UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF BOOST A CONVERTER USING PLANAR INDUCTOR FOR DUAL SUPPLY AUTOMOTIVE SYSTEM

SHASHIKUMAR A/L KRISHNAN

FK 2008 21

DESIGN AND DEVELOPMENT OF BOOST A CONVERTER USING PLANAR INDUCTOR FOR DUAL SUPPLY AUTOMOTIVE SYSTEM

By

SHASHIKUMAR A/L KRISHNAN

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

APRIL 2008

DEDICATION

With appreciation and respect

this thesis is dedicated

to my parents and

to my wife.

I owe my country a great debt.

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

DESIGN AND DEVELOPMENT OF BOOST A CONVERTER USING PLANAR INDUCTOR FOR DUAL SUPPLY AUTOMOTIVE SYSTEM

By

Shashikumar a/l Krishnan

APRIL 2008

Chairman: Norman Bin Mariun, PhD,

Faculty: Engineering

Today, innovation in electronic automobile components has resulted in the need for higher voltage power supplies. In future automotive vehicles will have 36V operating system. In order to convert to 36V operating system, a 14V/42V dual power supply design is currently being tested and implemented in electric and hybrid vehicles. In future all electrical and diesel vehicle components will be using 42V electronic components (bulbs, alarms, radio, ICU etc). Boost converter 14V step up to 42V will be an essential component in all vehicles.

This work comprises of designing an efficient boost converter which can be easily manufactured and will work for dual supply electrical vehicle as well as diesel vehicle. Current available electric vehicle converters are either buck or bidirectional

type. Various topologies have been used in electric vehicle converters. In the early days, auto-transformer topology was common, followed by toroidal inductor which became popular. Currently E-I planar core with spiral PCB inductor are being gradually applied in industry. Jumpstart post embedded in the converter is another key area of electric vehicle converters with dual power supply being studied.

The scopes of this research are to evaluate and experiment ideas before building and testing a design with auxiliary start (cracking) aid boost converter that would be compatible the 14V/42V power net. In this research dual supply vehicle boost converter prototype designs were experimented. The work consists of design study of CCM DC-DC Boost Converter with E-I Planar core spiral PCB inductor using a SMT UCC38C43D PWM chip controller. The experimental results are obtained using the Planar spiral inductor DC-DC boost converter, designed to operate in CCM for 120W with an efficient of 85% and output voltage ripple of 5%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan syarat bagi pengajian Sarjana Sains

MEREKABENTUK DAN PERBANGUNAN SEBUAH PENUKAR GALAK LONJAKAN YANG MENGGUNAKAN PLANAR INDUKTOR UNTUK SISTEM KENDERAAN DWI BEKALAN

oleh

Shashikumar A/L Krishnan

JUN 2008

Pengerusi: Norman Bin Mariun, PhD

Fakulti: Kejuruteraan

Pada masa kini, inovasi dalam komponen elektronik motokar telah menyebabkan keperluan untuk menggunakan bekalan kuasa voltan yang lebih tinggi. Pada masa hadapan sistem operasi semua kenderaan bermotor akan menggunakan 36V. Untuk membolehkan sistem beroperasi pada 36V, sebuah 14V/42V rekabentuk bekalan dwikuasa telah dipasangkan buat sementara waktu (tempoh peralihan) pada kenderaan elektrik dan hibrid. Untuk mengelakkan pembaziran dan mengurangkan kos, komponen elektrik dalam kenderaan elektrik dan disel masa hadapan akan menggunakan komponen elektrik pada tahap kuasa yang sama iaitu 42V (contohnya mentol, alat penggera, radio, ICU dll.) Penukar galak 14V meningkat ke 42V akan menjadi sebuah komponen yang penting untuk semua kenderaan.

Projek ini meliputi merekabentuk sebuah penukar galak yang efisyen dan yang boleh dibuat dengan mudah serta berfungsi untuk dwibekalan kenderaan elektrik dan disel. Penukar kenderaan elektrik yang sedia ada sekarang adalah jenis penurun atau pun dwi-arah sahaja. Terdapat pelbagai topologi yang digunakan dalam penukar elektrik kenderaan. Pada mulanya topologi pengubah-auto telah digunakan dengan luasnya diikuti dengan induktor teroidal. Pada masa kini E-I Planer bersama induktor spiral PCB mula digunakan dalam industri. Penggunaan kemudahan 'jumpstart' yang tertanam dalam penukar merupakan satu aspek kajian utama dalam penukar kenderaan elektrik yang menggunakan dwikuasa.

