DEVELOPMENT OF PID CURRENT CONTROL FOR DC MOTOR USING ARDUINO

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ABSTRACT

Power electronic systems have been widely used in varieties of domestic applications and industrial sector due to its reliability, simple construction and low weight. Therefore, this project is to design and to develop of PID Current Control that could be applied for the DC motor. The control technique was called as current control technique by comparing the output current with the reference current. Thus, the PID controller will force the output current to follow the reference current by creating the pulse with modulation (PWM) signals. The PID Controller was developed and simulated by using MATLAB/Simulink software and then implemented to the hardware by using Arduino microcontroller board as a digital signal processing system. The final observation from this project is by using Arduino Uno board, the current of DC motor can control but in small scale. This is due to the current sensor that used had range in small scale reading. Lastly, the result of the performance for this controller was explained in this report by observed in three condition; simulation, open loop control and closed loop control.

ABSTRAK

Sistem elektronik kuasa telah digunakan secara meluas untuk pelbagai kegunaan dalam pelbagai bidang kerana sifatnya yang boleh dipercayai, pembinaannya yang ringkas dan juga sifatnya yang ringan. Oleh yang demikian, projek ini adalah merekabentuk berkenaan dengan teknik pembangunan pengawal arus PID yang boleh diaplikasikan kepada motor arus terus. Teknik kawalan yang dinamakan sebagai pengawal arus ini adalah dengan membandingkan arus keluaran dengan arus rujukan. Jadi, pengawal PID akan memaksa arus keluaran untuk mengikut arus rujukan dengan menghasilkan isyarat lebar denyut modulasi. Pengawal PID telah dibangunkan dan diuji dengan menggunakan perisian MATLAB/Simulink dan kemudiannya dilaksanakan dalam bentuk sebenar dengan menggunakan Arduino sebagai sistem pemprosesan isyarat digital. Pemerhatian akhir tentang projek ini ialah dengan menggunakan papan Ardunio Uno, arus pada motor arus terus boleh di kawal tetapi hanya dalam skala yang kecil. Ini adalah kerana jenis pengesan arus yang digunakan adalah dalam skala bacaan yang kecil. Akhir sekali, segala hasil prestasi untuk pengawal ini telah di terangkan di dalam laporan ini dengan melihat kepada tiga situasi; simulasi, kawalan gelung terbuka dan kawalan gelung tertutup.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ω	–	Ohm
t	–	Time
u(t)	–	Output
e(t)	–	Error
DC	–	Direct current
MOSFET	–	Metal Oxide Semiconductor Field Effect Transistor
P	–	Proportional
PD	–	Proportional Derivative
PI	–	Proportional Integral
PID	–	Proportional Integral Derivative
MATLAB	–	Matrix Laboratory
PWM	–	Pulse Width Modulation
AC	–	Alternating current
A	–	Ampere
V	–	Volt
DAC	–	Digital to Analog Converter
Kp	–	Proportional controller mode gain
Ki	–	Integral controller mode gain
Kd	–	Derivative controller mode gain
VDD	–	Positive supply voltage
VSS	–	Negative supply voltage
CMOS	–	Complementary Metal Oxide Semiconductor
PCB	–	Printed Circuit Board
IGBT	–	Insulated Gate Bipolar Transistor
ADC	–	Analog to Digital Converter
PFC	–	Power Factor Correction
CGD	–	Conventional Gate Driver (CGD)

CHAPTER 1

INTRODUCTION

1.1 Project Background

Nowadays, almost every mechanical movement around the world is accomplished by an electric motor. The electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. The direct current (DC) motor is a device that used in many industries in order to convert electrical energy into mechanical energy. The result from the availability of speed controllers is wide range, easily and many ways. In most applications, speed control is very important. For example, consider the DC motor in radio controller car, if just apply a constant power to the motor, it is impossible to maintain the desired speed. It will go slower over rocky road, slower uphill, faster downhill and so on. So, it is important to make a controller to control the speed of DC motor in desired speed [1]. In this project, researcher used multifunction DC motor with Shunt Wound DC motor connection just to know whether this type of motor able to operate or not with this controller.

