



Cairo University

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

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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

Acknowledgement	i
Table of contents	ii
List of tables	v
List of figures	vi
List of symbols and abbreviations	x
Abstract	xi
Chapter 1 Introduction	
1.1 Introduction	1
1.2 Problems facing spread of EV.....	3
1.3 Matrix converters	5
1.3.1 MC basic concepts and operation	7
1.4 Sparse Matrix converters	10
1.5 Matrix converters in industry	12
1.6 Power factor (PF)	12
1.7 EV batteries and its technologies	14
1.7.1 Battery basics	14
1.7.2 Battery modeling	14
1.7.3 Cell Balancing	15
1.7.4 Lithium-ion batteries	17
1.8 Objectives of this these	18
Chapter 2 Ultra Sparse Matrix Charger Operation	
2.1 Introduction.....	19
2.2 USM Charger operation	20
2.2.1 First state three switches are turned on	20
2.2.2 Second state three switches are turned off	21
2.2.3 Third state one switch is turned on.....	22
2.2.4 Forth state two switches are turned on	22
2.3 Switching pattern	23

2.4 Design of the charger	24
2.4.1 Battery coil design	25
2.4.2 Input filter equation	26
2.4.3 Power devices ratings	26
2.5 Battery charging modes of operation	26
2.5.1 First mode Constant voltage (CV)	26
2.5.2 Second mode Constant current (CC)	27
2.5.3 Third Constant current constant voltage CCCV charging mode	27
2.6 Control technique	27
2.7 Case study	28
2.8 Software flowchart of charging modes	30
2.9 EV and smart grid	31

Chapter 3 Simulation and validation results

3.1 Introduction	32
3.2 First state three switches are turned on validation	32
3.3 Simulation using switching pattern	33
3.3.1 Resistive load test.....	34
3.3.2 Battery load test.....	38
3.4 Charging multiple batteries	41
3.4.1 First test with 24V battery	41
3.4.2 Second test with 36V battery.....	44

Chapter 4 Experimental validation work

4.1 Introduction	48
4.2 Case study charging modes.....	48
4.3 Circuit setup.....	48
4.3.1 Zero crossing circuit	49
4.3.2 Feedback circuit	50
4.3.3 Digital signal controller	51

4.3.3.1 Digital signal controller power supply.....	51
4.3.3.2 LCD interface	52
4.3.4 Input EMI filter	52
4.3.5 Power circuit.....	52
4.3.5.1 Gate drive circuit.....	55
4.3.6 Mains three phase transformer supply and Batteries	49
4.4 The control scheme	56
4.5 Experimental results.....	56
4.5.1 First test with resistive load at 12V.....	56
4.5.2 First test with battery load 12V.....	58
4.5.3 Second test with battery load 24V	60
4.5.4 Third test with battery load 36V.....	62
 Chapter 5 Conclusion and future work	
5.1 General conclusion	65
5.2 Thesis Conclusions.....	65
5.3 Future work.....	66
References	67

List of tables

Chapter 1

Table 1.1	Top EV selling of some commercial models	2
Table 1.2	Top countries by EV market share	2
Table 1.3	Chargers levels	3
Table 1.4	Manufactured EV	4
Table 1.5	Eighteen active space vectors	8
Table 1.6	Comparison between Lithium-ion batteries technologies	17

Chapter 2

Table 2.1	Switching sequence	17
Table 2.2	Case study circuit parameters	29

Chapter 3

Table 3.1	first state system parameters	32
Table 3.2	Resistive test parameters for the charger	33
Table 3.3	PF for different test cases	47

Chapter 4

Table 4.1	Experimental results conclusion	64
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List of figures

Chapter 1

Figure 1.1 Yearly sales in the world's top markets from 2011 to 2016	1
Figure 1.2 Full bridge push pull converter circuit stages	5
Figure 1.3 Commercial battery charger 3.3kW	5
Figure 1.4 Matrix Converter block diagram	6
Figure 1.5 Matrix Converter circuit diagram	6
Figure 1.6 Bidirectional switch configurations	7
Figure 1.7 MC switches labels	8
Figure 1.8 Vector sequence.....	9
Figure 1.9 Input current space vectors	9
Figure 1.10 Output voltage space vectors	9
Figure 1.11 Indirect Matrix Converter (IMC)	10
Figure 1.12 Voltage source back to back converter	10
Figure 1.13 Sparse Matrix Converters	11
Figure 1.14 Very Sparse Matrix Converter	11
Figure 1.15 Ultra Sparse Matrix Converter	12
Figure 1.16 Vectors of current, voltage, P, Q, and S	13
Figure 1.17 Distorted current waveform	13
Figure 1.18 Equivalent circuit model of battery	15
Figure 1.19 Cell balancing through Resistive discharge circuit	16
Figure 1.20 Cell balancing through Capacitive shuffling	16

Chapter 2

Figure 2.1 USMC rectifier side	20
Figure 2.2 Final USMC circuit diagram	20
Figure 2.3 USM Charger three switches are turned on.....	21

