# Speed Control of Three Phase Induction Motor Using Universal Bridge and PID Controller

**A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.**

**Submitted by**

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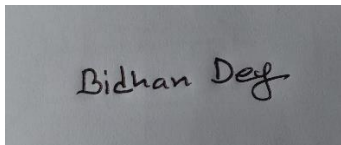
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# DECLARATION

I hereby declare that this project "**Speed Control of Three Phase Induction Motor Using Universal Bridge and PID Controller**" represents my own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval, and acknowledged my obligations and the rights of the participants.

**Signature of the candidates**

Name: Bidhan Dey

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# APPROVAL

The project entitled **"Speed Control of Three Phase Induction Motor Using Universal Bridge and PID Controller"** submitted by **Bidhan Dey (183-33-790)** Batch No: 28, Session: Fall 2018 has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **June, 2023.**

**Signature of the Supervisor:**



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**Mr. Md. Zakir Hasan**

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Daffodil International University

Dedicated

To

**Our Parents**

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| PID | Proportional-Integral-Derivative |
| PWM | Pulse Width Modulation |
| SVM | Space Vector Modulation |
| VSI | Voltage Source Inverters |
| SVPWM | Space Vector Pulse Width Modulation |
| SPWM | Sinusoidal Pulse Width Modulation |
| PMSM | Permanent Magnet Synchronous Motor |
| HVAC | Heating, Ventilation, and Air Conditioning |
| RPM | Revolutions Per Minute |
| AC | Alternating Current |
| DC | Direct Current |
| FOC | Field-Oriented Control |
| UB | Universal Bridge |
| AVR | Automatic Voltage Regulator |
| V/F | Voltage to Frequency |
| IGBT | Insulated Gate Bipolar Transistor |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| DSP | Digital Signal Processor |
| R-L Load | Resistive-Inductive Load |

# LIST OF SYMBOLS

| Symbol | Name of the symbol |
|--------|-------------------|
| λ | Wavelength |
| π | Damping ratio |
| f | Frequency |
| ρ | Magnitude coefficient |
| L | Inductance |
| C | Capacitance |
| Z0 | Impedance |
| h | Height |
| fr | Resonant frequency |
| L | Inductance |
| Γ | Reflection coefficient |
| ω | Angular frequency |
| fr | Resonant frequency |
| Δ | Delta |
| p | Number of Motor Poles |
| $n0$ | Synchronous Rotational Speed in rev/min |
| $\lambda_m$ | rated flux of the motor in Wb |
| $V_s$ | AC motor stator voltage |
| $f_s$ | frequency (Hz) of the AC motor stator voltage |
| Speed(rpm) | Mechanical Speed (rpm) of the AC motor |

# ACKNOWLEDGEMENT

First of all, we want to give thanks to **Almighty Allah**. With his blessing we are able to complete our work with best effort.

We want to pay our utmost respect to our Supervisor **Mr. Md. Zakir Hasan, Lecturer** of the **Department of EEE, Daffodil International University** for who has given us the chance to work on an impactful idea and taken care of every issue of development of this concept. Then we would like to take this opportunity to express gratitude to our supervisor for being dedicated in supporting, motivating and guiding us throughout this project. This project can't be done without his useful advice and help. Also thank him very much for giving us the opportunity to work with this project.

# ABSTRACT

In simpler terms, techniques to control speed are very important in a system that can change how fast it goes. A device called a three-phase voltage source inverter can give the system different levels of voltage and frequency power. This article explains how to use a device called a universal bridge and a method called pulse width modulation to change the speed of a motor that runs on a special type of electricity called three-phase voltage. The motor is called an induction motor. A machine was made to control the highest amount of electrical power in a device called a voltage source inverter. Matlab/Simulink is used to study the speed control systems and see how well they work if they are open or closed. The simulation showed that the speed controller works well and can make the induction motor work better.

**Keywords***:* Three Phase Induction Motor, Speed Control, Voltage Source Inverter, Universal Bridge, PID Controller**.**

# CHAPTER 1
# INTRODUCTION

## 1.1 Introduction

Asynchronous motors and induction motors are currently widely utilized in industrial drives due to their simplicity, low-cost engine construction and high durability. The high level of motor complexity makes this engine control complicated. To control motor engines, many control systems have been presented. PWM speed control is used in this method. With the development of power electronics, this control has expanded quickly. They have been successful in using inverter components, which has increased its popularity. Furthermore, PWM control is unfortunate since it is one of the widely used methods for managing the intricate nature of three-phase induction and asynchronous motor systems. With this method, the average voltage is set by varying the pulse width and pulse duty ratio. The waveform of the inverter's output signal can be improved by employing the PWM approach to reduce harmonic and ripple output torque. With this method, the inverter's design is simplified in order to quicken level adjustments and boost the system's dynamic reaction. The motor is crucial to finishing the variable-speed motor in the field of electric propulsion.

