THE DESIGN AND IMPLEMENTATION OF AUTOMOTIVE SWITCHING DC - DC POWER CONVERTER WITH NONLINEAR DYNAMICS ANALYSIS AND STABILITY CONTROL

Nuttawat Suppipat

A thesis Submitted in Fulfillment of Requirements for the Degree of Master of Engineering Technology Program in Engineering

Graduate School

Thai-Nichi Institute of Technology

Academic Year 2012

Thesis Title	The Design and Implementation of Automotive Switching DC-DC Power Converters with Nonlinear Dynamics Analyses and Stability Controls
By	Nuttawat Suppipat
Field of Study	Engineering Technology
Advisor	Dr. Wimol San-Um

The Graduate School of Thai-Nichi Institute of Technology has been approved and accepted as partial fulfillment of the requirement for the Master's Degree.

.... Dean of Graduate School.

(Assoc. Prof. Dr. Pichit Sukchareonpong)

Month .... Date ...., Year...........

Thesis Committees

.... Chairman.

(Assoc. Prof. Dr. Worapong Tangsrirat)

.... Committees.

(Dr. Warakorn Srichaveangsup)

.... Committees.

(Dr. Thitiporn Lertrusdachakul)

.... Advoisor.

(Dr. Wimol San-Um)

NUTTAWAT SUPPIPAT : THE DESIGN AND IMPLEMENTATION OF AUTOMOTIVE SWITCHING DC - DC POWER CONVERTER WITH NONLINEAR DYNAMICS ANALYSIS AND STABILITY CONTROL ADVISOR : DR. WIMOL SAN-UM, 59PP.

DC-DC power converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits with different voltage level requirements which are different from that supplied by the battery or external supplies and can be either higher or lower than the supply voltage. Additionally, the battery voltage declines as its stored power is drained. Switched DC-DC converters offer an operation to increase or decrease the voltage levels without multiple batteries in order to accomplish the DC operation.

The operating DC voltage of most electronic devices in electric cars is commonly lower than the power supply resources. The Buck DC-DC Converter is a suitable solution for this system. However, the output voltage generally contains a small ripple, which is an AC variation over the DC output. As a result, the accuracy of Buck DC-DC Converter may not high as required in the specification. Therefore, the Buck DC-DC converter to be studied in this thesis will focus on the reduction of ripple voltages in order to sustain the system stability with low-cost implementation.

This thesis therefore aims to study power conversion theories in automotive electric systems, and also study circuit topologies and operations of automotive DC-DC buck converters. In addition, low-cost high-stability automotive 42V-14V DC-DC buck converters are also designed and implemented. The scope of this thesis is to study circuit configurations of a 42V to 14V buck DC-DC converter with feedback control, and study the model and simulations of buck DC-DC converter with 42V input voltage and 14V output voltage using LTspice IV and MATLAB Simulink.

Graduate School	Student's Signature ....
Field of Engineering Technology	Advisor's Signature ....
Academic Year 2012	

Acknowledgements

The author wishes to express his profound gratitude and to respectfully dedicate this work to his parent and family members for their endless encouragements, love and sacrifices. The author is most grateful to his advisor, Dr. Wimol San-Um, for his valuable supervision, supports and encouragements throughout the study. Grateful acknowledgements are also made to Asst. Prof. Dr. Wipawadee Wongsuwan, the director of master of engineering technology program for her supports. In addition, grateful acknowledgements are made to Assoc. Prof.Worapong Tangsrirat, Asst. Prof. Dr.Warakorn Srichawenhsup, Dr. Thitiporn Lertratdechakul, members of thesis committee, for their valuable suggestions and comments. The author also wishes to acknowledge Thai-Nichi Institute of Technology for a great opportunity of master study and financial supports internships in Japan. The author sincerely appreciates all of his friends in Intelligent Electronic Systems Research laboratory for their friendships and goodwill.

Nuttawat Suppipat

NUTTAWAT SUPPIPAT : THE DESIGN AND IMPLEMENTATION OF AUTOMOTIVE SWITCHING DC - DC POWER CONVERTER WITH NONLINEAR DYNAMICS ANALYSIS AND STABILITY CONTROL ADVISOR : DR. WIMOL SAN-UM, 59PP.

DC-DC power converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits with different voltage level requirements which are different from that supplied by the battery or external supplies and can be either higher or lower than the supply voltage. Additionally, the battery voltage declines as its stored power is drained. Switched DC-DC converters offer an operation to increase or decrease the voltage levels without multiple batteries in order to accomplish the DC operation.

The operating DC voltage of most electronic devices in electric cars is commonly lower than the power supply resources. The Buck DC-DC Converter is a suitable solution for this system. However, the output voltage generally contains a small ripple, which is an AC variation over the DC output. As a result, the accuracy of Buck DC-DC Converter may not high as required in the specification. Therefore, the Buck DC-DC converter to be studied in this thesis will focus on the reduction of ripple voltages in order to sustain the system stability with low-cost implementation.

This thesis therefore aims to study power conversion theories in automotive electric systems, and also study circuit topologies and operations of automotive DC-DC buck converters. In addition, low-cost high-stability automotive 42V-14V DC-DC buck converters are also designed and implemented. The scope of this thesis is to study circuit configurations of a 42V to 14V buck DC-DC converter with feedback control, and study the model and simulations of buck DC-DC converter with 42V input voltage and 14V output voltage using LTspice IV and MATLAB Simulink.

Graduate School	Student's Signature ....
Field of Engineering Technology	Advisor's Signature ....
Academic Year 2012	

Acknowledgements

The author wishes to express his profound gratitude and to respectfully dedicate this work to his parent and family members for their endless encouragements, love and sacrifices. The author is most grateful to his advisor, Dr. Wimol San-Um, for his valuable supervision, supports and encouragements throughout the study. Grateful acknowledgements are also made to Asst. Prof. Dr. Wipawadee Wongsuwan, the director of master of engineering technology program for her supports. In addition, grateful acknowledgements are made to Assoc. Prof.Worapong Tangsrirat, Asst. Prof. Dr.Warakorn Srichawenhsup, Dr. Thitiporn Lertratdechakul, members of thesis committee, for their valuable suggestions and comments. The author also wishes to acknowledge Thai-Nichi Institute of Technology for a great opportunity of master study and financial supports internships in Japan. The author sincerely appreciates all of his friends in Intelligent Electronic Systems Research laboratory for their friendships and goodwill.

Nuttawat Suppipat

Table Contents

Table Contents (Continued.)

List of Figures

List of Figures (Continued)

List of Table

Table Contents

Table Contents (Continued.)

List of Figures

List of Figures (Continued)

List of Table

Chapter 1

Introduction

1.1 Background

DC-DC power converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits with different voltage level requirements which are different from that supplied by the battery or external supplies and can be either higher or lower than the supply voltage. Additionally, the battery voltage declines as its stored power is drained. Switched DC-DC converters offer an operation to increase or decrease the voltage levels without multiple batteries in order to accomplish the DC operation. Most DC- DC converters also regulate the output voltage. DC-DC Converter in real-world applications used in many fields. Basic example is Solar PV plant and Electric cars. in Solar PV plant electric from solar cell isn't equal DC-DC converter helped adjust voltage for balanced before convert to AC-Voltage by inverter.

From figure.1.1, electric cars have many module follow as inverter, DC-DC converter, EV-ECU, battery management unit, on-board charger, air condition. DC-DC converter is a one of those. Inverter is converted from DC voltage to AC voltage used in motor drive. EV-ECU unit is car system control. Battery management unit are manage voltage and warning when battery is low. On-board charger used to charge when battery is low. Air-conditioner ECU is control air-condition system. This work focused on DC-DC converter.

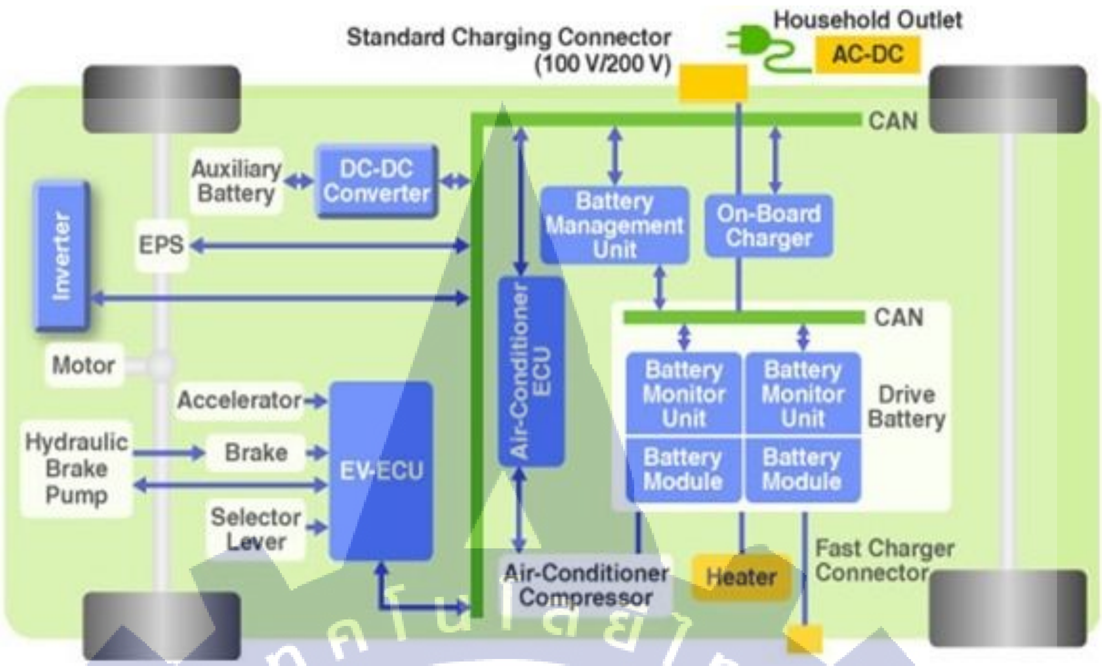


Figure 1.1 Illustrations of electric systems in Electric cars.

1.2 Classifications of DC-DC Switching Power Converters

Figure.1.2 shows the diagram of typical power supply system, showing the buck DC-DC converter as a minor part. The voltage can suppurate are two types, the first one is AC voltage and the second one is DC voltage. Generally the AC voltage used transformer to reduce or increase and DC voltage used DC-DC converter. DC-DC converter can suppurate are four types. A hybrid electric vehicle (HEV) combines the advantages of an electric motor and an internal combustion engine (ICE). HEVs are primarily driven by an electric motor whenever an ICE is not as efficient as an electric motor and otherwise run on the ICE. During braking, the electric motor works as a generator and recharges a battery by converting the vehicle kinetic energy into electric energy. HEVs can use a smaller drive battery pack than EVs because HEVs rely less on an electric motor. An electric car still uses a 12V system to power all of the original 12V accessories: lights, horn, etc. This may also power some control circuits for the electric drive system. However, unlike a gas car, there is no alternator to keep this battery charged. One option in the early days of EVs was to use a deep cycle 12V battery, as heavy duty as possible, and recharge it when you charge the main battery pack. This is not adequate if any amount of night driving is intended. As the battery drains in use, the headlights will grow dimmer and the turn signals flash more slowly. It can also affect the running of the car if some of the drive system components do not get the 12V signal they require. The solution is a car power technology dc-dc converter. This taps the full battery pack voltage and cuts it down to a regulated output, similar to that from an alternator. By tapping the full pack, there is no uneven discharge. Amperage required is so low that there is little effect on range. Isolation of the high and low voltage systems is maintained inside the DC/DC converter. This also eliminates the need for a separate 12V charging circuit for an auxiliary battery.

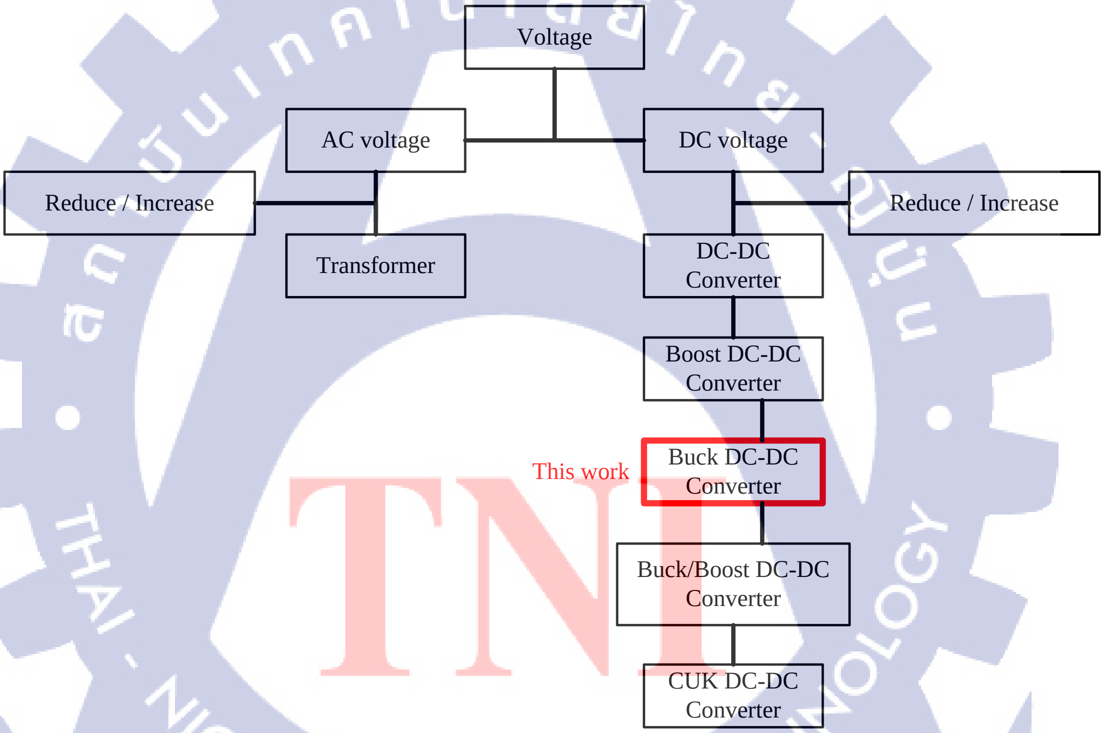


Figure 1.2 The diagram of power supply system, showing the buck DC-DC converter as a minor part.

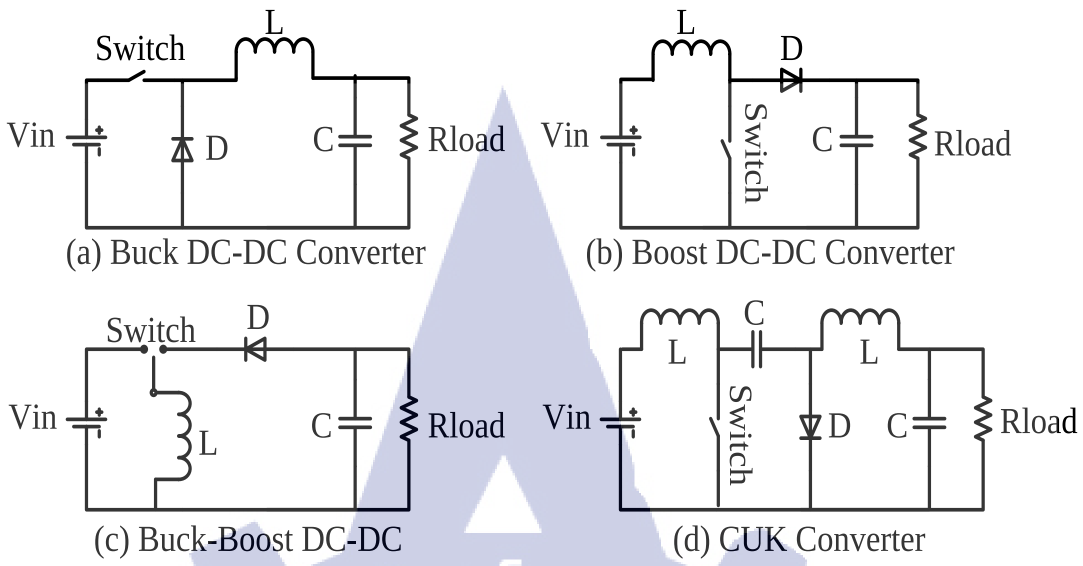


Figure.1.3 Types of DC-DC switching power converter.

