DEVELOPMENT OF DC-DC CONVERTER FOR DC MOTOR USING NEURAL NETWORK CONTROLLER

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For my beloved mother, father, wife and son

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ABSTRACT

A neural network of DC-DC converter is designed and presented in this project. In order to control the output speed of the DC-DC converter, the controller is designed to change the duty cycle of the converter. The mathematical model of DC-DC converter and neural network controller are derived to design simulation model. The simulation is developed on Matlab simulation program. To verity the effectiveness of the simulation model, an experimental set up is developed. The neural network controller to generate duty cycle of PWM signal is programmed. The simulation and experimental results will show output speed of the DC-DC converter can be controlled according to the value of duty cycle.

ABSTRAK

Neural Network dari penukar DC-DC direka dan dibentangkan di dalam projek ini. Dalam usaha untuk mengawal kelajuan output penukar DC-DC, pengawal direka untuk menukar kitaran tugas penukar. Model matematik penukar DC-DC dan neural network controller diperolehi untuk mereka bentuk model simulasi. Simulasi dibangunkan atas program simulasi Matlab. Untuk memastikan keberkesanan model simulasi,satu eksperimen dibangunkan. Neural network controller akan menjana kitaran tugas isyarat PWM diprogramkan. Simulasi dan keputusan eksperimen akan menunjukkan kelajuan output DC-DC converter boleh dikawal mengikut nilai kitar tugas.

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LIST OF SYMBOLS AND ABBREVIATIONS

D	-	Duty Cycle
T	-	Time
V_s	-	Supply voltage
V_o	-	Output voltage
M_v	-	Ratio
V_{ref}	-	Reference voltage
e	-	Error
J	-	Inertia
L	-	Inductance
C	-	Capacitor
R	-	Resistance
N_o	-	Output speed
N_{ref}	-	Reference speed
S_w	-	Switch

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 equipment, appliance control, telecommunication equipment, 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 control the output DC motor speed of a dc-dc buck converter through neural network control (NNC). Hence, this thesis focused open loop circuit, open loop circuit using proportional integral (PI) and neural network control (NNC) for dc-dc buck converter circuit. The circuit is design with the equation and the comparison of motor speed is shown in this report.

1.2 Project Background

General idea of DC-DC converter to convert a fixed voltage dc source into a variable voltage dc source. The output voltage of the DC-DC converter can be higher or lower than the input. DC-DC Converter widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide smooth acceleration control, high efficiency, and fast dynamic response. Dc converter can be used in regenerative braking of dc motor to return energy bake into the supply, and this feature results in energy saving for transportation system with frequent stop; and also are used, in dc voltage regulation. There are many types of dc-dc converter which is buck (step down converter), boost (step-up) converter, and buck-boost (step up- step-down) convertor. (Muhammad H. Rashid, 2004).

Classical PID controllers are commonly used in industries due to their simplicity and ease of implementation (Rubaai, A. et al., 2008). In linear system model, controller parameters of the PID controller are easy to determine and resulting good control performances. However, for nonlinear system model applications such as BLDC motor drive, control performance of the PID controller becomes poor and difficult to determine the controller parameters (Hong, W. et al., 2007 and Tipsuwanporn, V, et al.,2002).

In order to improve control performance of the BLDC motor drive, several intelligence controllers such as fuzzy logic control, neural network control and hybrid neuro-fuzzy control methods for BLDC motor have been reported in (Rubaai, A. et al., 2008, Tipsuwanporn, V. et al., 2002, Mahdavi, J. et al., 2011, Lee, B. K. et al., 2003, Cunkas, M. et al., 2010, Gokbulut, M. et al., 2007, Ji, H. et al., 2008 and Ji, H. et al., 1997).

In addition, the NNC also have been applied for several others power electronic and motor drive application (El-Balluq, T. NN. et al., 2004 and Shanmugasundram, R. et al., 2009). In order to improve performance of the NNC some researchers have been done to develop online learning scheme of the NNC.

In this project, a complete simulation model with neural network control (NNC) method for DC motor drive is proposed using MATLAB/Simulink. The develop NNC has the ability to learn instantaneously and adapt its own controller parameters based on external disturbance and internal of the converter with minimum steady state error, overshoot and rise time of the output voltage.