## 1.1.1  3-Phase Induction Motor

A 3-phase induction motor changes 3-phase electrical power into moving power.
A 3- Phase Induction Motor has two parts: the stator and the rotor. The rotor has a broken wire called rotor winding, and the stator has three wires called stator winding. The stator winding gets electricity from the three-phase supply. The rotor gets its electricity and energy from the stator using electromagnetic induction, which is why it's called that.

## 1.1.2 Working principles of three phase induction motor

A three-phase motor works in a different way than a single-phase motor. When three electrical currents are sent to the motor's coils, the coils are spun around at a certain angle. This produces a moving magnetic force inside the motor. The important parts of a three-phase AC induction motor are the stators and rotors that have three phases.

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When you give energy to the stator using a source of electricity with three parts, it makes electricity flow through it. The electric current in three parts creates a magnetic field that keeps moving smoothly even if the current changes. The rotor gets cut by a spinning magnetic field, which makes it spin because of the electricity it creates. See Figure 1. The rotor needs to spin more slowly than the magnetic field. The three-phase machine that can be adjusted will make the rotor spin in the opposite direction.
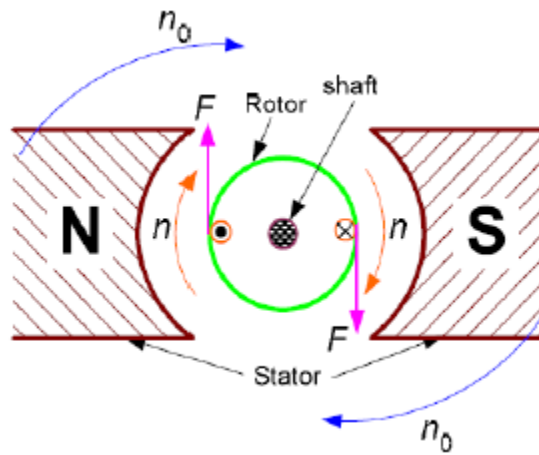


**FIG: Rotating magnetic flux of asynchronous motor**

While the field is spinning, the speed value is inversely proportional to the frequency and the polar pair number, and the direction is the same with phase current. This equation can be used to calculate the rotational magnetic field's speed n0 in units of minutes.

$$n0 = 120 \; x \; f/P$$

Where,

n0 = synchronous rotational speed in rev/min

f = power supply frequency in Hz

p = number of motor poles

The number of poles and the power source frequency decide how fast the stator flux rotates, which is the synchronous speed of the motor. In real life, the rotor spins slower than a specific speed called synchronous speed. Induction motors are called asynchronous motors because their rotor speed changes depending on the stator flux. The slip is caused by variations in the rotational flux of the stator and the rotor speed. Slip varies in value from 1% to roughly 6% of stator flux speed.

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### 1.1.3 Three Phase Induction Motor Advantages and Disadvantages

Here are the most important benefits of using a 3-phase induction motor:

- The design is simple and long-lasting.
- It does not need a lot of attention to keep it working properly.
- It costs less.
- It works really well and uses energy efficiently.
- It can start moving by itself without help.

Here are some problems that come with using a 3-phase induction motor:

- It is difficult to change the speed of 3-phase induction motors because they always run at the same speed.
- Three phase induction motors have a problem where they start with too much electricity and not enough power. It can be up to 8 times more electricity than they need.
- They always work efficiently, but when there is nothing to use them, they work poorly.

## 1.2 Problem Statement

The main reason behind this system to improve the tuning of PWM Generator and PID controller to gain better output from this system.

## 1.3 Aims/ Objectives

This project's and the thesis' goals are as follows:

i. To create a PID controller to control system design.

ii. Using MATLAB Simulink to simulate and create the PID controller model.

iii. Controlling the induction motor's current to examine the PID controller's performance.

iv. Adding the PID current control design to the induction motor hardware.

## 1.4 Brief Methodology

We'll use tools to make the project work well. These tools are MATLAB, Simulink, and Simpowersystem.

## 1.4.1 Asynchronous machine/induction machine (squirrel cage)

A type of motor called a three-phase asynchronous motor is shown as an induction/asynchronous machine block, and it can be either a wound rotor or squirrel cage model. This machine can work like a generator or a motor. How well the function works depends on the machine's torque value.