The Figure 1.3 (a) shows the circuit configuration of a simple buck DC-DC converter the circuit constrains four basics devices as follow: resister mosfet capacitor inductor. Buck Converter is a converter where output voltage is lower than the input voltage. This type is the simplest way to reduce the voltage of a DC supply is to use a linear regulator, but linear regulators waste energy as they operate by dissipating power as heat. Figure 1.3 (b) shows the circuit configuration of a simple buck DC-DC converter the circuit constrains four basics devices as follow: resister MOSFET capacitor inductor. Boost Converter is a converter that outputs a voltage higher than the input voltage. It is a class containing two semiconductor switches, i.e. a diode and a transistor, and a single energy storage element. Filters made of capacitors are normally added to the output of the converter to reduce output ripple voltage.

Figure 1.3 (c) shows the circuit configuration of a simple buck DC-DC converter the circuit constrains four basics devices as follow: resister MOSFET capacitor inductor. Buck-Boost Converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, from an output voltage much larger than the input voltage, down to almost zero. Figure 1.3 (d) shows the circuit configuration of a simple Cuk converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. Most DC to DC converters also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the input voltage.

1.3 Commercially Available DC-DC Buck Power Converters

An electric car still uses a 12V system to power all of the original 12V accessories: lights, horn, etc. This may also power some control circuits for the electric drive system. However, unlike a gas car, there is no alternator to keep this battery charged. One option in the early days of EVs was to use a deep cycle 12V battery, as heavy duty as possible, and recharge it when you charge the main battery pack. This is not adequate if any amount of night driving is intended. As the battery drains in use, the headlights will grow dimmer and the turn signals flash more slowly. It can also effect the running of

Table 1.1 Specification of some commonly available DC-DC buck converters.

Power	V-in	V-out	I-out	Weight (g)	Size
10W	12V	3.3V	3A	50g	46x27x14
20W	12V	9V	3A	50g	46x27x14
15W	12V	5V	3A	50g	46x27x14
15W	12V/24V	5V	3A	120g	58x27x22
36W	24V	12V	3A	100g	58x27x22

the car if some of the drive system components do not get the 12V signal they require.

1.4 Motivations

The electric car is increasingly important, because it reduces pollution. Generally voltage electric car is 42V. It higher than electronic car equipment requires. So Buck DC-DC Converter is alternative to reduce voltage. Voltage will be reduced because the 14V is the voltage applied to the standard equipment used in the electronic car. This research needs to be reduced from 42V to 14V voltage range using a Buck DC-DC Converter for the electric car.

1.5 Statement of Problems and Hypothesis

The operating DC voltage of most electronic devices in electric cars is commonly lower than the power supply resources. The Buck DC-DC Converter is a suitable solution for this system. However, the output voltage generally contains a small ripple, which is an AC variation over the DC output. As a result, the accuracy of Buck DC-DC Converter may not high as required in the specification. Therefore, the Buck DC-DC converter to be studied in this thesis will focus on the reduction of ripple voltages in order to sustain the system stability with low-cost implementation.

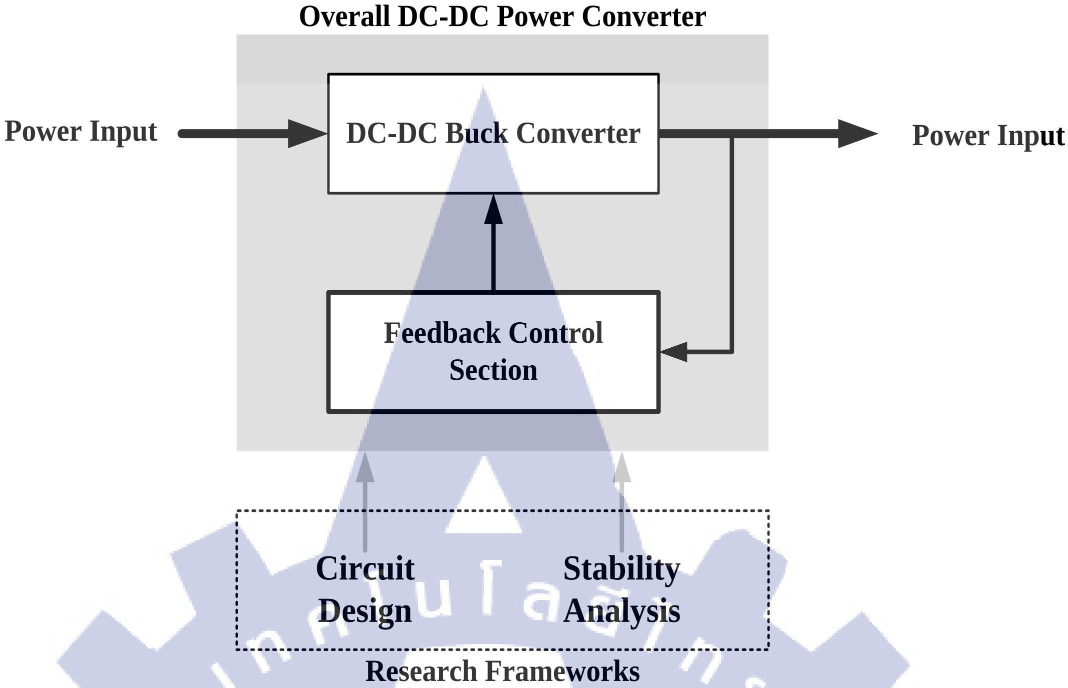


Figure 1.4 Block diagram of feedback control system.

1.6 Objectives

1.6.1 To study power conversion theories in automotive electric systems.

1.6.2 To study circuit topologies and operations of automotive DC-DC buck converters.

1.6.3 To analyze nonlinear dynamics and stability controls of automotive DC-DC buck converters mathematically.

1.6.4 To design and implement the low-cost high-stability automotive 42V-14V DC-DC buck converters.

1.7 Research Scopes

1.7.1 Study circuit configurations of a 42V to 14V buck DC-DC converter with feedback control.

1.7.2 Study the model and simulations of buck DC-DC converter with 42V input voltage and 14V output voltage using LT-spice IV and MATLAB Simulink.

1.7.3 Implement a buck DC-DC converter circuit with 42V input voltage and 14V output voltage.

1.7.4 Feedback control consist two types as follow: the stability control and chaos. This work was focused the feedback control system with reduce ripple voltage.

1.8 Expected Outcomes

1.8.1 Gain knowledge on power conversion theories.

1.8.2 Gain knowledge on circuit topologies and operations of automotive DC-DC buck converters.

1.8.3 Gain analyzes nonlinear dynamics and stability controls of automotive DC-DC buck converters mathematically.

1.8.4 Gain prototype of a 42V-14V buck DC-DC converter.

Chapter 2

Related Theories and Literature Reviews

2.1 Introduction

This chapter concerns with the related theories and literature reviews. The related theories focus on the buck DC-DC converter, circuit operations and calculation for device value. The feedback control in this work consists nonlinear dynamics and stability control for used in an automotive. Chaos will be used in the nonlinear dynamics feedback control system.

2.2 Related Theories

2.2.1 Circuit diagram of buck DC-DC Converter

Voltage regulation conventionally has been done by linear regulators but slowly is being replaced with switching regulators. To realize the importance of a switching regulator we will first compare its efficiency with a linear regulator. The resistance of the linear regulator varies in accordance with the load resulting in a constant output voltage.

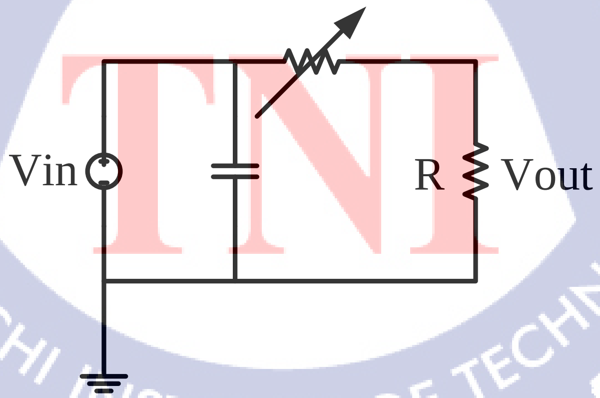


Figure 2.1 The circuit diagram of a linear regulator.

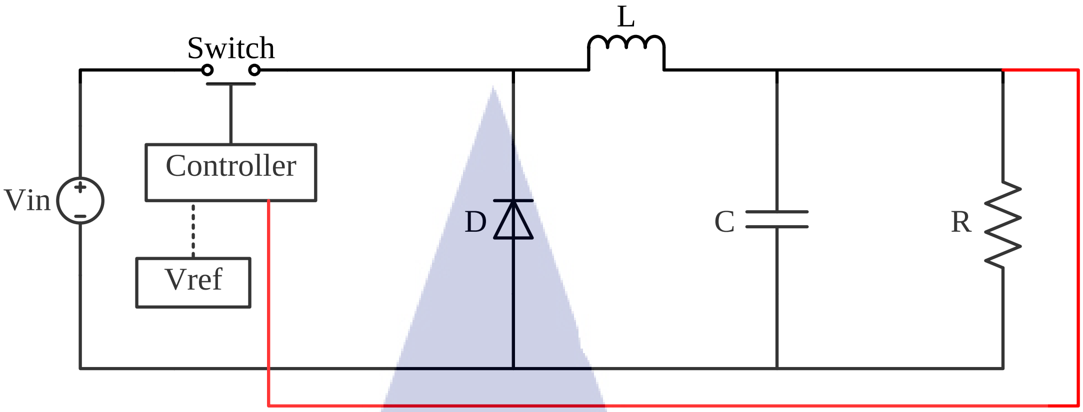


Figure 2.2 Basic element of the Buck DC-DC converter.

As shown in Figure 2.1, a circuit diagram of simple linear regulator. As for an example, the input voltage is 24V and the designed output is 12V. Using standard power equation, i.e.

$$P = I \cdot V \tag{2.1}$$

If the output current is 10A, this will result in (10A) (12V) equals 120W. Now the regulator must dissipate 120 W of heat energy. This results in a mere 50% efficiency for the linear regulator and a lot of wasted power which is normally transformed into heat. Provision for heat sinks for cooling makes the regulator bulky and large. Hence, where size and efficiency are critical, linear voltage regulators cannot be used.

Figure 2.2 shows the basic elements of the buck DC-DC converter, including the pulse-width modulating controller, a transistor switch, a inductor, a capacitor, and a diode. First, the switch can be a toggle switch which switches between the power supply voltage and ground, and is commonly implemented by transistors. Transistors should offer fast switching times and should be able to withstand the voltage spikes produced by the inductor. The input on the gate of the transistor is normally a Pulse Width Modulated (PWM) signal which will determine the ON and OFF states. Sizing of the power switch is determined by the load current and off-state voltage capability.

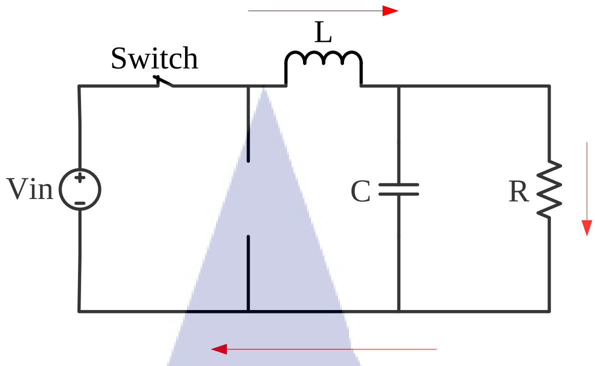
The power switch can either be a MOSFET, IGBT, JFET or a BJT. Power MOSFETs are the key elements of high frequency power systems such as high-density power supplies. At high voltages, MOSFETs still encounter some limitations. The intrinsic characteristics of the MOSFET produce a large on-resistance which increases excessively when the devices' breakdown voltage is raised.

Second, the function of the inductor is to limit the current slew rate through the power switch when the circuit is ON. The current through the inductor cannot change suddenly. When the current through an inductor tends to fall, the inductor tends to maintain the current by acting as a source. This limits the otherwise high-peak current that would be limited by the switch resistance only. The key advantage is when the inductor is used to drop voltage, it stores energy. Also the inductor controls the percent of the ripple and determines whether or not the circuit is operating in the continuous mode. Peak current through the inductor determines the inductor's required saturation-current rating, which in turn dictates the approximate size of the inductor. Saturating the inductor core decreases the converter efficiency, while increasing the temperatures of the inductor, the MOSFET and the diode. The size of the inductor and capacitor can be reduced by the implementation of high switching frequency, multi-phase interleaved topology, and a fast hysteric controller. A smaller inductor value enables a faster transient responses; it also results in larger current ripple, which causes higher conduction losses in the switches, inductor, and parasitic resistances. The smaller inductor also requires a larger filter capacitor to decrease the output voltage ripple. Inductors used in switched supplies are sometimes wound on toroidal cores, often made of ferrite or powdered iron core with distributed air-gap to store energy. A DC-DC converter transfers energy at a controlled rate from an input source to an output load, and as the switching frequency increases, the time available for this energy transfer decreases.

Third, the capacitor provides the filtering action by providing a path for the harmonic currents away from the load. Output capacitance (across the load) is required to minimize the voltage overshoot and ripple present at the output of a step-down converter. The capacitor is large enough so that its voltage does not have any noticeable change during the time the switch is off. Large overshoots are caused by insufficient output capacitance, and large voltage ripple is caused by insufficient capacitance as well as a high equivalent-series resistance (ESR) in the output capacitor. The maximum allowed output-voltage overshoot and ripple are usually specified at the time of design. Thus, to meet the ripple specification for a step-down converter circuit, we must include an output capacitor with ample capacitance and low ESR. The problem of overshoot, in which the output-voltage overshoots its regulated value when a full load is suddenly removed from the output, requires that the output capacitor be large enough to prevent stored inductor energy from launching the output above the specified maximum output voltage.

Fourth, the purpose of this diode is not to rectify, but to direct current flow in the circuit and to ensure that there is always a path for the current to flow into the inductor. It is also necessary that this diode should be able to turn off relatively fast. Thus the diode enables the converter to convert stored energy in the inductor to the load. This is a reason why we have higher efficiency in a DC-DC Converter as compared to a linear regulator. When the switch closes, the current rises linearly (exponentially if resistance is also present). When the switch opens, the freewheeling diode causes a linear decrease in current. At steady state we have a saw tooth response with an average value of the current.

Last, feedback and control circuitry can be carefully nested around these circuits to regulate the energy transfer and maintain a constant output within normal operating conditions. Control by pulse-width modulation is necessary for regulating the output. The transistor switch is the heart of the switched supply and it controls the power supplied to the load.



