VOLTAGE TRACKING OF A DC-DC BUCK CONVERTER USING NEURAL NETWORK CONTROL

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ABSTRACT

This master report presents a voltage tracking of a neural network for dc-dc buck converter. The mathematical model of Buck converter and artificial neural network algorithm is derived. The dc-dc Buck converter is designed to tracking the output voltage with three variation. This master report consists open loop control, closed loop control and neural network control. The Buck converter has some advantages compare to the others type of dc converter. However the nonlinearity of the dc-dc Buck converter characteristics, cause it is difficult to handle by using conventional method such as open loop control system and close loop control system like proportional-integral-differential (PID) controller. In order to overcome this main problem, a neural network controller with online learning technique based on back propagation algorithm is developed. The effectiveness of the proposed method is verified by develop simulation model in MATLAB-Simulink program. The simulation results show that the proposed neural network controller (NNC) produce significant improvement control performance compare to the PID controller for both condition for voltage tracking output for dc-dc Buck converter.

ABSTRAK

Kertas ini membentangkan kaedah mengesan voltan keluaran menggunakan kaedah jaringan saraf (NNC). Model untuk matematik bagi penukar arus terus (AT-AT) jenis Buck dan jaringan saraf tiruan (ANN) algoritma diterbitkan. Penukar Buck direka untuk mengesan voltan keluaran dalam 3 variasi. Kertas ini merangkumi rekabentuk penukar Buck jenis kawalan gelung buka, gelung tertutup dan jaringan saraf (ANN). Penukar Buck mempunyai banyak kelebihan berbanding berbanding dengan penukar arus terus yang lain. Walau bagaimanapun, ciri-ciri ketidaklelurusan atau tidak linear penukar Buck arus terus terlalu sukar untuk dikawal, dan menyebabkan ia sukar untuk ditangani dengan menggunakan pembezaan penting berkadar konvensional (PID) pengawal. Untuk mengatasi masalah utama ini, pengawal jaringan saraf dengan teknik pembelajaran dalam talian berdasarkan algoritma penyebaran belakang dibangunkan. Keberkesanan cara yang disarankan ini terbukti dengan membangunkan model simulasi dalam program MATLAB-Simulink. Keputusan simulasi menunjukkan bahawa pengawal jaringan saraf pembelajaran yang dicadangkan itu (NNC) menghasilkan peningkatan prestasi kawalan yang sejajar dibandingkan dengan pengawal PID untuk mengesan voltan keluaran pengawal penukar Buck arus terus.

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Symbol	
x	State vector
f	Function vector with n-dimension
u	Discontinuous control input
S	Sliding surface (manifold)
f^{+}, f^{-}	State velocity vector
f_N^{+}, f_N^{-}	Normal vectors
∇S	Gradient of sliding surface
e^{+}, e^{-}	Representative points
φ	Constant value
v_0	Output voltage
v_{con}	Control voltage
V_{ref}	Reference voltage
k_p, k_I	Proportional gain and integral gain of P-I controller
k_1	Voltage reduction factor
v_{ramp}	Sawtooth or Ramp voltage
V_U, V_L	Upper and Lower threshold voltages
q	Switching signal
h	Switching hypersurface
i_{ref}	Reference current

R_f	Proportionality factor
x_1	Voltage error
x_2	Voltage error dynamics
λ_1, λ_2	Line equations in phase plane
Δ	Small constant value
D	Diode
f_s	Switching frequency
T_S	Time period of external clock pulse
SMPS	Switched Mode Power Supply
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
SM	Sliding Mode
VSC	Variable Structure Control
VSS	Variable Structure System
PC	Proportional Control
PD	Proportional derivative Control
PID	Proportional integral derivative Control
EMI	Electromagnetic Interference
HM	Hysteresis Modulation
PWM	Pulse Width Modulation
GPI	Generalized proportional integral
PCCM	Pseudo continuous conduction mode
RP	Representative Point

CHAPTER 1

INTRODUCTION

1.1 Motivation

The switched mode dc-dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide applications like power supplies for personal computers, office equipments, appliance control, telecommunication equipments, DC motor drives, automotive, aircraft, etc.

The commonly used control methods for dc-dc converters are pulse width modulated (PWM) voltage mode control, PWM current mode control with proportional (P), proportional integral (PI), and proportional integral derivative (PID) controller. These conventional control methods like P, PI, and PID are unable to perform satisfactorily under large parameter or load variation.

Therefore, the motivation of this thesis is to improve the voltage tracking performance of a dc-dc buck converter through neural network control (NNC). Hence, this thesis focused open loop circuit, closed loop circuit using proportional integral derivative (PID) and neural network control (NNC) for dc-dc buck converter circuit. The circuit is design with the equation and the comparison of voltage tracking is shown in this report.

1.2 Project Background

With rapid development in power electronic technology, power semiconductor technology, modern control theory for dc to dc converter such as buck converter and manufacturing technology for step down voltage in industry, buck converter have been widely used in many fields. Step down buck converter are integral to modern electronic [6]. Step down converter transfer small packets of energy using a switch, diode, an inductor and several application. Through subtantially larger and noisier than their linear regulater counterparts, buck converters offer higher effiency in most cases.

On the other hand, DC power supplies are often utilized to provide electric power supply not only for portable electronic devices such as notebook computers, but also for electric vehicle and aerospace applications. To provide the DC voltage source level requirements of the load to the DC power supply, the DC-DC converter widely used.

