ANALYSIS OF CONTROL METHODS FOR BUCK DC-DC CONVERTER

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To my beloved father and mother, for their love, supports and blessings

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ABSTRACT

A DC to DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. There are three main topologies of converters which are buck converter, boost converter and buck-boost converter. This project is focus on Buck dc-dc converter using the hysteresis, PID and three-level hysteresis controllers. The buck dc-dc converter used to step down the input dc voltage from 24V to 12V. The hysteresis, PID and three-level hysteresis controllers are applied to control the switching of the switching device in buck converter so that the output voltage can be maintained 12V. The PID controller is the most common used in feedback control. The good output voltage can be obtained by well-tuning the P, I and D gains. The hysteresis control is a simplest method and inexpensive and easy in designing. The hysteresis band is derived from the converter current to predict the output voltage after the switching action. The term PID is defined as P for proportional, I for integral and D for derivative. The complete converter circuit is designed and implemented in MATLAB Simulink software. The analyses are carried out by make a comparison of the output voltage and load changes for all controllers.

ABSTRAK

Penukar DC ke DC ialah litar elektronik yang menukarkan sumber arus terus (DC) dari satu tahap voltan ke tahap yang lain. Terdapat tiga topologi utama penukar iaitu ‘buck converter’, ‘boost converter’ dan ‘buck-boost converter’. Projek ini memfokuskan kepada penukar ‘buck converter’ menggunakan histerisis, PID dan tiga tahap histerisis sebagai pengawal. ‘Buck converter’ akan menukarkan voltan masuk dari 24V kepada 12V. Kawalan histerisis, pengawal PID dan tiga tahap histerisis kawalan digunakan untuk mengawal suis di penukar buck supaya voltan keluaran boleh dikekalkan 12V. Kawalan histerisis adalah satu kaedah pengawalan yang paling mudah dimana pampasan tidak diperlukan. Jalur histerisis berasal dari penukar semasa untuk meramalkan voltan keluaran selepas tindakan menukar. Pengawal PID pula adalah pengawal maklum balas yang paling biasa digunakan. PID ditakrifkan sebagai P untuk berkadar terus, I untuk kamir dan D untuk pembezaan. Litar penukar yang lengkap direka dan dilaksanakan dalam perisian MATLAB Simulink. Analisis dijalankan dengan membuat perbandingan voltan keluaran dan perubahan beban untuk semua pengawal.

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LIST OF ABBREVIATIONS

DC	Direct current
Vi	Voltage input
Vo	Voltage output
S	Switch
D	Diode
R	Resistor
L	Inductor
C	Capacitor
PWM	Pulse width modulation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Dc-dc converter is a switching circuit which transforms the voltage of the dc source (Vi) into other desired voltage in the load side (Vo). This is achieving through a suitable switching process of the circuit. The dc-dc converters are widely used in regulated switching-mode DC power supply and in DC motor drive application [1]. For dc-dc converter, there are three main topologies which are buck converter (step-down), boost converter (step-up) and buck-boost converter (step down and up).

A buck converter or step-down switch mode power supply can also be called a switch mode regulator. Buck converter produces a lower average output voltage than the DC input voltage, V_i. When the switch *S* is on, the diode *D* in Figure 1.1 become reverse biased and the input provides energy to the load as well as to the inductor. While, when the switch is off, the inductor current flows through the diode *D*, transferring some of its stored energy to the load *R* [1][2].

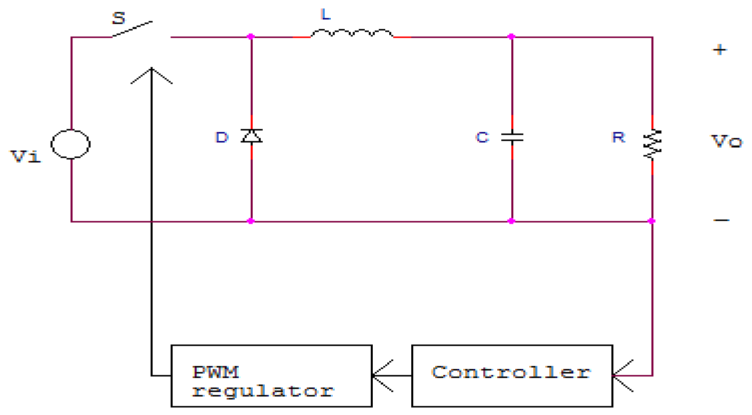

Figure 1.1: Buck converter

A boost converter or step-up converter is a power converter with an output DC voltage greater than its input DC voltage. The circuit of boost converter is shown in Figure 1.2. When the switch *S* is on, the diode *D* is reversed bias, thus isolating the output stage. The input supplies energy to the inductor. When the switch is off, the output stage receives energy from the inductor as well as from the input. The boost main application is in the regulated dc power supplies and the regenerative braking of dc motors [1].

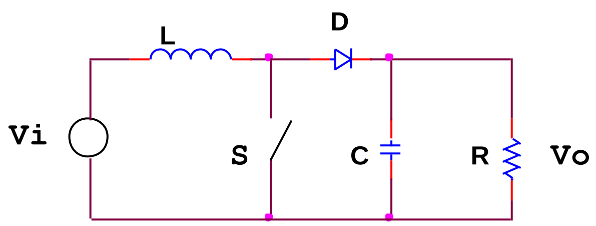

Figure 1.2: Boost converter

The buck–boost converter is a converter that has an output voltage that is either greater than or less than the input voltage. Buck-boost converter can be obtained by the cascade connection of the two basic converters which are the step down converter and step up converter. These two converters can be combined into the single buck- input provides energy to the inductor and the diode is reverse biased.

When the switch S is open, the energy stored in the inductor is transferred to the output [1]. No energy is supplied by the input during this interval. The main application of buck-boost converter is in the regulated dc power supplies.

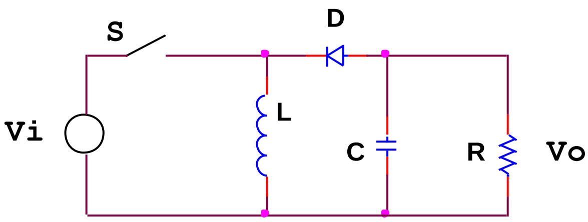

Figure 1.3: Buck-boost converter

From the mentioned topologies, the buck converter will be used in this thesis. Three types of controllers are proposed and approach to the converter i.e. PID, hysteresis control and three level hysteresis controllers. The hysteresis control is the one of the simplest control method besides PID. Hysteresis control also known as bang-bang control or ripple regulator control, maintains the converter output voltage within the hysteresis band centred about the reference voltage [3]. The hysteretic-controlled regulator is popular because of its inexpensive, simple and easy to design. The greatest benefit of hysteresis control is that it offers fast load transient response. The other well-known characteristic is the varying operating frequency.

The PID controller also implemented to buck dc-dc converter. PID controller can be viewed as three terms which is a proportional term, integral term and derivative term. PID controllers are also known as three-term controllers and three mode controllers. The PID is so popular among other controller because using PID gives the user a large number of options and those options mean that there are more possibilities for changing the dynamics of the system in a way that helps the users. Besides that a derivative control terms often produces faster response [4]. Figure 1.4 shows a block diagram of PID controller.

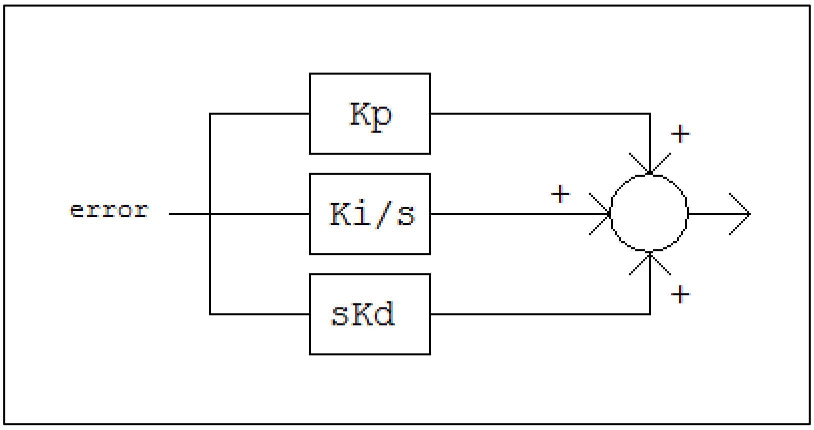

Figure 1.4: PID diagram

1.2 Problem Statement

a) The dc-dc converter is difficult to control since it depends on the switching characteristic to control the output voltage.

b) The dc-dc converter is difficult to obtain a good transient response.

1.3 Objective

a) The propose of this project is to analysis various control methods approach to buck dc-dc converter.

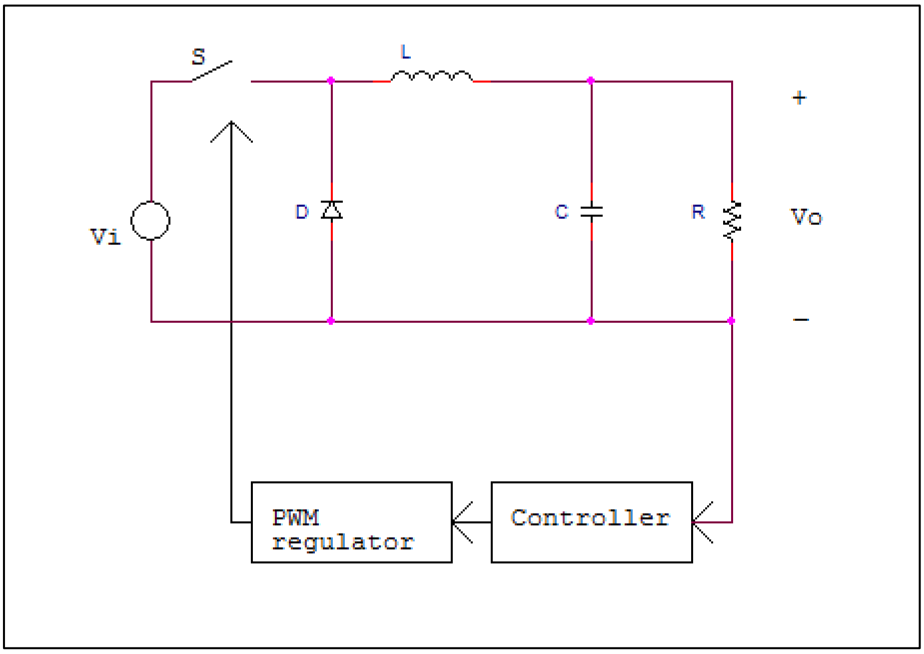

Figure 1.5: Controller with buck converter

b) To simulate the proposed controllers and make a comparison among them.

1.4 Project Scope

The scope of this project is to design the hysteresis controller, PID controller and three-level hysteresis control and implemented it to buck dc-dc converter by using matlab Simulink. The results of simulation will be analysed and compared.

1.5 Outline of Thesis

Chapter 1 consists of the overview of the project, which includes the problem statement, objectives and scope.

Chapter 2 summarizes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work.

Chapter 3 illustrates the operation and the parameters involved in the dc-dc buck converter. The controller that approach to dc-dc buck converter is described in detail.

Chapter 4 presents the simulation design of the dc-dc buck converter using MATLAB/Simulink. It also consists of the simulation results and discussion based on different controller.

Chapter 5 concludes the overall thesis and for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter includes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work. The related works have been referred carefully since some of the knowledge and suggestions from the previous work can be implemented for this project. Literature review has been done continuously throughout the whole process of the project. It is very essential to refer to the variety of sources in order to gain more knowledge and skills to complete this project.