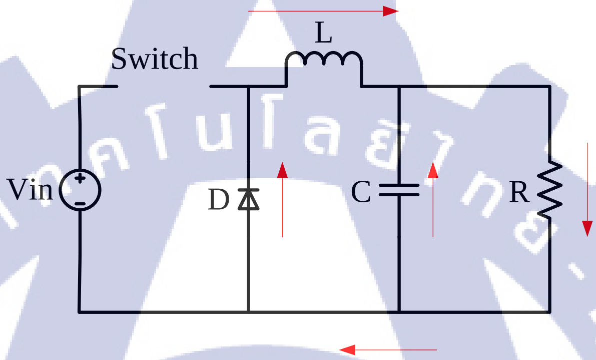


Figure 2.3 Circuit operations of buck DC-DC converter; (a) Operations during ON state, (b) Operations during OFF state.

2.2.2 Circuit operations of buck DC-DC converter

States of Operation There are two states in which the circuit given in Figure 2.3 operates. That is the ON State and the OFF State. These two states and the active circuit part for those given states are shown in the Figure 2.3 (a) and Figure 2.3 (b). On stage the operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load. In the OFF state the switch is open, diode D conducts and energy is supplied from the

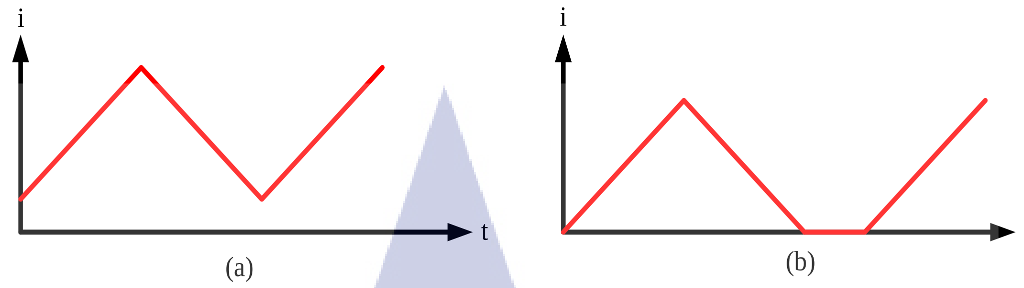


Figure.2.4 (a) Continuous Mode (b) Discontinuous Mode.

magnetic field of L and electric field of C. The current through the inductor falls linearly. When the FET switch is off, the inductor current discharges, inducing a negative voltage drop across the inductor. Because one port of the inductor is tied to ground, the other port will have a higher voltage level, which is the target output supply voltage. The output capacitance acts as a low-pass filter, reducing output voltage ripple as a result of the fluctuating current through the inductor. The diode prevents the current flowing from the inductor when the FET switch is off.

During the ON state and then the subsequent OFF state the Buck Converter can operate in Continuous Mode or Discontinuous Mode. The difference between the two is that in CCM the current in the inductor does not fall to zero. See Figure 2.4. Current flows continuously in the inductor during the entire switching cycle in steady state operation. In most Buck regulator applications, the inductor current never drops to zero during full-load operation. Overall performance is usually better using continuous mode, and it allows maximum output power to be obtained from a given input voltage and switch current rating. Energy from the battery is supplying the load and is being stored in the inductor L as a magnetic field. The current through the inductor is rising linearly. In the DCM the current in the inductor falls to zero and remains at zero for some portion of the switching cycle. It starts at zero, reaches a peak value, and returns to zero during each switching cycle. In applications where the maximum load current is fairly low, it can be advantageous to design for

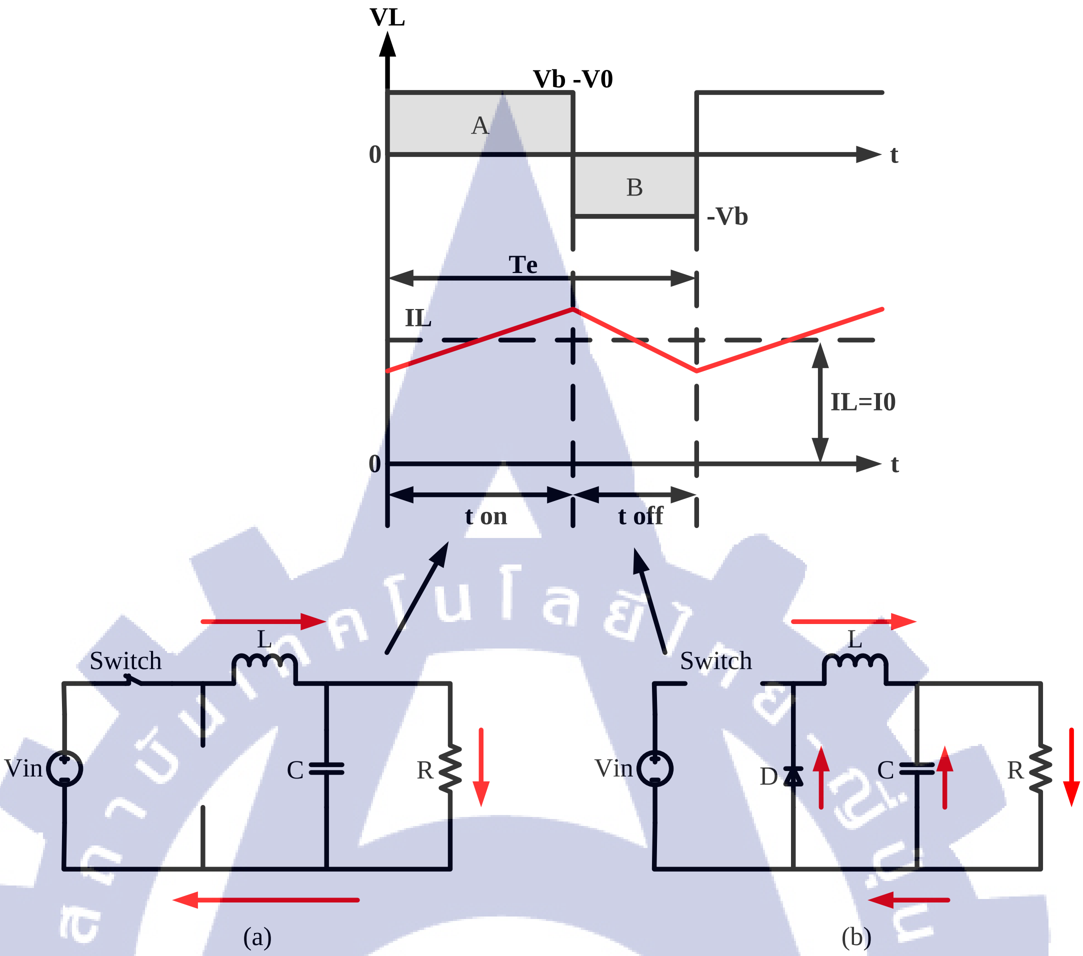


Figure 2.5 Voltage in each state.

discontinuous mode operation. In these cases, operating in discontinuous mode can result in a smaller overall converter size (because a smaller inductor can be used). Often the output capacitor must be large to keep the voltage constant.

2.2.3 Calculations of the Duty Ratio

For calculation of the duty ratio we will first of all assume that the converter is in steady state. The switches are treated as being ideal, and the losses in the inductive and the capacitive elements are neglected. Also it is important to point out that the following analysis does not include any parasitic resistances. The analysis also has the i.e. $i_L(t) > 0$. When the switch is on for time duration t_{ON}, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $V_L = -V_0$ across the inductor in Figure 2.5 (a). This voltage causes a linear increase in the inductor current i_L. When the switch is turned off, because of the inductive energy storage, L i continue to flow. This current now flows through the diode, and $V_L = -V_0$ in Figure 2.5 (b).

$$\int_0^{T_s} V_L dt = \int_0^{T_{ON}} V_L dt + \int_{T_{ON}}^{T_s} V_L dt = 0 = 0 \quad (2.2)$$

$$(V_d - V_0)t_{ON} = V_0(t_s - t_{ON}) \quad (2.3)$$

$$\frac{V_0}{V_d} = \frac{t_{ON}}{t_s} \text{ (Duty ratio)} \quad (2.4)$$

Hence in this mode, the voltage output varies linearly with the duty ratio of the switch for a given input voltage and does not depend on any other circuit parameter.

2.2.4 Calculation for Inductor

Calculation for Inductor from Figure 2.5 (a) we can derive a simplified differential equation based on the assumption that the voltage across the load, and thereby across the capacitor, is fairly constant. The differential equation in terms of the current through the inductor. We know the fact that the buck converter can either operate in its continuous conduction mode or discontinuous mode. When it operates in the continuous conduction mode, there is always a current in the inductor. The minimum current in the continuous conduction mode can be zero.

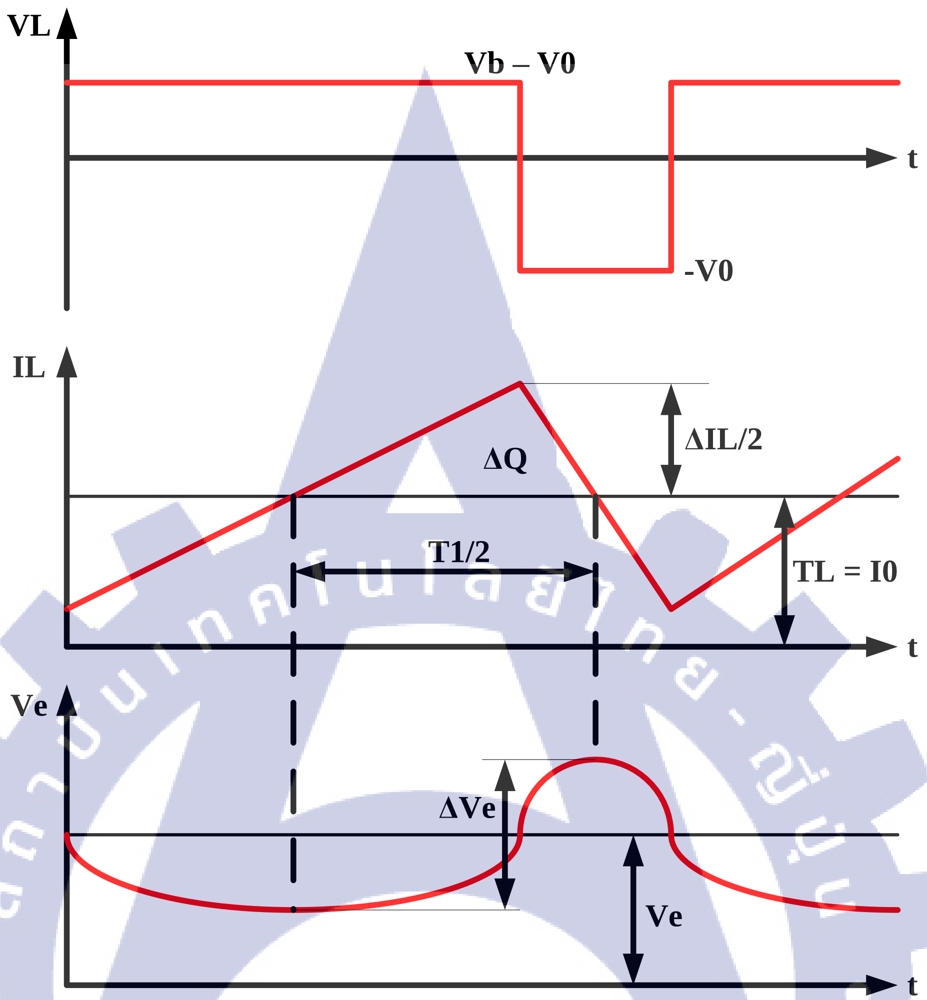


Figure 2.6 Output voltage ripple in a step-down converter.

$$L_{\min} = \frac{1-D}{2} RT = \frac{1-D}{2f} R \tag{2.5}$$

2.2.5 Calculation for Capacitor

The output capacitor is assumed to be so large as to yield $V_0(t) = V_0$. However, the ripple in the output voltage with a practical value of capacitance can be calculated by considering the waveforms shown in Figure 2.6 for a continuous-conduction mode of operation. Assuming that all of the ripple component in L_i flows through the capacitor and its average component flows through the load resistor. Therefore, the peak-to-peak voltage ripple ΔV_0 can be written as

$$\Delta V_0 = \frac{\Delta Q}{C} = \frac{1}{C}\frac{1}{2}\frac{\Delta I_L}{2}\frac{T_S}{2} \tag{2.6}$$

From during T_{off}

$$\Delta I_L = \frac{V_L}{L}(1-D)T_S \tag{2.7}$$

Therefore, substituting ΔI_L from (7) into the (6) gives

$$\Delta V_0 = \frac{T}{8C}\frac{V_0}{L}(1-D)T_S \tag{2.8}$$

$$\therefore \frac{\Delta V_0}{V_0} = \frac{1}{8}\frac{T_S^{\,2}(1-D)}{LC} = \frac{\pi^2}{2}(1-D)\left[\frac{f_c}{f_s}\right]^2 \tag{2.9}$$

Where switching frequency $f_s = \dfrac{1}{T_S}$ and

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{2.10}$$

Equation (2.9) shows that the voltage ripple can be minimized by selecting a corner frequency f_c of the low pass filter at the output such that $f_c << f_s$. Also, the ripple is independent of the output load power, so long as the converter operates in the continuous-conduction mode. We should note that in switch-mode dc power supplies, the percentage ripple in the output voltage are usually specified to be less than, for instance, 1%. The analysis carried out above assumes ideal components and if we were to make the analysis using all the non-ideal components it would make the derivation a bit more complex with a lot of other parameters included in the final equation. But for the calculation of initial values of the components the above approximations does result in reasonable values. It is also important to realize here that the ESR and ESL are also important and can even dominate.

2.2.6 Chaos Theory and Dynamic Systems

Chaos is a property of dynamical systems. And a dynamical systemic nothing more than a source of changing observations: Fibonacci imaginary garden with its rabbits, the Earth's atmosphere as reflected by a thermometer at London's Heathrow airport, the economy as observed through the price of IBM stock, a computer program simulating the orbit of the moon and printing out the date and location of each future solar eclipse. Indeed, one of the myths of chaos we will debunk is that chaos makes forecasting a useless task. In an alternative but equally popular butterfly story, there is one world where a butterfly flaps its wings and another world where it does not. This small difference means a tornado appears in only one of these two worlds, linking chaos to uncertainty and prediction: in which world are we? Chaos is the name given to the mechanism which allows such rapid growth of uncertainty in our mathematical models.

A dynamical system is one whose state changes in time. If the changes are determined by specie rules, rather than being random, we say that the system is deterministic, otherwise it is stochastic. The changes can occur at discrete time steps or continuously. Also, discrete-time systems have already been extensively explored, in part because they are more computationally tractable. Stochastic systems mimic many of the features of chaos, but they are not chaotic because chaos is a property of deterministic systems. Furthermore, introducing randomness into a dynamical model is a way of admitting ignorance of the underlying process and obtaining plausible behavior without a deep understanding of its cause.

A number of themes appear repeatedly in the study of dynamical systems such as properties of individual orbits, periodic orbits, typical behavior of orbits, statistical properties of orbits, randomness vs. determinism, entropy, chaotic behavior and stability under perturbation of individual orbits and patterns. Normally, the dynamical systems can be written in the system of mathematically equations that describe how each variable changes with time as follows;

$$\frac{dx_1}{dt} = f_1(x_1, x_2, ...x_n, t)$$
$$\frac{dx_2}{dt} = f_2(x_1, x_2, ...x_n, t) \quad (2.11)$$
$$\frac{dx_n}{dt} = f_n(x_1, x_2, ...x_n, t)$$

Where n species are given by $(x_1,....x_n)$ and the right side of each equation is a function of $(f_1..., f_n)$ that indicated the variables changes with time.

Table 2.1 Summary of related calibration techniques for automotive Buck DC-DC converters.