Moreover the DC-DC converter is also important in application such as power conditioning of the alternative electrical energy in photovoltaic, wind generator and full cell system. For these reason, DC-DC converter applications will become more potential market in the future.

Basically, the DC-DC converter consists of power semiconductor devices which are operated as electronic swtches. Operation of the switching devices causes the inherently nonlinear characteristic of DC-DC converter including one known as the Buck converter. Consequently, this converter requires are controller with a high degree of dynamic response. Proportional-Integral-Differential (PID) controllers have been usually applied to the converter because of their simplicity.

However implementations of this control method to the nonlinear plants such as the power converters will suffer from the dynamics response of the converter output voltage regulation.In the general, PID controller produces long rise time when the overshoot in output voltage decrease [9].

The study about neural network quickly developed in the past few decade in the control system has made great progress. Neural network reacted as an adaptive controller that has an ability to understand structure and parameters of controlled object and give the required control low without the accurate model of controlled object.

Therefore, neural network control method has good regulating capacity and robustness compared to Proportional-Integral-Differential (PID) control method [9].

To solve the problem, we can use intelligent controls, based on their ability to update the internal controller parameters, the nueral network control [NNC] are suitable for nonlinear system. Implementation of the NNC for DC-DC converter in computer simulation has been proposed. The develop online NNC has the ability to learn instantaneosly and adapt it own controller parameters based on external disturbance and internal variation of the converter with minimum steady state error, overshoot and rise time of the output voltage [1].

The back propogation (BP) neural network are capable to solve nonlinear control system and hence it can overcomes the problem that the conventional PID controller faced on difficulty to determine the parameters on line moment and effectively voltage tracking of buck converter , and it has a high value of practical application in the present neural network control.

1.2 Problem Statement

Most of the DC-DC converters such as Buck converter which is capable to step-down the output voltage produce higher current ripple. This will influenced and decreased the output voltage regulation and efficiency of the converter. This weaknesses can be overcomed by Buck converter which exhibit low input and output current ripple. Thus the efficiency of the converter will be increased. These factors also contribute to minimise the RFI, smaller size and weight.

The switching technique of the Buck converter causes the converter system to be nonlinear system. Nonlinear system requires a controller with higher degree of dynamic response. Proportional-Integral-Differential (PID) controllers has an advantages in term of simple structure and low cost.

However, PID controllers unable to adapt to the external disturbances and internal variations parameters and suffer from dynamic response of the system. PID controllers will produce higher overshoot, longer rise time and settling time which in turn will decreased the output voltage regulation of the Buck converter [7].

1.3 Project Objectives

The objectives of this project are:-

i. To show the voltage tracking of Buck converter using open loop control
ii. To improve the performance of Buck converter using PID controller (such as reduce overshoot, rise time and steady state error).
iii. To develop simulation of voltage tracking Buck converter using Neural Network Control (NNC) method.
iv. To compare the analysis for PID controller and Neural Network Control.

1.4 Project Scopes

The scopes of this project is to simulate the proposed method of voltage tracking Buck converter by using Neural Network Controller (NNC) with MATLAB Simulink software. The Neural Network Controller (NNC) learning developed in this project will use three layers with one neurons at input layer, three neurons at the hidden layer followed with an output layer.

1.5 Thesis Overview

Chapter 1 describes about motivation, project background, problem statement, project objectives and project scope for dc-dc buck converter. In chapter 2**,** a detailed explanation and classification of techniques for switched mode power supplies have been given. The chapter also defined and summarized, with the aid of mathematical equations for dc-dc buck converter.

The information about the different modes of operations that are continuous conduction mode (CCM), discontinuous conduction mode (DCM) has been given. Chapter 3 gives a detail study of methodology to build a Neural Network circuit for dc-dc buck converters. Chapter 4 shows the analysis for open loop, closed loop using pid and neural network using buck converter circuit. Lastly, a conclusion for this research is mention in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Technology Development

Switch mode DC-DC converters efficiently convert an unregulated DC input voltage into a regulated DC output voltage. Compared to linear power supplies, switching power supplies provide much more efficiency and power density. Switching power supplies employ solid-state devices such as transistors and diodes to operate as a switch either completely on or completely off [4].

Energy storage elements including capacitors and inductors, are used for energy transfer and work as a low-pass filter. The buck converter and the boost converter are the two fundamental topologies of switch mode DC-DC converters. Most of the other topologies are either buck-derived or boost-derived converters, because their topologies are equivalent to the buck or the boost converters [2].

Traditionally, the control methodology for DC-DC converters has been analog control. In the recent years, technology advances in very-large-scale integration (VLSI) have made digital control of DC-DC converters with microcontrollers and digital signal processors (DSP) possible.

The major advantages of digital control over analog control are higher immunity to environmental changes such as temperature and changing of components, increased flexibility by changing the software, more advanced control techniques and shorter design cycles.

2.2 Switch-Mode DC-DC Converters

Switch-mode DC-DC converters are used to convert the unregulated DC input to a controlled DC output at a desired voltage level. Switch-mode DC-DC converters include buck converters, boost converters, buck-boost converters, Cuk converters and full-bridge converters, etc. Among these converters, the buck converter and the boost converter are the basic topologies. Both the buck-boost and Cuk converters are combinations of the two basic topologies. The full-bridge converter is derived from the buck converter [12].