With the advancement of power electronics, microprocessors and digital electronics, typical electric drive systems nowadays are becoming more compact, efficient, cheaper and versatile. The voltage and current applied to the motor can be changed at will by employing power electronic converters [2]. Before the widespread use of power electronic rectifier, dc motors were unexcelled in speed control application [3]. To operating this DC motor, the rectifier is required. Active Rectifier is widely used in industrial applications because it has many advantages including unity power factor, low ripple of the DC voltage and low total harmonics distortion. Due to these features, the active rectifier is a good choice for application in industrial drives [4]. This rectifier activated by gate driver circuit that charge pump signal to the gate for MOSFET in rectifier circuit. So, for this project three phase controlled active rectifier is selected.

The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: Proportional (P) Controller, Proportional-Derivative (PD) Controller, Proportional-Integral (PI) Controller, Proportional-Integral-Derivative (PID) Controller, Fuzzy Logic Controller, Genetic Algorithm technique, Particle Swarm Optimization technique or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm [5]. For this project, with demanding and sophisticated application, the PID controller is designed accordingly with PWM current controller to produce a better controller for DC motor. Current sensor had used as a reference current to compare with setting current that setting in the MATLAB Simulink Toolbox software.

Due to their functional simplicity and reliability, the PID controller is one of the most popular controllers in the industry. It provides robust and reliable performance for most systems if the PID parameters are determined or tuned to ensure a satisfactory closed-loop performance [6]. A PID controller is designed using MATLAB Simulink functions to generate a set of coefficients associated with a desired controller's characteristics [7]. The controller coefficients are then included in MATLAB Simulink Toolbox functional block diagram that implements the PID controller. MATLAB has been selected for this work due to the fact that it is one of the most widely used software and it is almost accessible in all education institutions around the world [8].

Arduino Uno board microcontroller has been selected to store and run the program from MATLAB. This Arduino Uno board had chosen due to a simple board, easy to handle and its affordable cost. This board can be program by using C/C++ programming language, Java or using MATLAB Simulink Toolbox function block.

Figure 1.1 below shows the general block diagram for this project. This project consists of three phase controlled rectifier, three phase gate driver, Arduino

Uno board, current sensor, MATLAB R2013a Simulink Toolbox software and DC motor as a load.