2.1 Operation of buck dc-dc converter

The three basic dc-dc converters use a pair of switches, usually one controlled and one uncontrolled, to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output. They also filter or smooth voltage and current. The dc-dc converters can have two distinct modes of operation which is continuous conduction mode (CCM) and discontinuous conduction mode (DCM). [1][5]

When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage vL = Vg – Vo cross the inductor. This voltage causes a linear increase in the inductor current iL as shown in Figure 2.1. When the switch is turned off as shown in Figure 2.2, because of the inductive energy storage, iL continues to flow. This current now flows through the diode, and vL = -Vo for a time duration (1-D)T until the switch is turned on again. Figure 2.3 shown the buck converter waveform.[1][5]

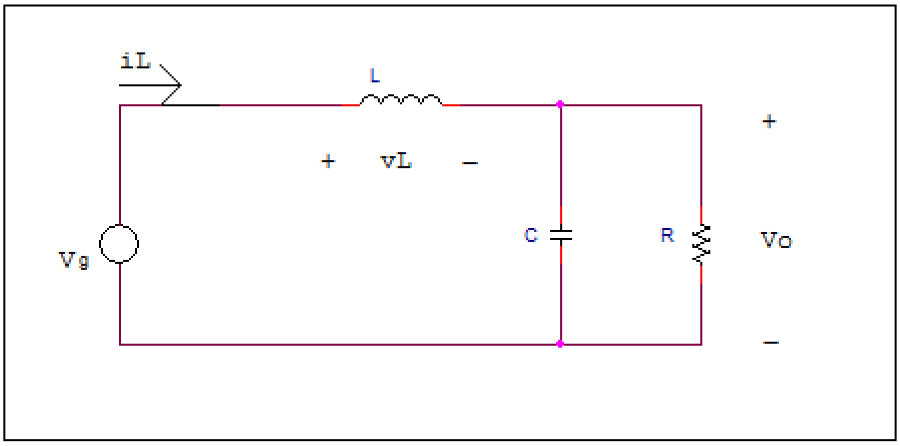

Figure 2.1: On mode

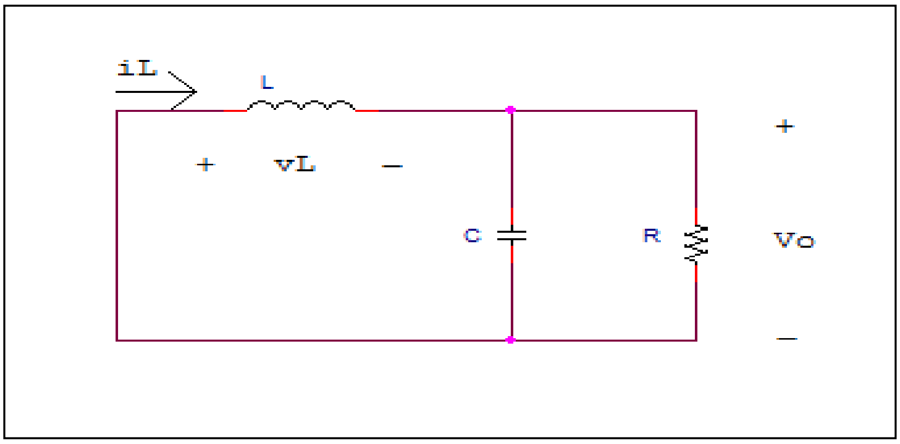

Figure 2.2: Off mode

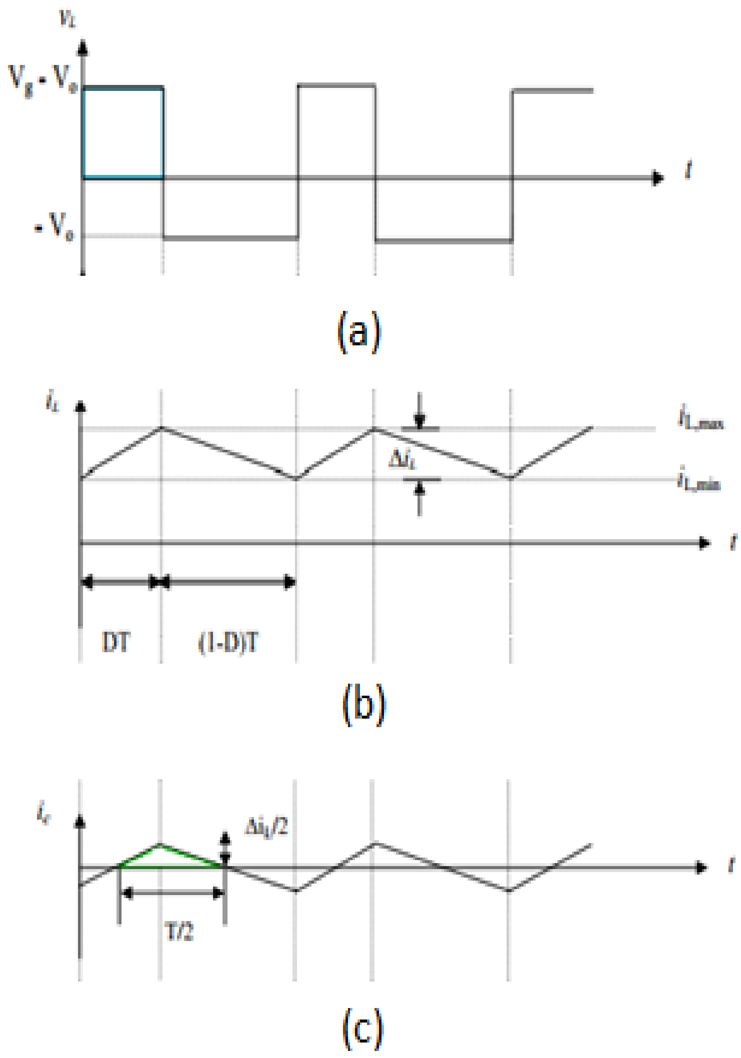

Figure 2.3: Buck converter waveforms; (a) inductor voltage; (b) inductor current; (c) capacitor current

2.2 Hysteresis Controller

V.M. Nguyen and C.Q. Lee (1995) entitlement, the ripple regulator is another name for the hysteresis control in which the error amplifier has been used to cancel the low-frequency poles of the output filter and to push the system closed-loop bandwidth up to high-frequency, while maintaining a high gain at low frequency. The tracking control law using state-feedback which has been used successfully in some other control applications can now be applied to control a general buck converter and as a result the response has been observed to be very fast and the waveform errors are minimized.[6]

Kelvin Ka-Sing Leung and Henry Shu-Hung Chung (2005) entitlement, the hysteresis band is derived from the output capacitor current that predicts the output voltage magnitude after a hypothesized switching action. The state-trajectory-prediction can effectively enhance the transient response of the buck converter using hysteresis control without significant modification in the control circuit. It can operate in both continuous and discontinuous conduction modes. The output can revert to the steady state in two switching actions after a large-signal disturbance.[7]

Szepesi and Thomas (1987) entitlement, a systematic investigation of methods to stabilize the operating frequency of hysteretic current-mode dc to dc converters through control of the current hysteresis is presented. The most commonly used peak current programmed mode the frequency control decreases the phase margin and can make the loop unstable. Using average current control, on the other hand, does not influence the dynamics of the voltage control loop; consequently, it is superior to the peak-current programmed version.[8]

L.K. Wong and T.K. Man (2008) entitlement, a hysteretic control buck converter is inherently a variable structure system owing to the presence of switching actions. Analysis results show the relationship between the steady state performance and a number of parameters, in particular the output capacitor's ESR. If the ESR is too small, the output voltage ripple will increase significantly and a phase shift is resulted. Hysteretic control response to disturbances and load change right after the transient take place so they give excellent transient performance.[9]

A. Borrell, M. Castilla, J. Miret, J.Matas and L. G. Vicuna (2011) entitlement, hysteretic controller for a multiphase synchronous buck converter supplying low voltage, high current, and high slew-rate loads. The control scheme implements the main control functions for powering such demanding loads, including output-voltage regulation, adaptive voltage positioning, current sharing, and phase interleaving. A control-design methodology based on output impedance analysis leads to optimal output-voltage transient response with a simple and low-cost control implementation.[10]

C.T. Tsai and H.P. Chou (2009) entitlement, an integrated DC-DC buck converter using the synthetic ripple hysteresis control scheme with a fast transient path to define the boundary of hysteresis band. The hysteresis band and switching frequency depend on load current changes. Therefore, it accelerates regulation and reduces overshoot. The ripple signal sensed from inductor current or output voltage is confined within a hysteretic band and used to control the power MOSFETs with simple logic gates. Hysteresis control is self-stabilized so additional frequency compensation capacitor is not needed. Therefore, leads to a very fast response.[11]

S. C. Huerta, P. Alou, J. A. Oliver, O. Garcia, J. A. Cobos and A. Abou-Alfotouh (2009) entitlement, the combination of non-linear control and linear control proposed in provides very fast transient response. This non-linear control is based on hysteretic control of the Cout current. This system is very sensitive to effects like aging, temperature, input and output voltage variation. This paper proposes a frequency loop to avoid the frequency variation and to adjust the switching frequency to the nominal value by changing the hysteretic band.[12]

T. Nabeshima, T. Sato, S. Yoshida, S. Chiba and K. Onda (2004) entitlement, the control circuit consists only of a comparator with a hysteresis and neither error amplifier nor a clock generator is used. The control signal voltage supplied to the comparator is obtained from a simple RC network connected to the inductor winding. The steady-state output voltage and the switching frequency are initially examined taking the propagation delay in the controller into account. The dynamic characteristics is then analysed both in frequency and time domains.[13]

2.3 PID controller

Hyun-Hee Park, Young-Jin Woo and Gyu-Hyeong Cho (2011) entitlement, to design a fully integrated compensator that is not sensitive to the output stage noise. In addition, an error amplifier is implanted without an additional compensation capacitor. To ensure fast load transient, it is required for such a compensator to have a wide bandwidth around 1/5 to 1/10 of the switching frequency and to be less sensitive to switching noise or high frequency poles. Therefore, the poles and zeros should be adjusted to proper values ensuring a total loop bandwidth.[14]

S. Chander, P. Agarwal and I. Gupta (2011) entitlement, an improved discrete auto-tuning PID scheme is developed for DC-DC converters where large load changes are expected or the need for fast response time. To improve the transient response and rise time of the converter, the controller parameters are continuously modified based on the current process trend.[15]

Hongmei LI and Xiao Ye (2010) entitlement, a sliding-mode PID controller is presented for controlling the DC-DC converter and the researches have validated that the system has good dynamic performance and fast system response. The unified dynamical model of DC-DC buck converter is set up and two sliding mode controllers are introduced called conventional sliding mode controller and sliding mode proportional integral derivative (PID) controller. The stability are analyzed for the DC-DC converter system controlled by the sliding mode PID, and the optimum sliding mode PID parameters are determined.[16]

2.4 Three level hysteresis control

The paper proposes a series resonant power converter that is driven by a pulse density modulation strategy combined with a three level hysteresis controller to adjust output power. The first part of the closed-loop regulation strategy is an anticipation loop. This instrument represents the inverse process of the system. It gives the sequence of modulation that corresponds to a given output power. The desired output power will be the entry for this sub-system. The goal is to increase the system's speed response. A three-level hysteresis controller permits the system to oscillate between modulation sequences in order to get an average output power delivered to the load, near the desired one.[17]

The paper presents a simple and effective method of implementing single phase hysteresis current regulation as a three level modulation process. The switching process is shown in figure 2.4 and 2.5 where the current error is bounded between the upper inner and lower outer hysteresis boundaries for a positive inverter output and between the lower inner and upper outer hysteresis boundaries for a negative inverter output. The new switching process introduces a positive or negative dc offset error into the average output current depending on the polarity of the active output voltage.[18]

