

# **DEVELOPMENT OF AN AC TO DC CONVERTER USING MICROCONTROLLER**

*A project report submitted in partial fulfillment of the requirements for  
the degree of*

*Bachelor of Technology in Electrical Engineering*

*By*

**RASHMI RANJAN ROUT**

**DURGA PRASAD TRIPATHY**



**National Institute of Technology, Rourkela**

**Rourkela-769008, Orissa.**

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## **CERTIFICATE**

This is to certify that the thesis entitled, “**DEVELOPMENT OF A PROTOTYPE OF AC TO DC CONVERTER FOR THE ELECTRICAL DEPARTMENT USING MICROCONTROLLER**” submitted by **Rashmi Ranjan Rout** for the partial fulfillment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

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## **ABSTRACT**

The aim of the project is to obtain a controlled DC output from a standard single phase 230V, 50Hz power supply. For this we first rectified the ac voltage using four diodes. Then the rectified DC voltage is used to get controlled DC voltage output using an IGBT with a pulse of variable duty cycle, generated by a microcontroller. By varying the duty cycle of the square wave pulse the average output DC voltage is regulated. For user interfacing, a knob is used to set the required voltage. This is achieved by converting the analog signal input, from the knob, to digital signal by using the internal Analog to Digital converter present in the microcontroller. The microcontroller sets the duty cycle of the PWM wave according to the ADC value obtained. This PWM wave is given as input to the IGBT to regulate its duty cycle, and hence the average output voltage is regulated. This is basically the open loop regulation of voltage. If the load varies, then we have to use closed loop control to automatically increase the duty cycle of the gate pulse to the IGBT if the output voltage falls below a set point and vice versa. The negative feedback loop is based on PID loop control. Thus the output voltage is continuously tuned with the set point voltage.

# **Chapter 1**

## **INTRODUCTION**

Many industrial applications make use of controlled DC power, like in steel rolling mills, paper mills and textile mills, which employ DC motor drives. The basic advantages of DC motor are high starting torque, high accelerating and decelerating torque. DC motor is easily adaptable for drives requiring wide range speed control and quick reversals. So DC machine possesses high degree of flexibility and versatility. The losses like eddy current loss, hysteresis loss are also absent in DC applications. For some industrial applications a versatile AC to DC converter is indispensable. Direct current is used to charge batteries, and in nearly all electronic systems as the power supply. Very large quantities of direct-current power are used in production of aluminum and other electrochemical processes. Direct current is also used for some railway propulsion, especially in urban areas. High voltage direct current (HVDC) is used to transmit large amounts of power from remote generation sites or to interconnect alternating current power grids.

DC is commonly found in many low-voltage applications, especially where these are powered by batteries, which can produce only DC, or solar power systems, since solar cells can produce only DC. Most automotive applications use DC, although the alternator is an AC device which uses a rectifier to produce DC. Most electronic circuits require a DC power supply. Applications using fuel cells (mixing hydrogen and oxygen together with a catalyst to produce electricity and water as byproducts) also produce only DC. Many telephones connect to a twisted pair of wires, and internally separate the AC component of the voltage between the two wires (the audio signal) from the DC component of the voltage between the two wires (used to power the phone). Telephone exchange communication equipment, such as DSLAM, uses standard -48V DC power supply. The negative polarity is achieved by grounding the positive terminal of power supply system and the battery bank. This is done to prevent electrolysis depositions. An electrified third rail can be used to power both underground (subway) and overground trains.

Direct-current installations usually have different types of sockets, switches, and fixtures, mostly due to the low voltages used, from those suitable for alternating current. It is usually important with a direct-current appliance not to reverse polarity unless the device has a diode bridge to correct for this.

In our model we have used one IGBT and four diodes to convert AC to DC, which is cost efficient. Power conversion applications consist of an AC-to-DC conversion stage immediately following the AC source. The DC output obtained after rectification is subsequently used for further stages. Current pulses with high peak amplitude are drawn from a rectified voltage source with sine wave input and capacitive filtering. Increasing demands for higher power density, smaller size, more portability and more flexible systems spur industry to continuously design new generations of AC-DC power supplies using power devices with the lowest switching and conduction losses to increase efficiency, reduce thermal problems and improve power density. We have preferred IGBT over other semi-converter devices like thyristor, BJT etc., because of lower gate drive requirements, lower switching losses of the IGBT and some other reasons stated

later. The turn-off process of IGBT is simple, compared to thyristor, as it does not require any commutation below the rated threshold collector current.

The aim of the project is to obtain a controlled DC output from a standard single phase 230V, 50Hz power supply. For this we first rectified the AC voltage using four diodes. Then the rectified DC voltage is used to get controlled DC voltage output using an IGBT with a pulse of variable duty cycle, generated by a microcontroller. By varying the duty cycle of the square wave pulse the average output DC voltage is regulated. For user interfacing, a knob is used to set the required voltage. This is achieved by converting the analog signal input, from the knob, to digital signal by using the internal Analog to Digital converter present in the microcontroller. The microcontroller sets the duty cycle of the PWM wave according to the ADC value obtained. This PWM wave is given as input to the IGBT to regulate its duty cycle, and hence the average output voltage is regulated. This is basically the open loop regulation of voltage. If the load varies, then we have to use closed loop control to automatically increase the duty cycle of the IGBT if the output voltage falls below a set point and vice versa. The negative feedback loop is based on PID loop control. Thus the output voltage is continuously tuned with the set point voltage.

# **Chapter 2**

## **INSULATED GATE BIPOLAR TRANSISTOR (IGBT)**

We are using Insulated Gate Bipolar Transistor (IGBT) for conversion of AC to controlled DC in our work. IGBT has been developed by combining into it the best qualities of both BJT and MOSFET. IGBT is also called Metal Oxide Insulated Gate Transistor (MOSIGT), Conductively Modulated Field Effect Transistor (COMFET) or Gain Modulated FET (GEMFET).

## **2.1 Advantages & disadvantages of IGBT over other semiconductor devices**

### **2.1.1 Advantages**

- IGBT possesses high input impedance like a MOSFET.
- IGBT possesses low on-state power loss as in a BJT.
- IGBT is free from the secondary breakdown problem that is present in BJT.
- IGBT possesses lower gate drive requirements.
- IGBT has smaller snubber circuit requirements.
- IGBT converters are more efficient with less size as well as cost, as compared to converters based on BJTs.
- Switching losses in IGBTs are lesser.
- Device rise and fall time switching capability is 5-10 times faster, resulting in lower device switching loss and a more efficient drive.
- The IGBT being a voltage rather than current controlled gate device has a lower base drive circuit cost that also results in lower drive package cost.
- Higher switching frequencies of IGBT drives produce less peak current ripple, thus producing less current harmonic motor heating and allowing rated motor torque with lower peak current than BJT drives.

### **2.1.2 Disadvantages**

- For a similar motor cable length as the BJT drive, the faster output voltage rise time of the IGBT drive may increase the dielectric voltage stress on the motor and cable due to a phenomenon called reflected wave.
- Faster output  $dv/dt$  transitions of IGBT drives also increase the possibility for phenomenon such as increased common mode electrical noise.
- Electromagnetic interference (EMI) problems and increased capacitive cable charging current problems.
- Any pulse width modulated (PWM) drive with a steep fronted output voltage wave form may increase motor shaft voltage and lead to a bearing current phenomenon known as fluting.

An IGBT is constructed in basically the same manner as a power MOSFET. There is however a major difference in the substrate. In IGBT there is a  $p^+$  layer substrate called collector C. Like a power MOSFET, an IGBT has also thousands of basic structure cells connected appropriately on a single chip of silicon.

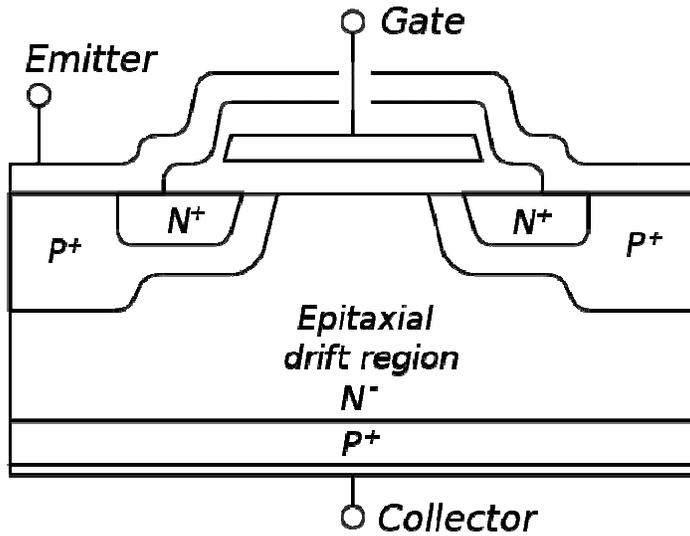
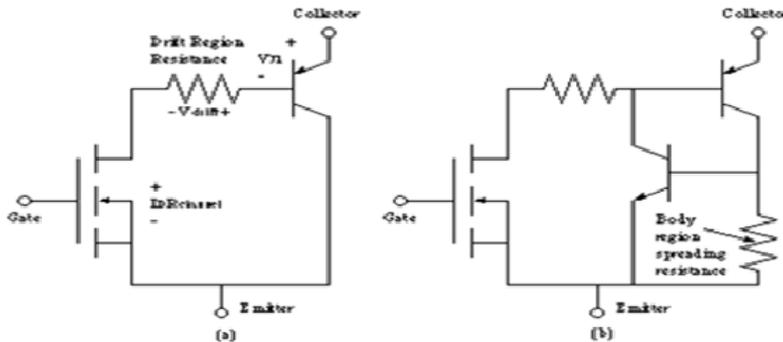


Figure taken from <http://www.igbts.co.uk/insulated-gate-bipolar-transistor-igbt-structure>

Figure 2.1 Structure of IGBT

In IGBT,  $p^+$  substrate is called injection layer because it injects holes into  $n^-$  layer. The  $n^-$  layer is called drift region. Thickness of  $n^-$  layer determines the voltage blocking capability of IGBT. The  $p$  layer is called body of IGBT. The  $n^-$  layer in between  $p^+$  and  $p$  regions accommodates the depletion layer of  $pn^-$  junction, which is junction J2.

## 2.2 Equivalent Circuit of IGBT



(a) Simple equivalent circuit for the IGBT; (b) more complete equivalent circuit showing the transistors which make up the parasitic thyristor

Figure taken from <http://www.esteempower.com/Pages/IGBT.htm>

Figure 2.2 Equivalent circuit of IGBT

Referring to the figure, IGBT can be approximately thought of as a combination of a MOSFET and a  $p^+n^-p$  transistor. There is also an  $n^-pn^+$  transistor formed. There is thus a parasitic thyristor formed by the two transistors  $p^+n^-p$  and  $n^-pn^+$ .  $R_d$  is the drift region resistance.  $R_{by}$  is the p-body region resistance.

## 2.3 Working Principle

When collector is made positive with respect to emitter, IGBT gets forward biased. With no voltage between gate and emitter, the two junctions  $J_2$  between  $n^-$  and  $p$  is reverse biased. So no current flows from collector to emitter. When gate is made positive with respect to emitter by a voltage more than the threshold voltage of IGBT, an n-channel or inversion layer is formed in upper part of p-region just below the gate. This n-channel short-circuits the  $n^-$  and  $n^+$  regions. So electrons from  $n^+$  region flow into  $n^-$  region.  $p^+$  is already injecting holes into  $n^-$  region. So the conductivity of  $n^-$  region increases considerably. IGBT gets turned on and starts conducting forward current  $I_C$ .