Ref.	**Years**	**Voltages (V)**		**Proposed Designs and Calibrations Techniques**
		Input	**Output**	
[1]	2002	42	14	The use of Electromagnetic Compatibility (EMC)
[2]	2003	42	14	Magnetic less bi-directional Technique
[3]	2004	42	14	The use of Zero-Volt Zero-Current System (ZVZCS)
[4]	2005	42	14	The use of digital control system
[5]	2006	42	14	The use of flying capacitor
[6]	2010	42	14	The use of Buck-Boost converter

2.3 Literature Reviews

Table 2.1 summarizes six related calibration techniques for Buck DC-DC converters, involving L.Jourdan; JL.Schanen; and J.Roudet (2002) [1], Fang Z. Peng; Fan Zhang; and Zhaoming Qian (2003) [2], A. Jangwanitlert J. C. Balda (2004) [3], Dwaraka S. Padimiti; and Mehdi Ferdowsi (2005) [4], Fan Zhang,Lei Du1; Fang Z. Peng; and Zhaoming Qian (2006) [5], Fan Zhang; Lei Du; and Fang Zheng Peng (2008) [6], Ian Nakashima; Eduardo F. Arcos; and Micah Ortzar (2010) [7]. All proposed techniques are applicable for automotive Buck DC-DC converters where the input and output voltages are 42V and 14V, respectively.

As shown in Table 2.1, L.Jourdan; JL.Schanen; and J.Roudet (2002) [1] proposes electrical power needs in automotive area that has led to several modifications in the power system architecture. This rapidly increasing request, it has been necessary to increase the voltage level, to decrease the currents: several car manufacturers have retained 42V, to not exceed 60V which is, for

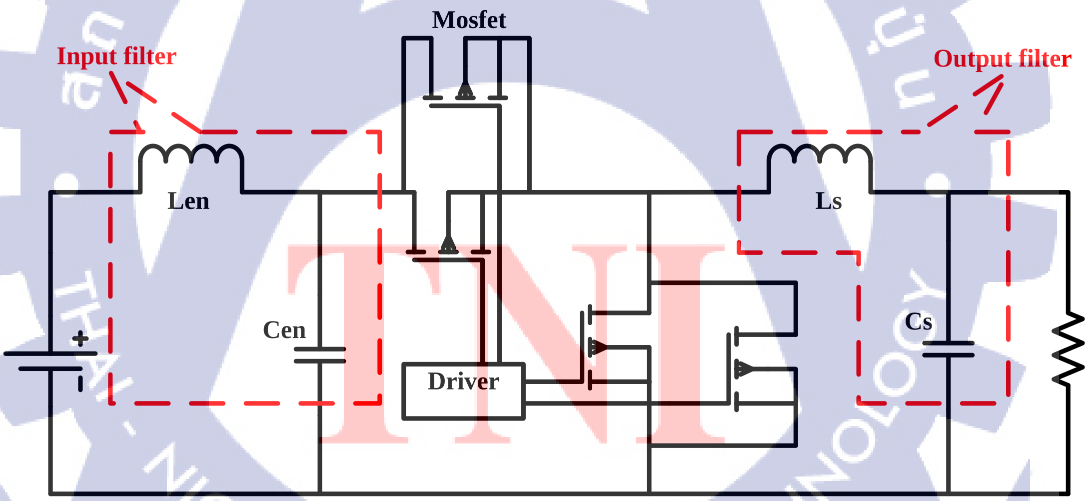


Figure 2.7 Synchronous Buck converter.

safety requirements, the maximum transient overvoltage allowed in a car. To design this converter, following automotive specifications must be fulfilled, including a 1 kW nominal power, a 42V input voltage with a 900 mV ripple voltage, a 14V output voltage with a 300 mV ripple voltage, a 100 ms time response, and respect automotive EMC.

Contrary to inductors, which much be designed according to circuit conditions, capacitors are to be chosen in a manufacturer catalogue. Once the capacitor value is defined, all data are available in the datasheet. This can be easily implemented under a numerical form, using tables. Unfortunately, this is once again not a derivable solution, since capacitor values are discrete. As a first result, it must be noticed that the switching frequency results from a trade-off between EMC and passive components volume: a too high switching frequency do not allow the respect of EMC standard, whereas a too low lead to prohibitive filtering elements. As far as optimization strategies are conceded, many of them have been tested, using the different models of section IV (derivable or not). The first optimization result uses linear model (method 1). It is more robust and quicker than using a binary indication of E.M.C. standard limits with sequential inductor model (method 2). Results is presented in the

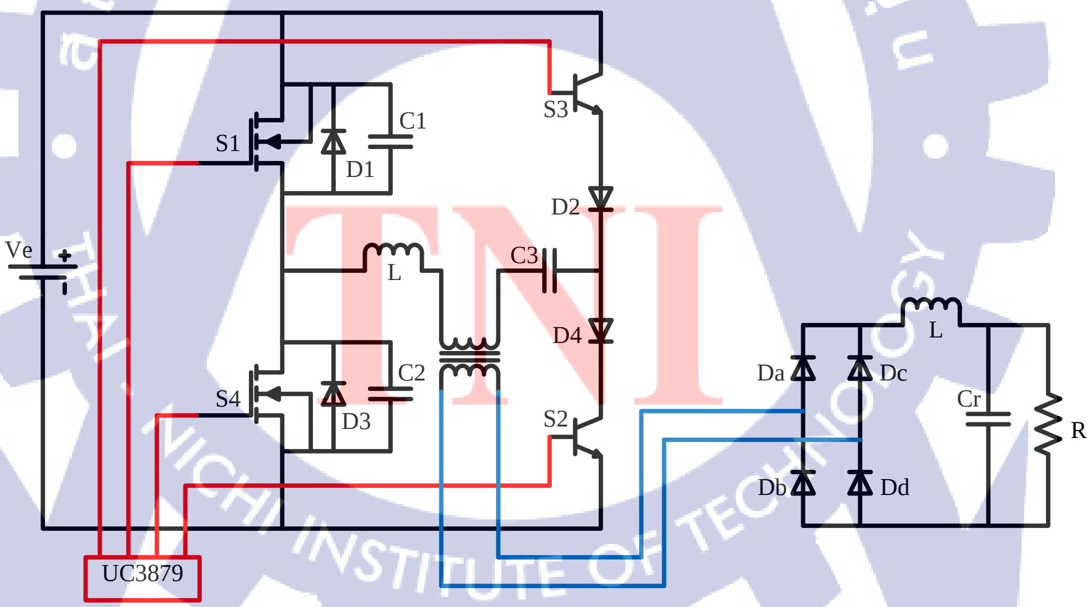


Figure 2.8 ZVZCS converter topology.

Table 2.1, the starting point is the same in both cases. It will also be really helpful to choose the best solution between several subcontractors, or even to evaluate their choices. Since this method can be applied to other power electronics equipment, this tool will also be useful to optimize their car conceptions as a whole.

Fang Z.Peng; Fan Zhang; and Zhaoming Qian (2003) [2] presents a compact, efficient, magneticless bi-directional DC-DC converter for 42/14 V automotive systems. The proposed converter has no or minimal requirement for magnetic components and can achieve an efficiency of 98%. The main circuit of the DC-DC converter is analyzed and its control scheme is presented in the paper. Simulation results and a 1 KW prototype are used to verify the analysis and to demonstrate the advantages. In the automotive industry, more electric needs in the next generation vehicles have been pushing toward 42V systems. Several dual voltage (42/14-V) architectures have been proposed for the transition and accommodation of 14V loads.

A. Jangwanitlert J. C. Balda Alrmact (2004) [3] analyzes two solutions for ringing voltage problems occurring in the output voltage of a arc- Voltage and Zero-Current Switching Phase-Shifted Pulsewidth Modulation Full-Bridge dc-de converter intended for automotive applications. An RCD snubber and an active snubber (thereafter called "modified flyback converter" since it includes a flyback converter to provide an additional power supply) are designed to reduce the ringing voltage caused by mainly the interaction among the transformer leakage inductance and circuit parasitic capacitances. This converter with the RCD snubber and the modified flyback converter has efficiencies of 91 YO and 92 %, respectively, at 42V 1 kW full load. The converter without any snubber has a lower efficiency of 88.7%. Experimental and simulation results are shown to complement the theoretical analysis. Fig. 10 shows the ZVZCS converter for automotive applications. This converter was designed so the switches of the leading and lagging legs operate under the ZVZCS mode during turn-on, the switches of the lagging leg under the ZCS mode during turn-off, and the switches of the leading leg under near ZVS mode during turn-off. The dead times for the leading and lagging legs are equal because the leading-leg switches are power MOSFETs with internal diodes and capacitors to reduce voltage spikes and the tail current (typical of IGBTs used in high power applications). An analysis of the problem of the ringing voltages encountered in ZVZCS converters was performed since the main drawback was a reduction of the converter efficiency.

Dwaraka S. Padimiti; and Mehdi Ferdowsi (2005) [4] in this paper were shown electric and hybrid electric vehicles need a power plant that includes dc-dc converters. While using these converters, their control plays an important role in the overall performance of the vehicle. Due to their several drawbacks including poor communications, analog control schemes are not suitable for the automotive industry, whereas digital control methods successfully meet the demands. Various types of digital control techniques for dc-dc converters are studied and classified in this paper. The drawbacks and advantages of each method are described. The conversion of automotive systems from 14V to 42V is inevitable in the future automobile industry. This transition to use 42V systems indicates the use of dc-dc converters. The electric vehicles and hybrid electric vehicles (EVs/HEVs) require dc-dc converters in addition to ac-dc/dc-ac converters. The control of these converters plays an important role in the overall performance of the HEV. Hence optimization of the efficiency and performance of various converters used in the HEV as well as the entire system level integration is the present major concern in the automotive industry. Control of dc-dc converters is racing towards complete digitalization so as to improve their performance. Even though digital control techniques are in the early stages they are proving to be the emerging technology of future.

Fan Zhang,Lei Du1; Fang Z. Peng; and Zhaoming Qian (2006) [5] presents flying capacitor technology is widely used in low power dc-dc converter, especially in power management of the integrated circuit. These circuits have a limitation: high pulse currents will occur at the switching transients, which will reduce the efficiency and cause EMI problems. This makes it difficult to use this technology in high power level conversion. This paper presents a new design method for dc-dc converter with flying capacitor technology. The new method can reduce the high pulse current which usually causes serious problem in traditional converters. Therefore the power level of this new designed converter can be extended to 1 kW or even higher. A 1 kW 42/14 V flying capacitor converter was designed for 42V automotive systems. The experimental results verified the analysis and the prototype achieved the efficiency close to 96% at full load.

Ian Nakashima; Eduardo F. Arcos; and Micah Ortzar (2010) [7] presents the sodium–nickel chloride battery, commonly known as ZEBRA, has been used for an experimental electric vehicle (EV). These batteries are cheaper than Li-ion cells and have a comparable specific energy (in watt–hours per kilogram),but one important limitation is their poor specific power (in watts per kilogram). The main objective of this paper is to demonstrate experimentally that the combination of ZEBRA batteries and ultra capacitors (UCAPs) can solve the lack of specific power, allowing an excellent performance in both acceleration and regenerative braking in an EV. The UCAP system was connected to the ZEBRA battery and to the traction inverter through a buck–boost-type dc–dc converter, which manages the energy flow with the help of DSP controllers. The vehicle uses a brushless dc motor with a nominal power of 32 kW and a peak power of 53 kW. The control system measures and stores the following parameters: battery voltage, car speed to adjust the energy stored in the UCAPs, instantaneous currents in both terminals (battery and UCAPs), and present voltage of the UCAP. The increase in range with UCAPs results also show that this alternative is cheaper than Li-ion powered electric cars.

Chapter 3
Research Methodology

3.1 Introduction

This chapter presents the research methodology for a nonlinear dynamics and stability controls for automotive switching DC-DC power converters. This chapter includes the overall research processes, utilizing data, research tools, data analysis methods, research procedures and conclusions.

3.2 Overall Research Processes

3.2.1 Study the related theories and circuits of automotive buck DC-DC converters.

3.2.2 Perform theoretical analysis for nonlinear dynamics and stability controls of automotive buck DC-DC converters through dynamical theories.

3.2.3 Perform circuit and system simulations of automotive buck DC-DC converters using MATLAB, Proteus simulation and Orcad capture.

3.2.4 Implement and test circuit prototypes of buck DC-DC converters and also perform the comparisons between circuit prototypes and simulation results.

3.3 Utilizing Data

Data to use in this work follow devices datasheets, limits of each equipment, maximum current load, maximum voltage, physical specification of device and related theories of the buck DC-DC converter generally using differential equation.

3.4 Research Tools

The theoretical analyses will be performed through dynamical theories and differential equation systems. Simulations will employ Simulink in MATLAB, Proteus simulation and Orcad capture.

3.5 Data Analysis Methods

3.5.1 Using differential equation and basic equation to solver the values of device in buck DC-DC converter circuit.

3.5.2 Simulation the circuit in MATLAB, Proteus simulation and Orcad capture.

3.5.3 Implement the buck DC-DC converter circuit and measurement.

3.6 Research Procedures

3.6.1 Study related theories and analyze the differential equations for the buck DC-DC converters.

3.6.2 Use the program MATLAB, Proteus simulation and Orcad capture to simulate and analyze all devices in the buck DC-DC converters.

3.6.3 Determine the value of devices in the buck DC-DC converter.

3.6.4 Apply the chaotic system and stability control technique for feedback control to reduce voltage ripple and implement the circuit prototype.

3.6.5 Make a comparison between the each prototype and simulation with respect the ripple voltage.

3.7 Conclusions

This chapter has presented the research methodology for a nonlinear dynamic and stability control for automotive switching DC-DC power converter, including the overall research processes, utilizing data, research tools, data analysis methods and research procedures.

Chapter 4

Research Results

4.1 Introduction

This chapter presents the research results for a nonlinear dynamics and stability controls for automotive switching DC-DC power converters. This chapter includes the overall research results.

4.2 Block diagram and trend of duty cycle

Buck DC-DC power converter suppurate into two sections. The first one is typical section and the second one is feedback control section as shown on the Figure 4.1. V_O from typical section must deride by R_1 and R_2 before input to error amp, loop filter finally comparator with ramp generator and got PWM to control MOSFET. If D is change V_0 can change Figure 4.2 shows trend of each duty cycle.