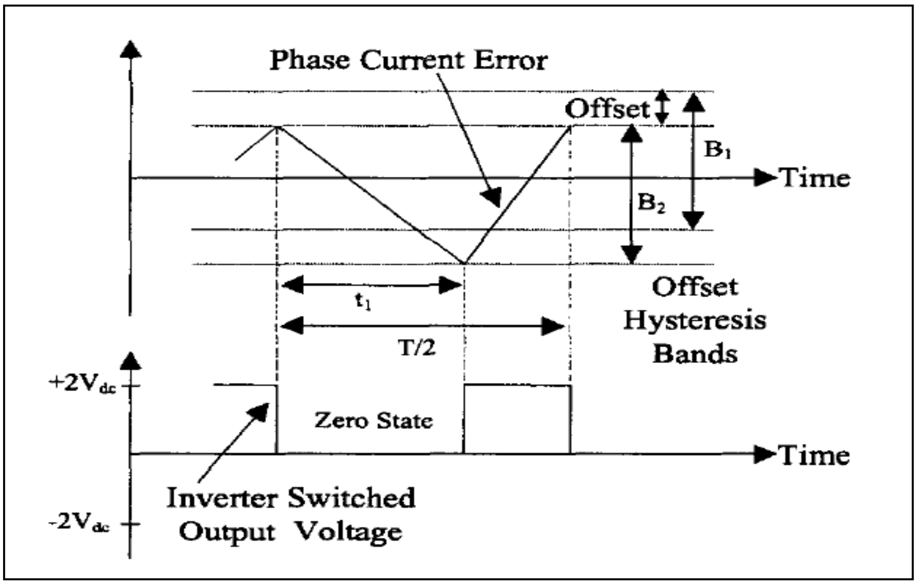

Figure 2.4: Positive inverter output

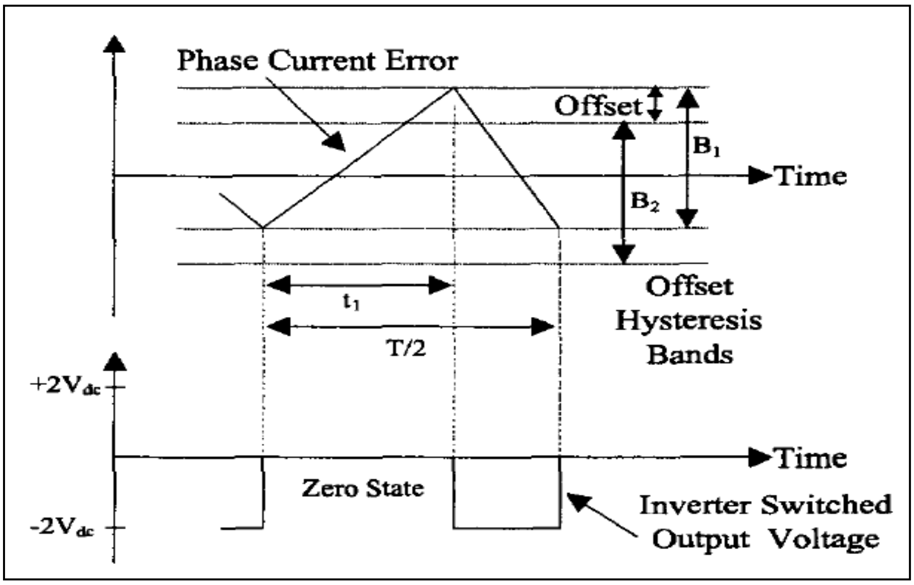

Figure 2.5: Negative inverter output

CHAPTER 3

METHODOLOGY

This study is using matlab Simulink to design the buck converter using different controller which is hysteresis controller, PID controller and three-level hysteresis control. The methodology of this project consist several steps as shown in Figure 3.1. This project begins with a through literature review on the basic concept of dc-dc buck converter. The theory of dc-dc buck converter is very important in this project in order to get clear understanding on what the project is all about.

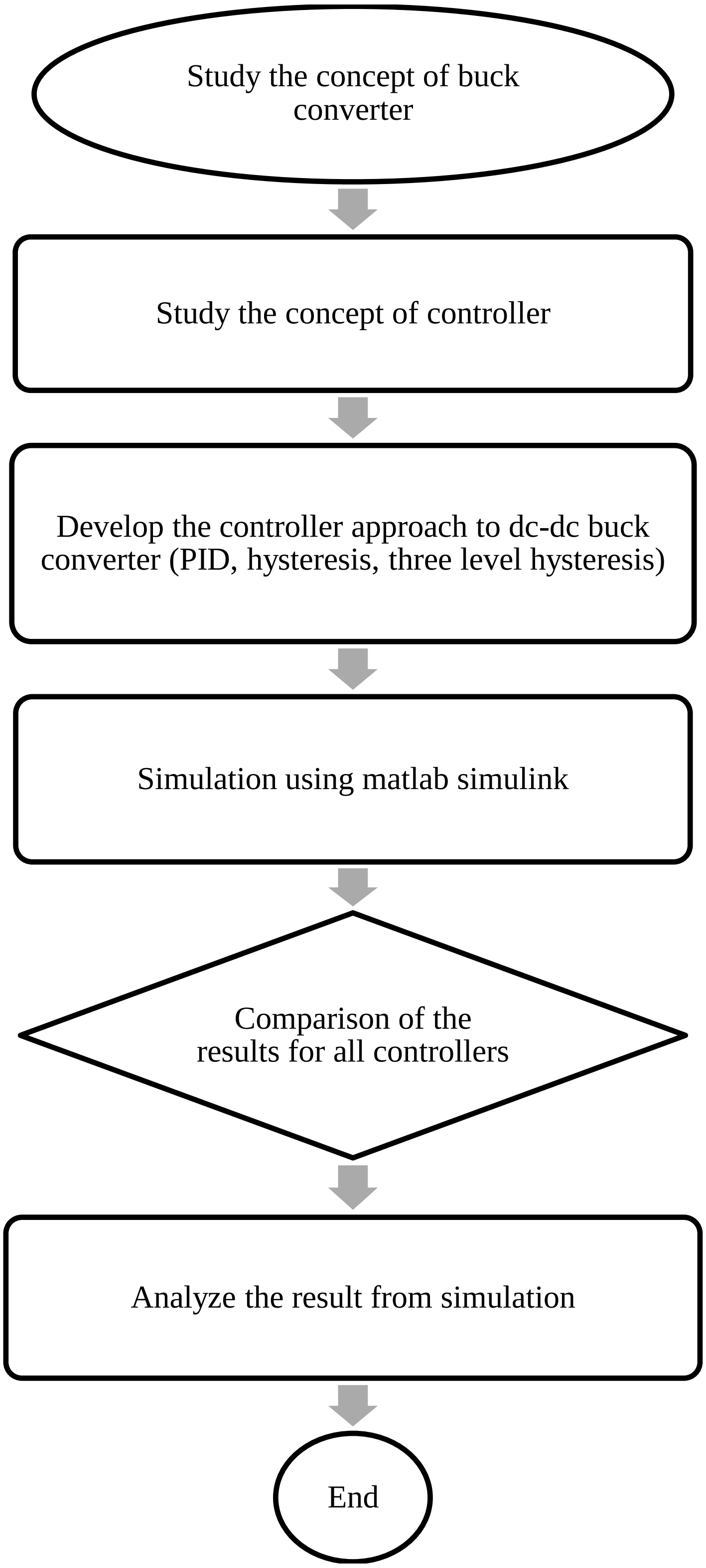

Figure 3.1: Flow of the project development

3.1 Circuit of buck converter

A basic circuit of a dc-dc buck converter was shown in Figure 3.2. This system consists of voltage source, ideal switch, series RL branch, series RC branch and resistor.

Block diagram is a diagram of a system, in which the principle parts of functions are represented by blocks connected by lines. For the block diagram of buck converter is connection by all main part of the system.

The circuit is simulated by using MATLAB/SIMULINK. The advantage of SIMULINK is that it is straightforward and user friendly for analysis and design purpose. MATLAB involves many high instructions and tools for some systems designing applications and developing power system analysis. Furthermore, since the MATLAB/SIMULINK contains Power System Toolbox, the software turns into a powerful power systems simulation and analysis tool. Other than that, this software is very helpful because it comes with demos of some power electronics circuit that student can refer to as references for circuit designing and simulation. It also provides help topics for students to refer to. It is very easy to create power system in SIMULINK environment, which allows users to build a model by simple “click and drag” procedures. In addition, the simulation system of block component can set relation electrical parameters from MATLAB commands. The results of the simulation work will be analyzed to determine the performance of buck converter by using hysteresis control, PID controller and three-level hysteresis control.

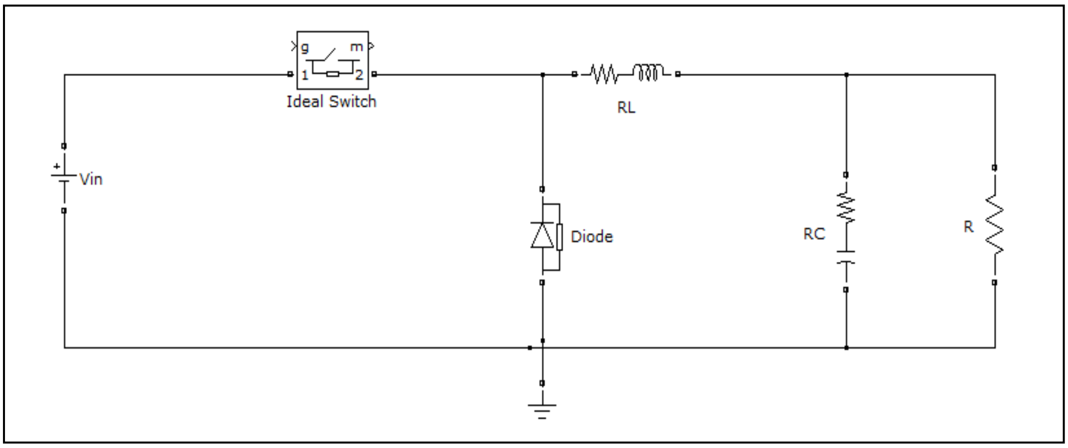

Figure 3.2: Basic circuit buck converter

3.1.1 DC voltage source

The DC Voltage Source block implements an ideal DC voltage source. The positive terminal is represented by a plus sign on one port. The voltage can be change at any time during the simulation. In this circuit, the voltage DC source has been set to 24V.

3.1.2 Ideal Switch

The Ideal Switch block does not correspond to a particular physical device. When it used with appropriate switching logic, it can be used to model simplified semiconductor devices such as a GTO or a MOSFET, or even a power circuit breaker with current chopping. The switch is simulated as a resistor R on in series with a switch controlled by a logical gate signal g. The Ideal Switch block is fully controlled by the gate signal (g > 0 or g = 0). It has the following characteristics:

- Blocks any forward or reverse applied voltage with 0 current flow when g = 0
- Conducts any bidirectional current with quasi-zero voltage drop when g > 0
- Switches instantaneously between on and off states when triggered

In this circuit, the ideal switch will control by three controllers which is hysteresis control, PID controller and three-level hysteresis control.

3.1.3 Diode

The Diode block models a piecewise linear diode. If the voltage across the diode is bigger than the forward voltage parameter value, then the diode behaves like a linear resistor with low resistance, given by the on resistance parameter value, plus a series voltage source. If the voltage across the diode is less than the forward voltage, then the diode behaves like a linear resistor with low conductance given by the off conductance parameter value.

3.1.4 Series RLC branch

The Series RLC Branch block implements a single resistor, inductor, or capacitor, or a series combination of these. The branch type parameter is used to select elements to include in the branch. This project has used series RL, series RC and resistor.