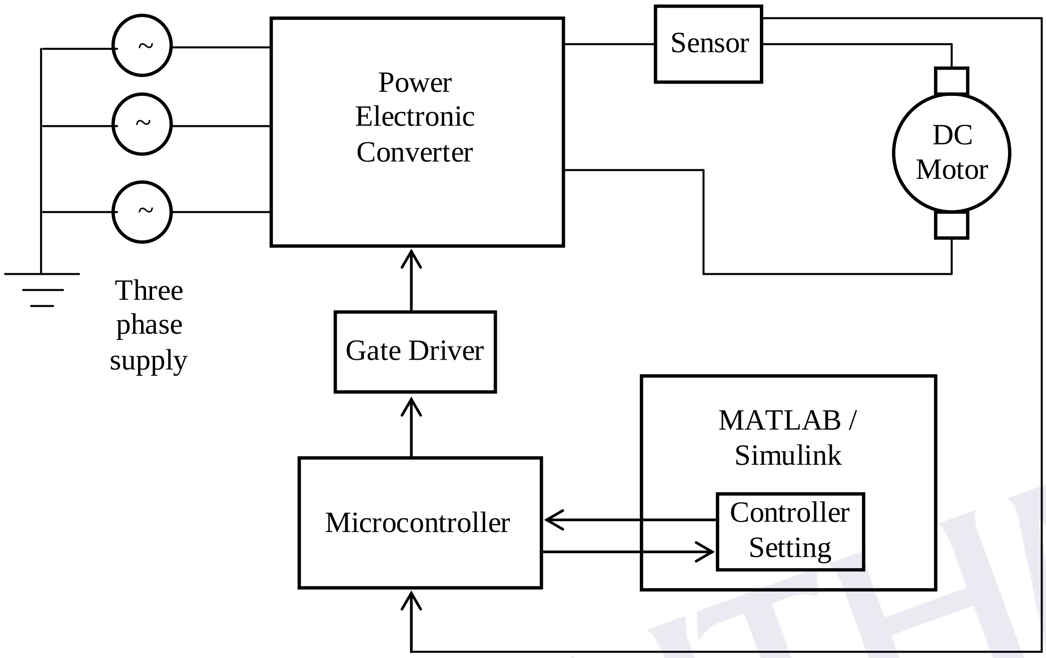

Figure 1.1: General block diagram of project

1.2 Problem Statement

The increase in the diversity and power values of semiconductors has led to rapid developments of simple control devices for DC motor. However, by far the majority of variable-speed drives consist of a basic DC shunt machine with external or static control units, usually of the resistance type. The replacement of an old variable speed drive by a new and more versatile one may prove a costly business, when all that may be required is the addition of a simple control device [9].

Nowadays, manual controller is also not practical in the technology era because it can waste time and cost. Operation cost regarding controller is got attention from industrial field. In order to reduce cost and time, making a controller based on computer because it is portable suggested. The user can monitor their system at certain place without need to going the plant (machine) especially in industrial implementation. From that, the man power can be reduced and reserve with computer which is more precise and reliable. The other product regarding this project where fully control motor via computer may be commercialized but their cost is very expensive. The hardware of may be complicated and maintenance cost is higher [1]. The simple electronic devices can be designed using power electronic control device to make a speed controller system.

This has led the researchers to consider the design and application of a power electronic control device to a DC motor. The adaptive PID controller is so designed that it can be used to overcome the problem in industry like to avoid machine damages and to avoid slow rise time and high overshoot. This is because when the starting voltage is high, it is not suitable for machine and can make machine damages. With the aid of feedback control, the controller monitors the armature current of the DC motor.

1.3 Objectives of Project

Basically, this project is listing four main objectives.

i. To develop the three phase controlled rectifier.

ii. To develop the three phase gate driver.

iii. To design the PID current control using MATLAB R2013a Simulink Toolbox function block.

iv. To study the communication between MATLAB R2013a Simulink software and Arduino Uno board.

1.4 Scope of Project

There are four main points in this project. These scopes parallel with the objectives of the project.

i. The rating for the three phase rectifier is the direct current (DC) output between 0V to 240V. For this project, 500V input voltage, 8A maximum current power MOSFET (IRF840) is selected to be used as switching device due to the specification of DC motor is 220V input voltage maximum, 1.8A maximum current and 300W output power.

ii. The rating for the three phase gate driver is (10V-15V) output that meets the specification of rectifier to activate. The aim of the circuit is to receive output signal that produced from MATLAB and Arduino Uno board and then deliver the output to rectifier. This gate driver consists of three inputs and six outputs.

iii. The third point of this project is to design the PID current control using MATLAB Simulink Toolbox function block. The version of MATLAB software that used is MATLAB R2013a software. From the PID controller block, it produced the pulse width modulation (PWM) input signal for gate driver.

iv. Studying the communication between MATLAB R2013a Simulink software and Arduino Uno board. This MATLAB R2013a Simulink software and Arduino Uno board microcontroller should be able to communicate each other.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will focus on studies, facts and past researches on this project title. There are several topics that would be taken up for references.

