DEVELOPMENT OF TIME DELAY CURRENT CONTROL FOR LEAD ACID BATTERY 12 V DC BY USING ARDUINO

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ABSTRACT

Development of time delay current control for lead acid battery 12 V dc by using Arduino is the aim of this thesis. The development problem is necessary before applying control techniques to guarantee the execution of any task according to a desired input with minimum error. The main objective of this thesis is to design the time delay has on the performance of a current controlled for the buck-boost converter. The time delay controller is generally regarded as a nuisance to a control system. In addition, the performance of the Arduino and MATLAB as a signal processing device interface time is used. The feedback of open loop and closed loop time delay controller is also been analyzed. Based on results, the experiment of closed loop hardware gives better results than simulation in terms of output current. Through this study it is proved that the time delay controller is successfully designed to control current for lead acid battery.

ABSTRAK

Pembangunan bagi masa tunda kawalan arus untuk asid plumbum bateri 12 V DC dengan menggunakan arduino adalah matlamat tesis ini. Masalah berkenaan dengan pembangunan diperlukan sebelum mengaplikasikan teknik kawalan untuk menjamin pelaksanaan apa–apa mengikut input yang dikehendaki dengan kesilapan yang minimum. Objektif utama projek ini adalah untuk mereka masa yang kelewatan mempunyai mengenai prestasi semasa dikawal. Pengawal kelewatan masa biasanya dianggap sebagai gangguan kepada sistem kawalan. Tambahan lagi, prestasi arduino dan MATLAB sebagai peranti isyarat kawalan pemprosesan masa ingin ditingkatkan. Maklumbalas gelung terbuka dan gelung tertutup kawalan masa tunda juga telah dianalisis. Berdasarkan keputusan yang diperolehi, eksperimen terhadap perkakasan gegelung tertutup memberikan keputusan yang lebih baik daripada simulasi dari segi keluaran arus. Melalui kajian ini dibuktikan bahawa kawalan masa tunda berjaya direka untuk mengawal arus bagi sistem pengecasan bateri.

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LIST OF SYMBOLS AND ABBREVIATIONS

$r, r(t)$	-	Reference input
$e, e(t)$	-	Error between the input signal and the output
$u, u(t)$	-	Input applied by the controller to plant
y, $y(t)$	-	Output of the closed loop control system
$G_p(s)$	-	Plant transfer function
$G_c(s)$	-	Controller transfer function
$G_d(s)$	-	Disturbance input to output transfer function
$H(s)$	-	Feedback measurement
$D_t(s)$	-	Disturbance input
$v_a(t)$	-	Input source voltage, [Volt]
$i_a(t)$	-	Armature current, [Ampere]
R_a	-	Armature resistance, [Ohm]
L_a	-	Electric inductance, [H]
T_i^{i-1}	-	Homogeneous transformation matrix of *I* relative to *i*-1
K_P	-	Proportional gain
K_D	-	Derivative gain
K_I	-	Integral gain
T_I	-	Integral time constant
T_D	-	derivative time constant
t_r	-	Rising time, [sec]
t_s	-	Settling time, [sec]
$\mu(u)$	-	Membership function
Φ	-	Null fuzzy set (Phi)
Δe	-	Change of the error
k_e	-	Scaling factor for error
k_{de}	-	Scaling factor for change of error
k_u	-	Scaling factor for output
n	-	Degree of freedom of robot manipulator (*n*-DOF robot manipulator)

i	-	Number of links
R	-	Number of the fuzzy rules
V	-	Voltage
DC	-	direct current
PWM	-	Pulse Width Modulation
ADC	-	Analog to Digital Converter
CC	-	Constant Current
CV	-	Constant Voltage
SOC	-	State of Charge

CHAPTER 1

INTRODUCTION

1.1 Project Background

There is a wide variety of batteries on the market today, which are Nickel Cadmium (NiCa/NiCd), Nickel Metal Hydride (NiMH), Lead acid and Lithium Ion (Li-Ion) batteries. The lead-acid battery is widely used as a supply of power because the maintenance is easy and it's convenient to be used [1]. However, as the repeated charging and discharging the capacity of lead-acid battery gets decreased, meanwhile, its life span become short as well. It's known that the charging process is the most important factor to the working life of lead-acid battery.