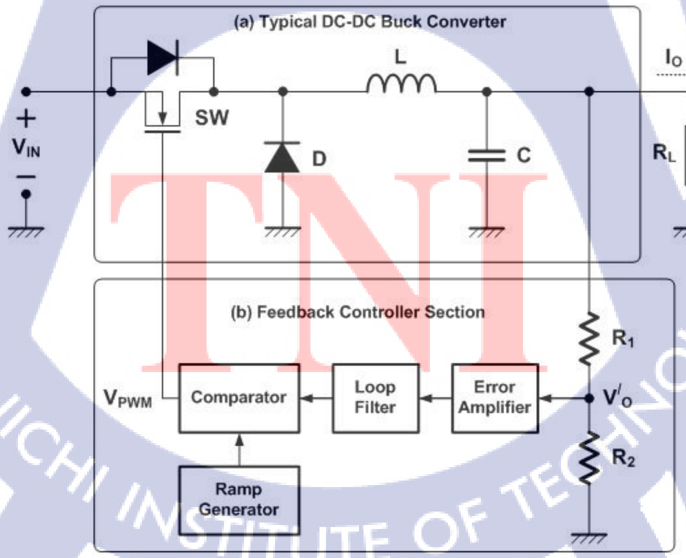


Figure 4.1 shown the block diagram of Buck DC-DC converter

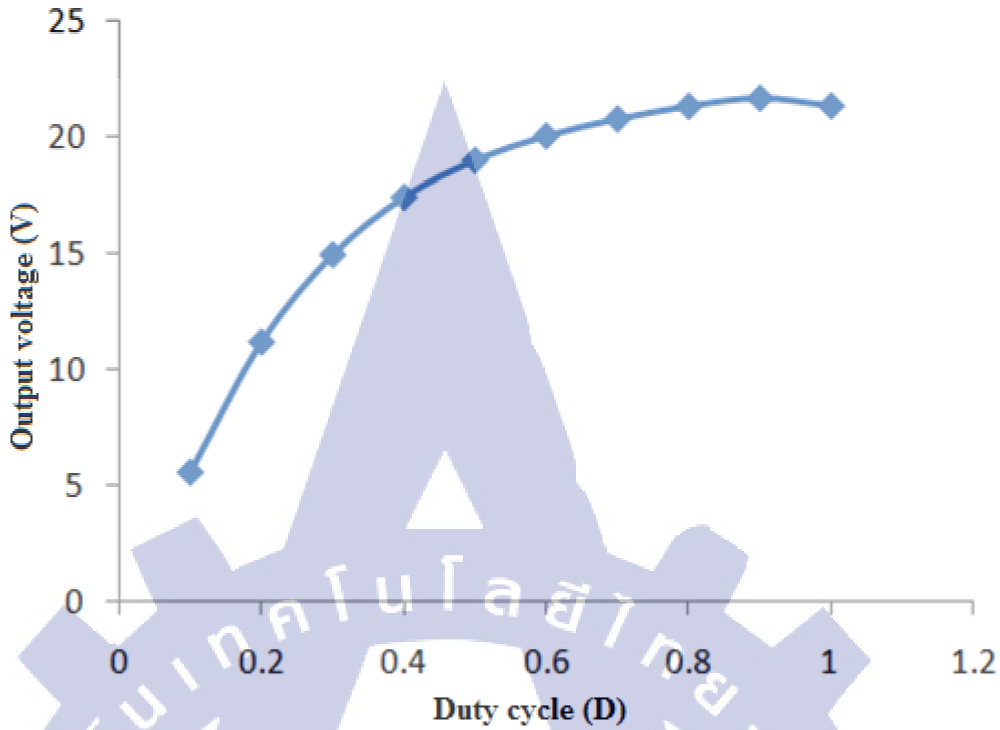


Figure 4.2 Trend of duty cycle.

In the feedback section after V_O, the device are R_1 and R_2 and input to error amp. The output voltage contains some ripples. In error amp ripple voltage compare with DC from regulator for get pulse signal before input to error amp.

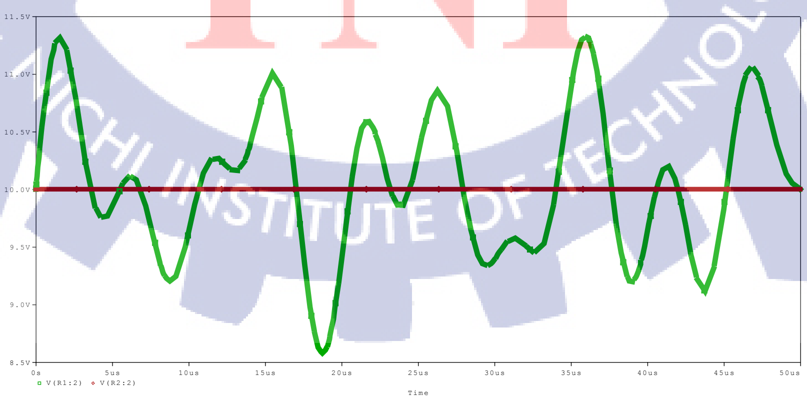


Figure 4.3 Ripple output and DC voltage from regulator.

Figure 4.3 shows simulation ripple output compared with DC voltage from regulator. In this figure green line is voltage ripple from typical section and the red line reference is dc voltage from regulator to got pulse signal. Then, voltage ripple compare with dc voltage we got pulse signal if voltage greater than dc voltage from regulator pulse signal is equal to the power of the opamp. Ramp generator in feedback control section used IC number NE555 to generate saw tooth signal.

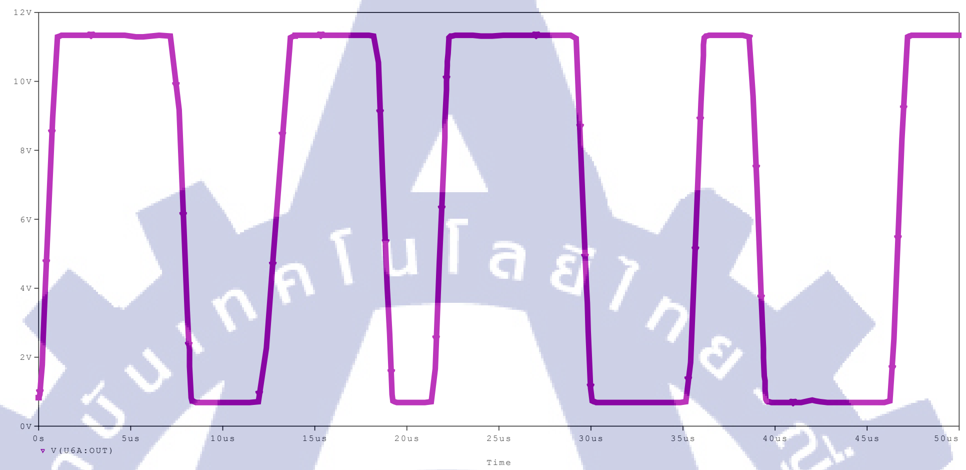


Figure 4.4 Pulse Width Modulation Signal.

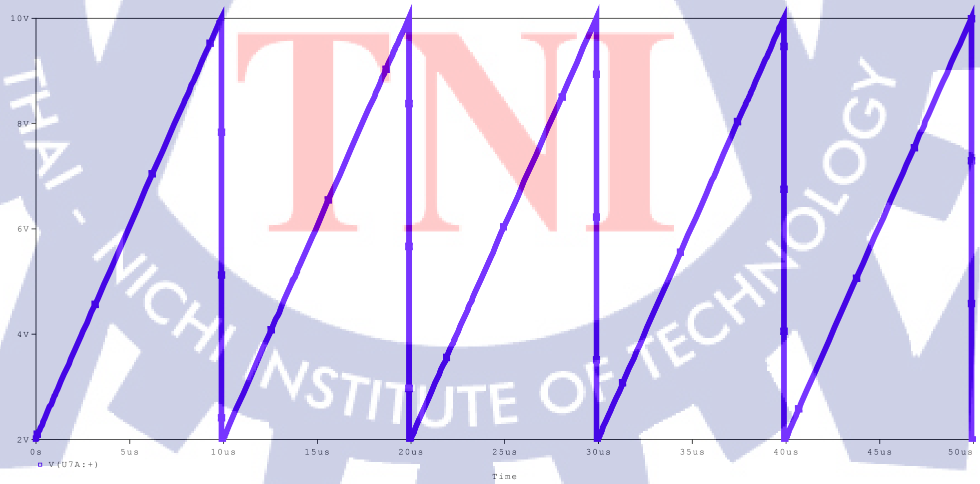


Figure 4.5 Sawtooth signal from IC number NE555.

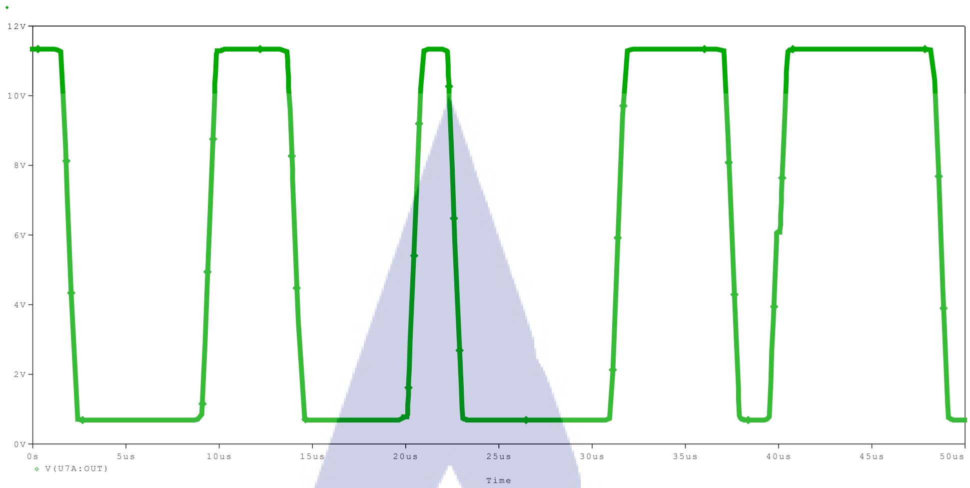


Figure 4.6 Sawtooth signal from IC number NE555.

Therefore, after compare between saw tooth signal from IC number NE555 and pulse signal got duty cycle the PWM feedback to control MOSFET. Then if output is change input isn't change. Based on Figure 4.1, the circuit is operated in two stages. When the switch is ON, the voltage and current of the inductor are given by

$$V_L(t) = L\frac{di_L(t)}{dt}; V_L = V_{in} - V_o$$

$$i_L{}' = \frac{V_{in}}{L} - \frac{V_0}{L} \quad (4.1)$$

Using Kirchhoff's Current Law analysis (KCL), the inductor current and the output voltage are given by

$$i_L = C\frac{dv_0}{dt} + \frac{V_0}{R}$$

$$V_0{}' = \frac{i_L}{C} - \frac{V_0}{RC} \quad (4.2)$$

In the case where the switch is OFF, the currents through the capacitors and the inductor can be found as follows;

$$i_C(t) = C\frac{dV_C(t)}{dt}; V_L = V_{in} - V_o$$

$$i_L' = -\frac{V_0}{L} \tag{4.3}$$

By using KCL, Equation (3) can be expressed as

$$0 = C\frac{dv_0}{dt} + \frac{V_0}{R}$$

$$V_0' = -\frac{V_0}{RC} \tag{4.4}$$

From all above equations, the state space of the Buck DC-DC converter for the state ON (t_{ON}) can be found as follows;

$$\begin{bmatrix} i_L \\ V_0 \end{bmatrix}' = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_0 \end{bmatrix} + \begin{bmatrix} \frac{d_1}{L} \\ 0 \end{bmatrix} [V_{in}] \tag{4.5}$$

In addition, the stage space averaging equation for the DC-DC Buck converter for the state OFF (t_{OFF}) can also be found as follows;

$$\begin{bmatrix} i_L \\ V_0 \end{bmatrix}' = \begin{bmatrix} 0 & -\frac{d_1 + d_2}{L} \\ \frac{d_1 + d_2}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_0 \end{bmatrix} + \begin{bmatrix} \frac{d_1}{L} \\ 0 \end{bmatrix} [V_{in}] \tag{4.6}$$

where d_1=(t_1/T) and d_2=([t_1-t_2]/T). T is a period of the pulse. The value of the output voltage is compared whit the ramp signal to generate the switching signal.

$$V_c \geq \frac{V_{ramp}}{k} + V_{ref} \tag{4.7}$$

The voltage across the capacitor is given by

$$\frac{dV_c}{dt} = \frac{1}{C}\left(i_L - \frac{V_c}{R}\right) \text{ and } \frac{di_L}{dt} = \frac{1}{L}(-V_c) \tag{4.8}$$

In the case where the inductor current is positive, and

$$V_c < \frac{V_{ramp}}{k} + V_{ref} \tag{4.9}$$

The voltage across the capacitor is consequently given by

$$\frac{dV_c}{dt} = \frac{1}{C}\left(i_L - \frac{V_c}{R}\right) \text{ and } \frac{di_L}{dt} = \frac{1}{L}(V_{in} - V_c) \tag{4.10}$$

Finally, in the case where there is inductor current in the circuit and,

$$V_c < \frac{V_{ramp}}{k} + V_{ref} \tag{4.11}$$

The voltage across the capacitor is consequently given by

$$\frac{dV_c}{dt} = \frac{1}{C}\left(-\frac{V_c}{R}\right) \text{ and } \frac{di_L}{dt} = 0 \tag{4.12}$$

It should be noted that the ramp voltage is given by

$$V_{ramp} = V_L + (V_U - V_L)\left(\frac{t}{T}\right) \mathrm{mod}\, 1 \tag{4.15}$$

when the V_U V_L are upper and lower voltages of ramp signal.

The simulations have been performed in MATLAB and Proteus simulation programs. Figure.4.7 shows the switching DC-DC buck converter circuit schematic in SIMULINK. Figure.4.8 shows the circuit diagram of the feedback-controller, including error amplifier, filter, and a ramp generator in Proteus Simulation. The DC-DC buck converter circuit was implemented on-board using a power MOSFET IRF9640 and power standard recovery diode 1N4001. The DC input voltage was varied from 20V to 60V as in mathematical model control circuit was supplied from a voltage supply. The ramp generator implemented based on a NE555 timer generates a saw tooth waveform.

A bandwidth dual operational amplifier TL082 is used as a comparator and a difference amplifier. Figure 4.9 shows the chaotic attractor of the output voltage versus the output current at different loading conditions, i.e. 22Ω, 30Ω, and 50Ω. It is apparent that the system can exhibit the chaotic attractors. The experimental result of chaotic attractor of the output voltage versus the output current at different loading conditions the output voltage waveforms in chaotic states, comparing between simulated and experimental values the inductor currents waveforms in chaotic states, comparing between simulated and experimental values. It can be seen from Figure 4.9 that the automotive can be operated in the chaotic modes. This suggests that the suitable conditions should be made in order to avoid the instability of the power conversion systems.

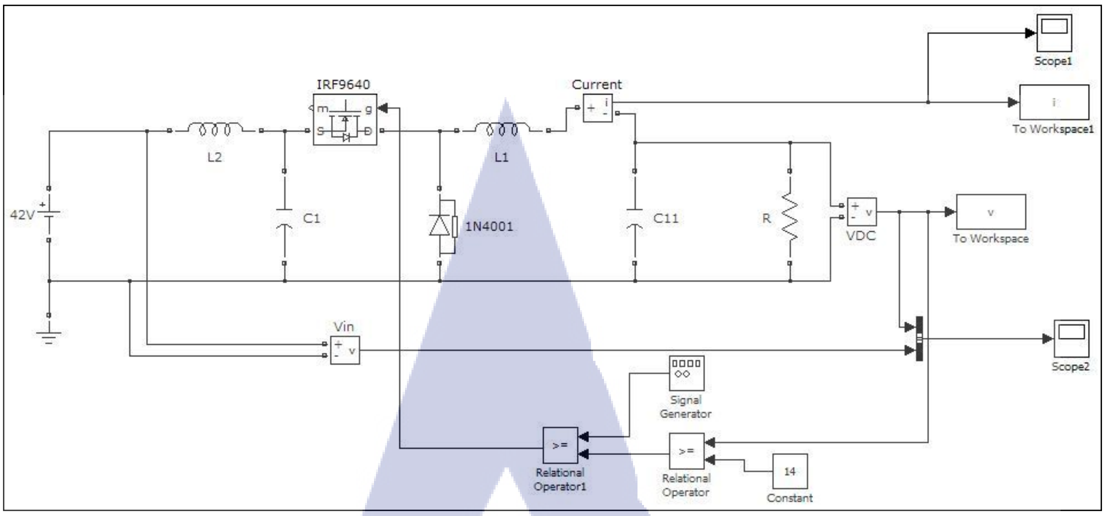


Figure 4.7 Circuit schematic in MATLAB Simulink.