Liputan penyelidikan ini adalah untuk menilai dan menguji idea sebelum membina dan menguji sebuah rekabentuk pembantu penghidup kenderaan yang serasi dengan 14V/42V power net. Sebuah rekabentuk topologi dan litar penukar galak kenderaan dwibekalan telah dibina dan diuji untuk projek ini. Projek ini meliputi kajian rekabentuk sebuah litar CCM penukar galak kenderaan dwibekalan, teras 'E-I keeping' pusar PCB induktor dengan mengunakan SMT UCC38C43D PWM bersepadu. Rumusannya, kajian ini menunjukkan bahawa penukar galak yang direkabentuk itu telah memenuhi matlamatnya dengan mencapai kecekapan pada 85% and keralatan voltan keluaran sebanyak 5% sahaja.

ACKNOWLEDGEMENTS

My deepest gratitude and respect to my parents for their support, guidance, encouragements and advice and to my wife for her assistance in typing.

Finally, I would like to express my deep appreciation and profound gratitude to my supervisors, Professor Dr. Norman Bin Mariun, Dr Mohd Hamiruce bin Marhaban and Mohd Amran bin Mohd Radzi for their guidance, encouragements and advice throughout my study.

I certify that an Examination Committee has met on _______ 2008 to conduct the final examination of Shashikumar a/l Krishnan on his Master of Science thesis entitled "Designing and Development of Boost Converter using Planar Inductor for Dual Supply Automotive System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Chairman, PhD.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Examiner 1, PhD.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Examiner 2, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

External Examiner, PhD.
Professor
Faculty of Graduate Studies
University Putra Malaysia
(External Examiner)

____

HASANAH MOHD. GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisor Committee were as follows

Norman Bin Mariun, PhD, PEng.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Hamiruce Bin Marhaban, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Amran Bin Mohd Radzi, MSc
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 11 September 2008

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously concurrently submitted for any other degree at UPM or other institutions.

SHASHIKUMAR A/L KRISHNAN

Date: 10 September 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PWM	Pulse Width Modulation
EV	Electric Vehicle
HV	Hybrid Vehicle
PCB	Printed Circuit Board
AC	Alternating Current
DC	Direct Current
EMC	Electromagnetic Compatibility
CAD	Computer Aided Design
PIC	Programmable Integrated Circuit
IC	Integrated Circuit
SMT	Surface Mounted Technology
CR-ZVS-MR	Constant Frequency and Zero-Voltage Switching and Multi-Resonant
SCR	Silicon Controlled Rectifier
MIT	Massachusetts Institute of Technology
TVS	Transient Voltage Suppresser
PLT	Plate

CHAPTER 1

INTRODUCTION

1.1 Background

In the early days of the automobile, a 6V battery was used to power various electronic components. In the 1950's, powerful engines like the V-8 were being introduced along with electronic components like radios and higher power headlamps. In turn, a larger power source was needed to facilitate these new introductions. Therefore, the automobile industry made a transition to a higher energy 12V battery. (Example in 1960's: mass-produced motor car power rail voltage change accords during VW-Beetle making in 1965) Today, innovations and transitions to electrical power are causing the automobile industry to face the same sort of situation faced in the 50's.

Therefore, manufacturers are investigating a dual voltage power source consisting of both 12V and 36V batteries. This power source would allow the introduction of more electro-mechanical systems like electronic brakes and electronic power steering. However, some components like incandescent light bulbs and motors prefer low voltage operation. Therefore, these lower components could be powered by the 12V battery or by the 36V battery if the voltage was transformed to 12V accurately.

1.2 The rule of Power Net Voltage

Today, innovation in electronic automobile components is creating the need for higher voltage power supply. Figure 1.1 shows an average passenger vehicle power requirement in the year 1990 was 1.8kWatts and estimated 15k to 40kWatts needed in the year 2030. Now more than 30 years later, the industry is preparing for a further increase of the current 14V working system.