Power conversion system is constructed to improve performance or reliability, or attain a high system rating [2]. Energy can flow from the highest cell to the lowest cell with the isolated buck - boost DC – DC converter. The control scheme implements the balancing with the least quantity of switches and cost [3]. Buck - boost converters are frequently used as a battery charging/discharging circuit in many photovoltaic power system, automotive power system and spacecraft power system [4].

The control parameters for the digital compensation are designed and fine – tuned using the Arduino in MATLAB software. Theoretical predictions are confirmed with both MATLAB simulation and measurement on an experimental prototype converter. Because battery-charge control is a slow process, microcontrollers with embedded ADCs such as the Arduino can be used inexpensive, signal conditioning, and PWM modules to directly control the charger's power-conversion circuits.

Figure 1.1 shows the block diagram of battery charger system which are consists of a power source, the buck – boost DC converter, control system and battery. Power source will supplied an input DC voltage. Then, the voltage will be converting to the stable voltage by using buck -boost DC converter. The control system will be monitoring the data of input voltage and output current. A battery as a load in the battery charging system.

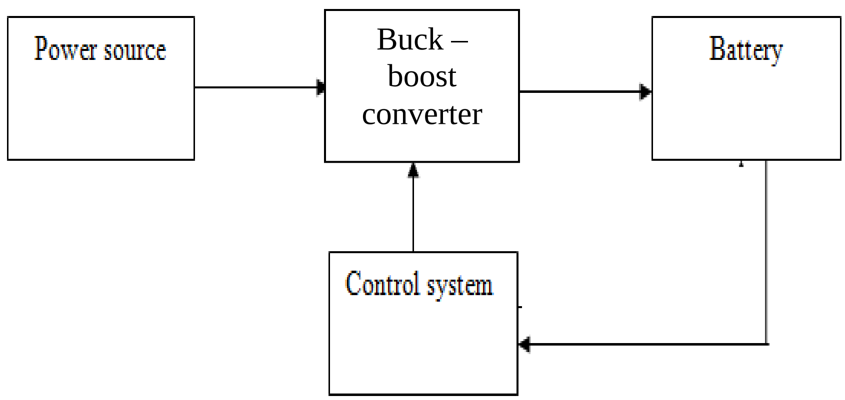

Figure 1.1: Block diagram of battery charger system

1.2 Problem Statement

To charge batteries, many battery charge strategies have been proposed. The constant-current constant - voltage charge strategy is the most popularly used one these days. However, a battery charge system with a high quality is still desired [5]. The controller such as PID, p-resonant, repetitive and time delay, fuzzy logic control and etc was applied in battery charge systems. Conventional controller has issued in handling charge current to increase battery charging performance.

In electrical vehicle applications power supply systems, the battery charger circuits require an output voltage which is usually less than the input voltage [2]. Regarding the battery condition, the buck – boost converter will work as a current source or as a voltage source. For the controller design the worst case to control switching of buck – boost converter has been taking into consideration. The output from buck – boost converter must be constant compare to an input which is variable.

1.3 Objectives

1. To design the time delay controller of a current controlled
2. To analyze the feedback of open and closed loop using time delay controller.
3. To enhance the performance of the Arduino and MATLAB for signal processing device interface time.
4. To design the gate driver circuit to control switching for a buck – boost converter.