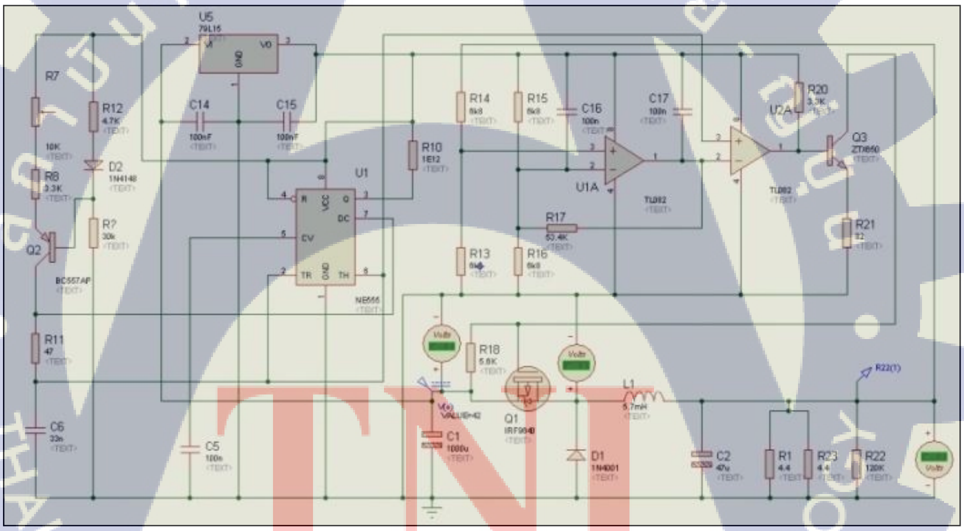
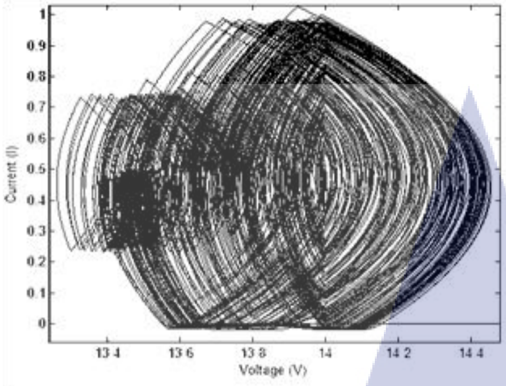
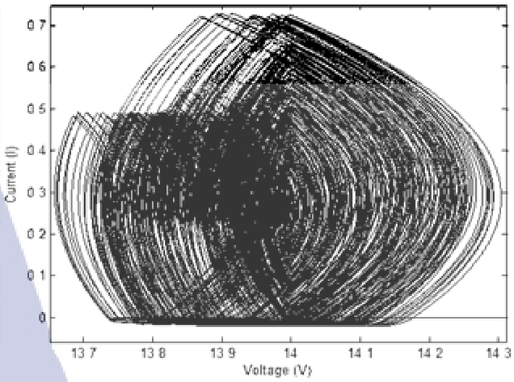


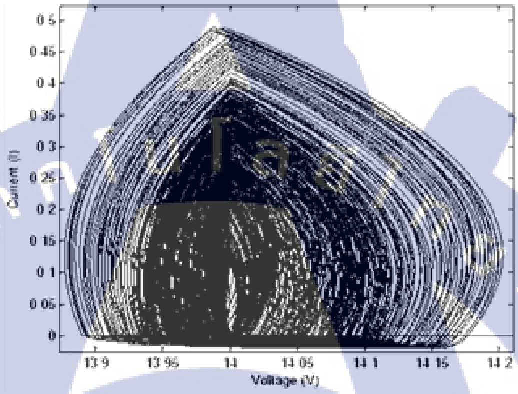
Figure 4.8 Circuit schematic in Proteus Simulation.



(a) Simulated attractor at R_L=22Ω

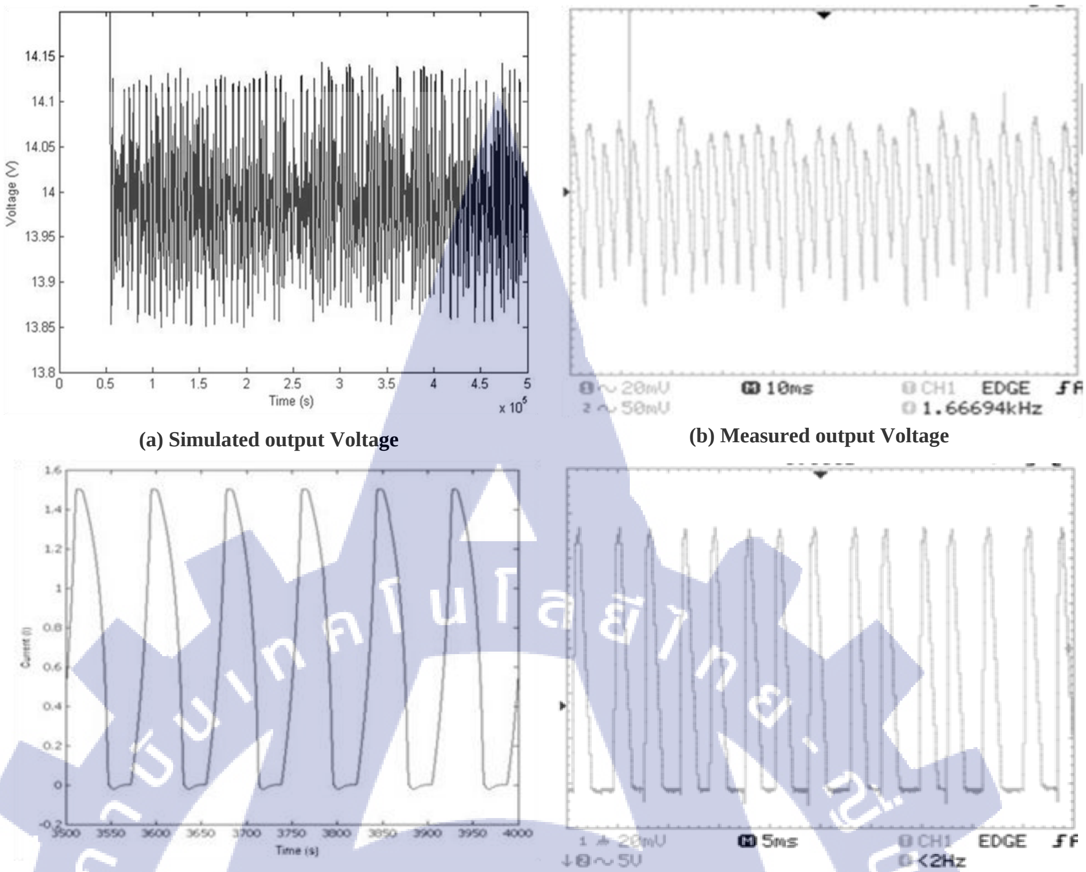


(b) Simulated attractor at R_L=30Ω



(c) Simulated attractor at R_L=50Ω

Figure 4.9 Simulation attractors for each loading condition.



(a) Simulated output Voltage

(b) Measured output Voltage

(c) Simulated output current

(d) Measured output current

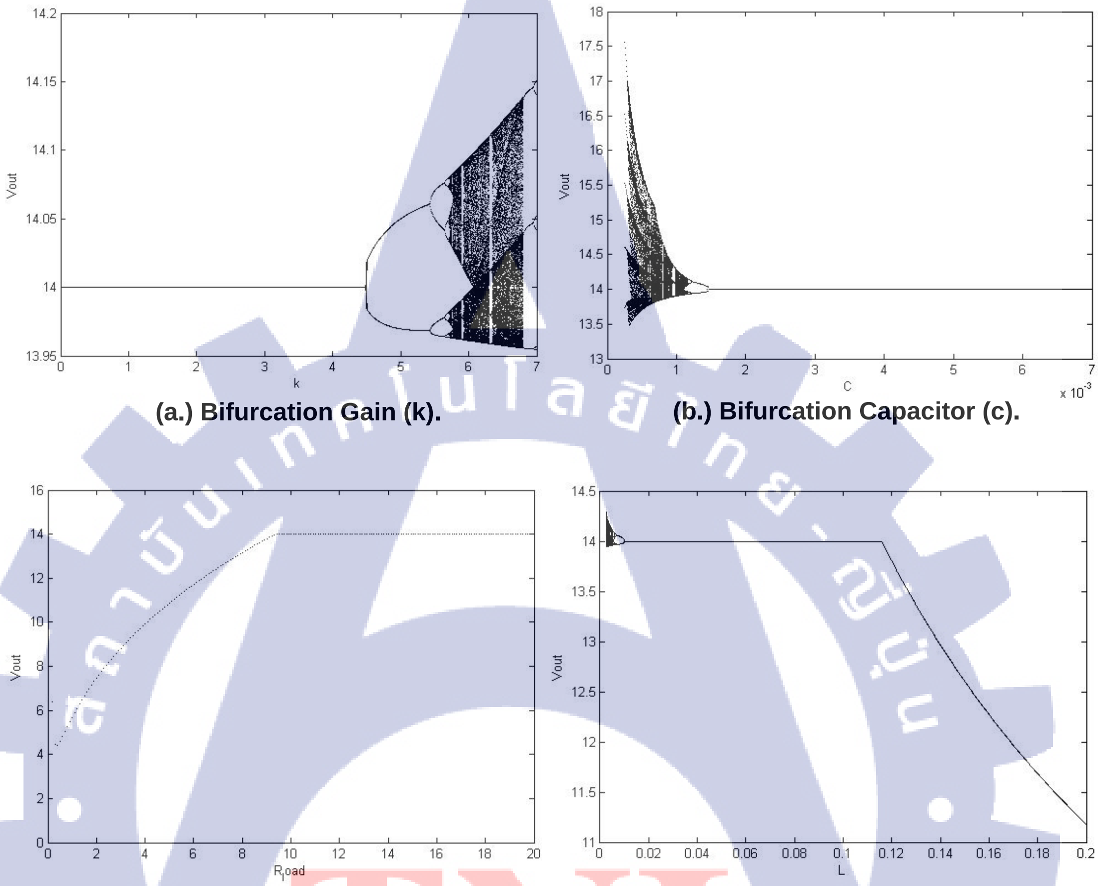
Figure 4.10 Simulation results of the Buck DC-DC converter, showing an output voltage of 14V with apparent voltage ripples.

4.3 Bifurcation

Bifurcation theory is the mathematical study of changes in the qualitative or topological structure of a given family, such as the integral curves of a family of vector fields, and the solutions of a family of differential equations. Most commonly applied to the mathematical study of dynamical systems, a bifurcation occurs when a small smooth change made to the parameter values (the bifurcation parameters) of a system causes a sudden 'qualitative' or topological change in its behavior. Bifurcations occur in both continuous systems (described by ODEs, DDEs or PDEs), and discrete systems (described by maps).

$$V_{c,n+1} = \frac{\alpha V^2{}_{c,n} + E(E - V_{c,n})\beta(H(D - k(V_{c,n} - V_{ref})))^2}{V_{c,n}} \tag{16}$$

Where $D=\sqrt{\dfrac{(1-\alpha)Vc^2}{\beta E(E-Vc)}}$, $\alpha = 1-\dfrac{T}{RC}+\dfrac{T^2}{2C^2R^2}$, $\beta=\dfrac{T^2}{2LC}$, $H(x)=\begin{cases}0,\_if\ \_x<0\\ 1,\_if\ \_x>1\\ x, otherwise\end{cases}$



(a.) Bifurcation Gain (k). **(b.) Bifurcation Capacitor (c).**

(c.) Bifurcation Rload (Ω). **(d.) Bifurcation Inductor (L).**

Figure 4.11 Bifurcation each variable.

On the figure 4.11 shown bifurcation results using equation (16) and variable parameter Gain (k) in figure 4.11 (a.), Capacitor (c) in figure 4.11 (b.), Rload (Ω) in figure 4.11 (c.), Inductor (L) in figure 4.11 (a.). From figure 4.11 found Gain and Capacitor are important with stability of system, if gain more than 4.5 it will be no stability (chaos) condition is fix C, L and R load. And then if C is less than 1.5×10^{-3} F it will be no stability (chaos) condition is fix Gain is 1, L and R load.

4.4 Lyapunov Exponent (LE.)

In mathematics the Lyapunov exponent or Lyapunov characteristic exponent of a dynamical system is a quantity that characterizes the rate of separation of infinitesimally close trajectories. Quantitatively, two trajectories in phase space with initial separation δZ diverge (provided that the divergence can be treated within the linearized approximation) at a rate given by $|\delta Z(t)| \approx e^{\lambda t}|\delta Z|$ where λ is the Lyapunov exponent. The rate of separation can be different for different orientations of initial separation vector. Thus, there is a spectrum of Lyapunov exponents— equal in number to the dimensionality of the phase space. It is common to refer to the largest one as the Maximal Lyapunov exponent (MLE), because it determines a notion of predictability for a dynamical system. A positive MLE is usually taken as an indication that the system is chaotic (provided some other conditions are met, e.g., phase space compactness). Note that an arbitrary initial separation vector will typically contain some component in the direction associated with the MLE, and because of the exponential growth rate, the effect of the other exponents will be obliterated over time. The exponent is named after Aleksandr Lyapunov.

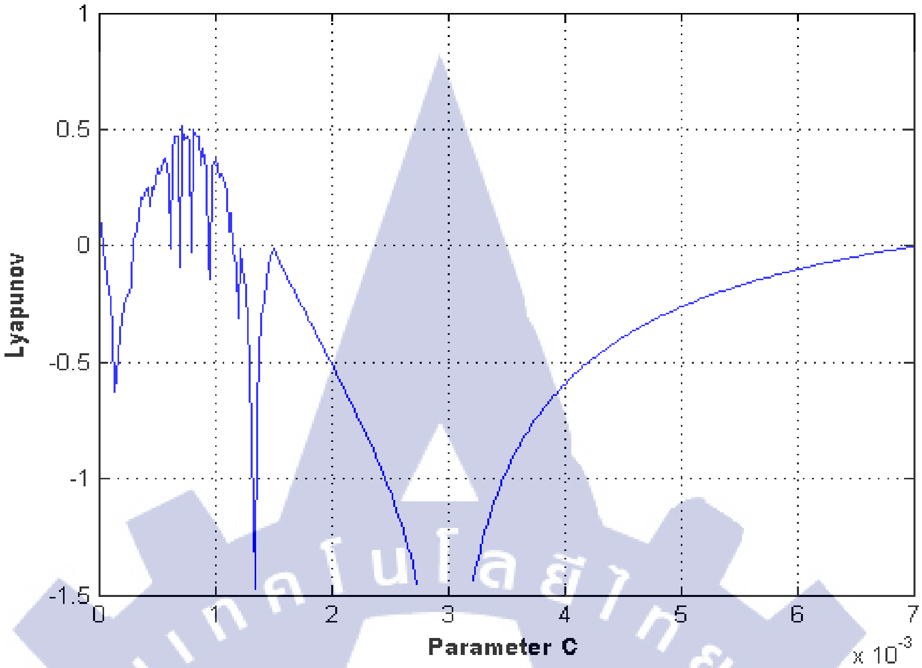


Figure 4.12 lyapunov exponent of capacitor.