3.2 Hysteresis control approach to buck converter

Hysteresis control has been implementing to buck converter as shown in Figure 3.3. The hysteresis control is done by using M-file in Matlab. The hysteresis control will control the switching of ideal switch to get the desired output voltage. The results of the simulation will be shown in Chapter 4.

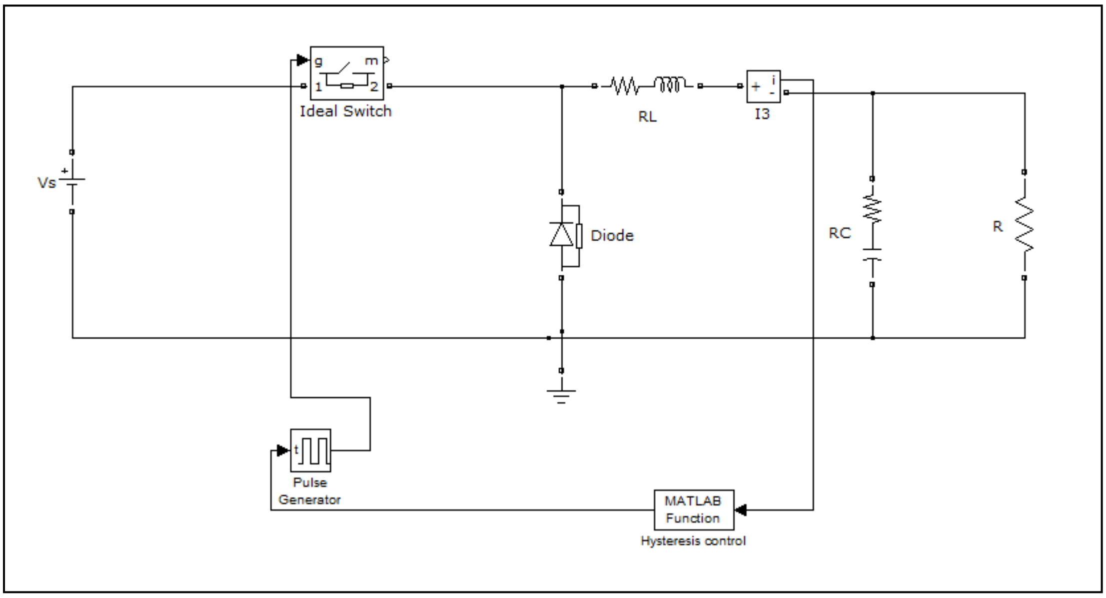

Figure 3.3 Buck converter with hysteresis control

In the proposed hysteresis control, two bounces are used, which is upper and lower bounces. Each bounce is set by using the calculated output current from the converter plus tolerance tuning ripple as in the following;

Iinf = 1/R * V_r (1)

Upper bounce = Iinf + 0.01

Lower bounce = Iinf – 0.01

Conventional hysteresis current control operates by comparing a current error against fixed hysteresis band.

From the setting bounces, if the sensed output current exceeds the upper bounce, the converter output control switching is set to low (= 0) and if falls below the lower bounce, converter output control switching is set to high (=1), otherwise, the output switching is set on the average. This process is shown as Figure 3.4.

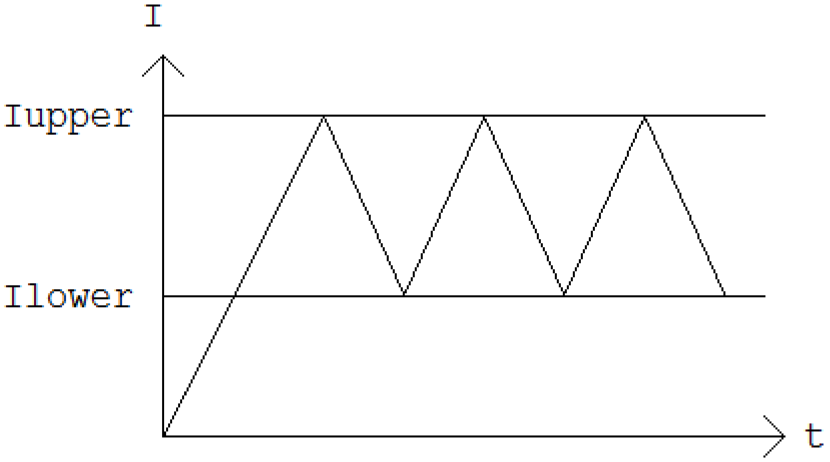

Figure 3.4: Iupper and Ilower

3.3 PID controller approach to buck converter

Another controller that has been implemented to buck converter is PID controller. The design of PID controller has been shown in Figure 3.5 and in Figure 3.6 shown the PID controller with buck converter.

There are several methods for tuning a PID loop. Table 3.1 shows three methods of tuning PID controller based on their advantages and the disadvantages.

Methodes	Advantage	Disadvantage
Manual Tuning (try and error)	No math required, online method.	Requires experienced personnel.
Ziegler–Nichols	Proven method, online method.	Process upset, some trial-and-error, very aggressive tuning.
Software Tools	Consistent tuning, online or offline method.	Some cost and training involved.

Table 3.1: Tuning methodsTable

For manual tuning method, first set K_i and K_d values to zero. Increase the K_p until the output of the loop oscillates, then the K_p should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase K_i until any offset is corrected in sufficient time for the process. However, too much K_i will cause instability. Finally, increase K_d, until the loop is acceptably quick to reach its reference after a load disturbance.

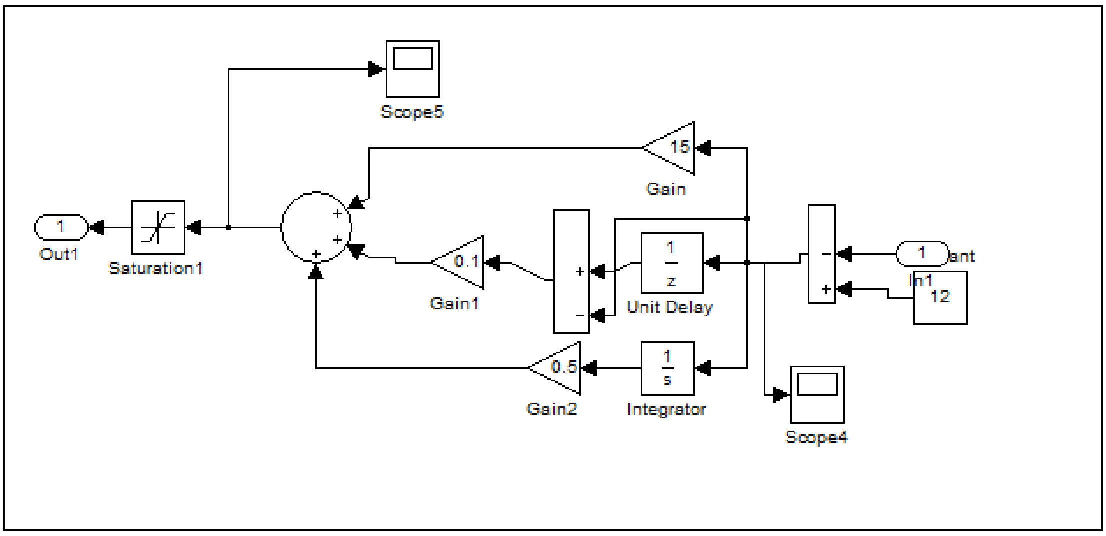

Figure 3.5: PID controller

3.3.1 Integrator

The integrator block outputs the integral of its input at the current time step.

3.3.2 Unit delay

The Unit Delay block delays its input by the specified sample period. This block is equivalent to the z^{-1} discrete-time operator. The block accepts one input and generates one output, which can be either both scalar or both vector. If the input is a vector, all elements of the vector are delayed by the same sample period.

3.3.3 Gain

The Gain block multiplies the input by a constant value. The tuning is performed by adjusting the gain until get the good response. Each gain represents the P, I and D respectively.

3.3.4 Saturation

The Saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the lower limit and upper limit parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the block clips the signal to the upper or lower bound. When the lower limit and upper limit parameters are set to the same value of positive and negative. The proposed for saturation limit is to avoid the integral wind-up from the summation of the error in integral element.

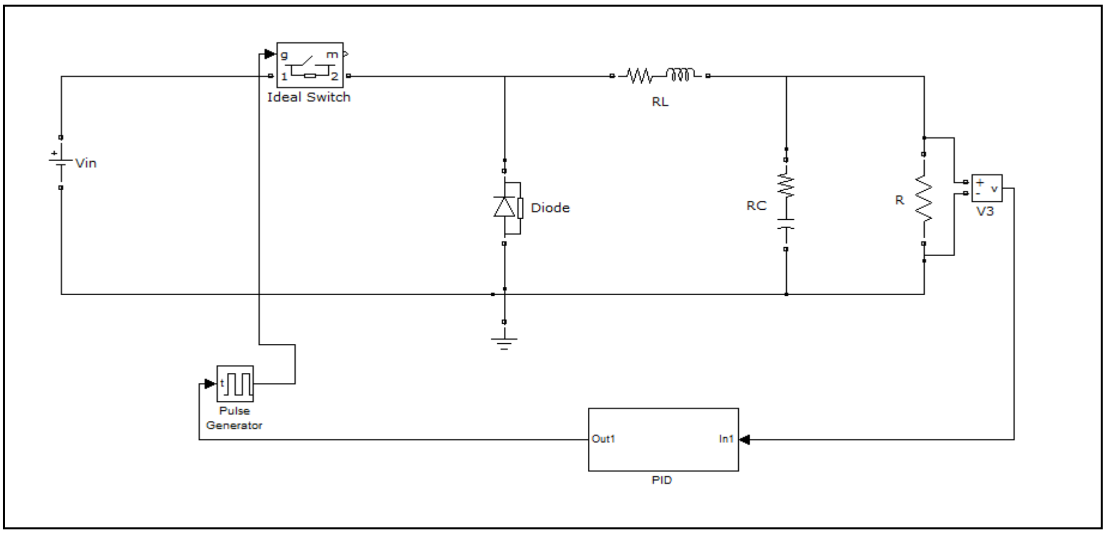

Figure 3.6: Buck converter with PID controller

3.4 Three level hysteresis control implements to buck converter

This controller is the extending from the hysteresis control by adds one band channel in the middle of upper and lower bounces of hysteresis control as shown in Figure 3.7. The three-level hysteresis control also has been created using M-file matlab as shown in Figure 3.8 and the result is shown in Chapter 4.

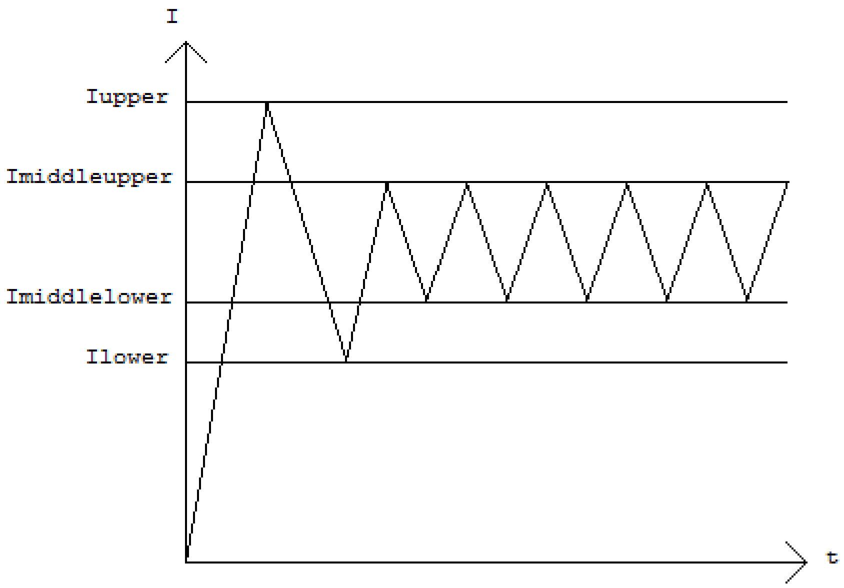

Figure 3.7: Iupper, Imiddleupper, Imiddlelower and Ilower

As this is extending from hysteresis control, the same calculated output current is used for added bounces as in the following;

Iinf = 1/R * V_r (1)

Upper bounce = Iinf + 0.05

Lower bounce = Iinf – 0.05

Upper middle bounce = Iinf + 0.009

Lower middle bounce = Iinf – 0.009

From the setting bounces, if the sensed output current exceeds the upper bounce, the converter output control switching is set to low (= 0), if falls below the lower bounce, converter output control switching is set to high (=1) and if the sensed output current fall between middle upper and middle lower the output switching is set on the average, otherwise, the output switching is set on the average.