The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (buck) from that input voltage, or higher (boost) or generic (buck–boost) [1]. Most used technique to control switching power supplies is Pulse-width Modulation (PWM) [2]. The conventional PWM controlled power electronics circuits are modeled based on averaging technique and the system being controlled operates optimally only for a specific condition [3]-[4]. The linear controllers like P, PI, and PID do not offer a good large-signal transient (i.e. large-signal operating conditions) [4]-[5]

There are usually two modes of operation for DC-DC converters: continuous and discontinuous. The current flowing through the inductor never falls to zero in the continuous mode. In the discontinuous mode, the inductor current falls to zero during the time the switch is turned off. Only operation in the continuous mode is considered in this dissertation. Therefore, research has been performed for investigating voltage tracking of dc-dc buck converter.

2.3 Theory of Operation Buck Converter

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.

The buck converter, shown in Figure 2.1, converts the unregulated source voltage Vin into a lower output voltage Vout. The NPN transistor shown in Figure 1 works as a switch. The ratio of the ON time (t_{ON}) when the switch is closed to the entire switching period (T) is defined as the duty cycle D = t_o/T. The corresponding PWM signal is shown in Figure 2.2 [10].

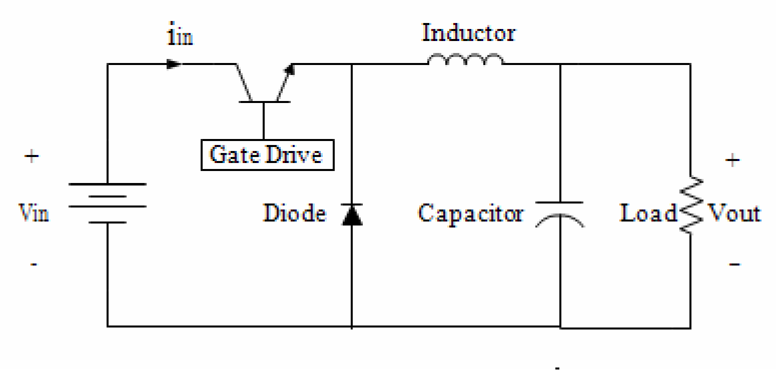


Figure 2.1: Buck Converter Circuit

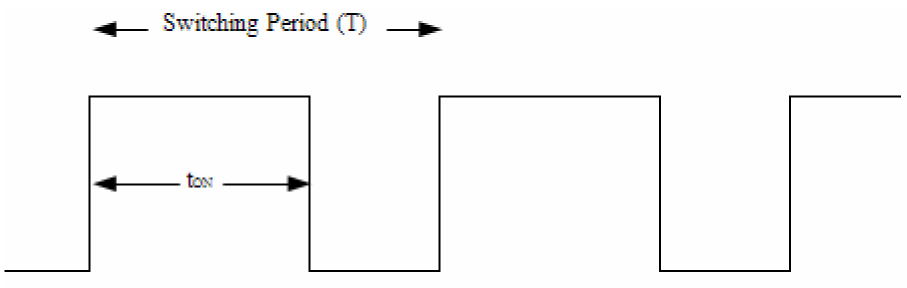


Figure 2.2: PWM signal to control the switches in the DC-DC converter

The equivalent circuit in Figure 2.3 is valid when the switch is closed. The diode is reverse biased, and the input voltage supplies energy to the inductor, capacitor and the load. When the switch is open as shown in Figure 2.4, the diode conducts, the capacitor supplies energy to the load, and the inductor current flows through the capacitor and the diode [2]. The output voltage is controlled by varying the duty cycle. On steady state, the ratio of output voltage over input voltage is D, given by *Vout/ Vin.*

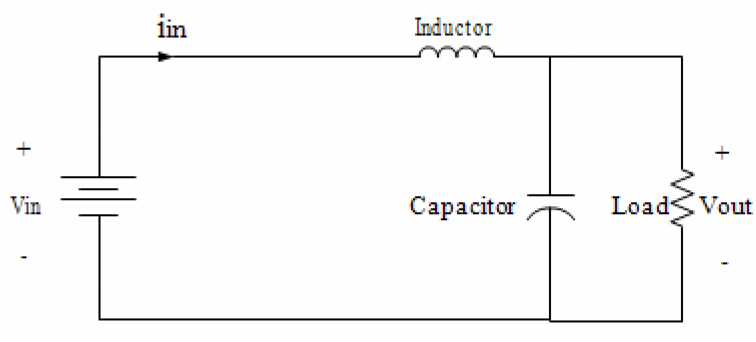


Figure 2.3: Equivalent circuit of the buck converter
when the switch is closed

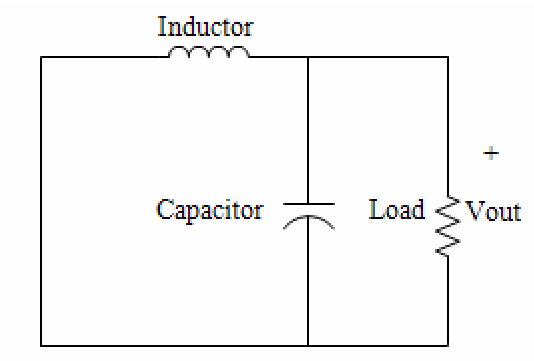


Figure 2.4: Equivalent circuit of the buck converter
when the switch is open

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor.