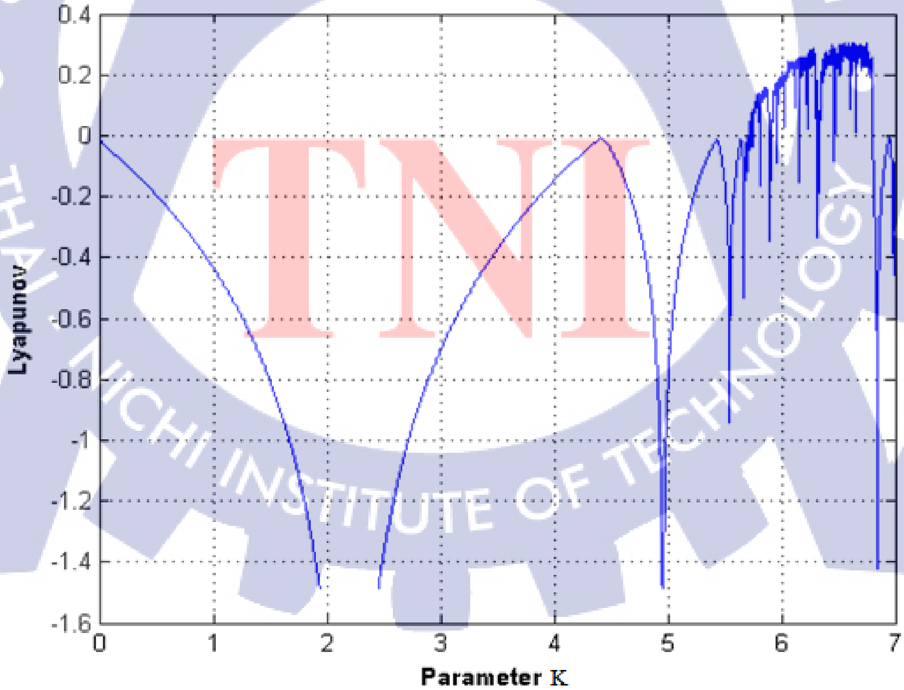


Figure 4.13 lyapunov exponent of gain.

From the bifurcation tropic Gain (k) and Capacitor (c) are important to the stability system. In the figure 4.12 and figure 4.13 shown LE of Capacitor (c) and Gain (k), if the value of LE more than zero that zone is non stability. The mapping between figure 4.12 and figure 4.13 by MATLAB Simulink results in Figure 4.14. From Figure 4.14 can used value only in white Buck DC-DC converter system results in is stability.

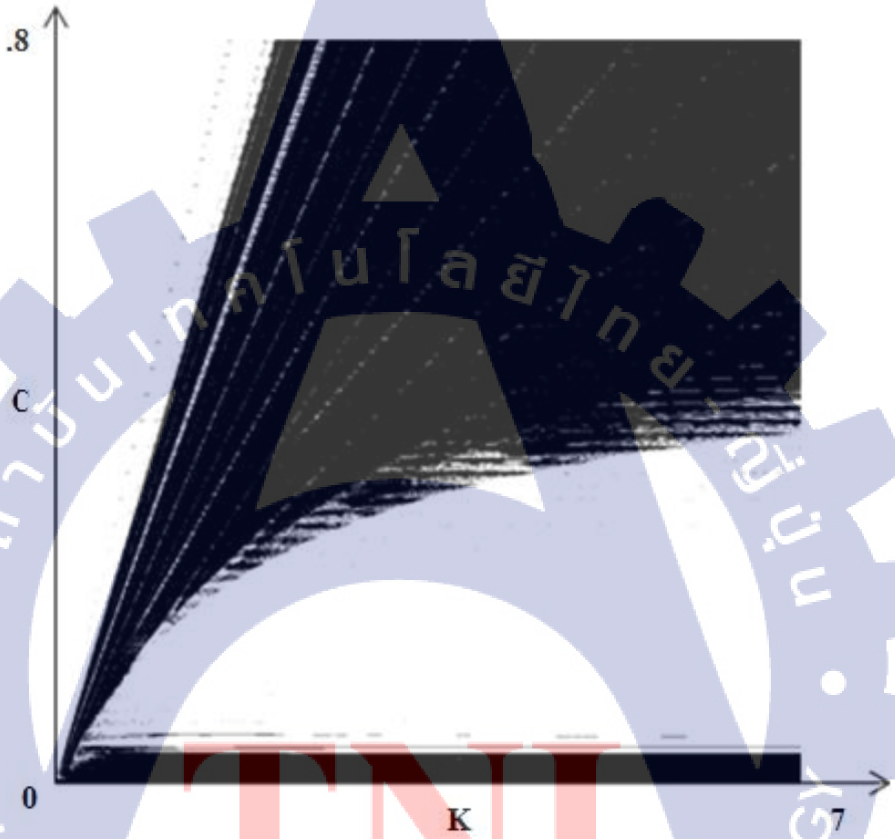


Figure 4.14 mapping with LE gain (k) and LE capacitor (c)

4.5 Implementation circuit

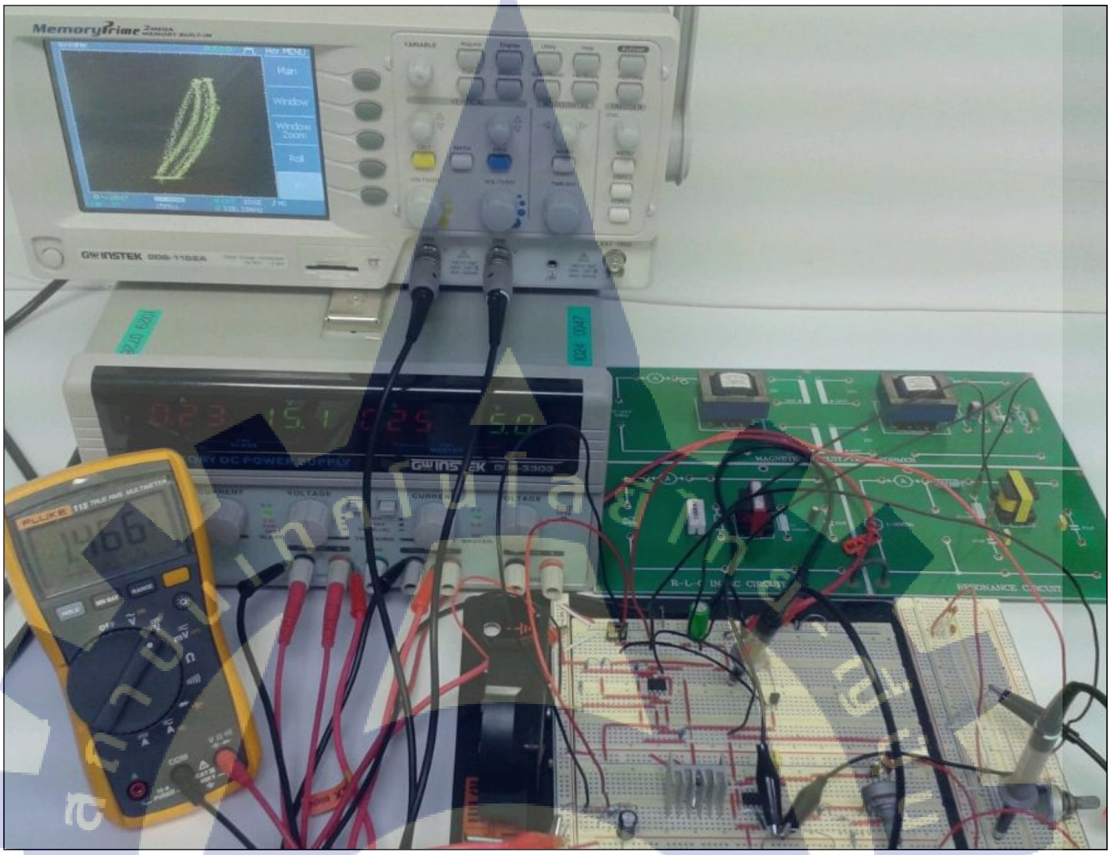
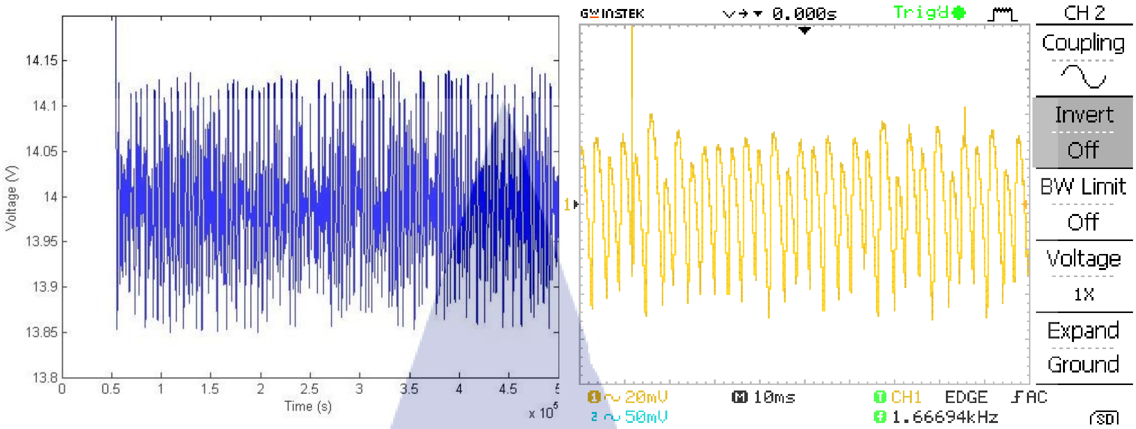


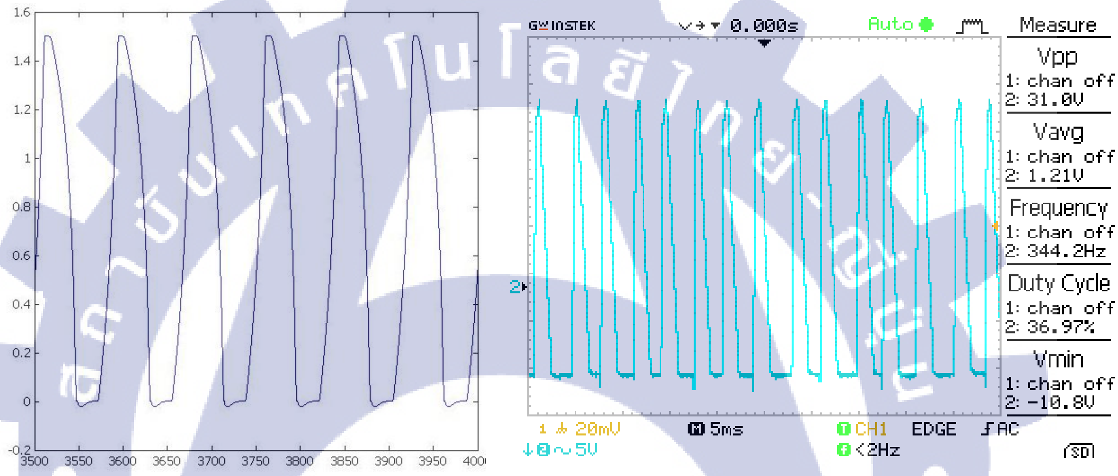
Figure 4.15 Implementation circuit using protoboard.

Figure 4.15 shows circuit implementations using protoboard. The DC-DC buck converter circuit was implemented on-board using a power MOSFET IRF9640 and power standard recovery diode 1N4001. The DC input voltage was varied from 20V to 60 V as in mathematical model; control circuit was supplied from a voltage supply. The ramp generator implemented based on a NE555 timer generates a sawtooth waveform. A bandwidth dual operational amplifier TL082 is used as a comparator and a difference amplifier. Compare with simulation set k = 7, C = 2200µF, R_{load} = 50kΩ, L=22mH, MOSFET = IRF9640 output voltage ripple about 27mV ;



Simulation Output Voltage Measurement Output voltage

(a)



Simulation Output Current Measurement Output Current

(b)

Figure 4.16 (a) Output voltage and (b) output current.

4.6 Conclusion

A switching DC-DC power converter has been employed in power electrical systems, ranging from small hand-held devices to large automotive and aircraft system, due to a small-size low-weight circuit implementation and high-efficiency in energy conversion process. However, the main problem in designs and implementations of such a switching DC-DC power converter is a varying nonlinear function that leads to complexity in dynamic behavior analysis. This work has presented the investigation of chaotic behaviors in the standard 42V-to-14V switching DC-DC power converter, which has been appointed for use in electric cars. The nonlinear dynamic is described based on the system of differential equation and stability condition. Simulation results are conducted using Simulink in MATLAB and Proteus Programs. The results are described in terms of time-domain ripple waveforms and chaotic attractors. Electronic circuit implementation and measurement are also presented. The proposed instigation method can be used for further stability control technique based on the calibration of closed-loop gain of the feedback section that suppresses the system from chaos regions, observing from the bifurcation boundary. Electronic circuit implementation and measurement have also presented.

Chapter 5
Conclusion and Suggestion

5.1 Conclusion

DC-DC power converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits with different voltage level requirements which are different from that supplied by the battery or external supplies and can be either higher or lower than the supply voltage. Additionally, the battery voltage declines as its stored power is drained. Switched DC-DC converters offer an operation to increase or decrease the voltage levels without multiple batteries in order to accomplish the DC operation.

The operating DC voltage of most electronic devices in electric cars is commonly lower than the power supply resources. The Buck DC-DC Converter is a suitable solution for this system. However, the output voltage generally contains a small ripple, which is an AC variation over the DC output. As a result, the accuracy of Buck DC-DC Converter may not high as required in the specification. Therefore, the Buck DC-DC converter to be studied in this thesis will focus on the reduction of ripple voltages in order to sustain the system stability with low-cost implementation.

The purposes of this thesis are to study power conversion theories in automotive electric systems, and also study circuit topologies and operations of automotive DC-DC buck converters. In addition, low-cost high-stability automotive 42V-14V DC-DC buck converters are also designed and implemented. The scope of this thesis is to study circuit configurations of a 42V to 14V buck DC-DC converter with feedback control, and study the model and simulations of buck DC-DC converter with 42V input voltage and 14V output voltage using LTspice IV and MATLAB Simulink.

The literature reviews have involved six related publications including L.Jourdan, JL.Schanen, J.Roudet (2002) [1], Fang Z. Peng , Fan Zhang, and Zhaoming Qian (2003) [2], A. Jangwanitlert J. C. Balda (2004) [3], Dwaraka S. Padimiti and Mehdi Ferdowsi (2005) [4], Fan Zhang,Lei Du1, Fang Z. Peng, and

Zhaoming Qian (2006) [5], Fan Zhang, Lei Du, Fang Zheng Peng (2008) [6], Ian Nakashima, Eduardo F. Arcos, and Micah Ortzar (2010) [7]. All proposed techniques are applicable for automotive Buck DC-DC converters where the input and output voltages are 42V and 14V, respectively.

The simulations have been performed in MATLAB and Proteus simulation programs. Simulations include bifurcation diagram and Lyapunov spectrum. The results show that some regions of operations exhibits chaotic behaviors which we should avoid from the real operations. For the circuit designs, the DC-DC buck converter circuit was implemented on-board using a power metal-oxide-semiconductor field effect transistor number IRF9640 and power standard recovery diode 1N4001. The DC input voltage was varied from 20 to 60 V as in mathematical model; control circuit was supplied from a voltage supply. The ramp generator implemented based on a NE555 timer generates a sawtooth waveform. A bandwidth dual operational amplifier TL082 is used as a comparator and a difference amplifier. Compare with simulation set k = 7, C = 2200µF, R_{load} = 50kΩ, L=22mH, MOSFET = IRF9640 output voltage ripple about 27mV as shown in Figure 5.1

The results are described in terms of time-domain ripple waveforms and chaotic attractors. Electronic circuit implementation and measurement are also presented. The proposed instigation method can be used for further stability control technique based on the calibration of closed-loop gain of the feedback.