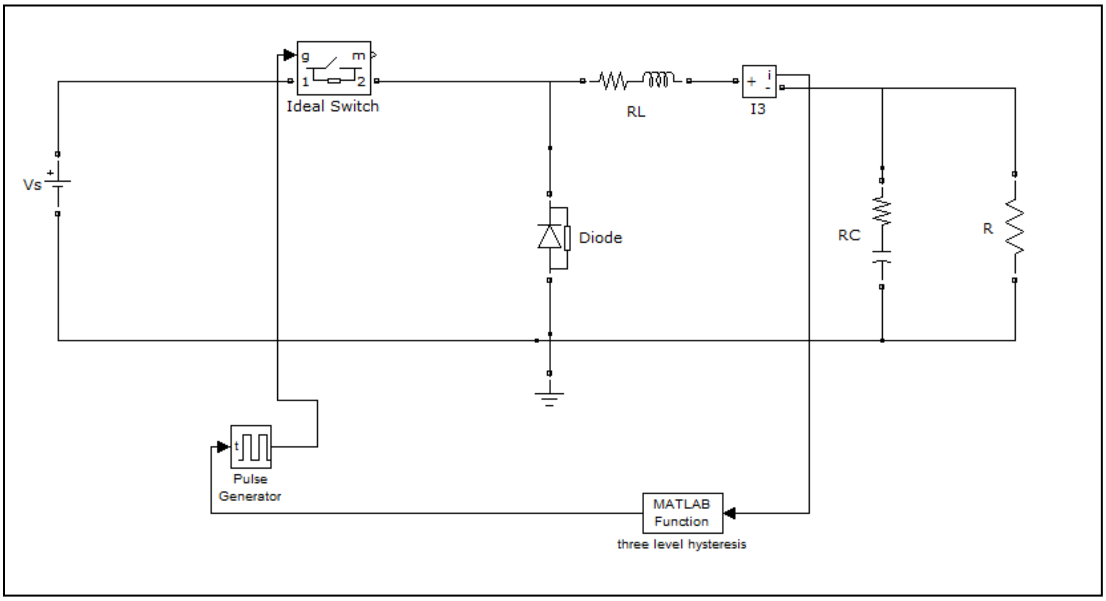

Figure 3.8: Buck converter and three level hysteresis control

3.5 Load changes

The load changes have been added to the circuit of buck converter as shown in Figure 3.9. The function of adding the load changes into this circuit is because to observe how fast the voltage will be back to the track if there is has disturbance. Besides that, this will show the controller good tracking.

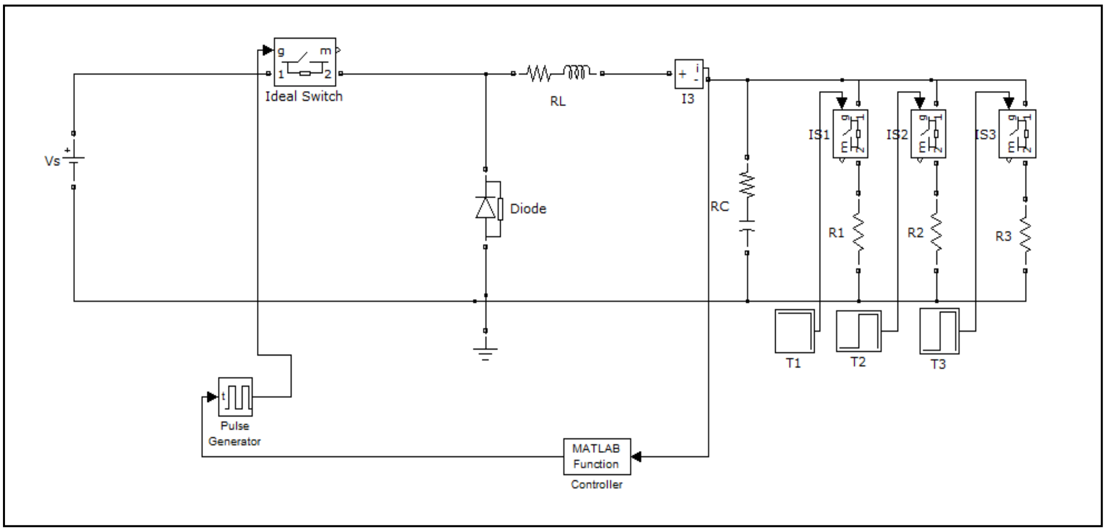

Figure 3.9 Load changes

CHAPTER 4

RESULT AND DISCUSSION

This chapter discuss about the results of the project and the analysing of control methods. The results were focus on start-up transient response and load changes of buck converter. All simulations are carried out using Matlab Simulink. The algorithms for hysteresis control and three-level hysteresis control is implemented in m-file integrated into simulink circuit.

4.1 Hysteresis control

The result of hysteresis control that implemented to buck converter has been compared by change the voltage reference at hysteresis control from 12V to 8V and 16V.

a) Voltage reference = 8V

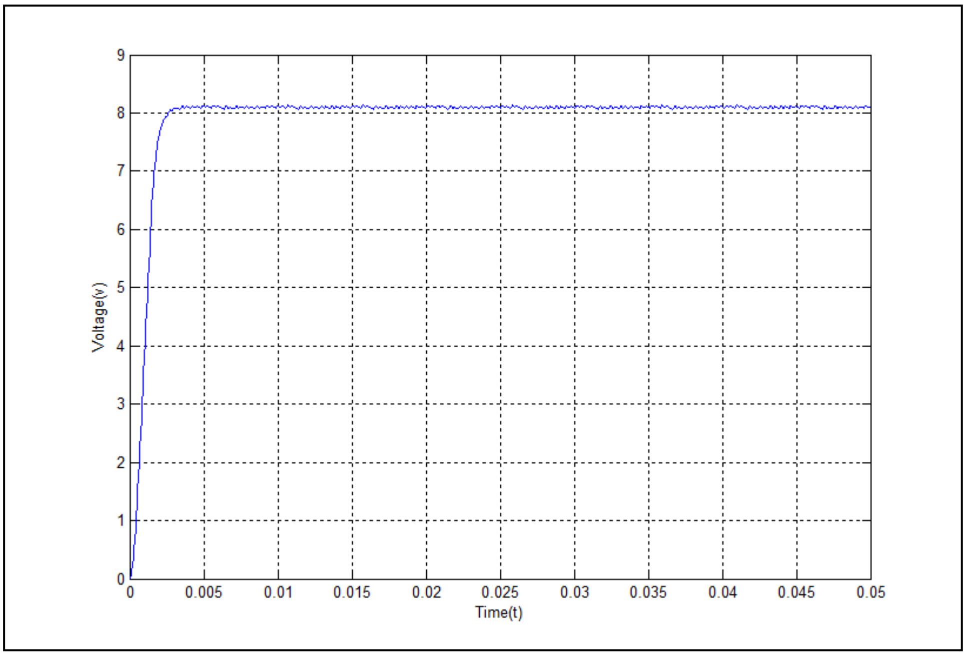

Figure 4.1: Output voltage hysteresis control when voltage reference = 8V

b) Voltage reference = 12V

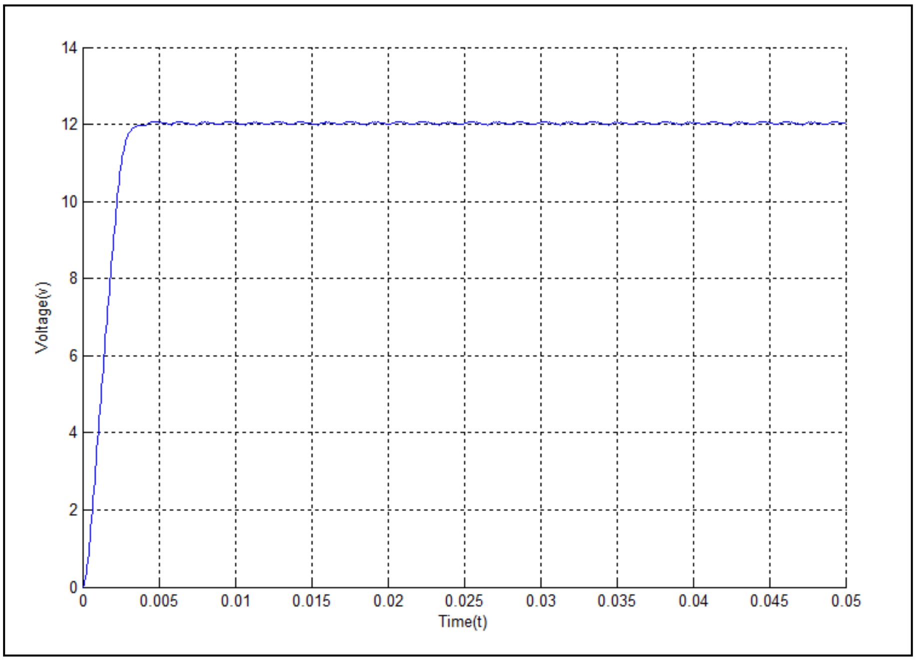

Figure 4.2: Output voltage hysteresis control when voltage reference = 12V

c) Voltage reference = 16V

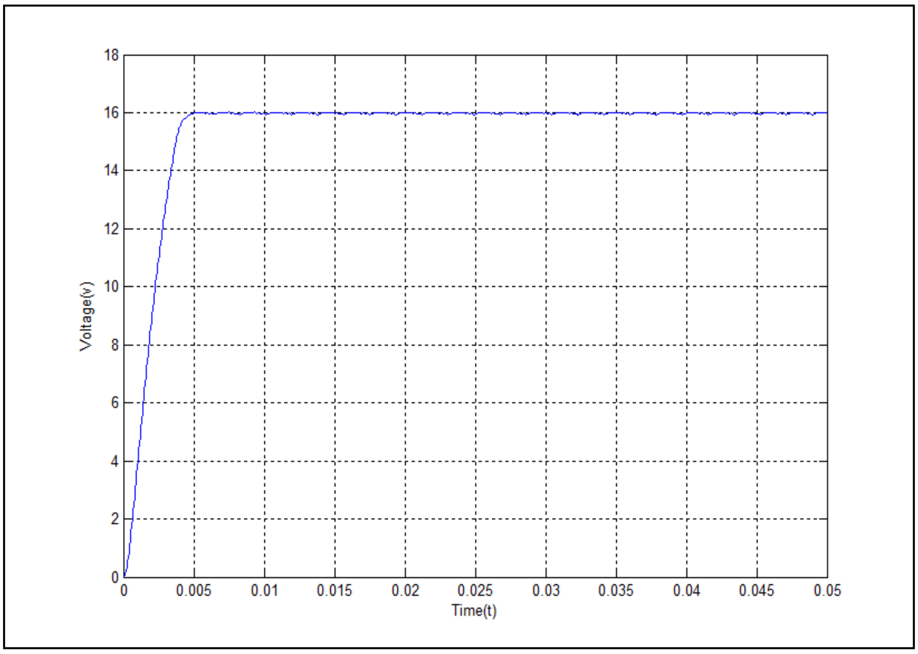

Figure 4.3: Output voltage hysteresis control when voltage reference = 16V

From the result, when the voltage reference is change, the transient have followed the voltage reference. Using hysteresis control it can provide fast transient response because the controller turns the switch on when the output is below the hysteresis band and vice versa.