## 2.4 Latch-up in IGBT

When IGBT is on, hole current flows through transistor  $p^+n^-p$  and p-body resistance  $R_{by}$ . If load current is large, then drop through resistance  $R_{by}$  will be large. This drop will forward bias  $n^-pn^+$  transistor. This further facilitates the turn on of  $p^+n^-p$  transistor. This can be a regenerative process. With parasitic thyristor on, IGBT latches up and after this collector current is no longer under the control of gate terminal. The only way now to turn off the latched-up IGBT is by forced commutation of current. If this latch-up isn't aborted quickly, excessive power dissipation may destroy the IGBT. Hence to avoid this latch-up, collector current mustn't exceed a certain critical value which must be specified by the manufacturer.

## 2.5 IGBT characteristics

### 2.5.1 Static I-V characteristics

Static I-V or output characteristics of an IGBT (n-channel type) show the plot of collector current  $I_C$  versus collector-emitter voltage  $V_{CE}$  for various values of gate-emitter voltages  $V_{GE1}$ ,  $V_{GE2}$ , etc. In the forward direction, the shape of the output characteristics is similar to that of BJT. But here the controlling parameter is  $V_{GE}$  as IGBT is a voltage-controlled device. When the device is off, junction  $J_2$  blocks forward voltage and in case reverse voltage appears across collector and emitter,  $J_1$  blocks it.

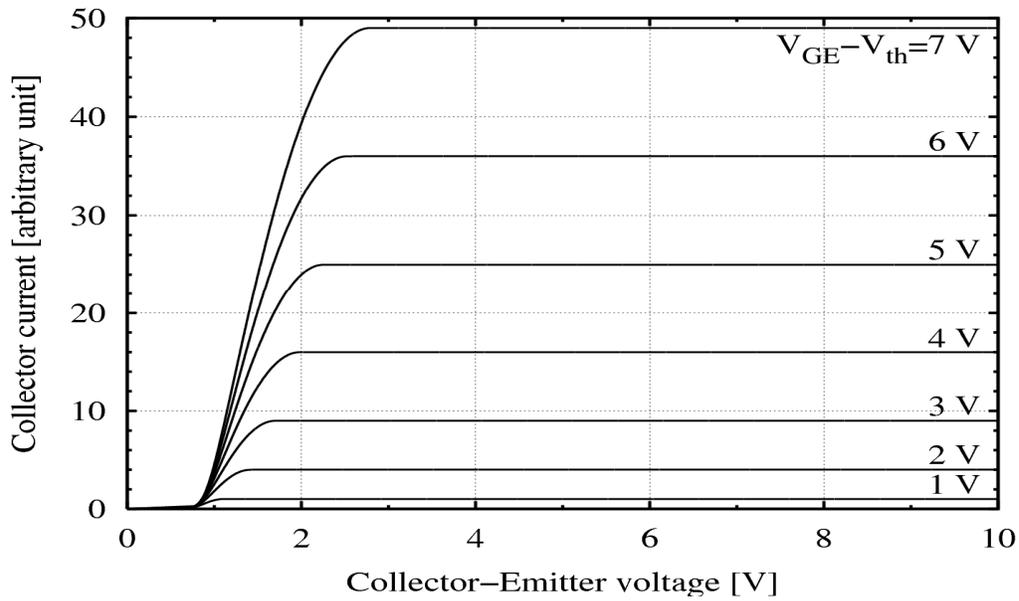


Figure 2.3 Static I-V characteristics of IGBT

Figure taken from [http://commons.wikimedia.org/wiki/File:IvsV\\_IGBT.png](http://commons.wikimedia.org/wiki/File:IvsV_IGBT.png)

### 2.5.2 Transfer Characteristics

The transfer characteristics of an IGBT is a plot of collector current  $I_C$  versus gate-emitter voltage  $V_{GE}$ . This characteristic is identical to that of power MOSFET. When  $V_{GE}$  is less than the threshold voltage ( $V_{GET}$ ), the IGBT is in off-state.

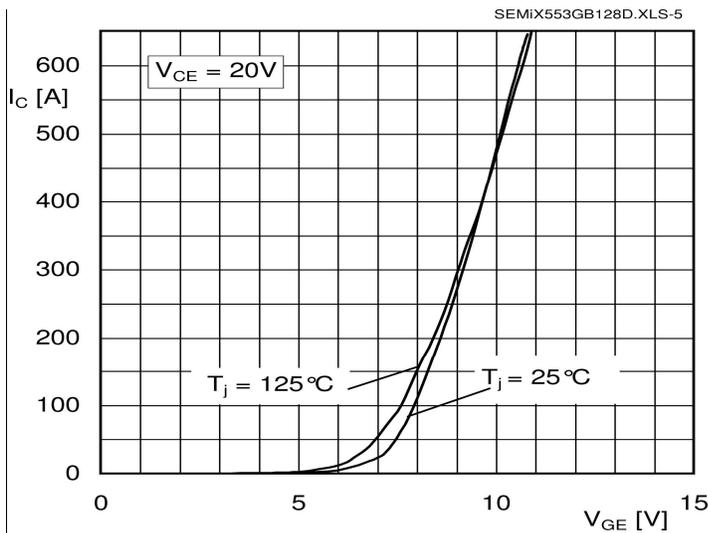


Figure taken from [www.semikron.com](http://www.semikron.com)

Figure 2.4 IGBT Transfer Characteristics

### 2.5.3 Switching Characteristics

The turn-on time is defined as the time between the instants of forward blocking to forward on-state. Turn-on time is composed of delay time  $t_{dn}$  and rise time  $t_r$ , i.e.  $t_{on}=t_{dn}+t_r$ . The delay time is defined as the time for  $V_{CE}$  to fall from  $V_{CE}$  to 90% of initial  $V_{CE}$ . Time  $t_{dn}$  may also be defined as the time for  $I_C$  to rise from its initial leakage current to 10% of final value of collector current.

The rise time  $t_r$  is the time during which  $V_{CE}$  falls from 0.9  $V_{CE}$  to 0.1  $V_{CE}$ . It is also defined as the time for  $I_C$  to rise from 0.1  $I_C$  to its final value  $I_C$ . After time  $t_{on}$ , collector current is  $I_C$ , and  $V_{CE}$  falls to small value called conduction drop= $V_{CES}$ , where subscript S denotes saturated value.

The turn-off time comprises three intervals:

- Delay time: Time during which gate voltage falls from  $V_{GE}$  to threshold voltage  $V_{GET}$ . The collector current falls from  $I_C$  to 0.9  $I_C$ . At the end of delay time,  $V_{CE}$  begins to rise.
- Initial fall time: Time during which collector current falls from 0.9 to 0.2 of its initial value  $I_C$ .
- Final fall time: Time during which collector current falls from 0.2 to 0.1 of  $I_C$ .

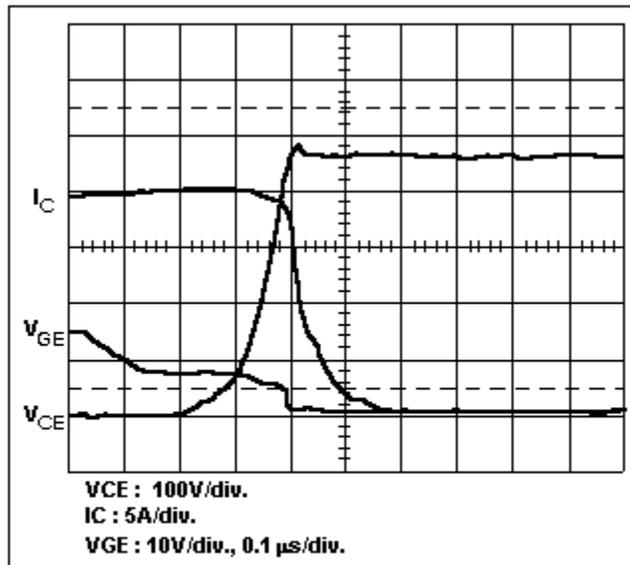


Figure taken from  
[www.semikron.com](http://www.semikron.com)

**Figure** Turn-off waveform of an IRGBC40F with a 47 $\Omega$  gate resistor.

Figure 2.5 Switching Characteristics of IGBT

# **Chapter 3**

## **BASIC COMPONENTS AND THEIR INTERFACING TECHNIQUES**

## 3.1 ATMEGA32L-8PU (AVR Series microcontroller)

### 3.1.1 Important Features

The ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

The important features of ATmega32 are listed below:

- Bytes of In-System Self-Programmable Flash (Endurance: 10,000 Write/Erase Cycles)
- 1024 Bytes EEPROM (Endurance: 100,000 Write/Erase Cycles)
- 2K Byte Internal SRAM
- Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
- One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
- Four PWM Channels
- 8-channel, 10-bit ADC (operated in both single and differential channel mode)
- 32 Programmable I/O Lines
- **Operating Voltages**
  - 2.7 - 5.5V for ATmega32L (device operate at 5V DC)
  - 4.5 - 5.5V for ATmega32
- **Speed of operation:**
  - 0-8MHZ for ATMEGA32L
  - 0-16MHZ for ATMEGA32
- **Power Consumption at 1 MHz, 3V, 25°C for ATmega32L**
  - Active: 1.1 mA
  - Idle Mode: 0.35 mA
  - Power-down Mode: less than 1mA.
- **Advanced RISC Architecture**
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier

### 3.1.2 PIN Configuration

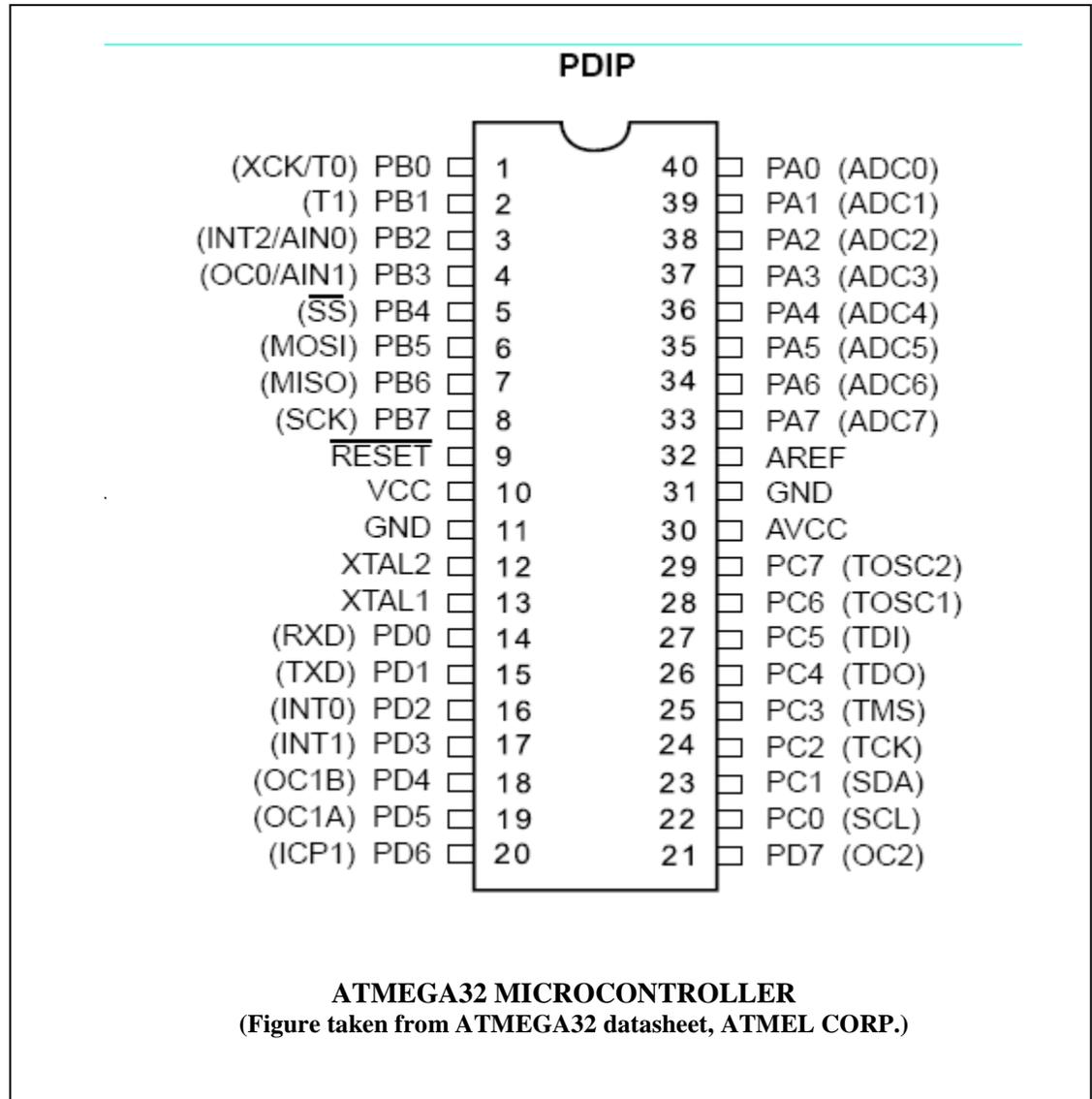


Figure 3.1 PIN Configuration of Atmega32 Microcontroller

### 3.1.3 Programming AVR Microcontroller

C language is used for programming AVR microcontroller. First requirement is a compiler, which is required to convert C code to machine code (Hex code), which is ultimately transferred to flash memory of microcontroller. I have used **WINAVR2006** compiler. The second requirement is a programmer which transfers the .hex file (created by the compiler) to the chip. **BSD programmer** is used for that. **AVRDUDE** software is used for programming ATMEGA32 CPU.

### 3.1.4 Installation of WINAVR Software

**WINAVR2006** compiler is installed in PC C drive. **install\_giveio.bat** (inside winavr/bin directories) file is executed to access parallel port of computer. One C file and one **make file** is required to generate hex code for AVR microcontrollers. Make file specifies the device (microcontroller) name, frequency of operation, output code format, programmer type, and PC port which is connected to the programmer etc. to the compiler. One make file editor and one .C file editor is located on desktop. One make file of a specific format is stored in the same folder where the .C file is created.

### 3.1.5 MAKEFILE Specifications

The following changes have been done in makefile editor to create **makefile for ATMEGA32 microcontroller**.

- MCU type – ATMEGA32
- PROGRAMMER – BSD
- PORT - LPT PORT
- DEBUGGER- AVR-EXT-COFF(AVRSTUDIO 4.07+, VMLAB 3.10+)
- TARGET- main.c (same as .c file name)

### 3.1.6 Installation of AVRDUDE

**AVRDUDE** is a full featured FreeBSD UNIX program for programming Atmel's AVR CPU's. It can program the Flash and EEPROM, and where supported by the serial programming protocol, it can program fuse and lock bits. AVRDUDE can be used effectively via the command line to read or write all chip memory types (EEPROM, flash, fuse bits, lock bits, signature bytes) or via an interactive (terminal) mode.

**AVRDUDE** software is installed in same drive in which **WINAVR** compiler is installed. WINAVR compiler internally use AVRDUDE programmer to transfer .hex file to microcontroller.

### 3.2 Components used

Serial number	Component	Quantity
1.	Diode(SB560)	5
2.	IGBT(IRG4PC30U)	1
3.	Atmega32 Microcontroller	1
4.	Potentiometer(100K)	1
5.	Comparator (LM324)	1
6.	1-phase Transformer(230V/6V,1Amp)	1
7.	Crystal Oscillator(6.5536MHz)	1
8.	Constant Voltage Regulator(L7805)	1
9.	DC Li ion battery(2000ma-hr,3.8V)	2

### 3.3 Softwares used

1. Multisim (Student Version 10.1, National Instruments) – Used for simulation purpose.
2. Diptrace (Evaluation Version 1.5) – Used for circuit layout design.
3. WinAvr compiler (Version 2.0.6.1) – Used as a C language compiler for Atmega32 microcontroller.
4. MATLAB and Simulink

## 3.4 Operation of the converter

### 3.4.1 Basic Function

A bridge rectifier configuration (Graetz Bridge) of four diodes (IN5406) is used to rectify the AC input of 230V, 50Hz supply. For many applications, especially with single phase AC where the full-wave bridge serves to convert an AC input into a DC output, the addition of a capacitor is desired because the bridge alone supplies an output of fixed polarity but continuously varying or pulsating magnitude.

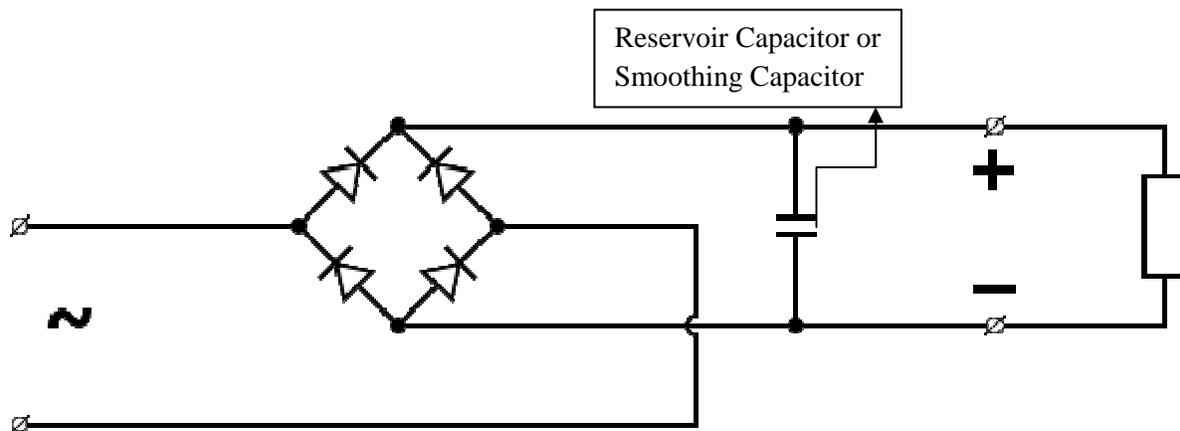


Figure 3.2 Graetz Bridge and smoothing capacitor

Figure taken from  
[http://en.wikipedia.org/wiki/Diode\\_bridge](http://en.wikipedia.org/wiki/Diode_bridge)

The function of this capacitor, known as reservoir capacitor or smoothing capacitor is to lessen the variation in (or 'smooth') the rectified AC output voltage waveform from the bridge. One explanation of smoothing is that the capacitor provides a low impedance path to the AC component of the output, reducing the AC voltage across, and AC current through, the resistive load. In less technical terms, any drop in the output voltage and current of the bridge tends to be canceled by loss of charge in the capacitor. This charge flows out as additional current through the load. Thus the change of load current and voltage is reduced relative to what would occur without the capacitor. Increases of voltage correspondingly store excess charge in the capacitor, thus moderating the change in output voltage/current.

The rectified AC is fed to the IGBT. To control the output DC voltage multipulse PWM (here 8-pulse) method is used, which varies the duty cycle of the IGBT. Different duty cycle value of PWM is used to control the switching of IGBT (IRG4PC30U) by which the average voltage or average time of power delivery from the source is controlled.

A pulse of constant frequency (400HZ) of adjustable duty cycle is generated using ATMEGA32 microcontroller (AVR series) in fast PWM mode. To produce a PWM two counters are used: one counter attributes to frequency of the PWM and the value of other counter is set to adjust the duty cycle. Across the load a freewheeling diode is connected which comes into play in case of inductive load.

### **3.4.2 Voltage Control by the Knob**

A knob is used for the user to control the voltage level. This knob is a potentiometer of value 100K. A voltage supply of 5V is applied across it and the middle terminal is connected to one of the input of the ADC channel at PORT A of the microcontroller. The ADC is operated at reference value 5V (constant) and resolution of 10bit (0.005V) in comparator mode. The duty cycle of the PWM is determined from the corresponding ADC value for a particular knob position.



# **Chapter 4**

## **SIMULATION IN MULTISIM (N.I.)**

## 4.1 Simulation Circuit Diagram

The complete simulation is carried out using Multisim software. The simulation diagram is given below:

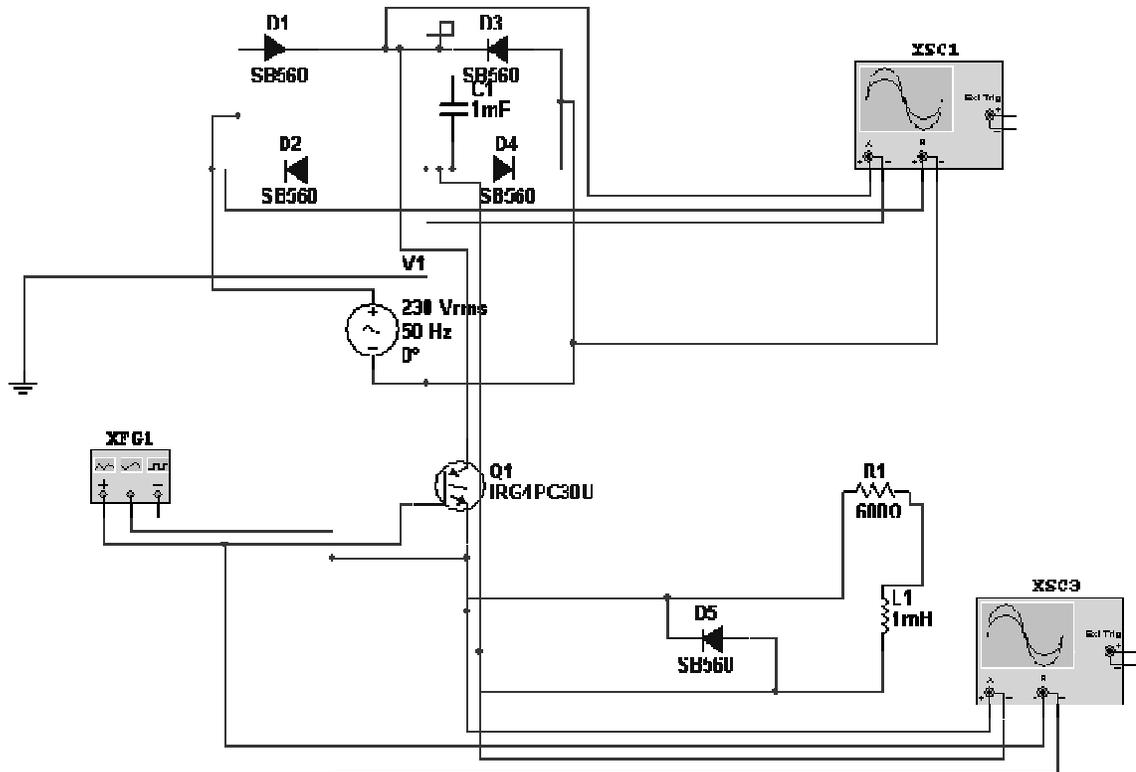


Figure 4.1 Simulation circuit in Multisim

## 4.2 Simulation Results

Simulations for different load conditions and different duty-cycles are carried out by using Multisim (Student Version) software. The waveforms are of output voltage and gate signals.