1.4 Research Scope

1. The size of the battery is 12 V 7 Ah lead acid.
2. The size of bidirectional converter is 10 - 18 V input voltage, 12 V output voltages with filter inductor value is 10mH, Filter capacitor value is 47µF.
3. Perform simulation of time delay controller. This simulation will be carried out on MATLAB platform with Simulink as it user interface.
4. Analyze the performance of time delay controller.
5. Development and implements the hardware of current control of battery for time delay control using the Arduino

CHAPTER 2

LITERATURE REVIEW

2.1 A Brief Review of Battery

Methods of fast charging of lead acid batteries have been studied and developed for the last 30 years. In 1973, there has been a publication outlining that fast charging has some chemical and physical effects on battery plates, and therefore reduces the battery life. These effects can be seen as gassing and heat generation [6]. It is desirable to be able to rapidly recharge its batteries within one hour or less. As is the case under any charging conditions, it is important to control the charge in order to maintain the batteries in good condition. The rise of temperature, the overcharge and gassing are more prone to occur during high-rate charging, charge control under these conditions is critical.

In recent years, the issues about greenhouse effect generated by carbon dioxide have been worried, so people know the importance of environmental protection. Common rechargeable batteries are NiMH battery, NiCd battery, lead-acid battery and Li-ion battery on the market that are shown in Table 2.1. Lead-acid battery is used in motor vehicles, industrial equipment and power-storage systems. NiMH battery and NiCd battery are used in cordless power tool and hybrid vehicles. Li-ion Battery is used in power packs portable electronics series. Because lead and cadmium are harmful for the environment and the human beings, lead-acid battery and NiCd batteries have been gradually replaced by NiMH battery. The NiMH battery with the conversion efficiency and problems with memory effect, have been replaced gradually by Li-ion battery. In these batteries, lead- acid battery has a long history and is safe, reliable and affordable[7].

Table 2.1: The comparison between rechargeable batteries

Type	Lead-acid battery	NiCad battery	NiMH battery	$LiCoO_2$ battery
Nominal Operating Voltage	2V	1.2V	1.2V	3.7V
Patent protection	No	No	No	No
Price	1	2	2.4	4
Security	Good	Good	Good	Bad
Green product	No	No	Yes	Yes
Memory effect	No	Yes	Yes	Yes
Energy efficiency	60%	75%	70%	90%
Cycle life	400	500	500	.500
Charge time	8hours	1.5Hours	4Hours	2-4Hours
Self-discharge	20%Month	30%Month	35%Month	10%Month

The battery plays very important role and the energy converters are operated based upon battery online conditions like state of charge (SOC), terminal voltage, and temperature etc of the battery. Most of time, the lead-acid battery is used for this purpose. The modeling of the battery is a complex process because many phenomenon are occurred inside the battery during its life cycle for example self-discharging, gassing effect, diffusion process, acid stratification etc [8].

The charge ends when the battery capacity is reached and the battery is going to discharge to register more information about the efficiency of the complete process. The value of capacity for each battery is taken of a database where the battery life is stored. The combined charge strategies is used to obtain a high charge efficiency with considerable reduction of the charge time, as well as keep the battery temperature between reasonable values (maximum value 50ºC) or not exceed the bubbling voltage (7.95 V, in these batteries). If the central cell temperature reaches 50ºC the software pauses the process until the temperature goes down a program value, then the charge is resumed [9].

The cycle-life of lead-acid batteries can indeed be improved by the use of high charge currents. We are working in the development of electronic systems of fast charge lead-acid batteries and so that this system can optimize the yield and the useful life of the battery, it is needed to provide to the battery the necessary load and with the most appropriate strategy [10].

A typical demand curve is shown in Figure 2.1. Battery charging activities during daytime need to be somehow restricted, and most of the plug-in electric vehicle loads need to be allocated to nighttime. An ideal is to prevent any new peak load from exceeding the natural peak. To fill the overnight demand valley of the electrical grid off – line algorithms have been studied recently for single cycle [11].