4.2 PID controller

The try and error is used for tuning the PID controller parameters. The final PID parameters are tuned as Kp=15, Ki=0.5, Kd=0.1. The first analysis is carried out when the reference voltage is changes to 8V and 16V. The nominal output voltage is 12V.

a) Voltage reference = 8V

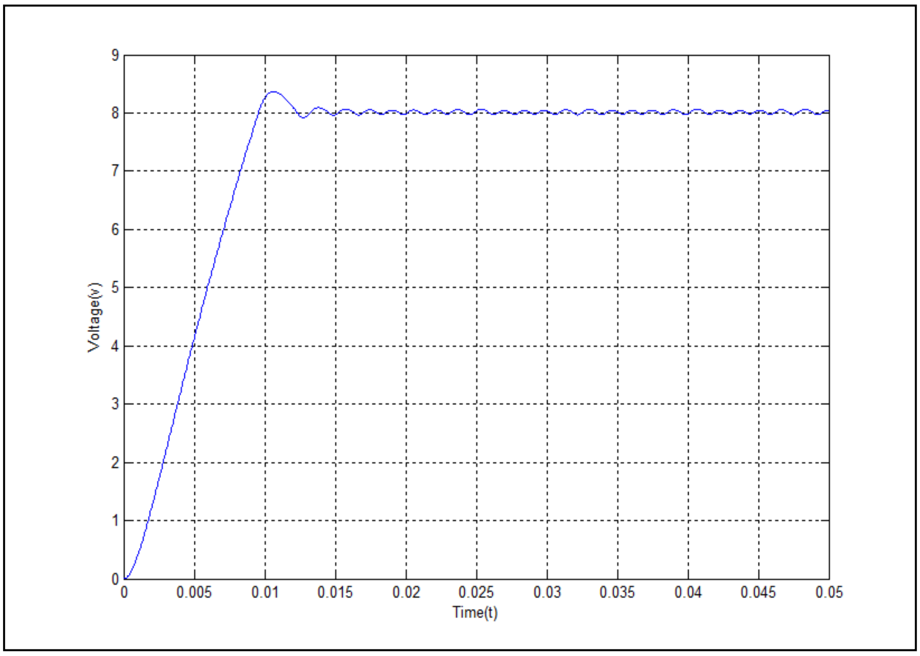

Figure 4.4: Output voltage PID controller when voltage reference = 8V

b) Voltage reference = 12V

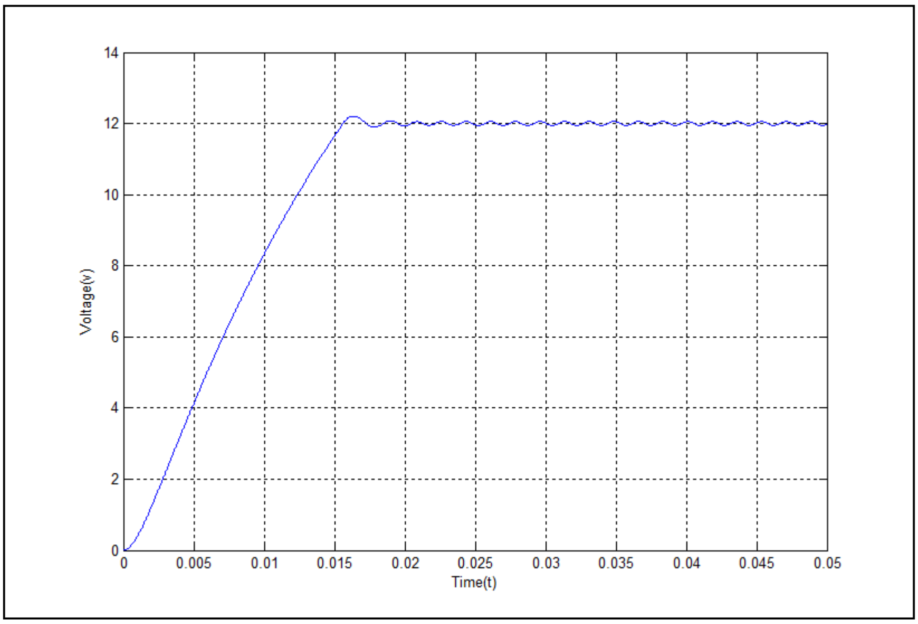

Figure 4.5: Output voltage PID controller when voltage reference = 12V

c) Voltage reference = 16V

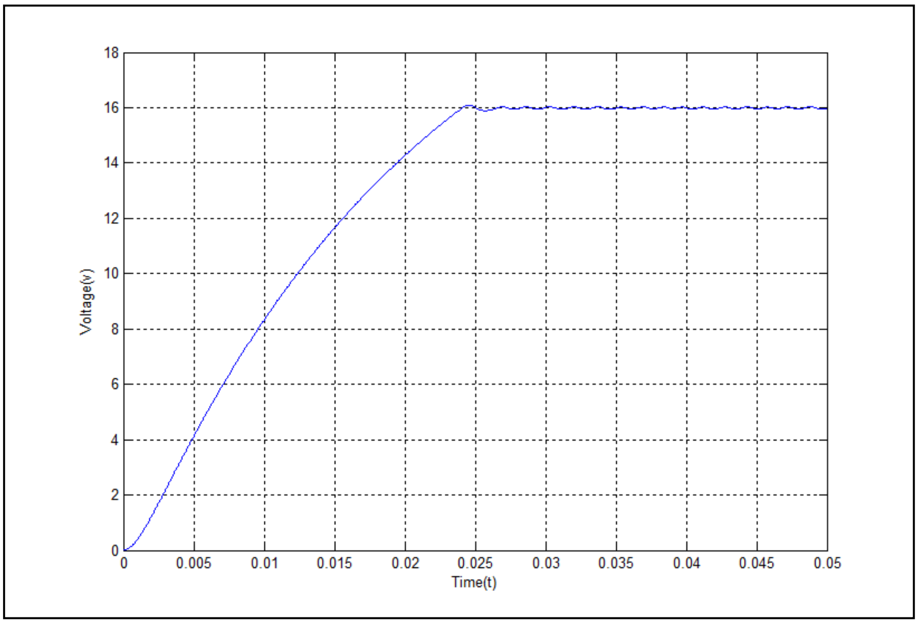

Figure 4.6: Output voltage PID controller when voltage reference = 16V

From the result PID controller compared with hysteresis control, the transient response was slow than hysteresis control. When the voltage reference is increase, the rise time for the transient to get steady state value is longer. When using PID controller, there is overshoot at the transient.

4.3 Three level hysteresis control

The analysis is carried out when the reference voltage is changes to 8V and 16V. The nominal output voltage is 12V.

a) Voltage reference = 8V

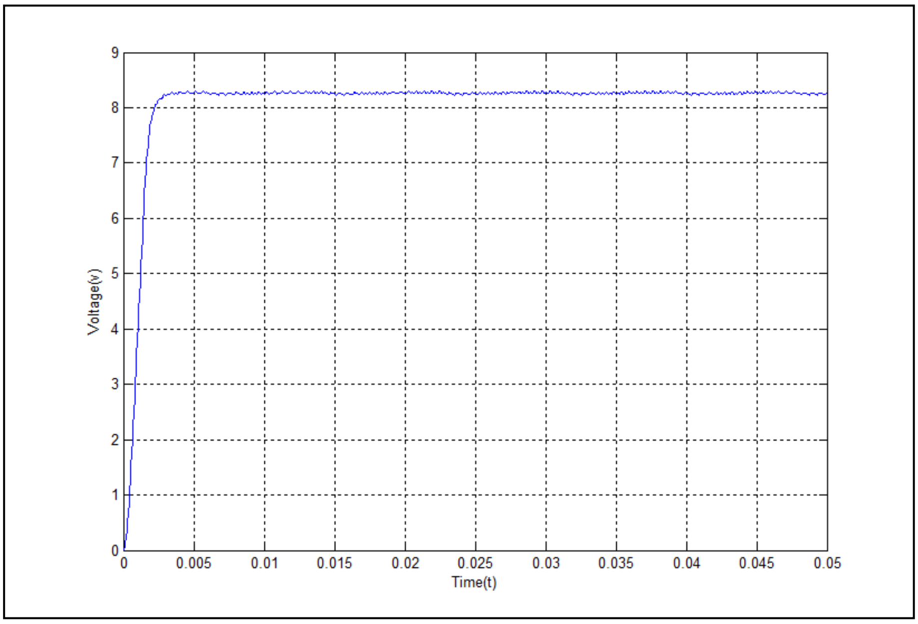

Figure 4.7: Output voltage three level hysteresis control when voltage reference = 8V

b) Voltage reference = 12V

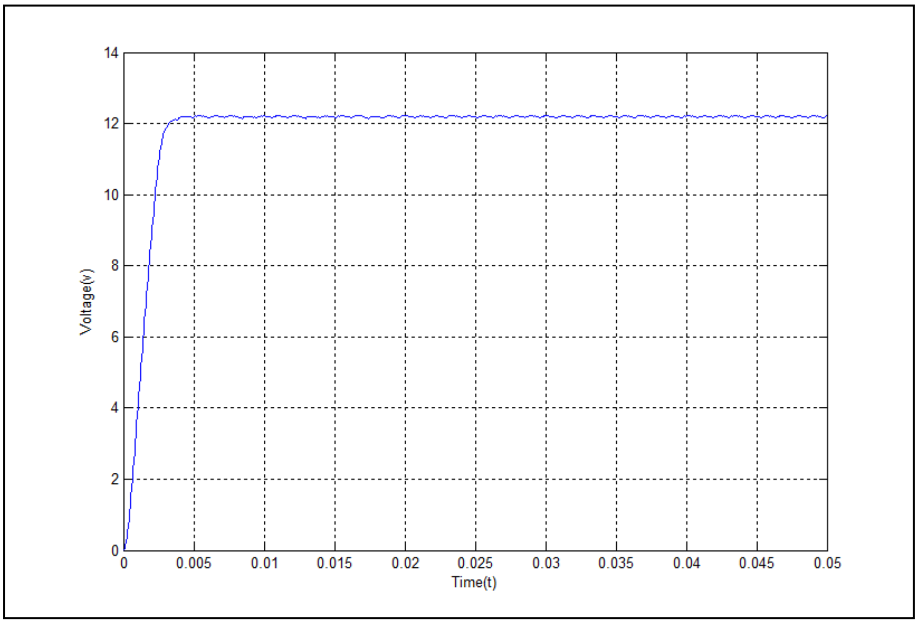

Figure 4.8 Output voltage three level hysteresis control when voltage reference=12V

c) Voltage reference = 16V

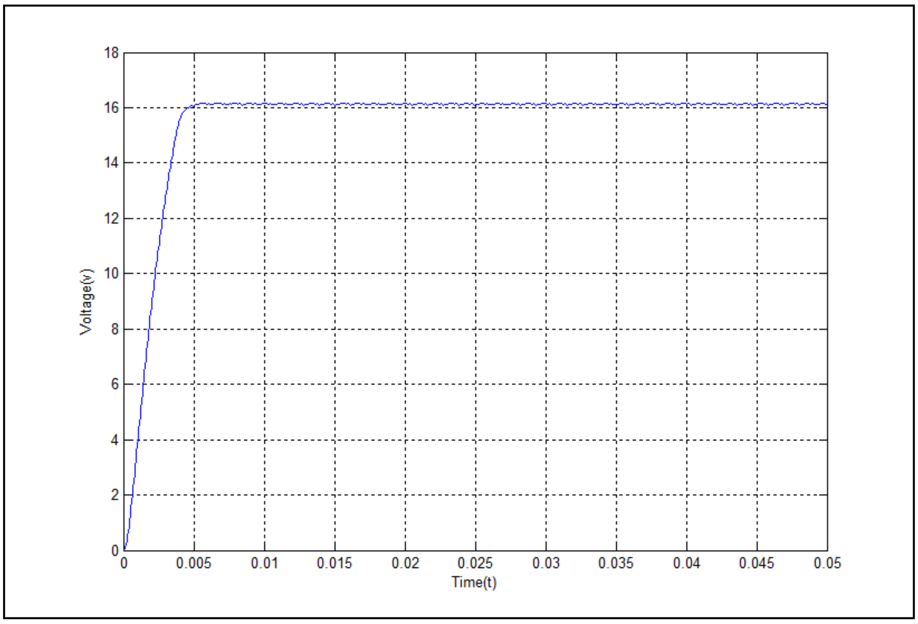

Figure 4.9 Output voltage three level hysteresis control when voltage reference=16V

For three level hysteresis control, the transient response is fast compared when using PID controller. The overshoot is not much compared to PID overshoot.