Scale: X axis: 1 big division = 5 milliseconds

Y axis: 1 big division = 200V

**Result 1- (for a load of 1K-ohms and duty cycle 90%)**

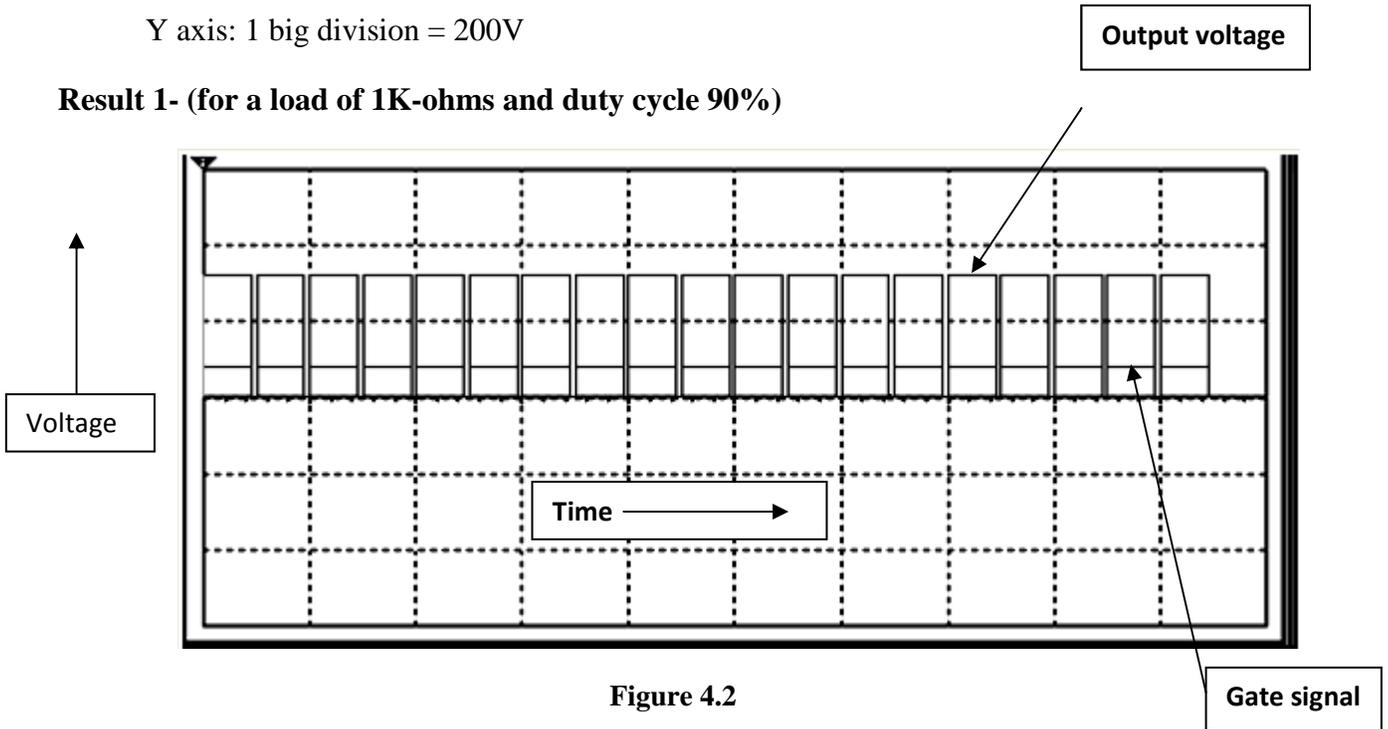


Figure 4.2

**Result 2- (for a load of 1K-ohms and duty cycle 60%)**

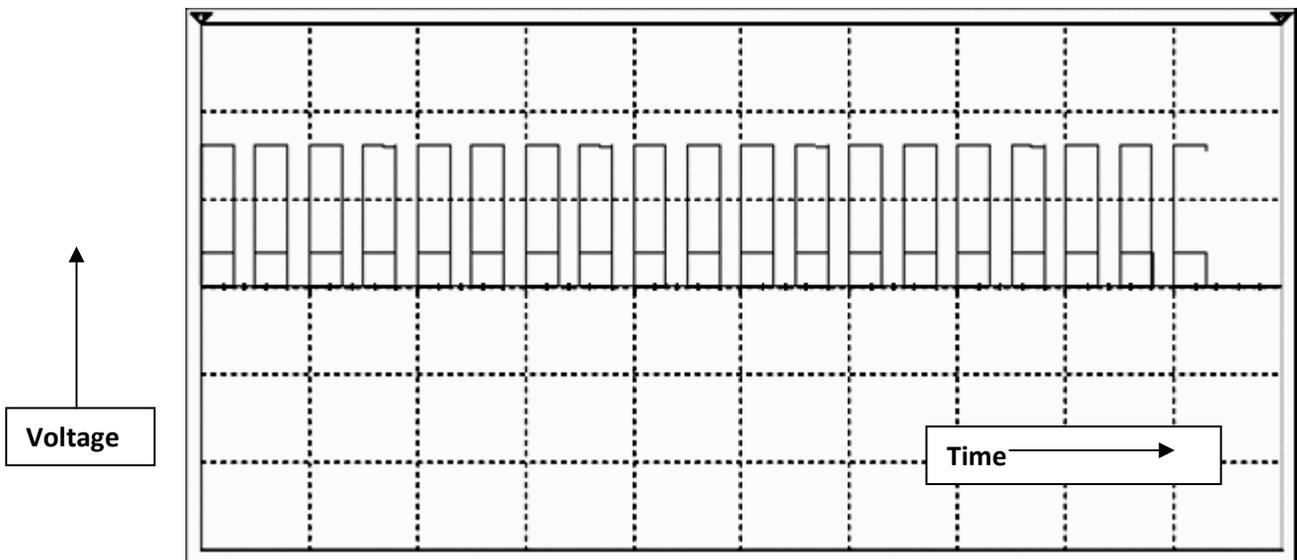
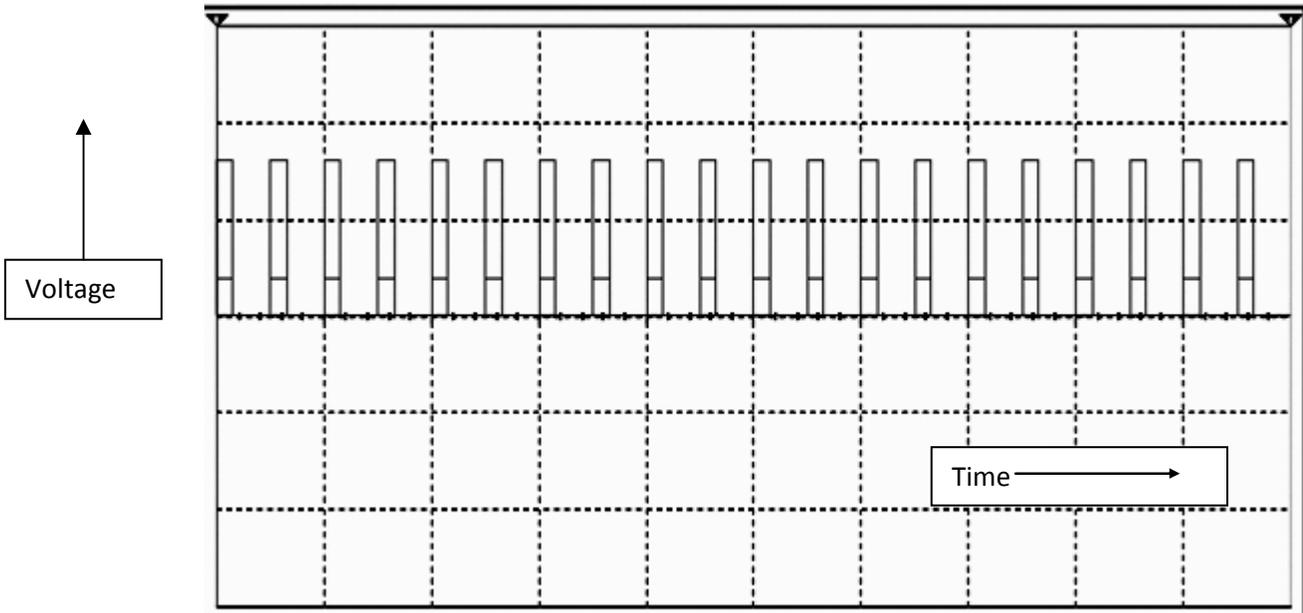