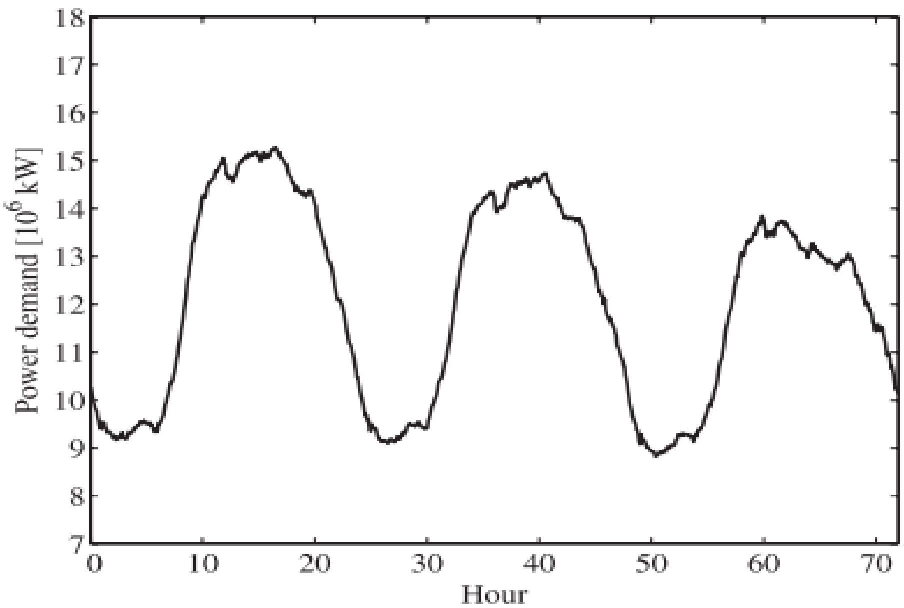

Figure 2.1: Load curve for Kyushu region in Japan August,2011

2.2 Single – Phase Buck – Boost Converter

Buck - boost converters are frequently used as a battery charging/discharging circuit in many photovoltaic power systems, automotive power systems, and spacecraft power system. In these applications, bidirectional converters often employ a multi-module structure in order to reduce the ripple component in the battery charging/discharging current. In particular the magnitude of the ripple component can be drastically shrunk by operating power modules with appropriate phase delays in their switch driving signals. This multi-module multi-phase operation reduces the switch current stress and inductor size. In addition, it could substantially improve the battery lifetime and system reliability [4].

Buck - Boost DC–DC converters allow the transfer of power between two DC sources in either direction. They are increasingly used in applications such as DC uninterruptible power supplies, battery chargers, multiplexed-battery systems, computer systems, aerospace systems, DC motor drives circuits and electric vehicles [12].

Buck converter and boost converter are usually used in maximum power point system because of their simplicity in structure and control scheme. Buck converter can generate a voltage below the input voltage, while boost converter steps up the input voltage to a higher voltage. While they are mostly used in high power PV system, both of them are not suitable for the application of energy-harvesting battery charger. Inverting buck-boost converters and Cuk converters are capable of converting supply voltages to both higher and lower voltages, but the polarity of the output voltage is opposite to the supply voltage, which makes it not applicable for multiple power source system [13].

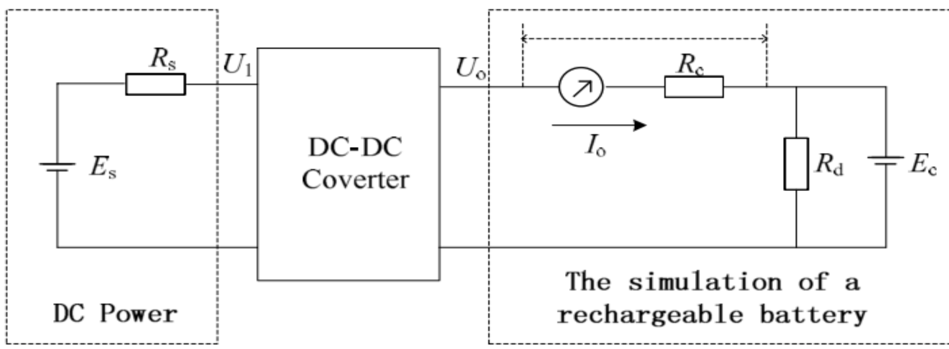

Figure 2.2: System block diagram

Therefore, a buck - boost DC-DC converter is one of the most important topics for power electronics. Figure 2.3 shows an example of its application. In these power system used in combination with buck – boost DC – DC converter and battery, the direction of the charge and discharge current is changed from time to time to perform power conversion between the different voltages. The batteries are connected to the buses with buck - boost DC-DC converters for ensuring a stable energy supply [14].