The buck converter reducing the dc voltage, using only nondissipative switches, inductors, and capacitors. The switch produces a rectangular waveform $v_s(t)$ as illustrated in Figure 2.5. The voltage $v_s(t)$ is equal to the dc input voltage V_g when the switch is in position *1*, and is equal to zero when the switch is in position *2*.

In practice, the switch is realized using power semiconductor devices, such as transistors and diodes, which are controlled to turn on and off as required to perform the function of the ideal equal to the inverse of the switching period T_s, generally lies in the range of switching speed of the semiconductor devices.

The duty ratio D is the fraction of time which the switch spends in position *1*, and is a number between zero and one. The complement of the duty ratio, D', is defined as (1-D) [2].

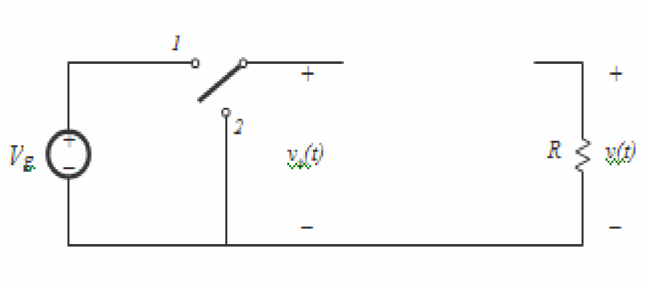


Figure 2.5: Ideal switch, (a) used to reduce the voltage dc component

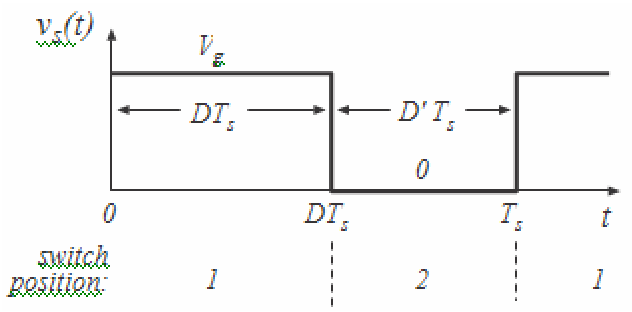


Figure 2. 6:(b) its output voltage waveform $v_S(t)$.

The switch reduces the dc component of the voltage: the switch output voltage $v_s(t)$ has a dc component which is less than the converter dc input voltage V_g. From Fourier analysis, we know that the dc component of $v_s(t)$ is given by its average value $<v_s>$, or

$$<Vs> = \frac{1}{Ts}\int_0^{T} Vs(t)dt \tag{2.1}$$

As illustrated in Figure 2.7, the integral is given by the area under the curve, or DT_sV_g. The average value is therefore

$$\langle Vs \rangle = \frac{1}{Ts}(DTsVg) = DVg \qquad (2.2)$$

So the average value, or dc component, of $v_s(t)$ is equal to the duty cycle times the dc input voltage V_g. The switch reduces the dc voltage by a factor of D.

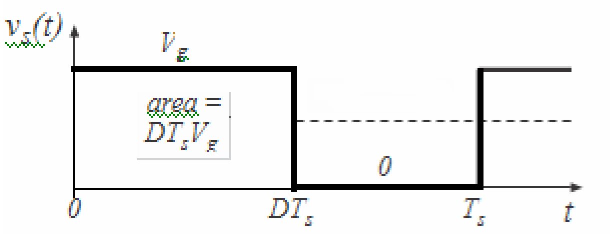


Figure 2.7: Output voltage dc component by the switching period.

What remains is to insert a low-pass filter as shown in Figure 2.7. The filter is designed to pass the dc component of $v_s(t)$, but to reject the components of $v_s(t)$ at the switching frequency and its harmonics. The output voltage $v(t)$ is then essentially equal to the dc component of $v_s(t)$:

$$V \; \langle Vs \rangle = DVg \qquad (2.3)$$

The converter of Figure 2.8 has been realized using lossless elements. To the extent that they are ideal, the inductor, capacitor, and switch do not dissipate power. For example, when the switch is closed, its voltage drop is zero, and the current is zero when the switch is open. In either case, the power dissipated by the switch is zero. Hence, efficiencies approaching 100% can be obtained. So to the extent that the components are ideal, we can realize our objective of changing dc voltage levels using a lossless network.

The network of Figure 2.8 also allows control of the output. Figure 2.9 is the control characteristic of the converter. The output voltage, given by equation (2.3), is plotted vs. duty cycle. The buck converter has a linear control characteristic. Also, the output voltage is less than or equal to the input voltage, since $0 \leq D \leq 1$. Feedback systems are often constructed which adjust the duty cycle D to regulate the converter output voltage. Inverters or power amplifiers can also be built, in which the duty cycle varies slowly with time and the output voltage follows [3].

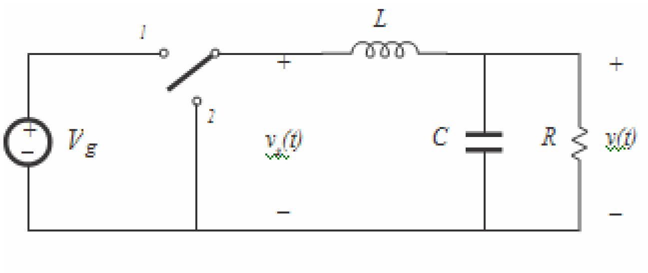


Figure 2.8 : Insertion of low-pass filter, to remove switching harmonics and pass only the dc component of $v_s(t)$ to the output.