1.3 Problem Statement

DC-DC converter consists of power semiconductor devices which are operated as electronic switches. Operation of the switching devices causes the inherently nonlinear characteristic of the DC-DC converters including one known as the Buck Converter. 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 (PI) is one of the controllers used as a switching device for the converter. However the PI controller is known to exhibit sluggish disturbance rejection properties [5].

A study by Zulkifilie Ibrahim and Emil Levi (2002) shows that the PI speed control offers high speed dip and large recovery time when the load is connected. Therefore the implementation of Neural Network that will deal the issue must be investigated. Since the Buck converter is a nonlinear system, the Neural Network controller method will be developed to improve overshoot speed at starting of the motor and settling time. The developed Neural Network controller has the ability to learn instantaneously and adapt its own controller parameters based on external disturbances and internal variation of the converter. Thus this neural network can overcome the problem stated to obtain better performances in terms of speed control.

1.4 Project Objectives

The objectives of this project are:-

i. To develop DC-DC buck converter using Proportional Integrated (PI) Controller

ii. To develop DC-DC buck converter using Neural Network Controller (NNC)

iii. To compare the NNC with PI performance in terms of speed overshoot, settling time and ripple factor

1.5 Project Scopes

The scopes of the project are:

i) Modelling the DC-DC Buck converter with DC Motor

ii) Modelling the Proportional-Integrated (PI) controller for speed control

iii) Modelling the Neural Network controller for speed control

iv) Compare the output speed of the DC motor for both PI and NN controller in terms of starting overshoot, ripple factor and settling time.

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 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 V_{in} into a lower output voltage V_{out}. 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].

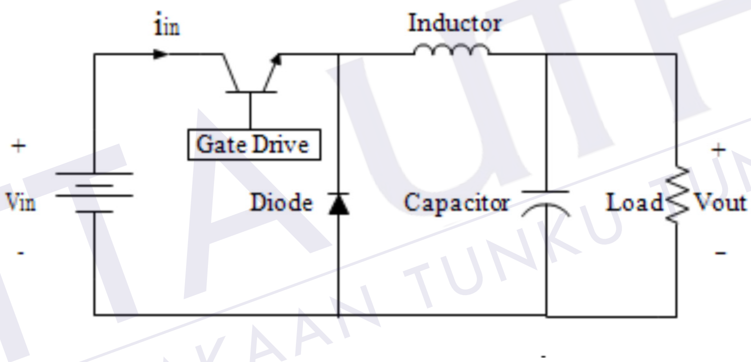


FIGURE 2.1: Buck Converter Circuit

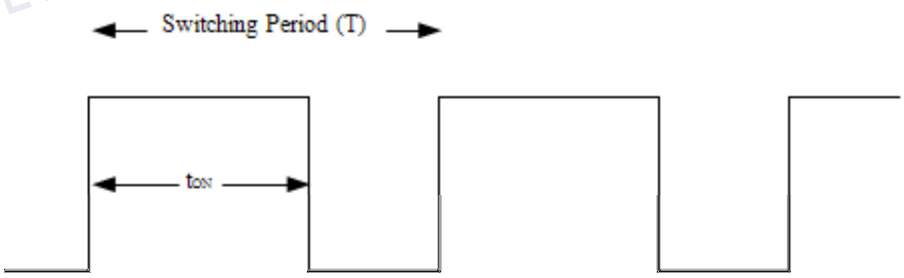


FIGURE 2.2: PWM signal to control the switches in the DC-DC converter

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*.