Figure 2.4 Output waveform of three switches are turned on.....	21
Figure 2.5 Freewheeling current path of coil "L"	22
Figure 2.6 USM Charger current flow in case of transferring energy from supply	22
Figure 2.7 Switching pattern for gate drive signal	23
Figure 2.8 USM Charegr circuit divisions.....	24
Figure 2.9 Turn on simplified circuit.....	25
Figure 2.10 Switch control signal and coil current	25
Figure 2.11 Constant voltage block diagram	26
Figure 2.12 Constant current mode charger block diagram.....	27
Figure 2.13 Constant current constant voltage mode charging time chart.....	27
Figure 2.14 Control technique	28
Figure 2.15 Control technique at CC mode	29
Figure 2.16 Control technique at CV mode	30
Figure 2.17 Charging flowchart	30
Figure 2.18 USMC Smart Charger circuit	31

Chapter 3

Figure 3.1 USM Charger Simulink model	32
Figure 3.2 Simulation output at three switches are turned on	33
Figure 3.3 MATLAB/SIMULINK model with control and resistive load.....	34
Figure 3.4 Three phase input voltage and current waveforms for resistive load	34
Figure 3.5 Harmonic spectrum of input voltage for resistive load test	35
Figure 3.6 Harmonic spectrum of input current for resistive load test	35
Figure 3.7 Active and reactive power with resistive load test	35
Figure 3.8 Output voltage and current for resistive load test	36
Figure 3.9 Switching pattern with resistive load test	37
Figure 3.10 MATLAB/SIMULINK model with control and battery load	38
Figure 3.11 Input voltage for 12V battery load.....	38

Figure 3.12 Input current for 12V battery load	39
Figure 3.13 Input voltage harmonic spectrum of battery load test	39
Figure 3.14 Input current harmonic spectrum of battery load test	39
Figure 3.15 Active and reactive power battery load test	40
Figure 3.16 Output voltage 12V battery tests	40
Figure 3.17 Output current 12V battery test	41
Figure 3.18 Input voltage for 24V battery load	41
Figure 3.19 Input current for 24V battery load.....	42
Figure 3.20 Input voltage harmonic spectrum for 24V battery	42
Figure 3.21 Input current harmonic spectrum for 24V battery	42
Figure 3.22 Input active and reactive power for 24V battery load test	43
Figure 3.23 Output voltage wave form for 24V battery.....	43
Figure 3.24 Output current waveform for 24V battery	44
Figure 3.25 Input voltage for 36V battery.....	44
Figure 3.26 Input current waveform for 36V battery.....	45
Figure 3.27 Input voltage harmonic spectrum for 36V battery.....	45
Figure 3.28 Input current harmonic spectrum for 36V battery.....	45
Figure 3.29 Input P and Q for 36V battery load test.....	46
Figure 3.30 Output voltage for 36V battery	46
Figure 3.31 Output current for 36V test.....	46

Chapter 4

Figure 4.1 Circuit block diagram	49
Figure 4.2 Zero crossing detection circuit	49
Figure 4.3 Zero crossing detection signal	50
Figure 4.4 Feedback circuit	50
Figure 4.5 Controller block diagram	51
Figure 4.6 Controller power supply circuit	51

Figure 4.7 Start screen on LCD.....	52
Figure 4.8 Input EMI filter circuit	52
Figure 4.9 Power circuit of USM Charger	53
Figure 4.10 MOSFET gate to source voltage and drain to source voltage.....	53
Figure 4.11 Output voltage and current	54
Figure 4.12 Gate drive power supply	54
Figure 4.13 All PCB photo	55
Figure 4.14 Control technique	56
Figure 4.15 Output voltage and current of 12V resistive load test.....	57
Figure 4.16 Input V&I and PF for 12V resistive test	57
Figure 4.17 Input voltage harmonic spectrum for 12V resistive test	58
Figure 4.18 Input current harmonic spectrum for 12V resistive test	58
Figure 4.19 Output V&I for 12V battery load test	59
Figure 4.20 Input V&I for 12V battery load test and PF	59
Figure 4.21 Input voltage spectrum for 12V battery load test	59
Figure 4.22 Input current spectrum for 12V battery load test	60
Figure 4.23 Output V&I for 24V battery load test.....	60
Figure 4.24 Input V&I for 24V battery load test and PF.....	61
Figure 4.25 Input voltage harmonic spectrum for 24V battery load test.....	61
Figure 4.26 Input current spectrum for 24V battery load test	61
Figure 4.27 Output V and I for 36V battery load test.....	62
Figure 4.28 Input V&I for 36V battery load test and PF.....	62
Figure 4.29 Input voltage harmonic spectrum for 36V battery load test	63
Figure 4.30 Input current harmonic spectrum for 36V battery load test	63
Figure 4.31 Output voltage and switch voltage drain to source (Vds)	63

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

$I_{2,\text{max},0,\text{n}}$: maximum output current when output frequency zero

$I_{2,\text{max},\text{fl},\text{n}}$:maximum output current when output frequency equal to input frequency

α_{-1} nominal output power per Si chip area, MU,12 voltage transfer ratio

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

V_d : charger input AC voltage is which has peak value of V_s .

E_b : battery nominal voltage and battery maximum allowable voltage is $E_{b\text{max}}$

I_b : battery charging current and $I_{b\text{min}}$ minimum output current of the charger

F_s : chopping frequency

ΔI_L : ripple in inductor current

L_f : input EMI filter inductor

L_c : input EMI filter capacitor

F_o : EMI filter cut off frequency

V_b : battery charging voltage in flowchart

D_u : duty cycle

D_{u++} : increase duty cycle

D_{u--} : 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