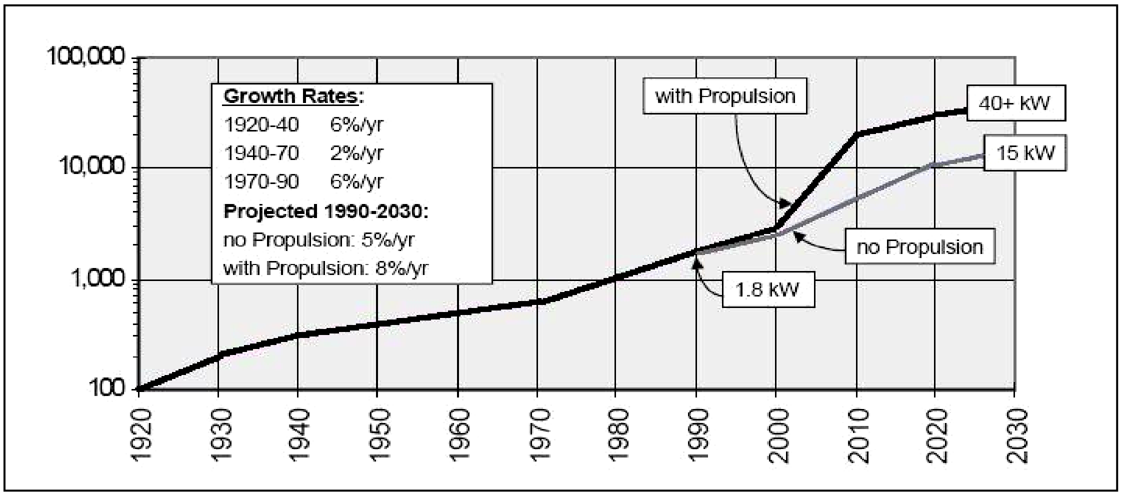


Figure 1.1. Generator peak power of average passenger vehicle in Watts, (Traub, 1999).

In 1990's the members of the automotive community met at MIT in the USA and Germany to debate and propose the next generation of electrical system that could provide the power levels being forecasted for the near future. The various working groups eventually decided on 42V, as this was the highest possible multiple of 14V meeting the internationally agreed definition of a safety extra low voltage. Along with the change in nominal system voltage have come recommended standards for 42V (Power Net) proposed in 1996 by participants in an 18 months series of workshop at MIT. The power net voltage standard requirements for 42V passenger vehicle systems a minimum start voltage of 21V and maximum dynamic over voltage 58V, as shown in Figure 1.2.

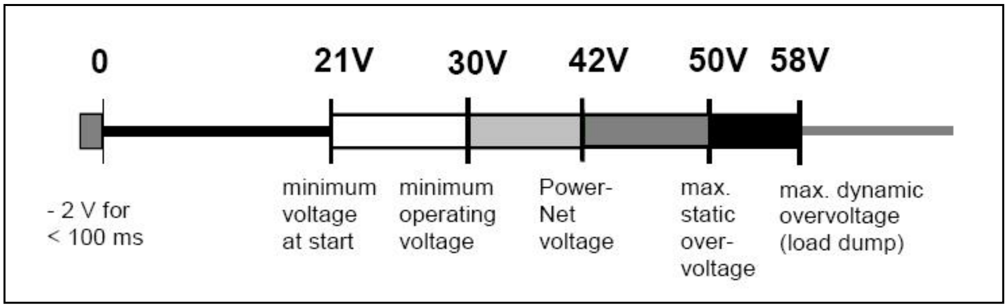


Figure 1.2. Power net voltage requirements for 42V (Traub, 1999).

Table 1.1. Wiring harness comparison 14V and 42V system (Neubert, 2000).

	14V	**42V**
Total no. of wires	293	293
0.3mm^2	41	202
0.5mm^2	94	25
0.75mm^2	68	16
1mm^2	19	36
1.5mm^2	25	11
2.5mm^2	35	2
4mm^2	9	1
6mm^2	1	0
Weight Cu (Kg)	4.64	2.53
Weight PVC (Kg)	2.2	1.35
Total Weight	**6.84kg**	**3.88kg**