2.2 Direct Current (DC) Motor

Direct current (DC) motors have variable characteristics and are used extensively in variable-speed drives. DC motors can provide a high starting torque and it is also possible to obtain speed control over a wide range. The methods of speed control are normally simpler and less expensive than those of ac drives [10]. Due to its wide range of application different functional types of dc motor are available in the market for specific requirements [11]. Figure 2.1 show the types of DC motor:

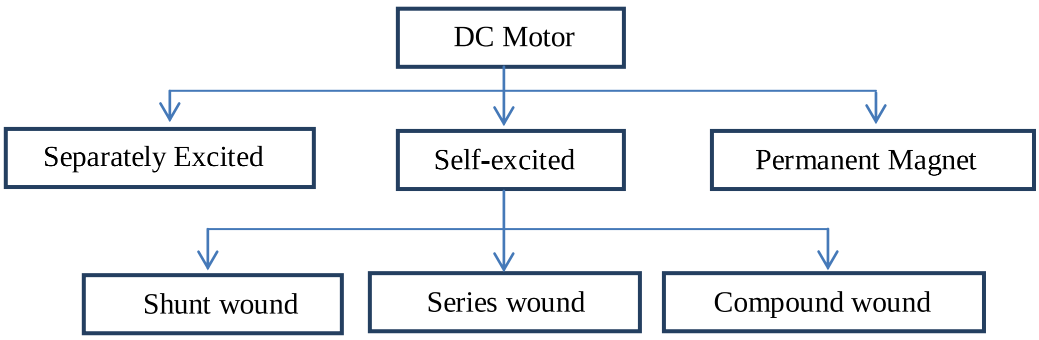

Figure 2.1: Types of DC motor

Direct current motors hold the very important status in the electric driving automatic control system. Relative to the alternating current motor, the performance of direct current motor's speed control is much better. It is the first choice in the applications which require wide range of speed regulation and high-precision speed, and it has been widely used in Computerized Numerical Control machine tools and process control [12].

DC Motors can be used in various applications and can be used as various sizes and rates. Today their uses isn't limited in the car applications (electrics vehicle), in applications of weak power using battery system (motor of toy) or for the electric traction in the multi-machine systems too. The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance [13].

2.2.1 Block diagram of DC Motor Closed-Loop Control

The speed of dc motors changes with the load torque. To maintain a constant speed, the armature (and or field) voltage should be varied continuously by varying the delay angle of ac-dc converters or duty cycle of dc-dc converters. In practical systems it is required to operate the drive at constant torque or constant power; in addition controlled acceleration and deceleration are required [10]. Nowadays, most industrial drives operate as closed-loop feedback system due to the system has the advantages of improves accuracy, fast dynamic response and reduced effect of load disturbances and system nonlinearities.

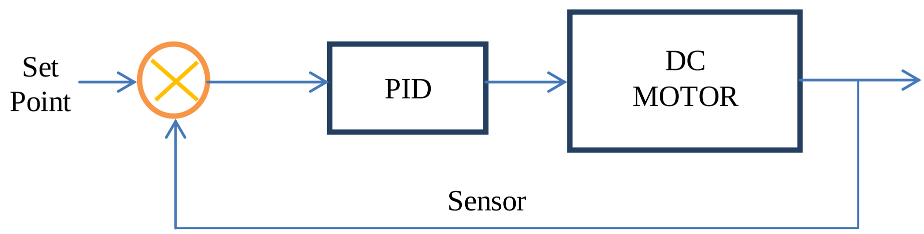

Figure 2.2: The block diagram of the DC motor closed-loop control

As it is seen from figure 2.2 the block diagram of the DC motor closed-loop control, the speed sensor (encoder) measure the speed of the DC motor. In these loops we have the actual speed of the DC motor with the desired one. The DC speed measurement gives the actual speed value. The error between theoretical and practical values is corrected with PID controller. The parameters of the PID controller are determined with MATLAB results which will be explained in the following sections. The output of the PID controller gives the duty cycle of the square wave generator [14].