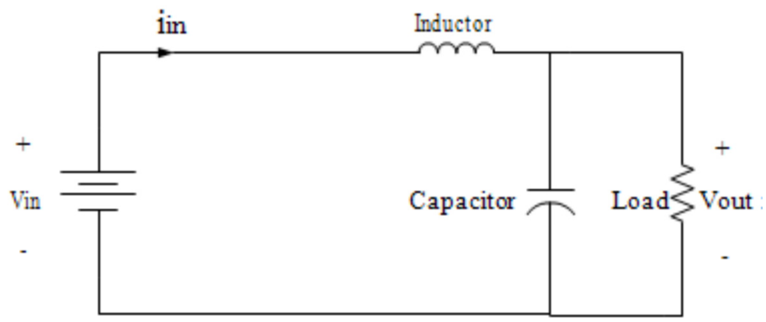


FIGURE 2.3: Equivalent circuit of the buck converter when the switch is closed

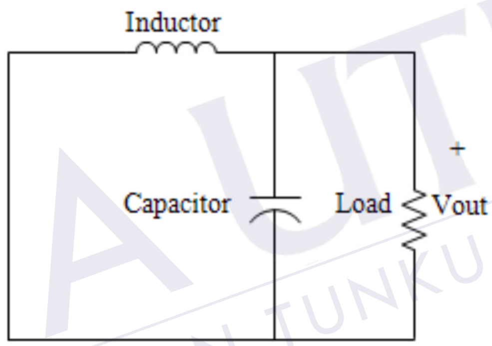


FIGURE 2.4: Equivalent circuit of the buck converter when the switch is open

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 non-dissipative 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].

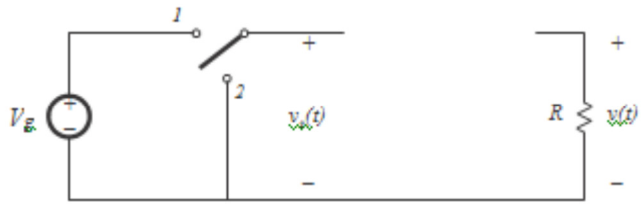


FIGURE 2.5: Ideal switch, (a) used to reduce the voltage dc component

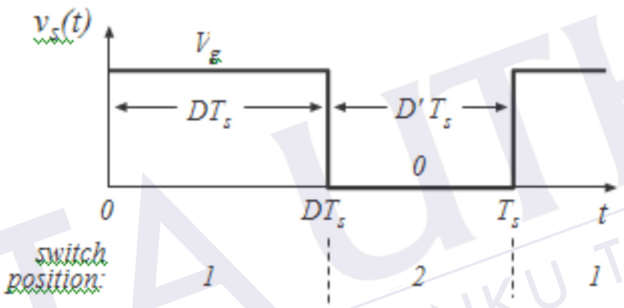


FIGURE 2.6: Output voltage waveform $v_s(t)$.

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

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

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

$$< V_s > = \frac{1}{Ts} DT_S V_g = DV_g \tag{2.2}$$

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*.

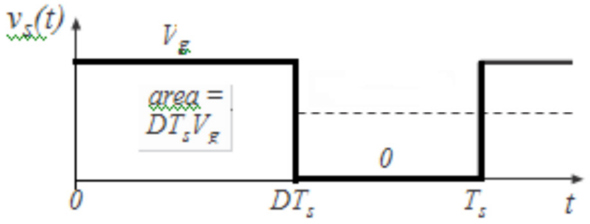


FIGURE 2.7: Output voltage dc component by the switching period

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 $v_s(t)$:

$$V < V_s >= DV_g \tag{2.2}$$

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 $0 \ll D \ll 1$. 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].

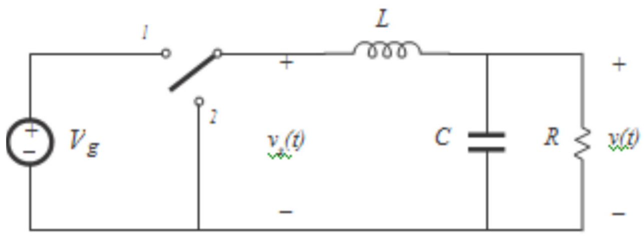


FIGURE 2.8: Insertion of low-pass filter, to remove switching harmonics and pass only the dc component of $v_s(t)$ to the output.

2.3 The DC-DC buck converter

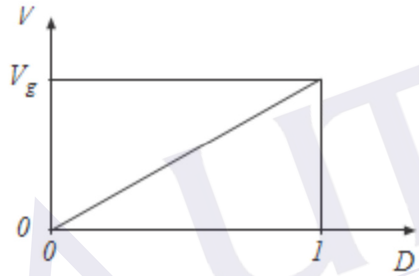


FIGURE 2.9: Buck converter dc output the voltage *V* vs. duty cycle *D*.