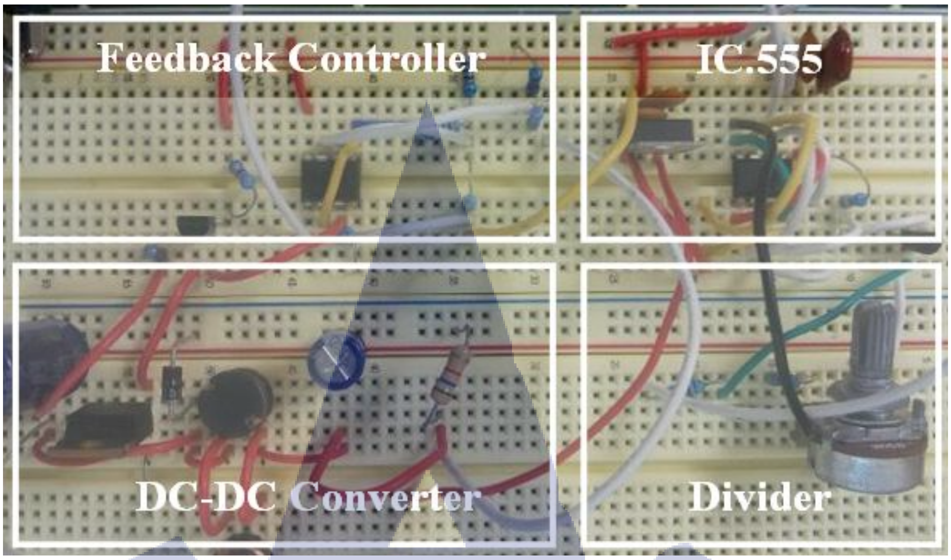


Figure 5.1 Prototype on protoboard.

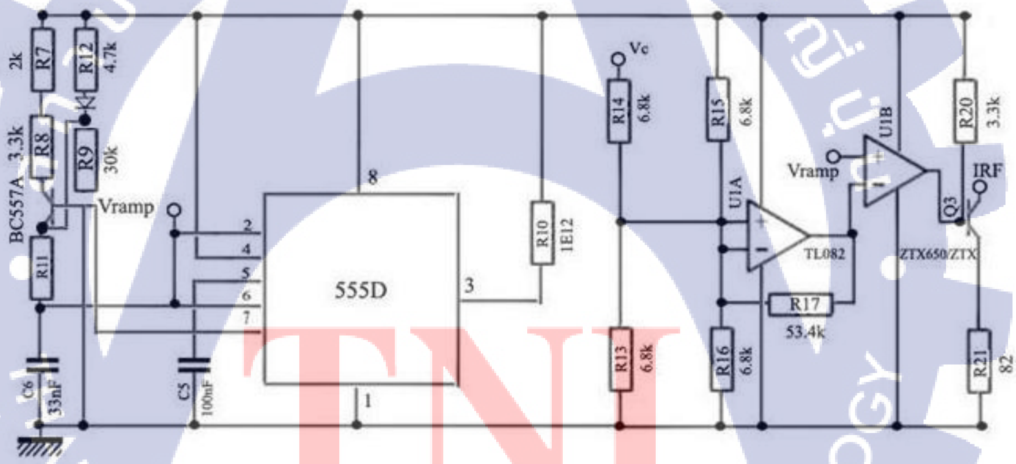


Figure 5.2 shown feedback control section and IC.555 diagram.

From bifurcation in chapter 4 gain (k) and capacitor (c) are important to system stability gain (k) in error amplified must less than 4.5 and capacitor must more than 1.5 x 10^{-3} F.

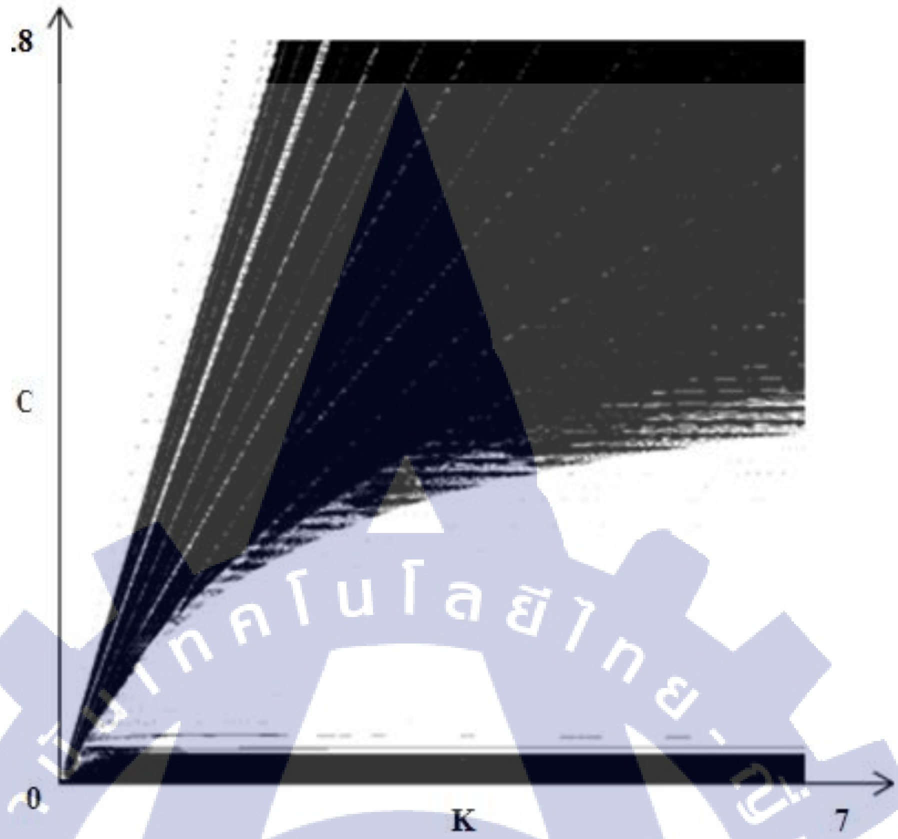


Figure 5.3 Lyapunov Spectrum of C-K mapping.

5.2 Suggestion

From LE in chapter 4 can made mapping help decision to choose value of device in Buck DC-DC Converter circuit stability system. In figure 5.2 have advantages for choose value easily. Figure 5.2 shown LE value Y axis is LE value of capacitor and X axis is LE value of gain. This work or other work to need high stability system of Buck DC-DC Converter can used only value in white color, it is stability zone. In the black color is chaos or non stability zone.

References

References

[1] L.Jourdan; JL.Schanen; and J.Roudet. (2002). **Design Methodology for Non Insulated DC-DC Converter: Application to 42V-14V**. Power Electronics Specialists Conference. 2002. pesc 02. 2002 IEEE 33rd Annual. pp. 1,679 – 1,684.

[2] Fang Z. Peng; Fan Zhang; and Zhaoming Qian. (2003). **A Novel Compact DC-DC Converter for 42 V Systems**. Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual. pp. 33 – 38.

[3] A. Jangwanitlert J. C. Balda. (2004). **Phase-Shifted PWM Full-Bridge dc-dc Converters for Automotive Applications: Reduction of Ringing Voltages**. pp. 111-115.

[4] Dwaraka S. Padimiti; and Mehdi Ferdowsi. (2005). **Review of Digital Control Techniques for Automotive DC-DC Converters**. Vehicle Power and Propulsion, 2005 IEEE Conference. pp. 653 – 657.

[5] Fan Zhang,Lei Du; Fang Z. Peng; and Zhaoming Qian. (2006). **A New Design Method for High Efficiency DC-DC Converters with Flying Capacitor Technology**. Applied Power Electronics Conference and Exposition, 2006. APEC '06. Twenty-First Annual IEEE. pp. 92 – 96.

[6] Fan Zhang; Lei Du; and Fang Zheng Peng. (2008). **A New Design Method for High-Power High-Efficiency Switched-Capacitor DC–DC Converters**. IEEE Transactions on Power Electronics. pp. 832 – 840.

[7] Ian Nakashima; Eduardo F. Arcos; and Micah Ortzar. (2010). **Electric Vehicle Using a Combination of Ultracapacitors and ZEBRA Battery**. IEEE Transactions on Industrial Electronics. pp. 943 - 947.

[8] Muhammad Aaad Rahman. (2007). **Buck Converter Design Issues**. 4th Edition. Orlando: Linköping Institute of Technology.

[9] Ned Mohan; Tore M. Undeland; and William P. Robbins. (2008). **Power Electronics: Converters, Applications, and Design**. 3rd Edition. Wiley : McGraw-Hill.

[10] Hayt; Kimmerly; and Durbin. (2007). **Engineering Circuit Analysis**. 8th Edition. Wiley : McGraw-Hill.

[11] Donald A. Neamen. (2008). **Microelectronics Circuit Analysis and Design**. 4th Edition. Wiley : McGraw-Hill.

[12] McGraw-Hill Julien Clinton Sprott. (2006). **Elegant Chaos World Scientific**. 4th Edition. Wiley : McGraw-Hill.

[14] Fang Zheng Peng. (2003). **A Magnetic-Less DC–DC Converter for Dual-Voltage Automotive Systems**. IEEE Transactions on Industry Applications. pp.511-518.

[15] Jens Czogalla, Jieli Li; and Charles R. Sullivan. (2003). **Automotive Application of Multi-Phase Coupled-Inductor DC-DC Converter**. Industry Applications Conference, 2003. 38th IAS Annual Meeting. pp.1,524-1,529.

[16] Serguei Moisseev; Yoshinon Ishigami; Student Member; Koji Soshin and Mutsuo Nakaoka. (2004). **Tapped Inductor Filter-Assisted Soft-Switching PWM DC- DC Power Converter with High Frequency Transformer i&k For Automotive AC Power Supply**. Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual. pp.1,689-1,694.

[17] J. Popović, J.A. Ferreira. (2005). **Design and Evaluation of Highly Integrated DC-DC Converters for Automotive Applications**. Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting. Conference Record of the 2005. pp.1,152-1,159.

[18] A. Nasiri. (2005). **Different Topologies of Active EMI/Ripple Filters for Automotive DC/DC Converters**. Vehicle Power and Propulsion, 2005 IEEE Conference. pp. 168-173.

[19] Wilmar Hernandez. (2005). **Robust Control of a Buck-Boost DC-DC Switching Regulator for the Electronic Systems of Next-Generation Cars**. Industrial Electronics Society, 2005. IECON 2005. 31st Annual Conference of IEEE. pp.225-230.

[20] B.P. Divakar; and D. Sutanto. (2005). **A Novel Converter for Fuel-Cells Applications**. Power Electronics and Drives Systems, 2005. PEDS 2005. International Conference on. pp.162-165.

[21] Jacobo Alvarez; Alfonso Lago; and Andres Nogueiras. (2006). **FPGA Implementation of a Fuzzy Controller for Automobile DC-DC Converters**. Field Programmable Technology, 2006. FPT 2006. IEEE International Conference on. pp.237-240.

[22] Krishna P. Yalamanchili; and Mehdi Ferdowsi. (2006). **New Double Input DC-DC Converters for Automotive Applications**, Vehicle Power and Propulsion Conference, 2006. VPPC '06. IEEE. pp.512-516.

[23] Faisal H. Kha; and Leon M. Tolbert. (2007). **5 kW Multilevel DC-DC Converter for Hybrid Electric and Fuel Cell Automotive Applications**. Industry Applications Conference, 2007. 42nd IAS Annual Meeting. Conference Record of the 2007 IEEE. pp.628-635.

[24] Martin Pavlovsky; Yukinori Tsuruta; and Atsuo Kawamura. (2008). **Pursuing High Power-Density and High Efficiency in DC-DC Converters for Automotive Application**. Power Electronics Specialists Conference, PESC 2008. IEEE. pp.4,142-4,148

[25] K.Ejjabraoui; C.Larouci; P.Lefranc; and C.Marchand. (2009). **A Pre-sizing Approach of DC-DC Converters Application to Design a Buck Converter for the Automotive Domain**. Power Electronics and Motion Control Conference, 2009. IPEMC '09. IEEE 6th International. 517-523.

Appendix

Appendix

Appendix A - MATLAB Simulink Bifurcation code.

```
function Solution = Bifurcation
    clear
    scale = 10000; % determines the level of rounding
    maxpoints = 250; % determines maximum values to plot
    N = 500; % number of "r" values to simulate
    a = 0; % starting value of "r"
    b = 7; % final value of "r"... anything higher diverges.
    rs = linspace(a,b,N); % vector of "r" values
    M = 1000; % number of iterations of logistics equation

    % Loop through the "r" values
    for j = 1:length(rs)

    r=rs(j); % get current "r"
    x=zeros(M,1); % allocate memory
    x(1) = 14; % initial condition (can be anything from 0 to 1)

    R = 50;
    L = 22e-3;
    C = 2200e-6;
    Vref = 14.00000000000001;
    E = 42;
    K = r;
    T = 1/1300;
    Vc = Vref;
    B = (T^2)/(2*L*C);
    A = 1-((T)/(R*C))+((T^2)/(2*(C^2)*(R^2)));
    D = (((1-A)*(Vc^2))/(B*E*(E-Vc)))^0.5;
```

```
    for i = 2:M, % iterate
    x(i) = ((A*(x(i-1)^2))+((E*(E-x(i-1)))*B*( (H(D-K*(x(i-1)-Vref))) )^2))/(x(i-1));

    %x(i) = sin(r*x(i-1));
    end
    % only save those unique, semi-stable values
    out{j} = unique(round(scale*x(end-maxpoints:end)));
    end

    % Rearrange cell array into a large n-by-2 vector for plotting
    data = [];
    for k = 1:length(rs)
    n = length(out{k});
    data = [data; rs(k)*ones(n,1),out{k}];
    end

    % Plot the data
    figure;
    h=plot(data(:,1),data(:,2)/scale,'k.');
    set(h,'markersize',0.1);
    xlabel('a'); ylabel('Xn');


function ans_x = H(x)

if x < 0
    ans_x = 0;
elseif x > 1
    ans_x = 1;
else
    ans_x = x;
```

```
end
```

Appendix B - MATLAB Simulink lyapunov exponent (LE.) code.

```
% Note that all lyapunov exponents are well estimated here
    % ----------------------- METHOD 2- using derivative along 1 orbit (better)
    function qw = qqq
    as = 0:0.001:7; % note this takes about 10 sec to run!
    hs = zeros(size(as));
    for j=1:numel(as)
    a = as(j);
    R = 50;
    L = 22e-3;
    C = 2200e-6;
    Vref = 14.0000000000001;
    E = 42;
    K = a;
    T = 1/1300;
    Vc = Vref;
    B = (T^2)/(2*L*C);
    A = 1-((T)/(R*C))+((T^2)/(2*(C^2)*(R^2)));
    D = (((1-A)*(Vc^2))/(B*E*(E-Vc)))^0.5;

    f = @(x) ((A*(x^2))+((E*(E-x))*B*( (H(D-K*(x-Vref))) )^2))/(x);
    df = @(x) (2*A*x - B*E*(tanh(500*D - 500*K*(x - Vref))/2 + 1/2)^2 +
500*B*E*K*(tanh(500*D - 500*K*(x - Vref))/2 + 1/2)*(tanh(500*D - 500*K*(x -
Vref))^2 - 1)*(E - x))/x - (A*x^2 + B*E*(tanh(500*D - 500*K*(x - Vref))/2 +
1/2)^2*(E - x))/x^2; % derivative of logistic map

    N = 100; % number of iterations (can use more than above)
    x = zeros(1, N+1);
    x(1) = 42; % IC
```

```
deriv = 1; % start counting the

for n=1:N
x(n+1) = f(x(n));
deriv = deriv * df(x(n)); % update product of derivatives
end

hs(j) = log(abs(deriv)) / N; % implement Defn 3.1 in book.
end
figure; plot(as, hs); xlabel('a'); ylabel('lyap exp h'); % as before
% Note that all lyapunov exponents are well estimated here
function ans_x = H(x)

if x < 0
    ans_x = 0;
elseif x > 1
    ans_x = 1;
else
    ans_x = x;
end
```