2.2.2 Shunt Wound DC Motor

The multifunction DC motor with Shunt Wound DC motor connection had used for this project. A shunt-wound motor is a dc machine that has field winding connected parallel to armature. It means that current from a source is sum of armature current and field current. Equivalent circuit of a shunt-wound motor is shown on figure 2.3. Symbols meaning is as follow: V is supply voltage [V], vi is induced voltage [V], Ra is armature winding resistance [Ω], La is armature winding inductance [H], Rf is field winding resistance [Ω] and Lf is field winding inductance [H] [15].

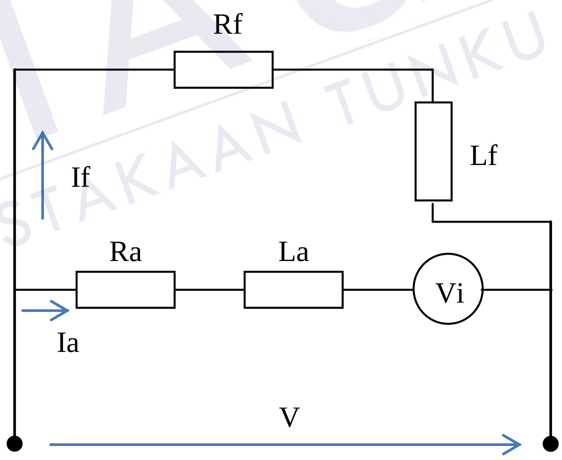

Figure 2.3: Equivalent Circuit of Shunt Wound DC motor

An electrical part of shunt-wound motor can be described by following equations (refer to Figure 2.3):

$$Va = Ra * ia(t) + La * \frac{d}{dt} ia(t) + C * if(t) * \omega(t) \quad (1)$$

$$V = Rf * if(t) + Lf * \frac{d}{dt} if(t) \quad (2)$$

Here, Va is voltage on armature (i.e. supply voltage V minus brush drops) [V], $ia(t)$ is armature current [A], $if(t)$ is shunt winding current [A], C is constant (dimension of product $C \cdot if(t)$ is [$V \cdot s^{-1}$]) and $\omega(t)$ is angular velocity [$rad \cdot s^{-1}$]. Current $i(t)$ from a source is

$$i(t) = ia(t) + if(t) \quad (3)$$

To completing the shunt-wound motor description, mechanical equation is needed:

$$C * if(t) * ia(t) = TL + J * \frac{d}{dt}\omega(t) + D * \omega(t) \quad (4)$$

Where TL is load torque [Nm], J is inertia moment [$kg \cdot m^2$] and D is friction coefficient [$Nm \cdot s \cdot rad^{-1}$].

Figure 2.4 shows the connections of a shunt motor. From these connections, the field current is constant, since it is connected directly to the supply which is assumed to be at constant voltage. Hence the flux is approximately constant and, since also the back e.m.f is almost constant under normal conditions the speed is approximately constant. It is usual for all practical purpose to regard the shunt motor as a constant speed machine. It is employed in practice for drives, the speeds of which are required to be independent of the loads. The speed can be varied by the inclusion of a variable resistor in series with the field winding as figure 2.4 below [16].

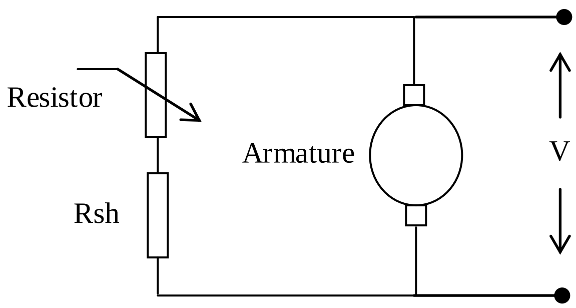

Figure 2.4: Connections of Shunt motor

2.3 Three Phase Controlled Rectifier

In general, control strategy for switching patterns and their duty cycles on the rectifier uses voltage or current. Figure 2.5 represents the topology of the three phase active rectifier proposed. The dynamic model of rectifier consists of a three-phase network connected to three-phase supply voltage ea , eb , ec by assuming a balanced three-phase system, the three-phase input line currents ia, ib, ic and va, vb, vc which represent the three-phase voltages generated by the PWM active rectifier. R and L are the resistance and inductance of the line, a smoothing capacitor, and the load represented by a current source [4].