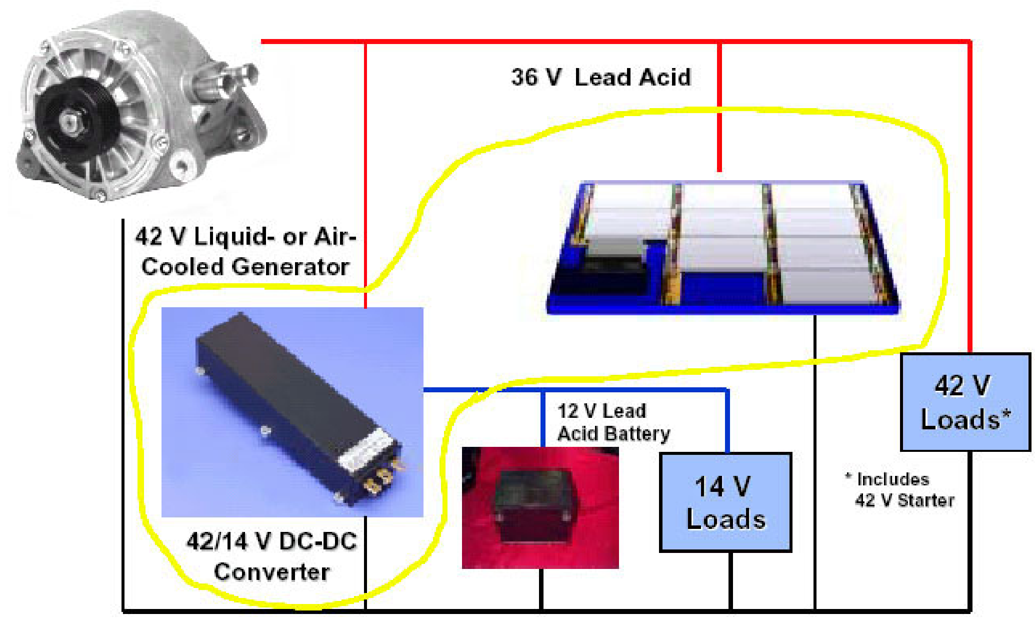
The transition was not as simple as 45 years ago when the increase was from 6V to 12V. Today there are so many electrical subsystems in 14V vehicles, it will be much more difficult to make the transition to a single higher voltage 42V electrical system. Therefore most likely the next step will be a dual voltage (14V/42V) electrical system. Table 1.1 shows that thick wires are not necessary for a 42V passenger vehicle system making the car lighter and saving fuel.

1.3 Electrical Systems in Electric Vehicles

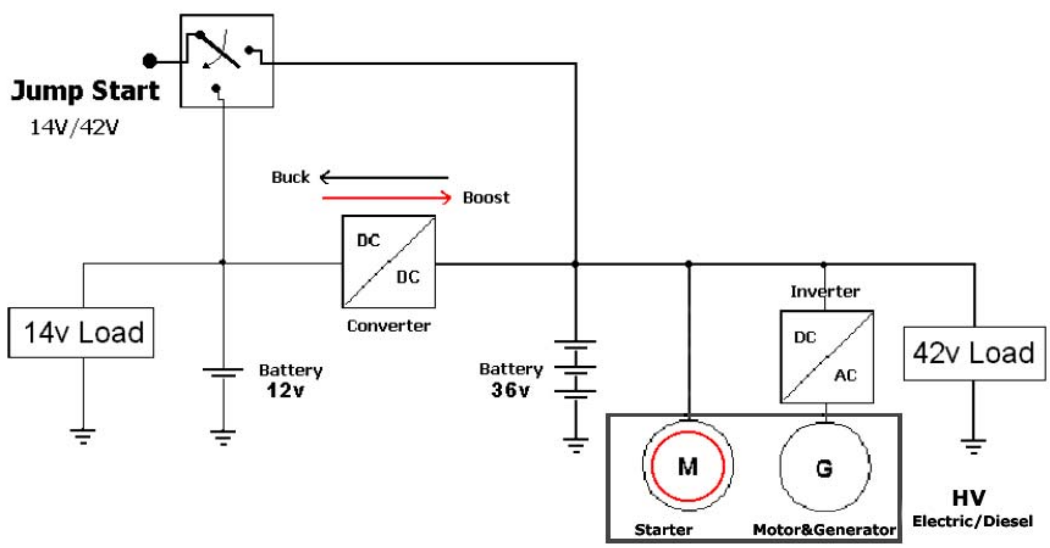
Traditional architecture of 14V system diesel vehicle has a 14V alternator (generator) connected to the engine to charge the electrical system of the vehicle. In 42V Hybrid Vehicle (HV) the 42V alternator is connected to the 36V battery and the 42V electrical system as shown in Figure 1.3 (a). A 42V starter is also connected to the 42V electrical system of the hybrid electrical vehicle. Complete circuit diagram of 42V HV system with jump start post is shown in Figure 1.3 (b). The circuit main electronics components are 14V/42V bidirectional DC-DC converter, AC-DC inverter and jump start post. The DC-DC converter will be most of the time running in buck mode during the car in run mode. The boost mode only runs during starting (cranking engine) process to assist the starter motor.

Table 1.2. Summary of comparisons of the main components and the converter input output specification of a Hybrid vehicle (HV) and Fuel Cell Electric vehicle (EV).

Specification	Hybrid Vehicle	Fuel Cell EV
Engine Type	• Diesel • Electric Motor	• Electric Motor
High Side Source	• 36V Battery • 42V Generator	• 36V Battery • 42V Generator
Low Side Source	• 12V Battery	• 12V Ultra Capacitor
Converter High Side Input	• 42.5V / 4A	• 42.5V / 10A
Converter Low Side Input	• 14.6V / 15A	• 14.6V / 30A
Max power	• 170W	• 420W



(a)



(b)

Figure 1.3. (a) Basic block diagram of 42V HV electrical architecture system. (b) Block circuit diagram of 42V HV system with jump start post. The bidirectional converter handles the power transition of the two different bus system 14V and 42V. The main source of power comes from the 12V battery, 36V battery and the 42V generator (Traub, 1999).