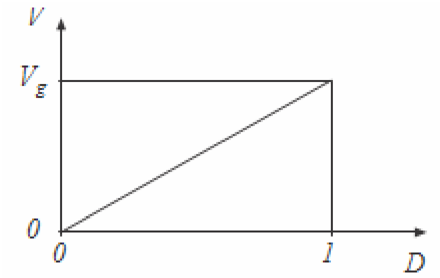


Figure 2.9: Buck converter dc output the voltage V vs. duty cycle D.

2.4 The dc-dc Buck Converter

The buck converter circuit converts a higher dc input voltage to lower dc output voltage. The basic buck dc-dc converter topology is shown in figure. 2.10. It consists of a controlled switch S_W, an uncontrolled switch D (diode), an inductor L, a capacitor C, and a load resistance R.

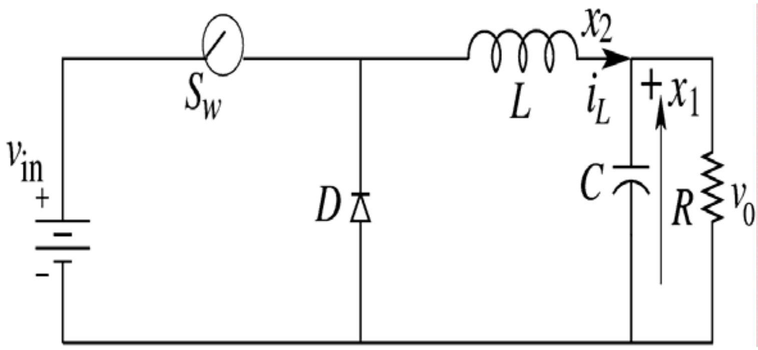
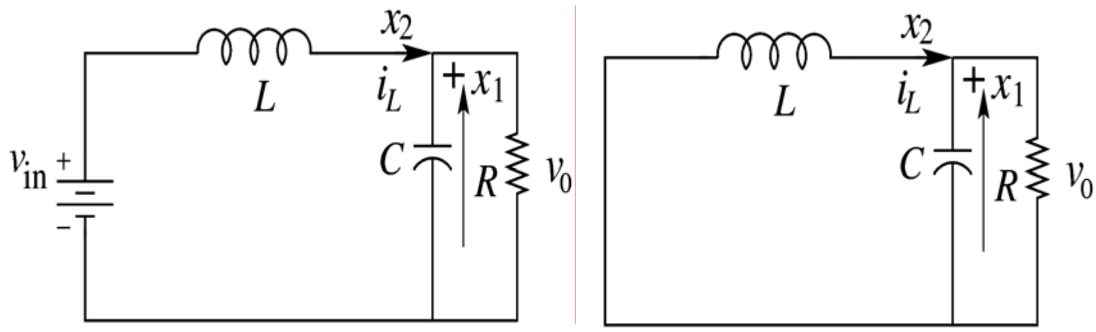


Figure 2.10: Dc-dc buck converter topology



(a) (b)

Figure 2.11: Buck converter circuit when switch: (a) turns on (b) turns off

In the description of converter operation, it is assumed that all the components are ideal and also the converter operates in CCM. In CCM operation, the inductor current flows continuously over one switching period. The switch is either on or off according to the switching function q and this results in two circuit states. The first sub-circuit state is when the switch is turned on, diode is reverse biased and inductor current flows through the switch, which can be shown in figure 2.11(a). The second sub-circuit state is when the switch is turned off and current freewheels through the diode, which is shown figure 2.11(b).

When the switch S_1 is on and D is reverse biased, the dynamics of inductor current i_L and the capacitor voltage V_c are

$$\frac{di_L}{dt} = \frac{1}{L}\ v_{in} - v_0 \quad \text{and} \quad \frac{dv_0}{dt} = \frac{dv_C}{dt} = \frac{1}{C} i_C \tag{2.4}$$

When the switch S_1 is off and D is forward biased, the dynamics of the circuit are

$$\frac{di_L}{dt} = -\frac{1}{L} v_0 \quad \text{and} \quad \frac{dv_0}{dt} = \frac{dv_C}{dt} = \frac{1}{C} i_C \tag{2.5}$$

When switch S_1 is off and D is also not conducting,

$$\frac{di_L}{dt}=0 \text{ and } \frac{dv_0}{dt}=\frac{dv_C}{dt}=\frac{1}{C}i_C \tag{2.6}$$

The state space representation for converter circuit configuration can be expressed as

$$\frac{d\mathrm{x}}{dt}=\begin{cases}\mathrm{A_1x+B_1U}; & \text{when } S \text{ is closed,}\\ \mathrm{A_2x+B_2U}; & \text{when } S \text{ is opened.}\end{cases} \tag{2.7}$$

where $\mathrm{x}=[x_1 \;\; x_2]^T=[v_C \;\; i_L]^T$ is the state vector and A"s and B"s are the system matrices.