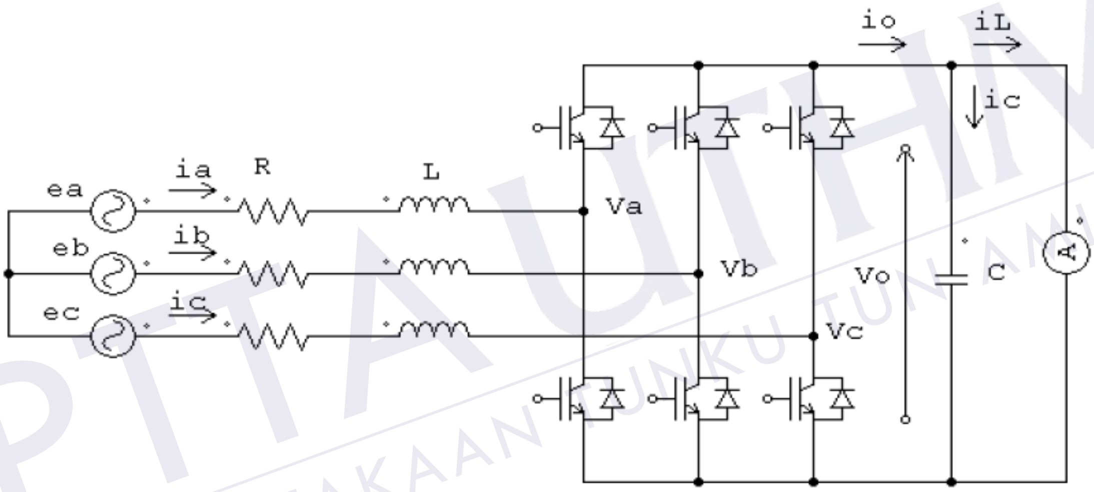

Figure 2.5: Three-phase active rectifier system [4]

A three-phase synchronous controlled rectifier is very efficient rectifier which uses power MOSFETs in place of passive pn-diodes. The advantage of power MOSFETs is that the conduction path for the current does not go across a pn junction. The problem with pn junctions is that they have an inherent, current independent voltage drop of around 0.7V for silicon. Power MOSFETs have a continuous n-doped conduction channel in the on state, which has no current independent voltage drop and behaves like a resistive element. By reducing the resistance of the channel 1 by cry cooling and paralleling of MOSFETs, arbitrarily low on-state voltages and corresponding low losses can be achieved. The design discussed here uses the reverse (body) diodes of the n-channel power MOSFETs for passive rectification which can be switched to active (synchronous) rectification by applying appropriate gate drive pulses to the power MOSFETs [17].