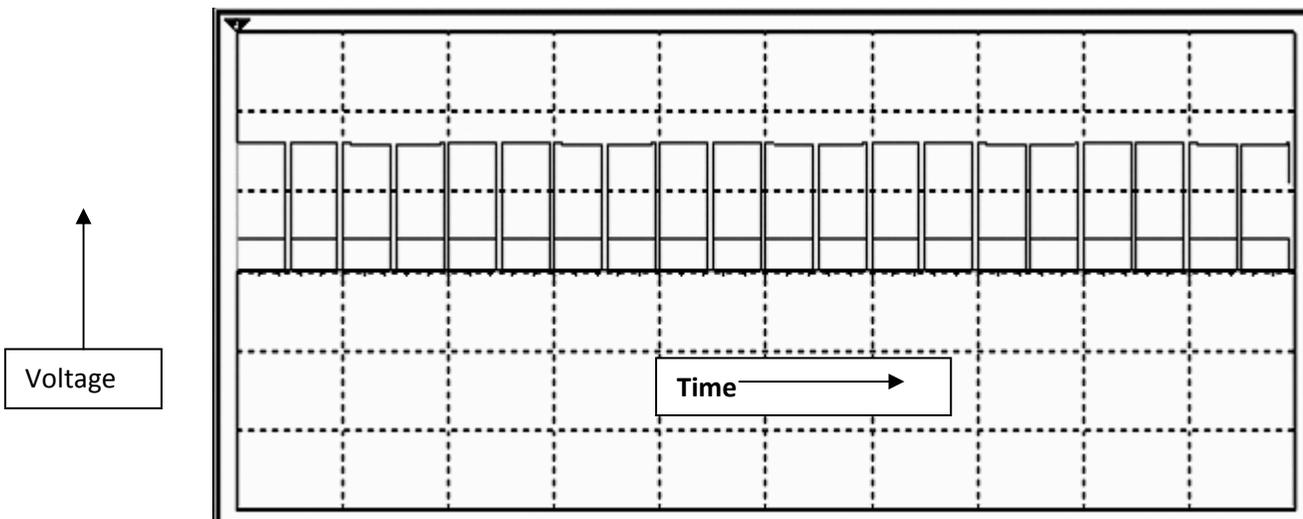
Figure 4.3

**Result 3- (for a load of 1K-ohms and duty cycle 30%)**



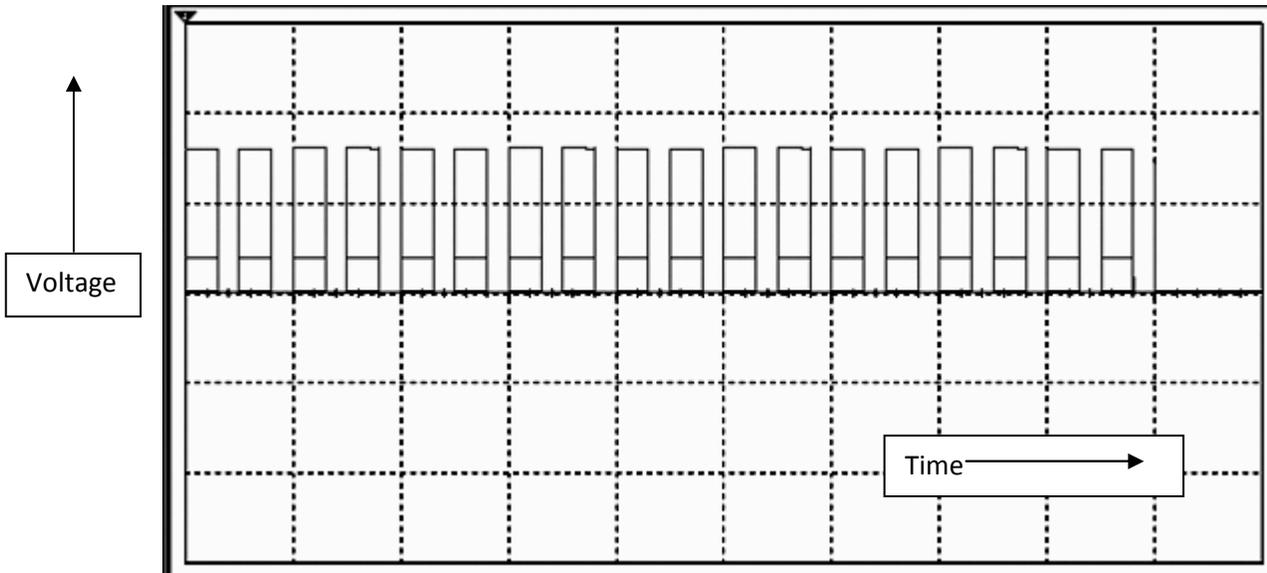
**Figure 4.4**

**Result 4- (for a load of 500 ohms and duty cycle 90%)**



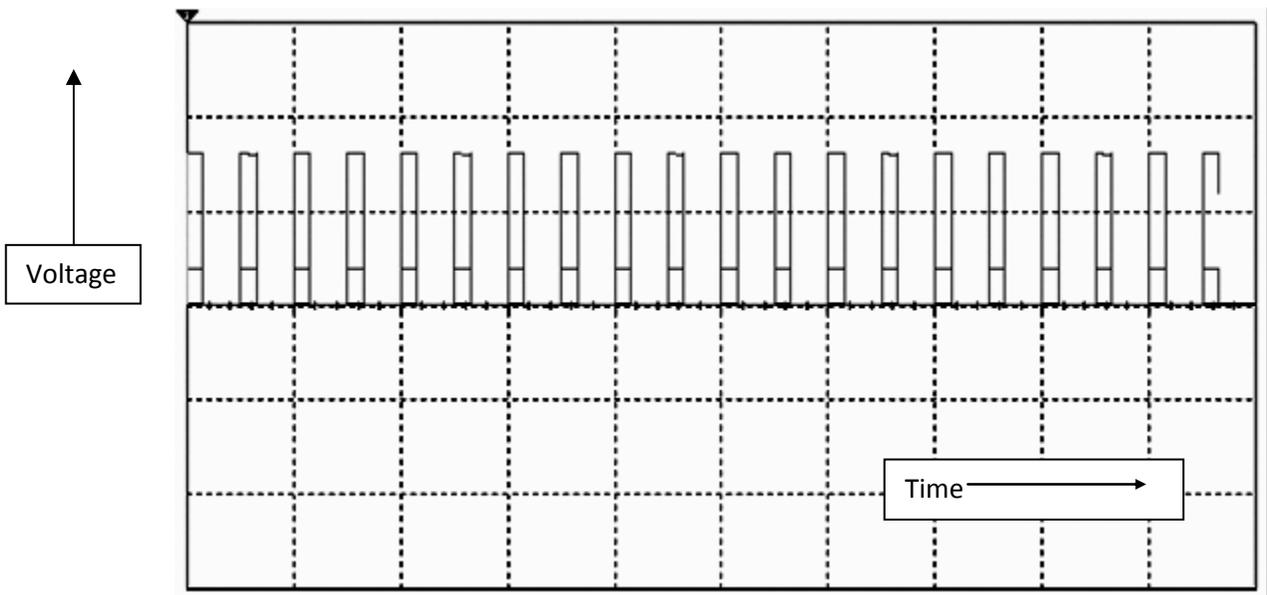
**Figure 4.5**

**Result 5- (for a load of 500 ohms and duty cycle 60%)**



**Figure 4.6**

**Result 6- (for a load of 500 ohms and duty cycle 30%)**



**Figure 4.7**

# **Chapter 5**

## **VOLTAGE CONTROL USING PID ALGORITHM**

The PID algorithm is the most popular feedback controller used within the process industries. It has been successfully used for over 50 years. It is a robust and easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant.

## 5.1 The Proportional-Integral-Derivative (PID) algorithm

As the name suggests, the PID algorithm consists of three basic modes, the Proportional, the Integral and the Derivative modes. When utilizing this algorithm it is necessary to decide which modes are to be used (which combinations of P, I and D?) and then specify the parameters (or settings) for each mode used. Generally, three basic algorithms are used P, PI or PID.

### 5.1.1 A Proportional algorithm

The mathematical representation is,

$$\frac{mV(s)}{E(s)} = \mathbf{k_c} \text{ (Laplace domain)}$$

or

$$mv(t) = mv_{ss} + \mathbf{k_c} \cdot e(t) \text{ (time domain)}$$

The proportional mode adjusts the output signal in direct proportion to the controller input (which is the error signal,  $e$ ). The adjustable parameter to be specified is the controller gain,  $k_c$ . This is not to be confused with the process gain,  $k_p$ . The larger  $k_c$  the more the controller output will change for a given error. For instance, with a gain of 1 an error of 10% of scale will change the controller output by 10% of scale. Many instrument manufacturers use Proportional Band (PB) instead of  $k_c$ .

The time domain expression also indicates that the controller requires calibration around the steady-state operating point. This is indicated by the constant term  $mv_{ss}$ . This represents the 'steady-state' signal for the mv and is used to ensure that at zero error the cv is at set point. In the Laplace domain this term disappears, because of the 'deviation variable' representation.

A proportional controller reduces error but does not eliminate it (unless the process has naturally integrating properties), i.e. an offset between the actual and desired value will normally exist.

### 5.1.2 A proportional integral algorithm

The mathematical representation is,

$$\frac{mV(s)}{E(s)} = k_c \left[ 1 + \frac{1}{T_i s} \right]$$

or

$$mv(t) = mv_{ss} + k_c \left[ e_t + \frac{1}{T_i} \int e(t) dt \right]$$

The additional integral mode (often referred to as reset) corrects for any offset (error) that may occur between the desired value (set point) and the process output automatically over time. The adjustable parameter to be specified is the integral time (Ti) of the controller.

### 5.1.3 A Proportional Integral Derivative algorithm

The mathematical representation is,

$$\frac{mV(s)}{E(s)} = k_c \left[ 1 + \frac{1}{T_i s} + T_D s \right]$$

or

$$mv(t) = mv_{ss} + k_c \left[ e_t + \frac{1}{T_i} \int e(t) dt + T_D \frac{de(t)}{dt} \right]$$

Derivative action (also called rate or pre-act) anticipates where the process is heading by looking at the time rate of change of the controlled variable (its derivative). TD is the 'rate time' and this characterizes the derivative action (with units of minutes). In theory derivative action should always improve dynamic response and it does in many loops. In others, however, the problem of noisy signals makes the use of derivative action undesirable (differentiating noisy signals can translate into excessive mv movement). Derivative action depends on the slope of the error, unlike P and I. If the error is constant derivative action has no effect.

## 5.2 The characteristics of P, I and D controllers

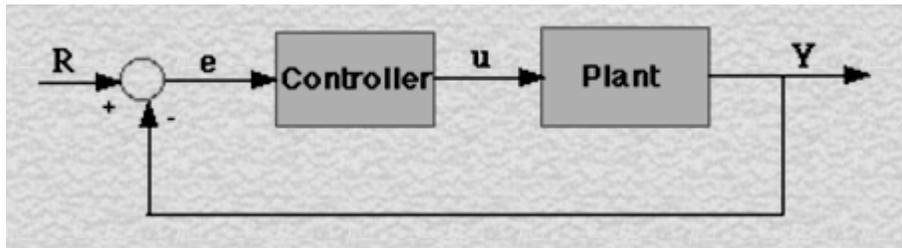


Figure 5.1 Block diagram of a plant with a controller

**Plant:** A system to be controlled.

**Controller:** Provides the excitation to the plant; designed to control the overall system behavior.

A proportional controller ( $K_p$ ) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control ( $K_i$ ) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control ( $K_d$ ) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers  $K_p$ ,  $K_d$ , and  $K_i$  on a closed-loop system are summarized in the table shown below.

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
<b><math>K_p</math></b>	Decrease	Increase	Small Change	Decrease
<b><math>K_i</math></b>	Decrease	Increase	Increase	Eliminate
<b><math>K_d</math></b>	Small Change	Decrease	Decrease	Small Change

These correlations may not be exactly accurate, because  $K_p$ ,  $K_i$ , and  $K_d$  are dependent of each other. Changing one of these variables can change the effect of the other two. For this reason, the table is only used as a reference while determining the values for  $K_i$ ,  $K_p$  and  $K_d$ .