The state matrices and the input vectors for the ON and OFF periods are

$$\mathrm{A_1{=}A_2} \quad =\begin{bmatrix}-\frac{1}{RC} & \frac{1}{C}\\ -\frac{1}{L} & 0\end{bmatrix}, \quad B_1=\begin{bmatrix}0\\ \frac{1}{L}\end{bmatrix}, \quad B_2=\begin{bmatrix}0\\0\end{bmatrix}$$

$$\text{and } \mathrm{U} = V_{in} \;\; 0$$

2.5 Modes of Operation

The operation of dc-dc converters can be classified by the continuity of inductor current flow. So dc-dc converter has two different modes of operation that are (a) Continuous conduction mode (CCM) and (b) Discontinuous conduction mode (DCM). A converter can be design in any mode of operation according to the requirement.

2.5.1 Continuous Conduction Mode

When the inductor current flow is continuous of charge and discharge during a switching period, it is called Continuous Conduction Mode (CCM) of operation shown in figure 2.12(a). The converter operating in CCM delivers larger current than in DCM.

2.5.2 Discontinuous Conduction Mode

When the inductor current has an interval of time staying at zero with no charge and discharge then it is said to be working in Discontinuous Conduction Mode (DCM) operation and the waveform of inductor current is illustrated in figure 2.12(c). At lighter load currents, converter operates in DCM. The regulated output voltage in DCM does not have a linear relationship with the input voltage as in CCM.

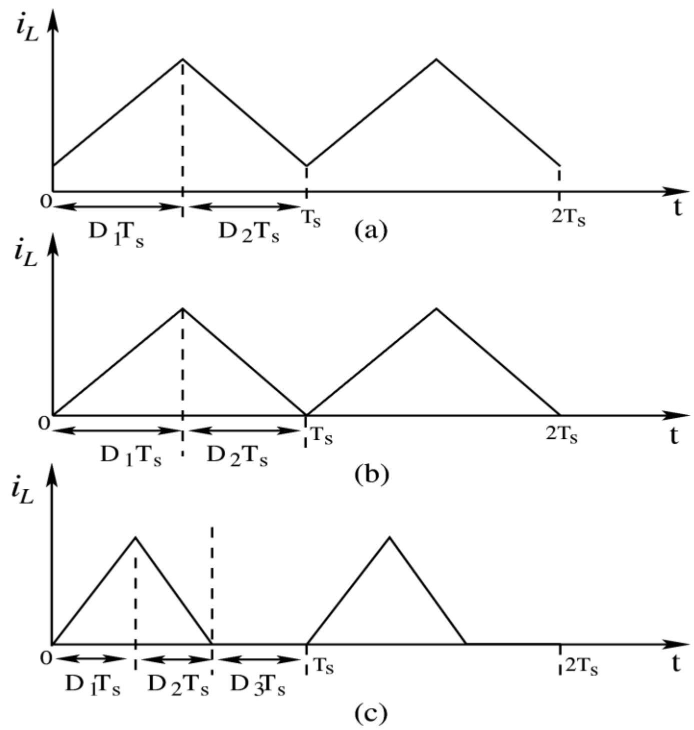


Figure 2.12: Inductor current waveform of PWM converter (a) CCM (b) boundary of CCM and DCM (c) DCM

2.6 Critical Component Values

Since the inductor current magnitude at the end of the switching period must equal the inductor current magnitude at the beginning of the next period at steady state, the change in current over the switching period must equal zero.

Using this knowledge yields the following:

$$\Delta i_{L.period} = \Delta i_{L.closed} + \Delta i_{L.open} = 0 \qquad (2.8)$$

Substituting equations (2.4) and (2.8) into (2.9) and solving for *D* yields:

$$D = \frac{V_{out}}{V_{in}} \qquad (2.9)$$

Now the average inductor current equals the average of the minimum and maximum inductor current values, so the maximum inductor can be found using equation (2.11) nothing that either $\Delta i_{L,closed}$ or $\Delta i_{L,open}$ can be used.

$$I_{Lmax} = I_L + \frac{|\Delta i L|}{2} \qquad (2.10)$$

Using the rule known as amp-second balance, which states the average current through a capacitor at steady state must equal zero, the average inductor current must equal the average output current.

$$I_L = I_{out} = \frac{V_{out}}{R} \qquad (2.11)$$

Substituting equations (2.8) and (2.12) into (2.11) and simplifying yields:

$$I_{Lmax} = V_{out} \cdot \left| \frac{1}{R} + \frac{(1-D)}{2.L.f} \right|$$

The minimum inductor current can be found in the same manner as the maximum inductor current:

$$I_{Lmin} = I_L - \frac{|\Delta i L|}{2} \qquad (2.12)$$

Substituting equations (2.8) and (2.12) into (2.14) and simplifying yields:

$$I_{Lmin} = V_{out} \cdot \left| \frac{1}{R} - \frac{(1-D)}{2.L.f} \right| \quad (2.13)$$

The minimum inductor current is an important value, because as mentioned previously, it determines the mode of conduction. Since all previous equations were derived using the assumption of CCM, for them to remain valid i_{Lmin} can never go below zero. So by setting equation (2.15) equal to zero and rearranging to solve for L, the minimum inductor value can be found to keep the converter in CCM:

$$L_{min} = \frac{(1-D).\ R}{2.f} \quad (2.14)$$

Once the inductor value is determined, the minimum capacitance to maintain the desired output ripple voltage can be found. This can be done by finding how much charge is supplied by the capacitor when the switch is on or off. By using amp-second balance the average current through a capacitor must equal zero if the circuit is in steady state.