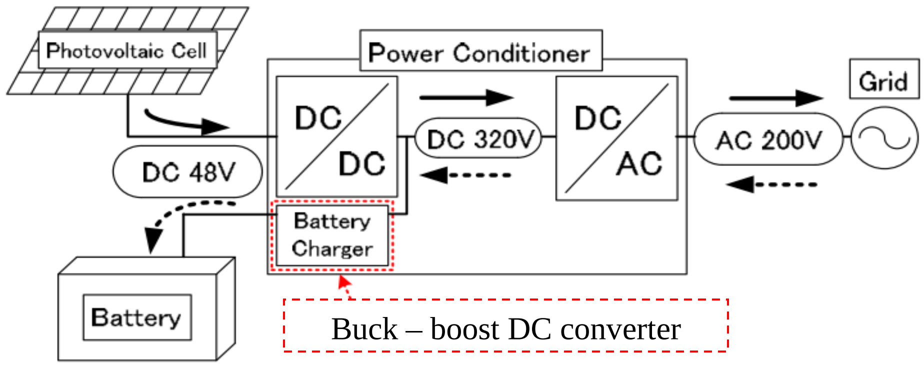

Figure 2.3: Photovoltaic power system

2.3 Control Method between Buck-Boost and Battery

A buck - boost DC – DC converter connects two sources/loads, it has two modes of operation (see Figure2.4): 1- Discharging mode; the power is fed forward from the battery to load. 2-Charging mode; where the power is fed back to the battery.

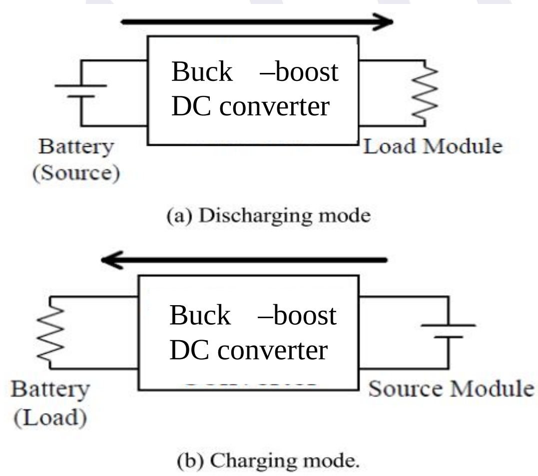

Figure 2.4: The Conventional dynamic model of buck - boost converter.

Using different takes charging methods influences the life of battery. It spends too much time and cost to charge batteries by the methods which are safe and high efficient according to the service manual that the battery manufacturer offered. Therefore, the characteristics of fast and less influence of the charging methods are proposed successively.

As shown in Figure 2.5, there is only the voltage feedback in voltage-mode control. Duty ratio d is determined by the comparison of the sawtooth waveform and the control voltage v_c, which is the amplified error of voltage reference v_r and the feedback voltage v_f. PWM transfers v_c to d [15].