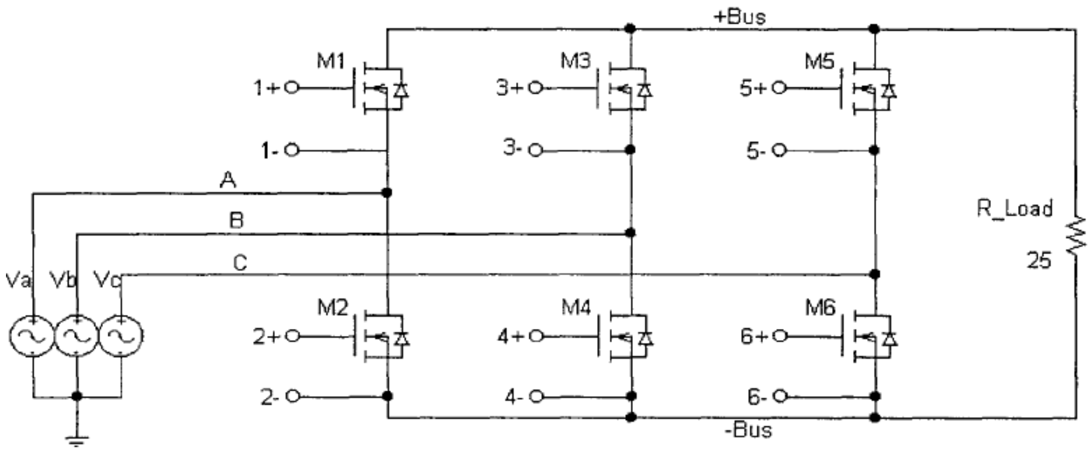

Figure 2.6: Three-phase active rectifier system using MOSFET [17]

The developing trend in switching power supply system has been aiming high-efficiency and low-cost power converters. A conventional power supply commonly has a simple diode rectifier, which consists of several diodes, an output inductor and a capacitor. However, AC/DC diode converter with low output voltage, total loss is consumed over 85% by the diodes, and the output inductor; for this reason, AC/DC power MOSFET rectifier is developed to operate with low power loss, unity power factor, low harmonic and low output ripple [18].

2.4 Three Phase Gate Driver

There are numerous IC gate drives that are commercially available for gating power converters. These include pulse-width modulation (PWM) control, power factor correction (PFC) control, combined PWM and PFC control, current mode control, bridge driver, servo driver, hall-bridge drivers, stepper motor driver and thyristor gate driver [10].

Recently, the interest with solid state pulsed power modulator has been growing because of many advantages such as long life span, rectangular pulse waveforms and easiness of controlling the pulse width and repetition rate [19].

Efficiency is one of the most important issues among high power converters where IGBTs are widely used, and the gate drive circuit serving as the interface between the IGBT power switches and the logic-level signals can be optimized to achieve low losses. Conventional Gate Driver (CGD) circuits have employed fixed gate voltage and resistor networks, which are selected to minimize switching losses, suppress cross-talk and EMI noise, and also limit the power device stresses at switching transients. However, these conflicting requirements are difficult to be realized in a conventional gate driver [20].

Basically, the purpose of using a gate driver is the application of to charge pump circuit to the gate of the MOSFET in the rectifier circuit. The gate requirements for a MOSFET or an IGBT switch are satisfy as follows; i) Gate voltage must be 10V to 15V higher than the source or emitter voltage. Because the power drive is connected to the main igh voltage rail +Vs, the gate voltage must be higher than the rail voltage. ii) The gate voltage that is normally referenced to ground must be controllable from the logic circuit. Thus, the control signals have to be level shifted to the source terminal of the power device, which in most applications swings between the two rails V^+. iii) A low-side power device generally drives the high-side power device that is connected to the high voltage. Thus, there is one high-side and one low-side power device. The power absorbed by the gate drive circuitry should be low and it should not significantly affect the overall efficiency of the power converter [10].

2.5 Controller Method

This part expresses the type of controlled method that most widely used. The explanation about those controllers aid with block diagrams. The description control method focused for Proportional (P) controller, Proportional-Integral (PI) controller, Proportional-Derivative (PD) controller and Proportional-Integral-Derivative (PID) controller.

2.5.1 Proportional (P) Controller

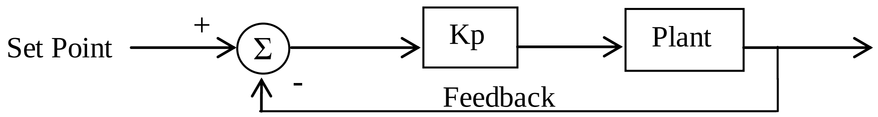

Figure 2.7: Proportional controller block diagram

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