- If the Tm value is positive, the device will work like a motor.
- If Tm is a minus number, the device will work like a machine that makes electricity.

## 1.4.2 Universal bridge

A device called "universal bridge block" is used to convert electricity in a three-phase power system. There are six switches connected together like a bridge in this area. The universal bridge gives power to things that use electricity.

## 1.4.3 Pulse Width Generator

Pulse width modulation (PWM) means making the average voltage higher or lower by changing how long the pulses are in a period. In telecommunications, we use something called data modulation. We also use PWM for things like controlling power or voltage going to a device, making sound effects, and boosting the volume of audio. To make a PWM signal, you can compare two voltages using a circuit with an op-amp comparator. One voltage is a sawtooth waveform and the other is a fixed reference voltage. This analog works by comparing voltages to sawtooth waveforms. If the reference voltage is bigger than the sawtooth (zigzag), the comparator will say "yes" and give a high output. If the reference voltage is lower than the carrier voltage, then the output of the comparator will be low. The level of voltage can be adjusted by changing how frequently the output signal turns on and off. This happens because of how the comparator works.

### 1.4.4 System overview

MATLAB/ Simpowersystem had been used to build and simulate the system's proposed circuit. illustrates the suggested model's Simulink circuit.

### 1.4.5 Open loop system

There are four basic parts to the open loop system. These are the Asynchronous machine block, PWM generator, universal bridge, and DC voltage supply. The speed cannot be controlled via feedback in an open loop system. Hence, the speed is dependent on the supply's dc voltage value. Many induction motors often employ the open loop control technique for control. This control is easy to develop because it only requires a few components.

### 1.4.6 Closed loop system

Closed loop systems are better than open loop systems. A closed loop system has five basic parts. This is made up of different blocks like a motor, a voltage source, a controller, a bridge, and a generator. This picture shows the circuit of the closed loop system. Speed sensors are used to give information to control systems so they can keep things at the right speed. The mistake is when the speed you drive your vehicle is not the same as the recommended rotations per minute. The mistake is fixed by the PID block which controls the voltage sources. The thing that helps the universal bridge work, called the controlled voltage source, creates a changeable steady electric current. The universal bridge is changed by using special sources of electricity that can change from direct current to alternating current. This bridge makes electricity in three parts to run a special motor. The speed of the asynchronous motor depends on the voltage and frequency of the output from the universal bridge. The speed is adjusted to get as close as possible to a set speed.

## 1.5 Implementation Schedule / Gantt Chart

| ID | Task Name | Start | Finish | Duration |
|----|-----------|-------|--------|----------|
| 01 | Discussion about the thesis topic | 12-05-2022 | 12-06-2022 | 30 Days |
| 02 | Problem Analysis | 13-06-2022 | 13-07-2022 | 30 Days |
| 03 | Finalizing the thesis topic | 14-07-2022 | 23-07-2022 | 10 Days |
| 04 | Initial Design review | 24-07-2022 | 23-08-2022 | 30 Days |
| 05 | Discussion on Design Improvisation with Supervisor | 24-08-2022 | 07-09-2022 | 15 Days |
| 06 | Design Improvisation | 08-09-2022 | 22-09-2022 | 15 Days |
| 07 | Result Evaluation | 23-09-2022 | 12-10-2022 | 20 Days |
| 08 | Final Design for Approval | 13-10-2022 | 27-10-2022 | 15 Days |
| 09 | Report Writing | 28-10-2022 | 05-03-2023 | 129 Days |
| 10 | Plagiarism check in the library | 28-04-2023 | 09-05-2023 | 12 Days |
| 11 | Thesis Submission | 10-05-2023 | 15-06-2023 | 37 Days |

## 1.6 Structure of the Report

Chapter 1 Is the beginning part of the thesis that talks about what the thesis is about, what it aims to achieve, and how the research for it was done.

Chapter 2 Talks about reviewing other people's work, comparing and contrasting different studies, and summarizing the key findings.

Chapter 3 Talks about the Things and Steps Involved in Designing a System, such as Materials, Methods, Components, and Standards. It also Explains how to Analyze and Test the System using Simulations, and Provides a Summary of the Project.

Chapter 4 Talks about what we found out and the conversations we had about it.

Chapter 5 Teaches about managing projects, managing resources and costs, and learning from past experiences.

Chapter 6 Explains how to measure the effects of the project.

Chapter 7 Is the end part of the work and suggests ways to improve it for the future. Thinking deeply and reflecting.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Introduction

The purpose of the literature review in this document would be to provide a comprehensive analysis and synthesis of existing research on this topic, which would help to identify the current state of knowledge, identify gaps in the literature, and inform the development of the new research presented in the document.

