheem Gilany (Internal Examiner)

Prof. Osama A. Mahgoub (Thesis Main Advisor)

Title of Thesis:

Design and Implementation of High Power Factor Battery Charger

Key Words:

Battery Charger; Electric Vehicle; Ultra Sparse Matrix Converter; Matrix Converter; High power factor

Summary:

In this thesis, Electric Vehicle battery charger with high power factor is discussed. Ultra Sparse Matrix Converter is used to convert Supply voltage to suitable Battery voltage level. Hysteretic Average mode control is used to control charging modes of operation. The work is done through analysis for the converter, then simulation for the charger, then hardware experimental validation. The charger achieved Minimum Power Factor with value 0.91 and Maximum Power Factor with value 0.94.

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Table of contents

List of tables

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of symbols and abbreviation

η_{nom} :efficiency

η_{25} : efficiency at 25% of rated output power

ρ :power density

γ : power to mass ratio

$I2_{,max,0,n}$: maximum output current when output frequency zero

$I2_{,max,fl,n}$:maximum output current when output frequency equal to input frequency

$\acute{\alpha}_{-1}$ nominal output power per Si chip area, MU,12 voltage transfer ratio

$V_{LL\ peak}$:peak value of voltage line to line

Vd : charger input AC voltage is which has peak value of Vs.

Eb : battery nominal voltage and battery maximum allowable voltage is Ebmax

Ib: battery charging current and Ibmin minimum output current of the charger

Fs: chopping frequency

ΔI_L : ripple in inductor current

Lf : input EMI filter inductor

Lc : input EMI filter capacitor

F_o: EMI filter cut off frequency

Vb: battery charging voltage in flowchart

Du: duty cycle

Du++: increase duty cycle

Du--: decrease duty cycle

PF: power factor

P: active power

Q: reactive power

S: apparent power

CMC: Conventional Matrix Converter

IMC: Indirect Matrix Converter

Abstract

Compared to conventional cars, Electric Vehicle (EV) dramatically lessens greenhouse gas emissions. This fact remains valid even after accounting for the power plants emissions that supply the battery chargers. That's why environmental groups and automakers are accelerating switching to plug-in cars. Nowadays there are more than 1.3 million EVs on the roads, and the global monthly sales are about 50,000 units. EV has many advantages over internal combustion engine (ICE) vehicle. The main advantage is EV saves energy because its efficiency is about 60% and the efficiency of internal combustion engine is about 20%. So, many countries encourage EV manufacturers by bonuses and tax exemption

Many challenges face the rapid growth of EVs in use. As EV battery needs to be charged after 100km to 150km, the commercial success of EVs will depend on the deployment of a network of charging stations that will allow consumers to safely recharge vehicle batteries. There are many schemes about using the EV and consequence charging process. First scheme (for light use) EV battery can be charged at home during night and at work during morning. Another scheme, for frequent use, that EV can be charged everywhere. For the last scheme, chargers must be everywhere as charging stations areas at many places such as cinemas, theaters, shopping malls, parking places…etc. The charging time is another problem against EV.

Charging time for normal EV is about 8 hours and it is very long time compared with fuel refilling process. So, in order to minimize charging time, a high power battery charger should be implemented. Many high power chargers based on traditional converters are available like full bridge push pull converter. However, traditional converters inject harmonics to the electrical network and suffer from poor power factor (PF). So high power chargers need power factor correction devices or additional circuit stage to increase PF value and that increases the complexity of the charger, and the overall cost.

Matrix converter (MC) has been introduced as an AC-to-AC direct power conversion converter that can generate variable voltage and/or variable frequency output. MC has sinusoidal input current with high power factor. Different modifications and updates are applied to MC that have been introduced in literature trying to reduce number of active switches like Sparse Matrix Converter (SMC), Very Sparse Matrix Converter (VSMC), and Ultra Sparse Matrix Converter (USMC). By employing a suitable PWM technique, these switches can control the output voltages and input current simultaneously.

In this thesis, Ultra Sparse Matrix Charger (USM Charger) is selected to replace old traditional converters. USM Charger is composite from the rectifier stage of USMC and inductor for smoothing charging current. The adopted battery charger topology attains the same advantage of input stage of MCs. This converter has advantages of high power factor, high efficiency, and low total harmonic distortion. This converter saves volume, weight, and money. USM Charger consists of only one stage to convert