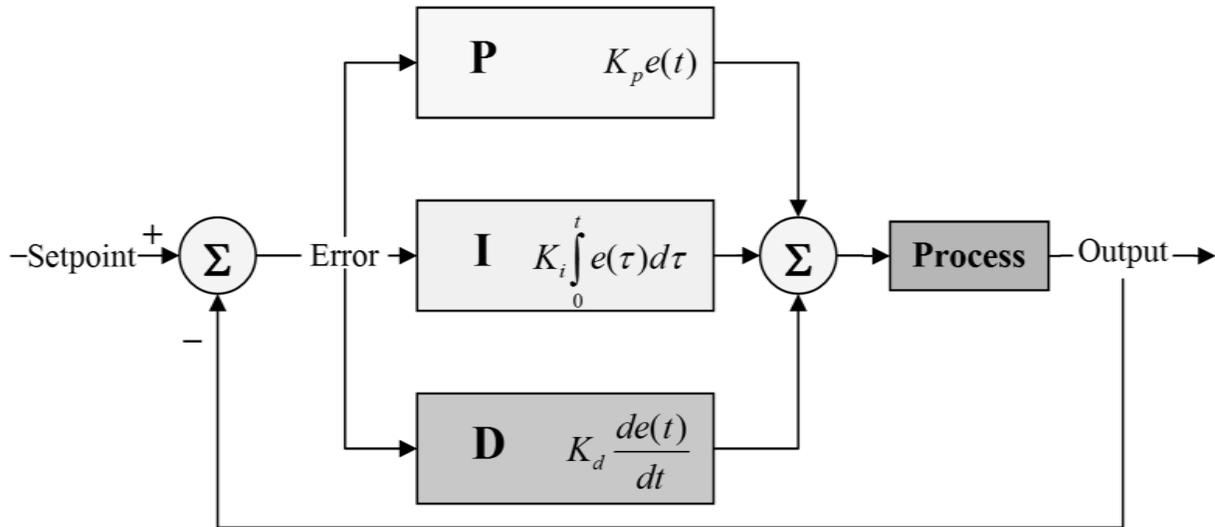


Figure 5.2 Block diagram of a PID controller

### 5.3 PID implementation on Output voltage control

PID algorithm is applied to control the output voltage of the converter on load variation. The basic algorithm compares the input set point (desired voltage) with the average output voltage of the converter at certain load, to produce the error signal. Using this error signal the PID controller generates the control signal for the converter to continuously tune up the average voltage with the set point.

The total control process is handled by a single microcontroller (AVR series ATMEGA32). The basic process flow is described hereafter.

### 5.3.1 Determination of Average output voltage

The maximum DC output voltage is equal to  $230 \sqrt{2} = 325\text{V}$  for single phase 230V AC power supply. If the duty cycle is 'D' then the average voltage is  $325 \cdot D$ . The microcontroller can only handle voltage upto 5V. Hence the output voltage at the converter end has to be first scaled down to a range in between 0V to 5V. This is achieved using a potentiometer of high resistance value ( $1\text{M}\Omega$ ), in order to reduce losses.

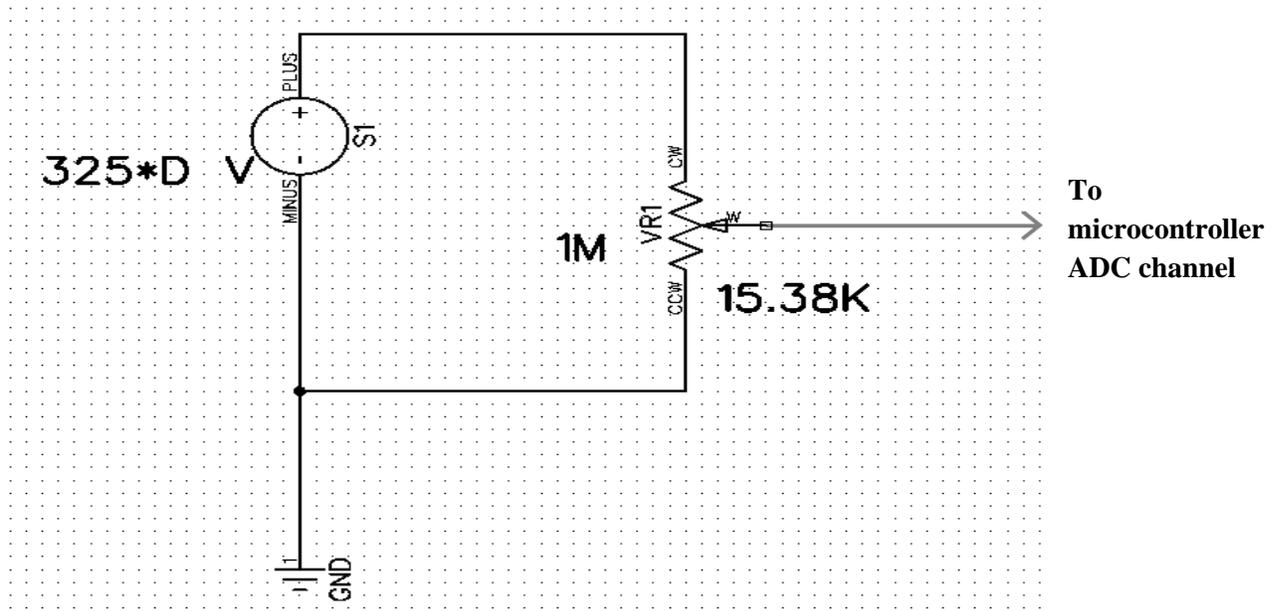


Figure 5.3 Measurement of output voltage by microcontroller

Analysis of the above figure shows that for  $D=1$  (maximum value), the input voltage is 5V. So the transformation ratio is  $325/5=65$ . So the input voltage to microcontroller ADC channel has to be multiplied by 65 to get the corresponding output voltage of the converter.

The different values of the output voltage are stored in the microcontroller for a time period of 2.5 milliseconds ( $1/400\text{Hz}$ ). After getting all those values for a cycle the average voltage  $V_o$  is calculated and scaled up by a factor of 65.

### 5.3.2 PID implementation

The error in the voltage is calculated by comparing the average output voltage  $V_o$  and set point voltage  $V_{set}$ . This is given as

$$e(t) = V_{set}(t) - V_o(t)$$

After getting the error signal, the PID algorithm is applied to generate necessary control action for the plant. The input to the plant is generated by processing the error signal and hence the desired voltage is achieved by adjusting the duty cycle of the gate pulse to the IGBT.

### 5.3.3 The Plant Model

The converter including the source can be modeled as shown in figure.

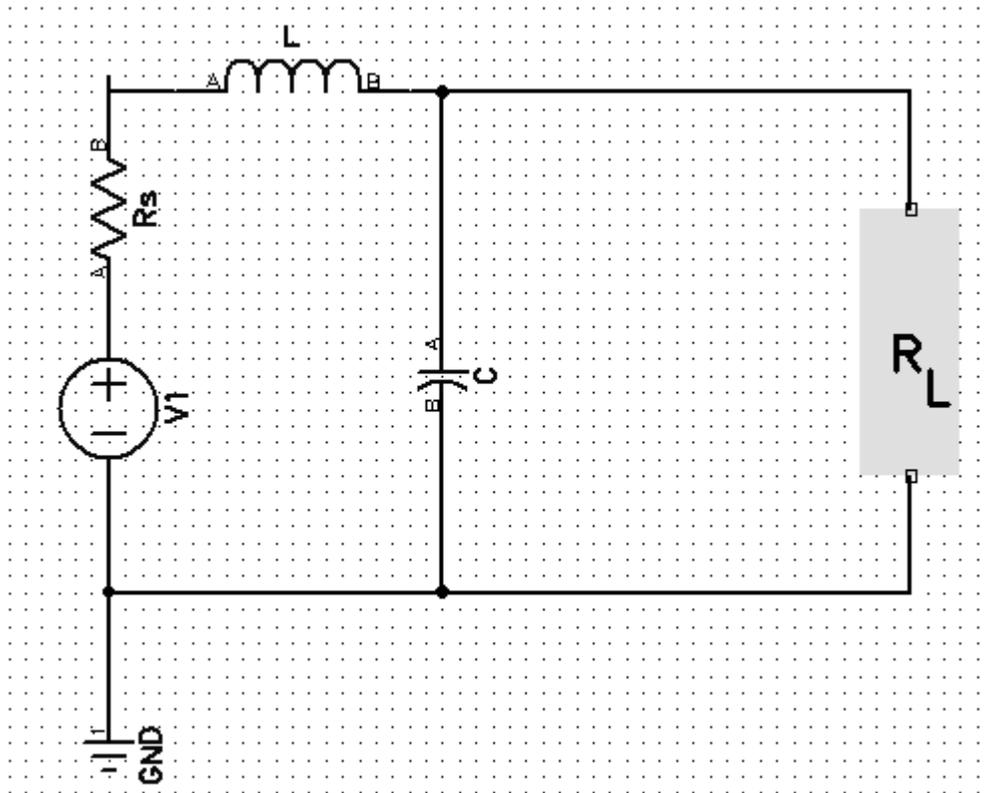


Figure 5.4 Plant Model

Let \$V\_1\$ = source dc voltage, \$V\_L\$ = voltage across the load, \$R\_s\$ = source resistance

The transfer function of the open loop gain is found as:

$$H(s) = \frac{V_L(s)}{V_1(s)} = \frac{R_L}{s^2(R_s * L * C) + s(R_L * R_s * C + L) + (R_L + R_s)}$$

The open loop response of the model, obtained by Matlab, to step input of 20V is shown below. The response shows that, the output voltage never reaches the same as the input voltage.

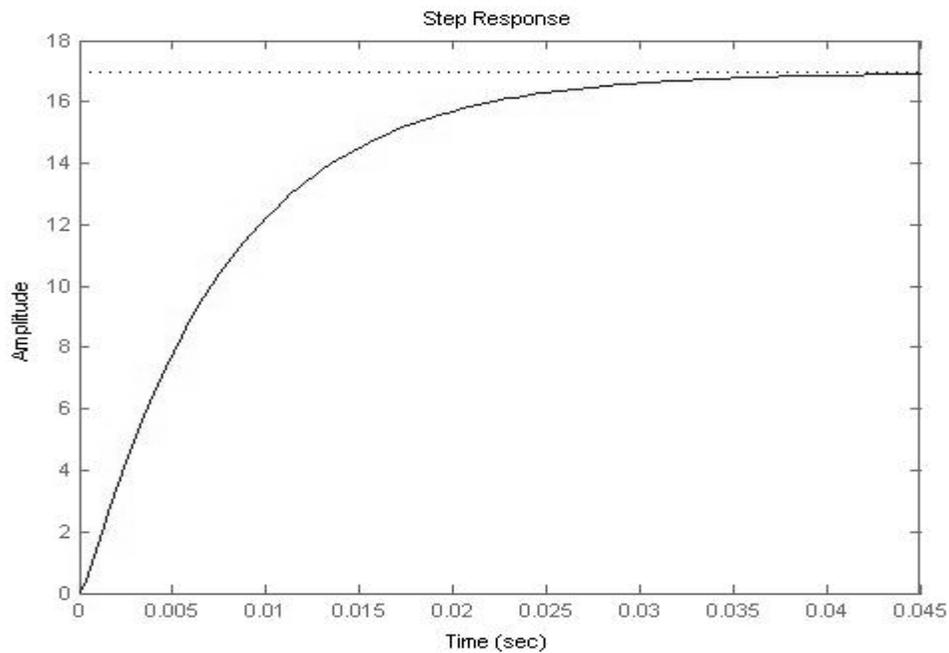


Figure 5.5 Open loop response

### MATLAB program

```
clc;
clear all;
close all;
E0=1;
rs=1;rl=50;L=0.015,C=10(-3);
num=[ rl];
den=[ rs*L*C rl*rs*C+L rl+rs];
u=20/E0;
step(u*num,den);
```