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

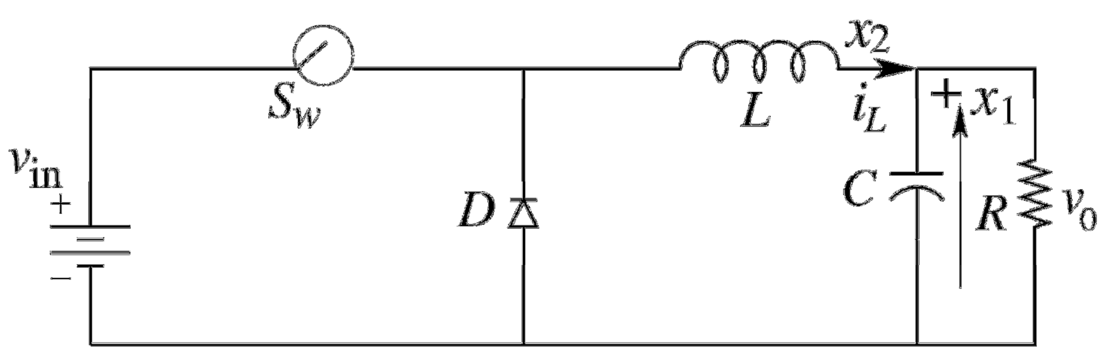
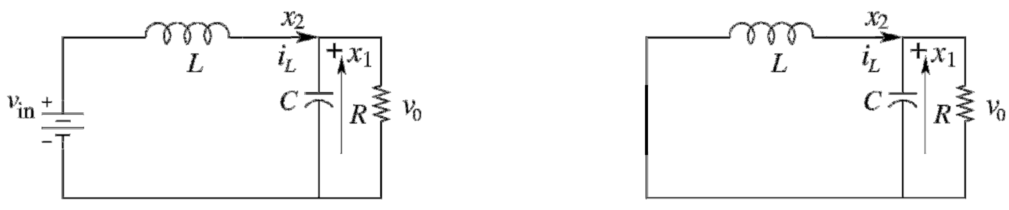


FIGURE 2.10: DC buck converter topology



(a) (b)

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

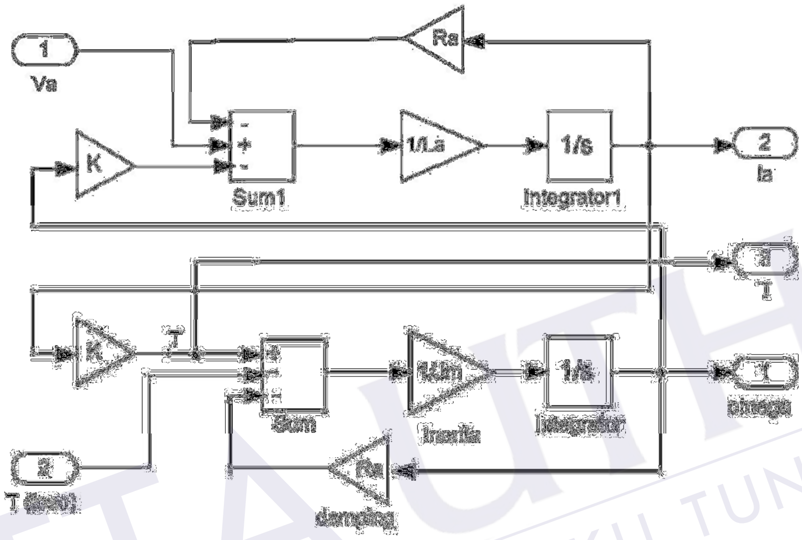


FIGURE 2.12: Matlab/Simulink model of DC motor

2.4 Neural network

Figure 2.1 illustrates a Multilayer Perceptron Neural Network model. This network consists of an input layer (on the left) with three neurons, one hidden layer (in the middle) with three neurons and an output layer (on the right) with three neurons. Each layer has some neurons that are connected to the next layer through the link. The input layer of the neural network serves as an interface that takes information from the outside world and transmits it to the internal processing units of the network. Similarly, the output layer sends information from neural network's internal unit to the external world. The nodes in hidden layers are the neural network's processing units.