4.4 Switching frequency

The second analysis is by increase the switching frequency of the converter to 100 kHz. The nominal switching frequency is 20 kHz. Figure 4.10, 4.11, 4.12, 4.13, 4.14 and 4.15 show the results for hysteresis, PID and three-level hysteresis respectively.

a) f_s =20 kHz

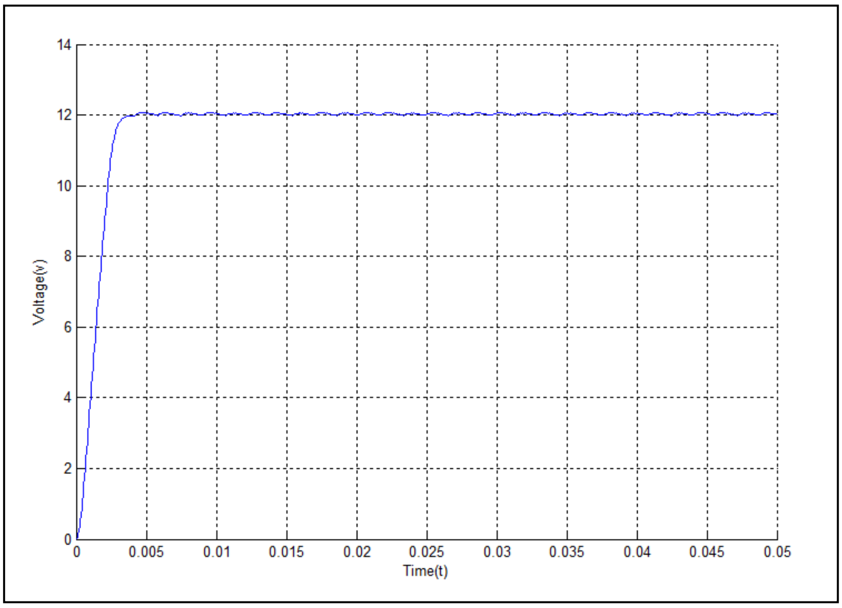

Figure 4.10: Using hysteresis controllers, f_s = 20 kHz

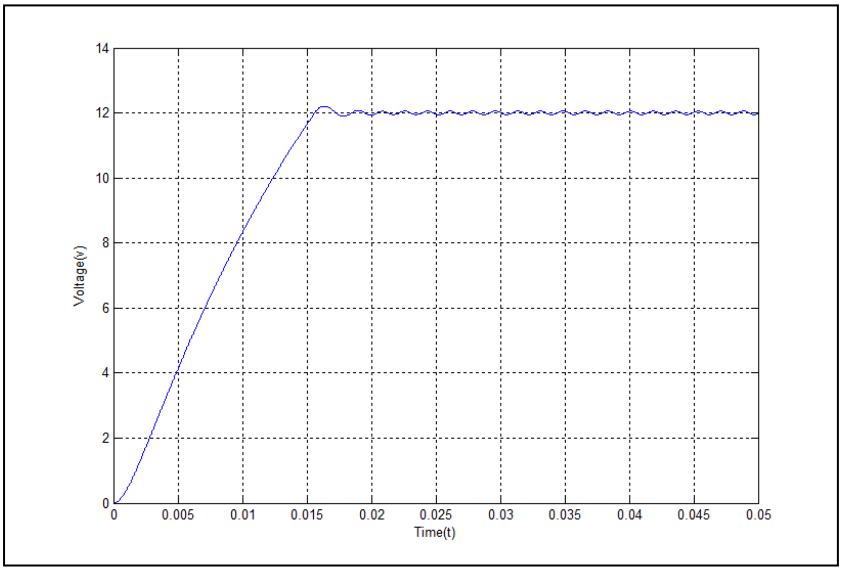

Figure 4.11: Using PID controllers, f_s = 20 kHz

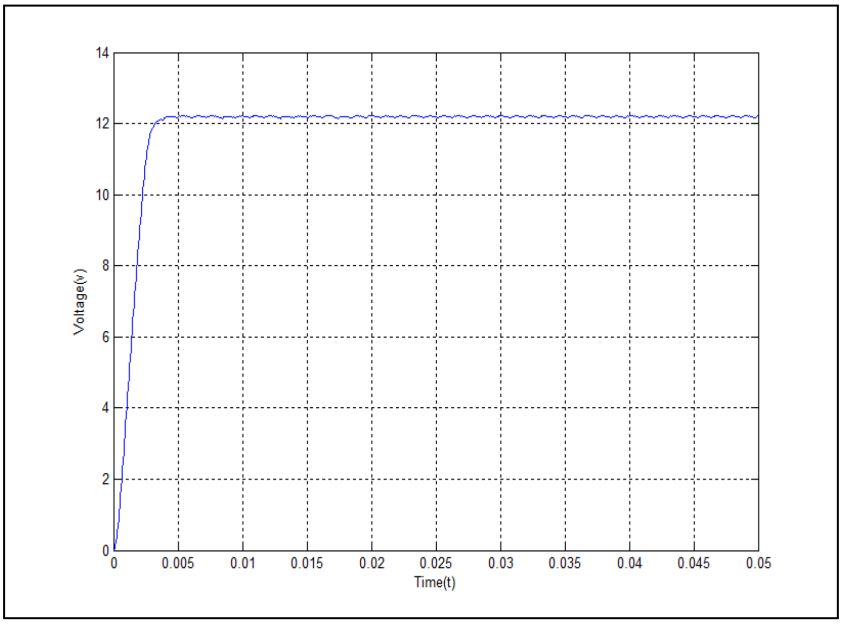

Figure 4.12: Using three level controllers, f_s = 20 kHz

b) f_s = 100 kHz

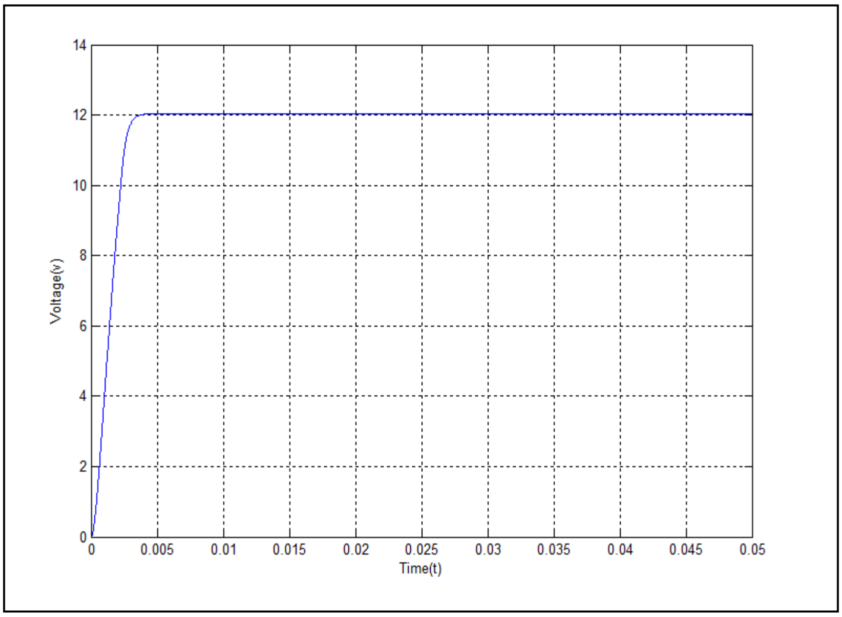

Figure 4.13 Using hysteresis controllers, f_s = 100 kHz

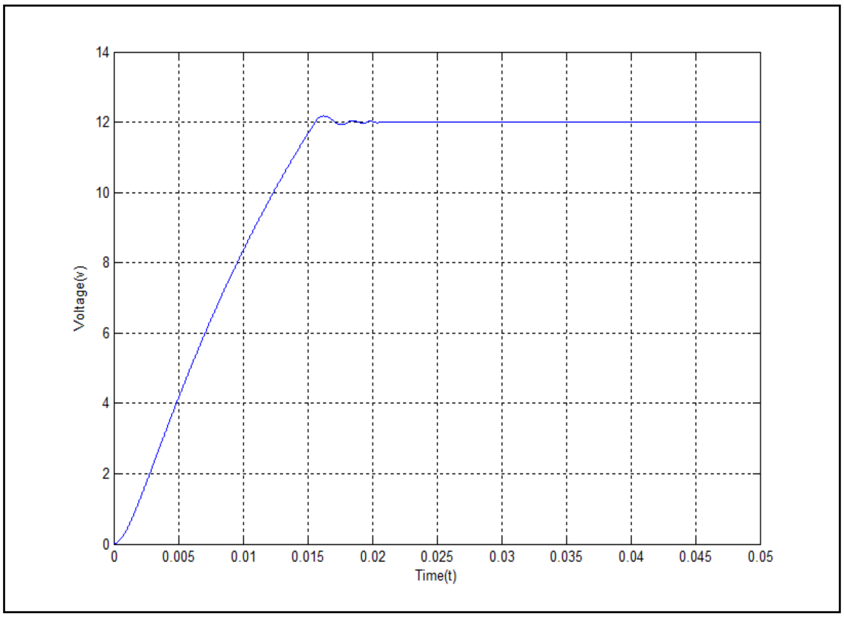

Figure 4.14 Using PID controllers, f_s = 100 kHz

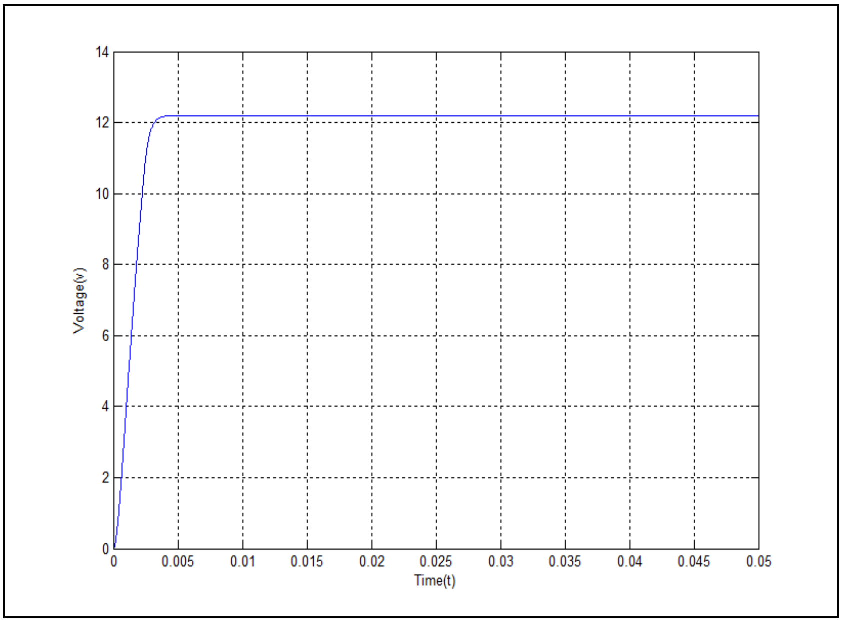

Figure 4.15 Using three level controllers, f_s = 100 kHz

From the result, the ripple voltage is occurring when the switching frequency is set to 20 kHz. When increase the switching frequency from 20 kHz to 100 kHz, it can reduce the ripple voltage. There are two advantages when the switching frequency is increase, which is as frequency goes up, parts usually get smaller, lighter and cheaper. So that, it get a lot of power from a small volume of stuff or a high power density. Second is the delay from input to output created by the switching time (Ts) becomes smaller. As a result, it can reduce the voltage ripple and the overshoot when applied to buck converter.