Then by calculating the area under the current wave form either when the switch is on or off will yield the change in charge. Since the current wave form is triangular the area can be found by using the formula one half times the triangle's base times the triangles height. Where the height equals the change in current divided by two, and the base is the switching period divided by two.

$$\Delta Q = \frac{1}{2} \cdot \left| \frac{\Delta iL}{2} \right| \cdot \frac{T}{2}$$

In this case the change of charge (ΔQ) is easier to calculate using the change in current when the switch is off ($\Delta i_{L,open}$).

Substituting equation (2.8) into (2.17) and simplifying yields:

$$\Delta Q = V_{out} \cdot \frac{(1-D)}{8.L.f2} \qquad (2.15)$$

$$C = \frac{\Delta Q}{\Delta V_{out}}$$

Substituting equation (2.18) into equation (2.19) yields the equation for selecting the minimum output capacitor for the desired output ripple voltage.

(2.20)

$$C_{min} = \frac{1-D}{8.L.\,\Delta V_{out}\,.f}.V \qquad (2.17)$$

2.6.1 Inductor Calculation

The minimum inductor value to keep the converter operating in continuous conduction mode down to 10% of full load is calculated by finding the output resistance that represents this load and inserting into equation (2.16).

$$P_{10\%} = 0.10 \,.\, P_{out} = 0.10 \,.\, 150\text{ W} = 15\text{W}$$

$$R_{10\%} = \frac{V_{out}^2}{P_{10\%}} = \frac{(12V)^2}{15W} = 9.6W$$

$$L_{min} = \frac{(1-D)\,.\,R}{2.f} = \frac{(1-0.348).9.6\Omega}{2.100kHz} = 31.3\mu H$$

Now that the minimum inductor value is known to keep the converter operating in continuous conduction mode, a slightly larger inductor is selected to maintain a performance margin.

A 56µH inductor was selected for L, since it is a standard value and 1.8 times larger than the calculated L_{min} value. By substituting L and $R_{10\%}$ into equations (2.13) and (2.15) the minimum and maximum inductor current values are calculated.

$$i_{Lmin} = 12\text{ V} \cdot \left[\frac{1}{9.6} - \frac{(1-0.348)}{2.56\mu H \cdot 100Hz}\right] = 0.551\ A$$

$$i_{Lmax} = 12\text{ V} \cdot \left[\frac{1}{9.6} + \frac{(1-0.348)}{2.56\mu H \cdot 100Hz}\right] = 1.949\ A$$

The difference between the maximum and minimum inductor current equals the inductor's ripple current.

$$\Delta i_L = i_{L\max} - i_{L\min} \tag{2.18}$$

Inserting the maximum and minimum inductor current values into equation yields:

$$\Delta i_L = 1.949A - 0.551A = 1.398A$$

2.6.2 Capacitor Calculation

Using the output ripple voltage found in table 1.2, and the value of the inductor found in section 2.2.2, the minimum output capacitance can be found using equation

$$C = \frac{1-0.348}{8.56\mu H\,(100kHz)2} \cdot \frac{12V}{0.24V} = 7.3\mu F$$

2.7 Artificial Neural Network (ANN)

The term neural network was traditionally used to refer to a network or circuit of biological neurons. The modern usage of the term often refers to artificial neural networks, which are composed of artificial neurons or nodes. Thus the term has two distinct usages. There are biological neural networks and artificial neural networks.

Biological neural networks are made up of real biological neurons that are connected or functionally related in a nervous system. In the field of neuroscience, they are often identified as groups of neurons that perform a specific physiological function in laboratory analysis.

Artificial neural networks are composed of interconnecting artificial neurons (programming constructs that mimic the properties of biological neurons). Artificial neural networks may either be used to gain an understanding of biological neural networks, or for solving artificial intelligence problems without necessarily creating a model of a real biological system. The real, biological nervous system is highly complex: artificial neural network algorithms attempt to abstract this complexity and focus on what may hypothetically matter most from an information processing point of view.

Good performance (e.g. as measured by good predictive ability, low generalization error), or performance mimicking animal or human error patterns, can then be used as one source of evidence towards supporting the hypothesis that the abstraction really captured something important from the point of view of information processing in the brain. Another incentive for these abstractions is to reduce the amount of computation required to simulate artificial neural networks, so as to allow one to experiment with larger networks and train them on larger data sets.

Figure 10 illustrates a Multilayer Perceptron Neural Network Model. This network consists of an input layer (on the left) with three neuron, one hidden layer (in the iddle) with three neurons and an output layer (on the right) with three neurons. Each layer has some neorons that are connected to the next layer through the link.