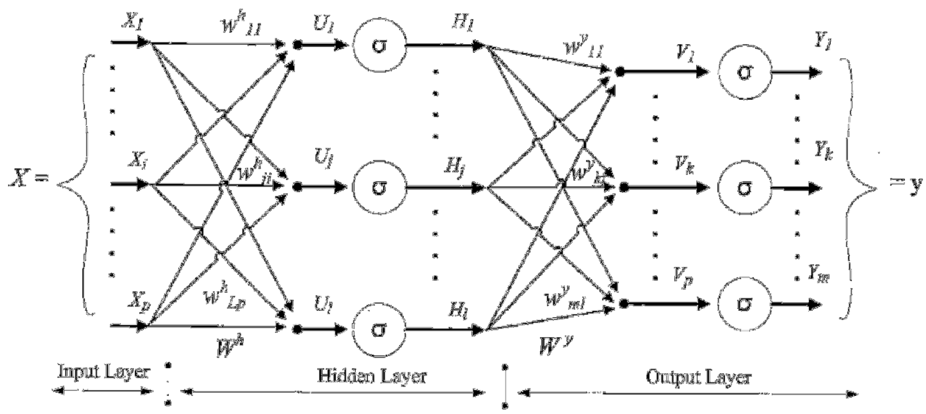


FIGURE 2.13: A perceptron network with three layers

Input layer is a vector of variable (x1....xp) that represented to the input. 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 constant input of 1.0, called the bias that fed to each of the hidden layers. The bias is multiplied by a weight and added to the sum going into the neuron. During hidden layer, the value from each input neuron is multiplied by a weight (wji), and the resulting weighted values are added together producing a combined value uj. The weighted sum (uj) is fed into a transfer function, σ which outputs a value hj. The outputs from hidden layer are distributed to the output layer.

Output layer occurred when the value from each hidden layer neuron is multiplied by a weight (wkj), and lastly the weighted values are added together producing a combined value vj. The weighted sum (vj) is converted into a transfer function, σ which output a value yk. The y values are the outputs of the network

2.5 DC motor

The resistance of the field winding and its inductance of the motor used in this study are represented by R_f and L_a respectively in dynamic model. Armature reactions effects are ignored in the description of the motor. This negligence is justifiable to minimize the effects of armature reaction since the motor used has either interpoles or compensating winding. The fixed voltage V_f is applied to the field and the field current settles down to a constant value.

A linear model of a simple DC motor consists of a mechanical equation and electrical equation as determined in the following equations 3.1 and 3.2

.

$$J_m \frac{d\omega_m}{dt} = K_m \emptyset I_a - b\omega_m - M_{load} \quad (2.1)$$

$$L_a \frac{dI_a}{dt} = V_a - R_a I_a - K_b \emptyset \omega_m \quad (2.2)$$

Where

R_a = Armature Resistance (Q).

L_a =Armature Inductance (H).

J_m = Motor of inertia (kg.m ^{2}/S^2).

K =K_bØ=Motor Constant (Nm / Amp).

K =K_mØ =Motor Constant (Nm I Amp).

b = Damping ration of mechanical system (Nms).

2.6 PID Controller

Consider the characteristics parameters – proportional (P), integral (I), and derivative (D) controls, as applied to the diagram below in Fig.2, the system,

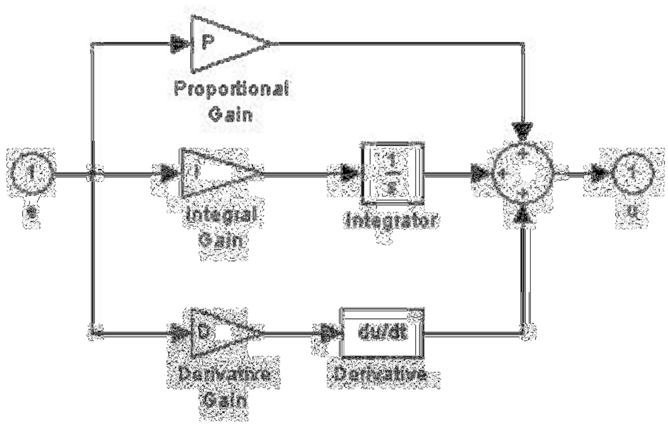


FIGURE 2.14: A simulation model of PID controller

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