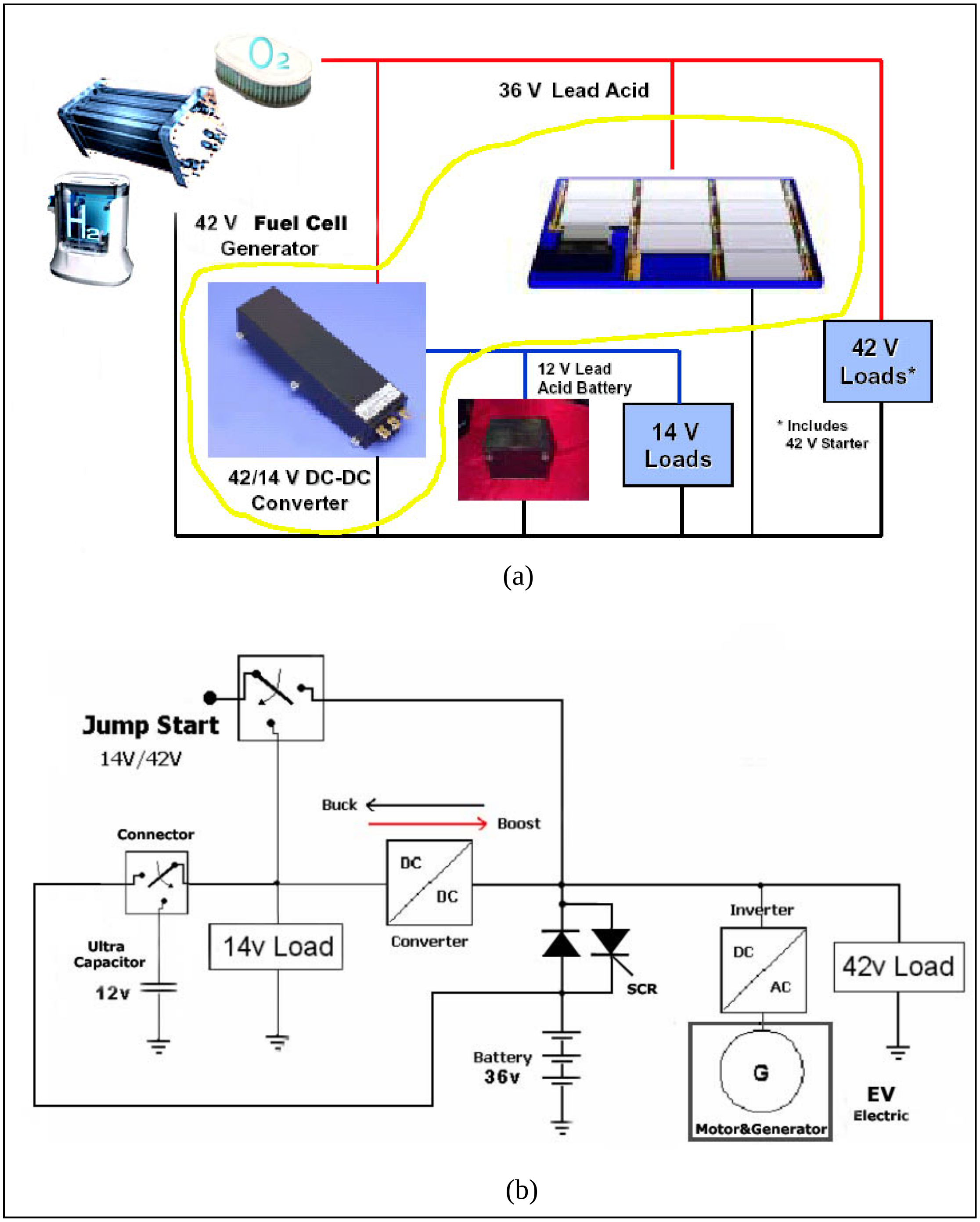


Figure 1.4. (a) Basic block diagram of 42V EV electrical architecture system. (b) Block circuit diagram of 42V EV system with jump start post. The bidirectional converter handles the power transition of the two different bus system 14V and 42V. The main source of power comes from the 12V ultra capacitor, 36V battery and the 42V generator (Traub, 1999).