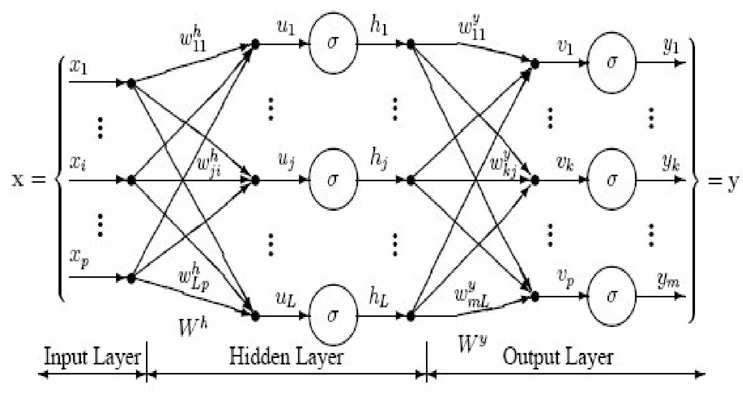


Figure 2.13. A perceptron network with three layer

Input Layer is a vector of predictor variable values ($x_1 ... x_p$) is presented to the input layer. The input layer (or processing before the input layer) standardizes these values so that the range of each variable is -1 to 1. The input layer distributes the values to each of the neurons in the hidden layer. In addition to the predictor variables, there is a constant input of 1.0, called the *bias* that is fed to each of the hidden layers; the bias is multiplied by a weight and added to the sum going into the neuron [1].

Hidden Layer is a arriving at a neuron in the hidden layer, the value from each input neuron is multiplied by a weight (w_{ji}), and the resulting weighted values are added together producing a combined value u_j. The weighted sum (u_j) is fed into a transfer function, σ, which outputs a value h_j. The outputs from the hidden layer are distributed to the output layer.

Output Layer is a arriving at a neuron in the output layer, the value from each hidden layer neuron is multiplied by a weight (w_{kj}), and the resulting weighted values are added together producing a combined value v_j. The weighted sum (v_j) is fed into a transfer function, σ, which outputs a value y_k. The y values are the outputs of the network.

If a regression analysis is being performed with a continuous target variable, then there is a single neuron in the output layer, and it generates a single y value. For classification problems with categorical target variables, there are *N* neurons in the output layer producing *N* values, one for each of the *N* categories of the variable.

CHAPTER 3

METHODOLOGY

3.1 Research Design

The proposed general block diagram for Voltage tracking of Buck converter using Neural Network Controller (NNC) is shown in Figure 3.1. The operation of this circuit consists buck converter and neural network circuit (NNC). The source for this circuit is dc input and reference voltage Vref. The output for step down buck converter is controlled by Neural Network Control (ANN) and feedback element for the error automatically process to the summing point.

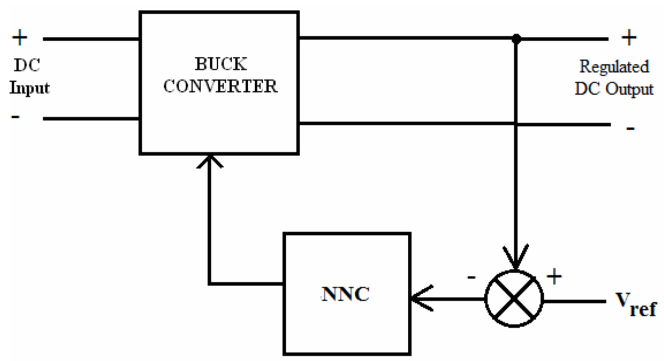


Figure 3.1: Block diagram of the proposed NNC of Buck Converter

To investigate the effectiveness of the proposed NNC controller, simulation using MATLAB Simulink will be conducted. In the simulation, the conventional method of PID controller will be compared to the proposed NNC.

3.2 Mathematical Modeling of Buck Converter

3.2.1 State-Space Representations

The buck converter is nonlinear, time-dependent system and its operation is described by the two modes, illustrated in Figure 12 (a) and (b). The system is linearized through switch averaging method about a selected operating point, and with respect to the transistor duty cycle, *k*.

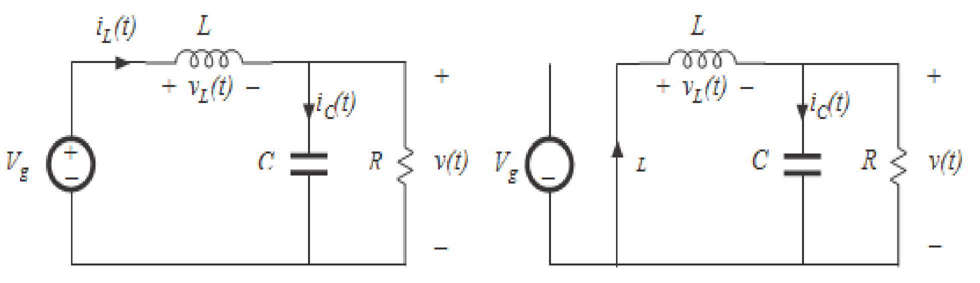


Figure 3.2 : a) Mode 1 (b) Mode 2

Mode 1 of operation is described by two differential equations derived from the circuit in Figure 3.2 (a) and consistent with transistor Q switch being turn on:

$$\begin{cases} \dfrac{diL(t)}{dt} = 0.iL(t) - \left(\dfrac{1}{L}\right)Vc(t) + \left(\dfrac{1}{L}\right)Vg & (3.1) \\ \dfrac{dVc(t)}{dt} = \left(\dfrac{1}{C}\right)iL(t) - \left(\dfrac{1}{Rload.C}\right)Vc(t) + 0.Vg & (3.2) \end{cases}$$

The state-space representation for mode 1 (transistor is on) is given by:

$$\begin{cases} x = A1.x(t) + B1.u(t) \\ y = C1.x(t) + D1.u(t) \end{cases} \quad (3.3)$$

$$x(t) = \begin{bmatrix} iL(t) \\ Vc(t) \end{bmatrix} \quad (3.4)$$

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