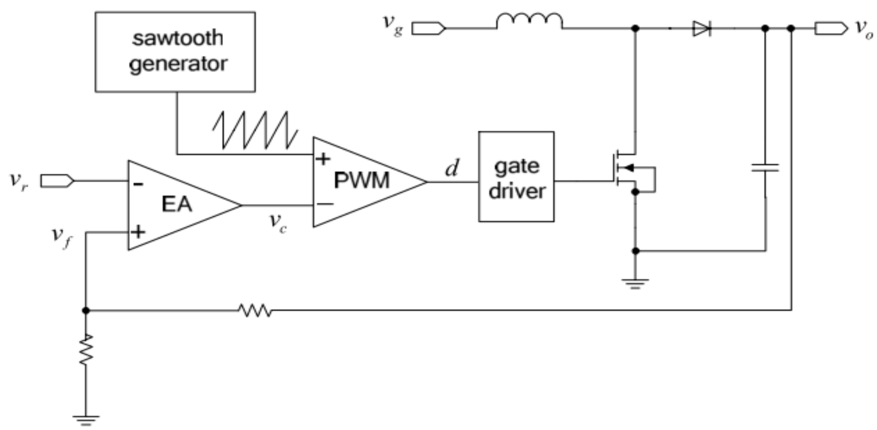

Figure 2.5: Scheme of voltage-mode controlled boost DC/DC converter

Figure 2.6 illustrates the time-delay τ between v_c perturbation and the system response in the form of adjusting d. Thus, PWM in voltage-mode control is modeled as

$$F_m(s) = \frac{\hat{d}(s)}{\hat{v_c}(s)} = \frac{1}{S_e T_s} e^{-\tau s} \quad \text{.........(2.1)}$$

Where Se is the slope of the sawtooth waveform, Ts is the switching period.

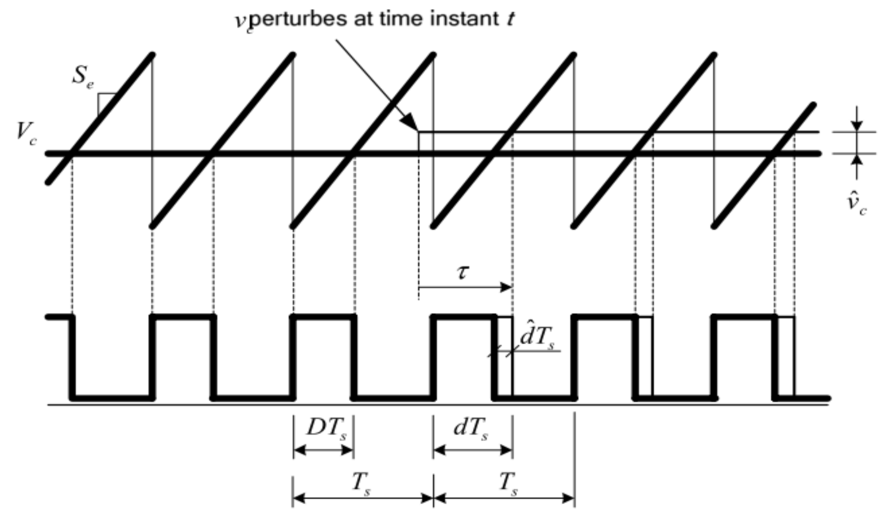

Figure 2.6: Time-delay introduced by PWM in voltage-mode control

The time-delay model of PWM in voltage-mode control

$$F_m(s) = \frac{1}{S_e T_s} e^{-\tau s} \Big|_{\tau \sim U[0,T]} \quad \text{........(2.2)}$$

Figure 2.7 shows that in current-mode control there is an additional current loop inside the outer voltage loop. The duty-ratio is no longer an independent variable but is controlled by the inductor – current i_L.