### 5.3.4 Proportional Integral Derivative control (PID)

The close loop transfer function (G) ,in laplace domain,of the model including the PID controller is given as follows.

$$G(s) = \frac{(K_p + \frac{K_i}{s} + s * K_d) * H(s)}{1 + (K_p + \frac{K_i}{s} + s * K_d) * H(s)}$$

or

$$G(s) = \frac{s^2(K_d * R_L) + s(K_p * R_L) + K_i * R_L}{s^3(R_s * L * C) + s^2(R_L * R_s * C + L + K_d * R_L) + s(R_L + R_s + K_p * R_L) + K_i * R_L}$$

Where  $K_p$  = Proportional gain

$K_d$  = Derivative gain

$K_i$  = Integral gain

### 5.3.5 Application of Proportional control (P)

Applying proportional control only we get the following response for a voltage variation of 20V, due to load change. Here  $K_p = 50$ ,  $K_d=0$ ,  $K_i=0$

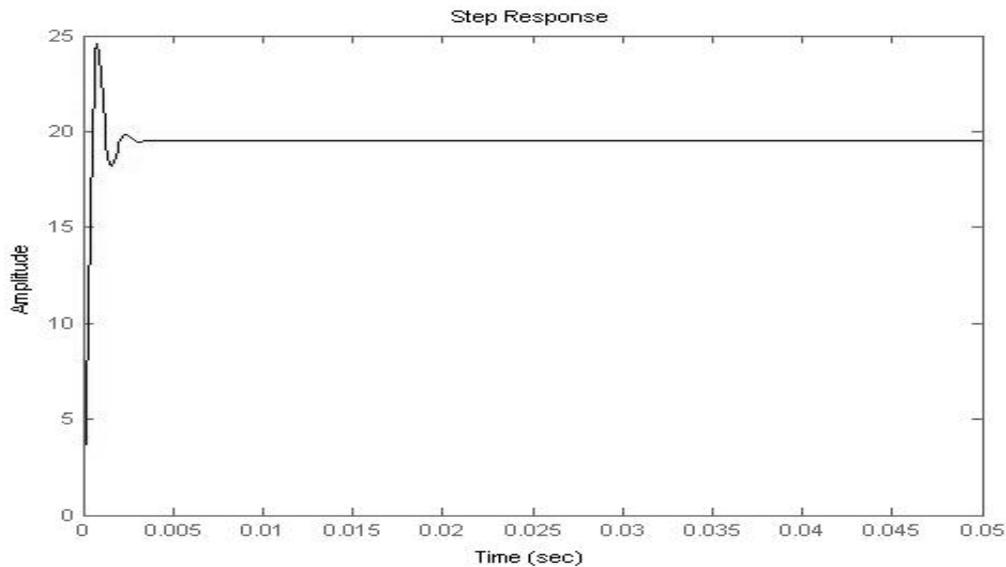


Figure 5.6 Response due to proportional control

### MATLAB program

```
kp=50;
ki=0;
kd=0;
num2=[ kd*rl kp*rl ki*rl];
den2=[ rs*L*C rl*rs*C+L+kd*rl rl+rs+kp*rl ki*rl];
figure;
t=0:0.0001:0.05;
step(u*num2,den2,t);
```

### 5.3.6 Application of Proportional Integral control (PI)

Applying Proportional-Integral control we get the following response for a voltage variation of 20V, due to load change. Here  $K_p = 50$ ,  $K_d=0$ ,  $K_i=200$

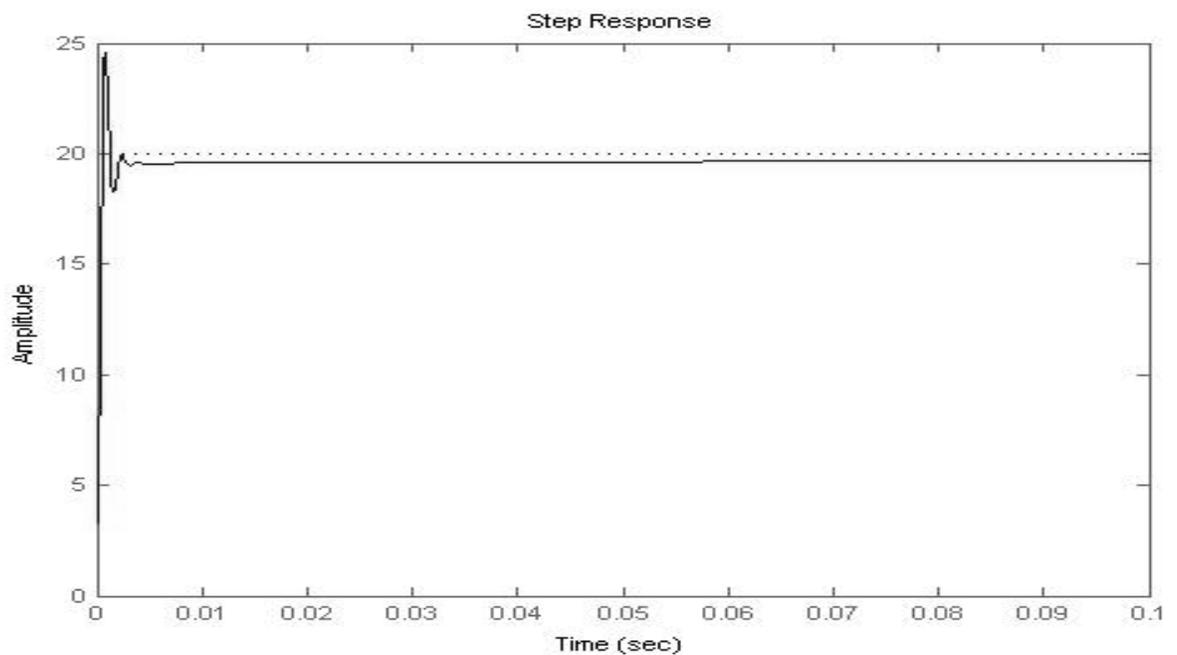


Figure 5.7 Response due to P-I control

## MATLAB program

```
kp=50;  
ki=200;  
kd=0;  
num2=[ kd*rl kp*rl ki*rl];  
den2=[ rs*L*C rl*rs*C+L+kd*rl rl+rs+kp*rl ki*rl];  
figure;  
t=0:0.0001:0.1;  
step(u*num2,den2,t);
```

### 5.3.7 Application of Proportional-Integral-Derivative control (PID)

Applying Proportional-Integral-Derivative control we get the following response for a voltage variation of 20V, due to load change. Here  $K_p = 50$ ,  $K_d=0.03$ ,  $K_i=200$

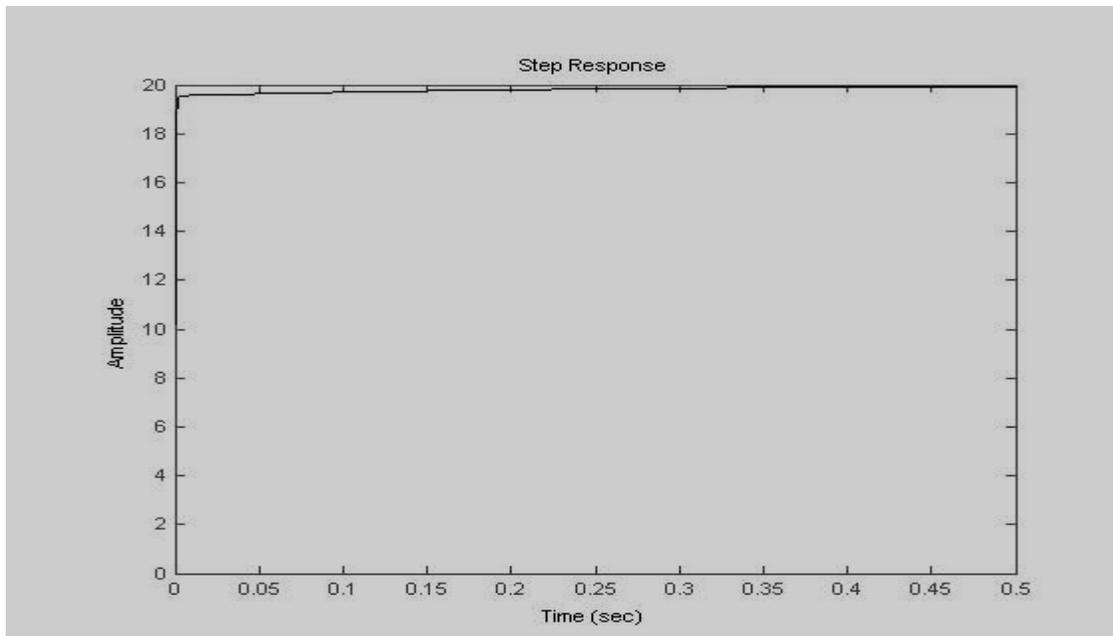


Figure 5.8 Response due to P-I-D control

## MATLAB program

```
kp=50;
ki=200;
kd=0.03;
num2=[ kd*rl kp*rl ki*rl];
den2=[ rs*L*C rl*rs*C+L+kd*rl rl+rs+kp*rl ki*rl];
figure;
t=0:0.0001:0.5;
step(u*num2,den2,t);
```

### 5.3.8 Simulation of output voltage in Simulink

When the current changes, the output voltage fluctuates but comes back to set-point voltage due to application of P-I-D control. Total P-I-D control algorithm is simulated using Simulink.

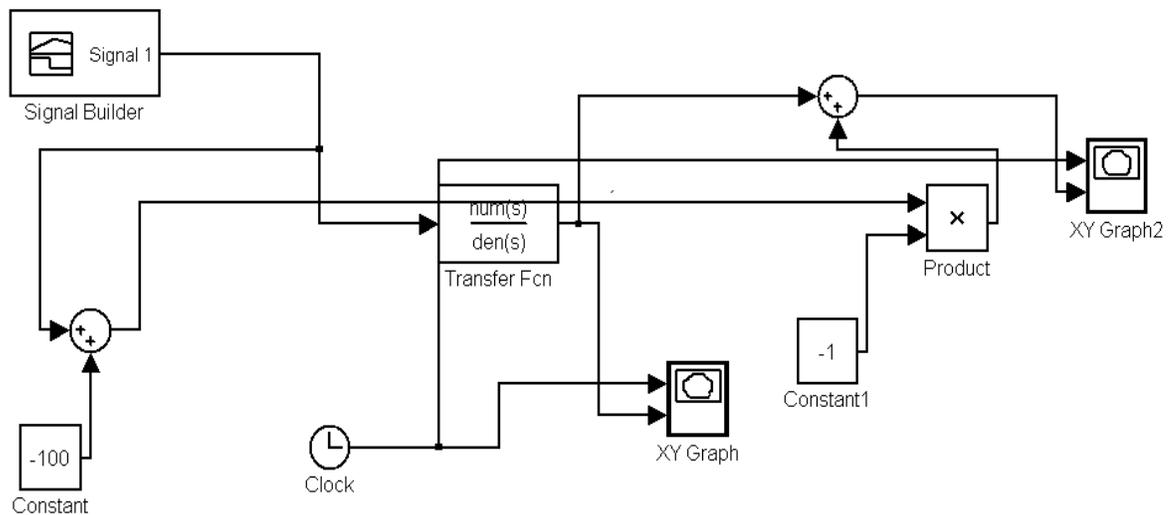


Figure 5.9 Simulink Block diagram

The graphs showing the load voltage variation with P-I-D control and without control is shown below. are shown below.