4.5 Load changes

In this analysis, the load is increased and decreased from the nominal value. The response is investigate for all controllers.

a) Hysteresis control (10Ω to 15Ω to 8Ω)

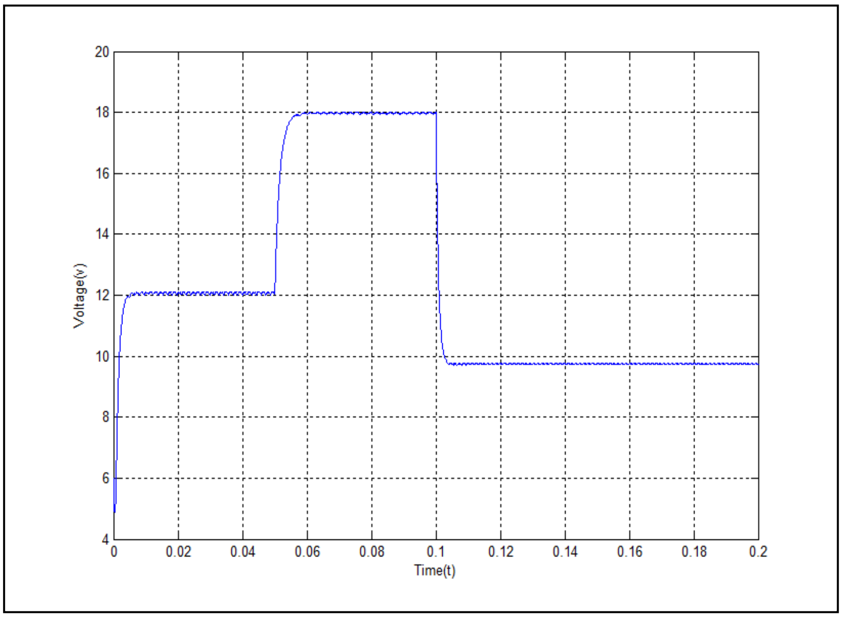

Figure 4.16: Load change using hysteresis control

b) PID controller (10Ω to 15Ω to 8Ω)

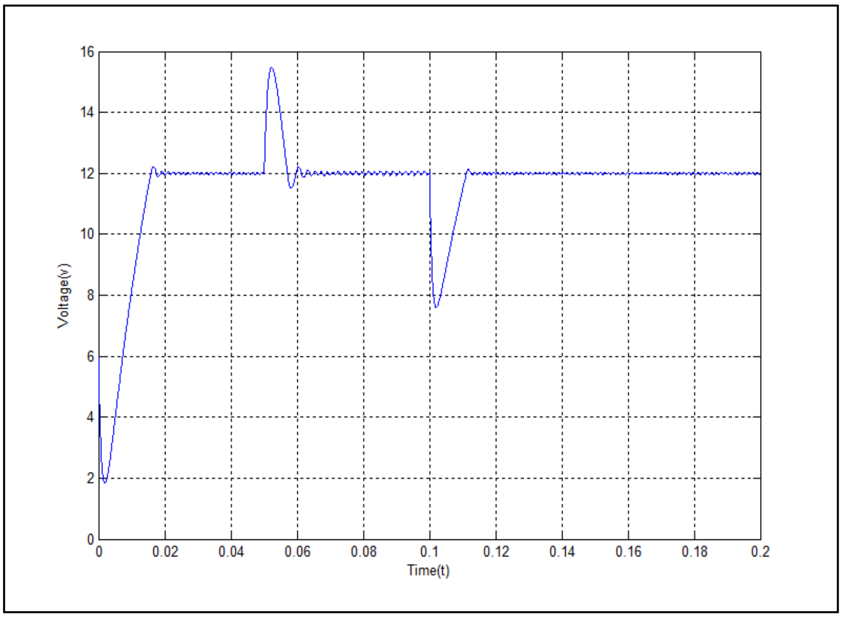

Figure 4.17 Load change using PID controller

c) Three level hysteresis control (10Ω to 15Ω to 8Ω)

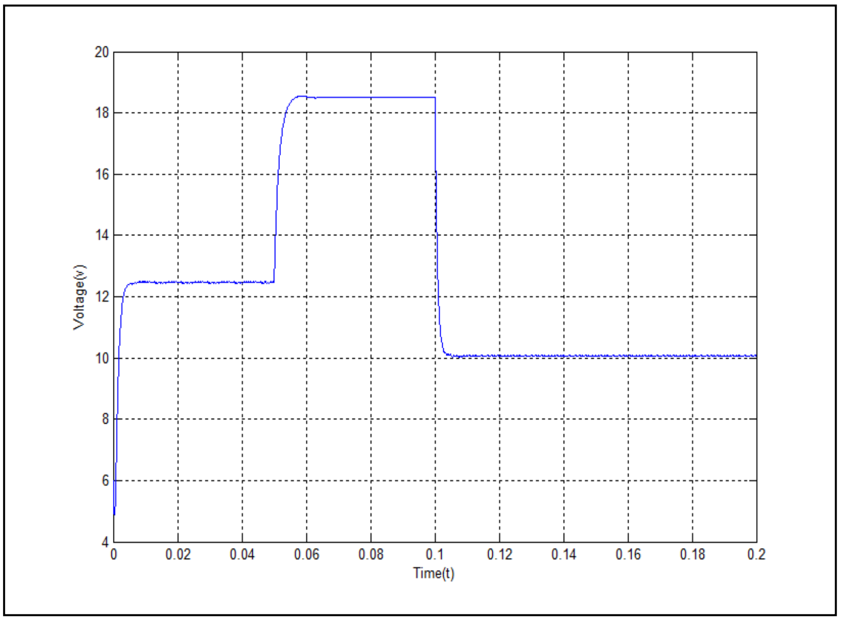

Figure 4.18: Load change using three level hysteresis control

From the result of load change, when using hysteresis control and three level hysteresis control, after the load disturbance, the voltage output is not back to the reference voltage. Compare when using PID controller, after the load disturbance, the voltage have follow the voltage reference and back to the steady state.

CHAPTER 5

CONCLUSION

From the three controllers, each of the controllers has their advantage and disadvantage. The hysteresis control and three-level hysteresis control has disadvantage when there is load disturbances. The output voltage converges to a certain value where the constant output voltage cannot be maintained. This problem can be solved by add a load identification or using another loop feedback control to control the constant output voltage in any load changes. The advantage of using hysteresis control and three-level hysteresis control is they provide a fast transient response compared to PID controller. While the PID controller has higher overshoot and slow rise time response compared to hysteresis control. The PID parameters are tuned manually (by using try and error) process.

Overall, the hysteresis and three-level hysteresis control show a good performance beside the load changes compared to very famous controller PID. In future, the continuous study must be carried out in hysteresis control to tackle the problem of load disturbances.

REFERENCES:

[1] Ned Mohan, Tore M. Undeland and Williamp P. Robbins, Power Electronic: Media Enhanced Third Edition, 2003.

[2] http://www.jaycar.com.au/images_uploaded/dcdcconv.pdf

[3] http://powerelectronics.com/mag/602PET20.pdf

[4] http://www.facstaff.bucknell.edu/mastascu/eControlHTML/PID/PID3.html

[5] http://encon.fke.utm.my/nikd/SEM4413/AnalysisConverter-buck.pdf

[6] Nguyen, V.M. and Lee, C.Q.,” Tracking control of buck converter using sliding-mode with adaptive hysteresis”, *Power Electronics Specialists Conference, 1995. PESC '95 Record., 26th Annual IEEE*,vol.2,pp 1086-1093,1995.

[7] Kelvin Ka-Sing Leung and Henry Shu-Hung Chung, “Dynamic hysteresis band with fast transient response”, *IEEE Trans. On Circuit and Systems-II: Express Briefs*, vol.52, no.7, July 2005.

[8] Szepesi and Thomas,” Stabilizing the Frequency of Hysteretic Current-Mode DC/DC Converters”, *Power Electronics, IEEE Transactions*,vol.2, no.4,pp 302-312,1987.

[9] Wong, L.K., and Man, T.K.,” Steady state analysis of hysteretic control buckconverters”, *Power Electronics and Motion Control Conference, 2008. EPE-PEMC 2008. 13th* ,pp 400-404,2008.

[10] Borrell, A., Castilla, M., Miret, J., Matas, J., and de Vicuna, L.G.,” Simple low cost hysteretic controller for Multiphase Synchronous Buck Converters”, *Industrial Electronics, IEEE Transactions* ,vol.58,no.6,pp 2355-2365,2011.

[11] Tsai, C.T. and Chou, H.P.,”A synthetic ripple buck converter with dynamic hysteretic band modulation”, Power Electronics and Drive Systems, 2009. PEDS 2009. International Conference, pp 170-174, Nov. 2009.

[12] Huerta, S.C., Alou, P., Oliver, J.A., Garcia, O., Cobos, J.A. and Abou-Alfotouh, A.,”A very fast control based on hysteresis of the Cout current with a frequency loop to operate at constant frequency”, Power Electronics Conference and Exposition, 2009. APEC 2009. Twenty-Fourth Annual IEEE, pp 799-805, Feb. 2009.

[13] Nabeshima, T., Sato, T., Yoshida, S., Chiba, S. and Onda, K.,” Analysis and design considerations of a buck converter with a hysteretic PWM controller”, Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual, vol. 2, pp 1711-1716, June 2004.

[14] Hyun-Hee Park, Young-Jin Woo and Gyu-Hyeong Cho,” A fully integrated wide-band PID controller with capacitor-less compensation for step-down DC-DC converter”, Circuits and Systems (ISCAS), 2011 IEEE International Symposium, pp 506-509, May 2011.

[15] Chander, S., Agarwal, P. and Gupta, I.,”Auto-tuned, discrete PID controller for DC-DC converter for fast transient response”, Power Electronics (IICPE), 2010 India International Conference, pp 1-7, Jan. 2011.

[16] Hongmei LI and Xiao Ye,”Sliding-mode PID control of DC-DC converter” Industrial Electronics and Applications (ICIEA), 2010 the 5th IEEE Conference, pp 730-734, June 2010.

[17] Demian Pimentel, Ahmed Cheriti and Mohammed Ben Slima “Three-Level Hysteresis Power Control for Pulse-Density-Modulated Series Resonant Converters”, Electrical and Computer Engineering, 2006. CCECE '06. Canadian Conference, pp 2237-2240, May 2006.

[18] Bode, G. H., Holmes, D. G., “Implementation of three level hysteresis current control for a single phase voltage source inverter”, Power Electronics Specialists Conference, 200. PESC 00. 2000 IEEE 31st Annual, vol 1, pp 33-38, 2006