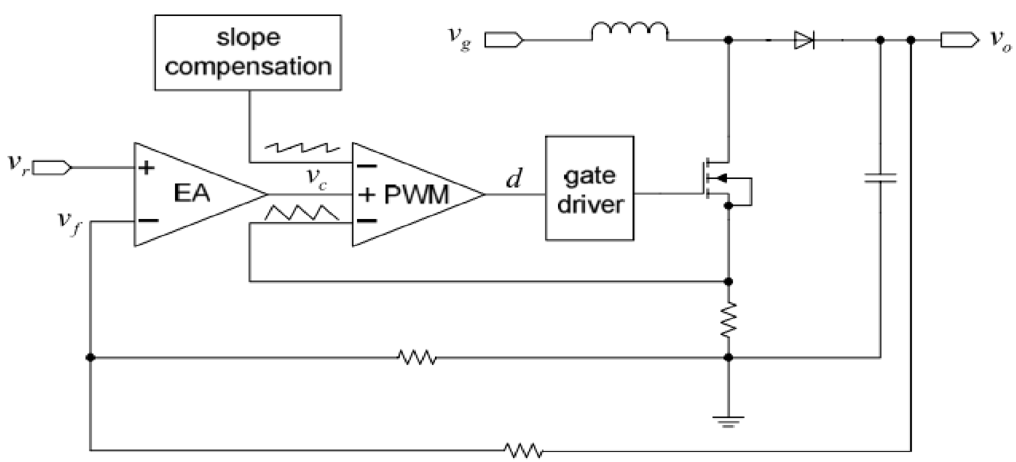

Figure 2.7: Scheme of current-mode controlled boost DC/DC converter

Assume each variable only perturbs in the small-signal limit, Figure 2.8 illustrates that the duty-ratio plays a decisive role in the stability of current loop, which is one of the most important issues of current-mode control. Similar as (2.1), the time-delay model of PWM operating in current-mode control is

$$F_m(s) = \frac{\hat{d}(s)}{\widehat{v_c}(s)} = \frac{1}{(S_e+S_n).T_s} e^{-\tau s} \Big|_{\tau \sim U[0,T]} \text{ ....(2.3)}$$

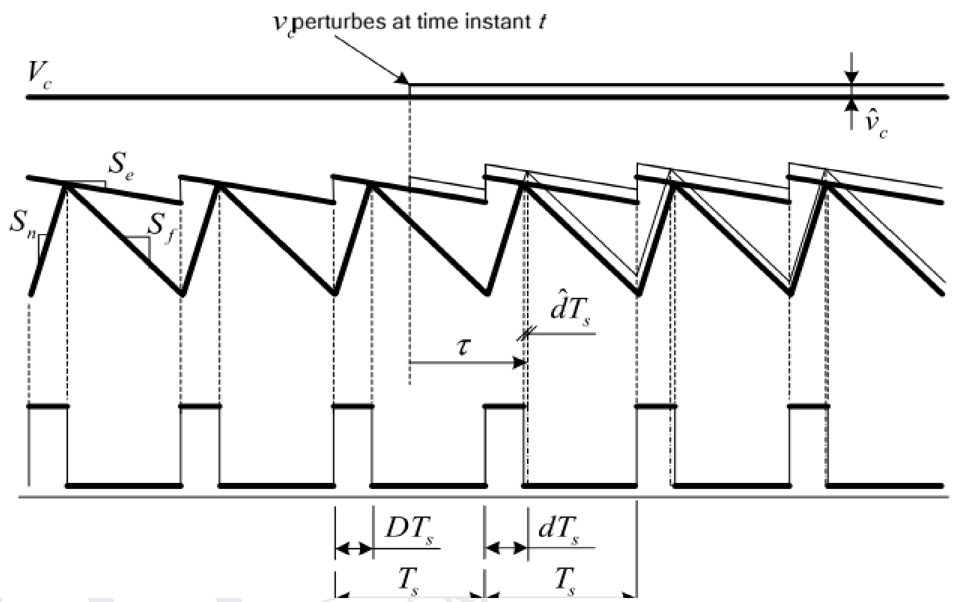

Figure 2.8: Illustration of the stability of current loop is stable when D < 0.5

Figure 2.9 shows the common buck – boost circuit diagram. This circuit consist two switches, an inductor, two diodes, a capacitor and two resistors. If the input voltage is higher than reference voltage, the circuit will in buck condition as shown in Figure 2.10 while the input voltage is low than reference voltage, the circuit will be in boost condition as shown in Figure 2.11.

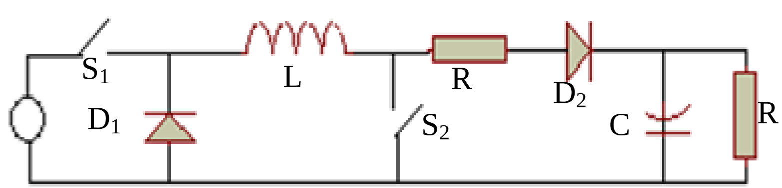

Figure 2.9: Common Buck – Boost circuit

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