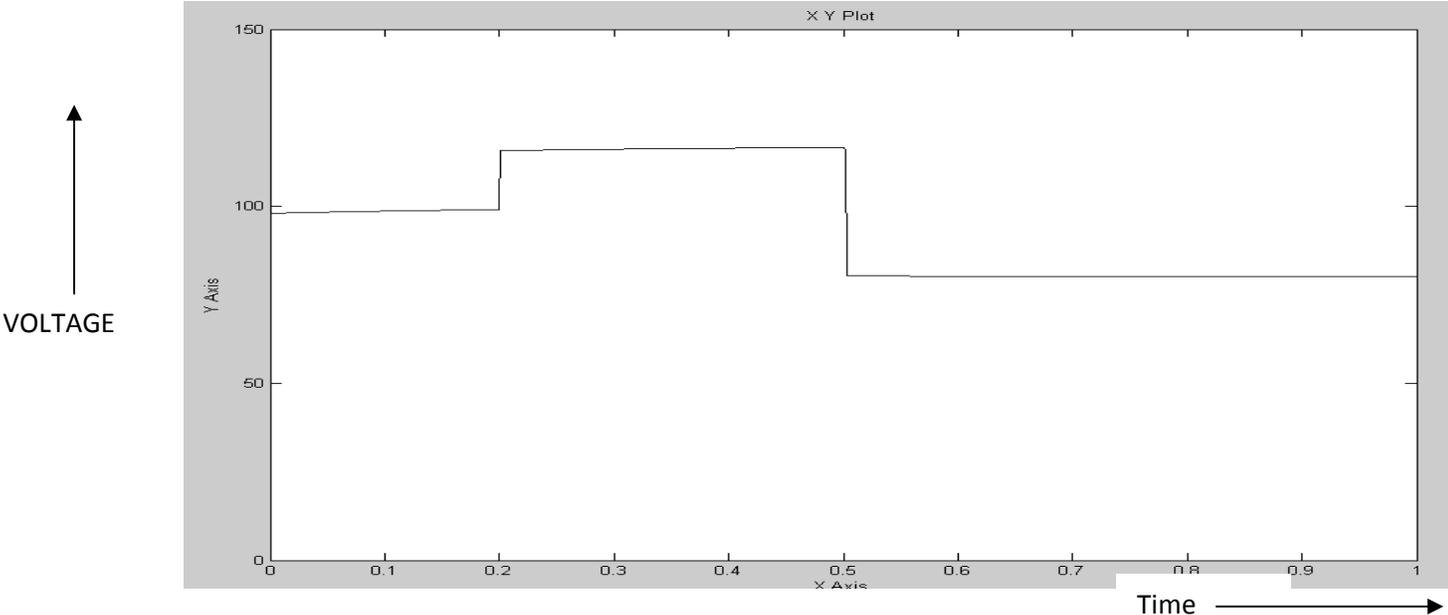


Figure 5.10 Voltage variation due to load change without control

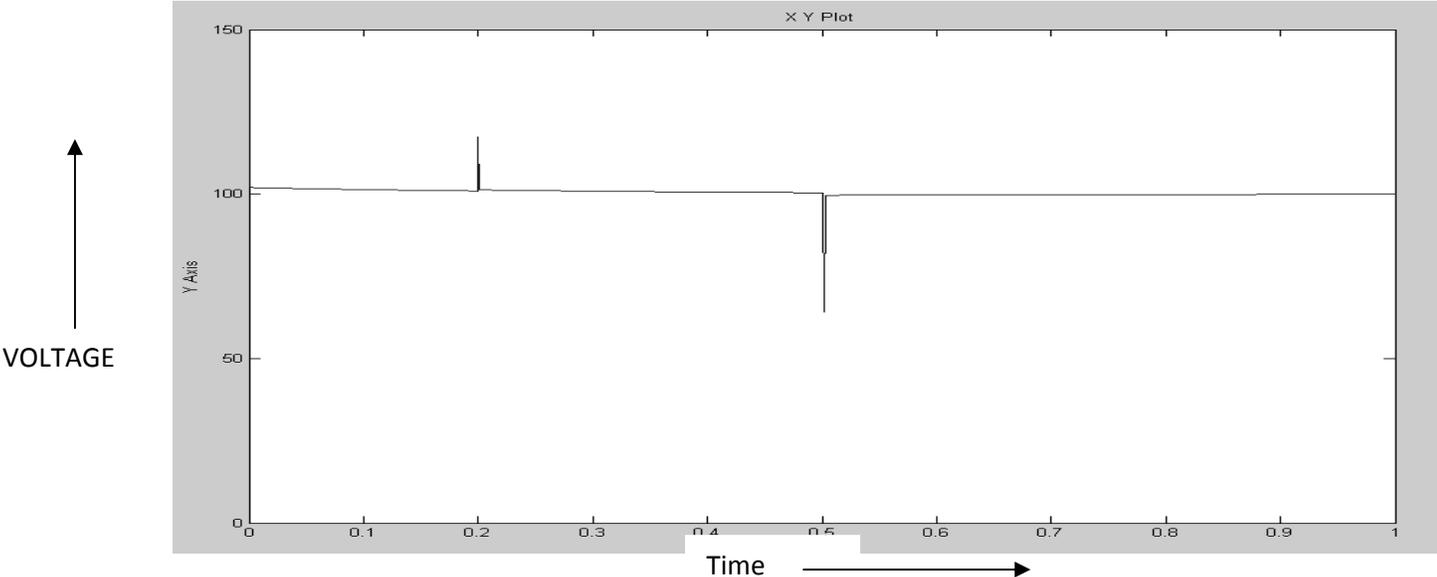


Figure 5.11 Voltage variation with P-I-D control

### 5.3.9 Load resistance measurement

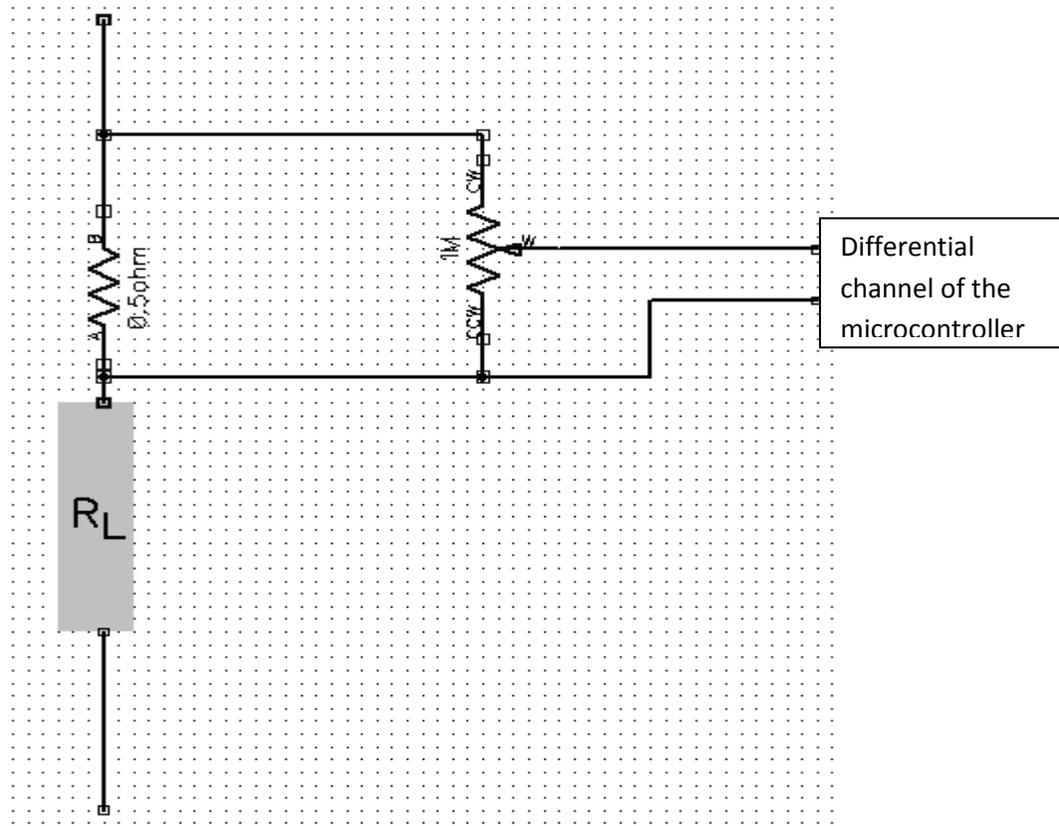


Figure 5.12 Calculation of load resistance

Design is being done for the maximum load current of 30A. Hence the drop across the test resistance ( $0.5\ \Omega$ ) is 15V (maximum). This voltage is scaled down by the potentiometer of  $1\ \text{M}\Omega$  to a range of 0V to 5V, in order to make it compatible with the microcontroller, and measured by using the differential channel of the microcontroller. Hence load current in the circuit is determined. Now dividing the load voltage by the load current the load resistance is determined.

### 5.3.10 Voltage control across the load due to AC voltage fluctuation

Maximum DC voltage is given as :  $V_{dc, mx} = V_{rms/ac} * \sqrt{2} = 230 * 1.414 = 325.27V$

Average voltage across the load is given as:  $V_L = D * V_{dc, mx}$

Where D = duty cycle of the gate pulse

$V_{dc, mx}$  is calculated by scaling down the voltage at the rectifier end by a  $1M\Omega$  potentiometer to a voltage range of 0v to 5v range, in order to make it compatible with the microcontroller, and connected to the ADC channel(PA3 pin) of ATNEGA32. For a given output load voltage( $V_L$ ) the ratio between  $V_L$  and  $V_{dc, mx}$  , which is same as the duty cycle, is calculated and the is change d to the new calculated value to maintain the constant set-point voltage across the load.

The microcontroller is programmed to work for certain tolerance limit of AC voltage fluctuation, beyond which the circuit is isolated by switching of the gate pulse.

# **CONCLUSION**

We draw the following conclusions

1. We have performed the simulation work and could able to vary the average voltage using
2. PWM technique with a low fluctuation.
3. IGBTs possess many desirable properties including high switching speed, low conduction voltage drop, high current carrying capability, and a high degree of robustness.
4. The availability of IGBTs lowers the cost of systems and enhances the number of economically viable applications.
5. The insulated gate bipolar transistor (IGBT) combines the positive attributes of BJTs and MOSFETs. BJTs have lower conduction losses in the on-state, especially in devices with larger blocking voltages, but have longer switching times, especially at turn-off while MOSFETs can be turned on and off much faster, but their on-state conduction losses are larger, especially in devices rated for higher blocking voltages. Hence, IGBTs have lower on-state voltage drop with high blocking voltage capabilities in addition to fast switching speeds.
6. By varying the duty cycle of the gate pulse of IGBT, the output voltage was effectively varied.
7. By use of multipulse triggering, the harmonics were significantly reduced.
8. When load varies, the output voltage fluctuates. So PID control algorithm is used.
9. In proportional control error is reduced but can't be eliminated. In P-I control error is completely eliminated after certain time, but overshoot is increased. In P-I-D control, due to derivative gain, the overshoot is minimized.

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