Three-phase motors are often used in industries because they work well, are dependable and strong. It's hard to control the speed of these motors, and it needs special techniques. The literature review will discuss different ways to control the speed of three-phase induction motors. It will include using universal bridge and PID controllers, as well as other advanced methods. The review will talk about the good and bad things of each approach, and suggest ideas for more research.

## 2.2 Related Research/ Works

The plant is represented without respect to its physical constraints when dealing with real systems PI tweaking. As a result, the PI output may continue to increase in value indefinitely; this process is known as windup. This research includes a review and a comparison between alternative Anti-Windup PI techniques utilized in speed motion and position control for Matrix Converter PMSM servo systems. [1]

In this study, a speed tracking control method using pulse width modulation (PWM) is developed for three-phase induction motors used in electric vehicles. The PWM design method is used to create controllers. The PWM control strategy is designed by integrating the three-phase bridge rectifier into the motor based on the PWM technology. The disadvantage of the motor in the conventional design process is capable of being overcome by the proposed control approach. Additionally, it is demonstrated that all closed-loop signals are bounded and that tracking error converges to a tiny neighborhood of all origin. The outcomes of the MATLAB simulation show how effective the suggested method is. [2]

Since the use of renewable energy sources has grown and will continue to grow significantly in the future. Particularly, solar energy will be a key source of energy in the future. Since the inverter's output is direct current, it becomes essential for the movement of electricity from solar panels to storage batteries, loads, and grids. An inverter based on sinusoidal pulse width modulation will be used as a three-phase voltage source. A sinusoidal reference wave with the desired frequency is compared to a high frequency triangular carrier wave. Each pulse's width varies according to the amplitude of a sine wave known as SPWM. The advantage of SPWM approach is that it minimizes the harmonic contents of the output voltage compared to single pulse width modulation and multi-pulse modulation. The benefit of an inverter with two stage three-phase bipolar SPWM is good performance and efficiency since it twice the inverter voltage's switching frequency, which makes the output filter smaller, less expensive, and simpler to use. With and without a filter across a resistive load, a three phase, two level SPWM inverter-based voltage source inverter will be simulated using MATLAB, and the total harmonic distortion of both cases will be compared. The volts/hertz approach is used to implement the application of SPWM inverter in three phase induction motor speed control. Induction motor speed control MATLAB simulation is carried out, and its THD analysis along with current and voltage are performed. An induction motor speed control hardware implementation is created. [3]

Another alternative modulation method that was found to be superior than SPWM methods in some areas will be used in this work, called space vector modulation (SVM). While building three phase sine wave voltage source inverters (VSI) in parallel to drive three-phase motors utilizing vector control methods, Space Vector Pulse Width Modulation (SVPWM) has proven to be a successful technique. For the three-phase induction motor, the VSI has six legs, and eight switching sequences have been simulated in MATLAB/SIMULINK. The simulation's outcome demonstrates the viability of the modulation strategies for driving three-phase induction motors that have been suggested. [4]

Variable speed drive demand can be linked to new applications in process drives, HVAC drives, professional hand tools, automotive accessories, fans, and home appliances. Nearly many of these applications are low performance because they don't need precise positioning or speed control. Notwithstanding their benefits in terms of

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energy savings, control, and operational flexibility, they are particularly cost-sensitive because the choice to introduce them is mostly based only on the cost. The inverter Due to the inexpensive cost of the motor and its inherent features, such as its brushless design and operation, robust and tested construction, and proven operation, controlled induction motor drives are a strong competitor for such applications. These applications typically call for low performance motors. However, the inverter and its controller account for the majority of the cost of the variable speed induction motor drive. A principle of v/f control of the output voltage in PWM voltage-source inverters is described. [5]

The design and implementation of PID current control for an induction motor are presented in this project. The PID controller is used to regulate the induction motor's output current. The implementation of the control system design is controlled by Arduino board devices. MATLAB/Simulink software is used to create and simulate the PID controller. downloading to Arduino, which then produces the PWM signal the signals are then sent to the gate driver of a three-phase inverter to provide the induction motor with a stable performance. By comparing the motor's actual measured currents to its reference current, performance can be improved. After that, the discrepancy is adjusted, reducing the present inaccuracy. To prove the viability of this strategy, a straightforward hardware implementation of the PID current controller is constructed, and experimental findings are shown. Three conditions—simulation, open-loop control, and close-loop—are used to observe the results. The intended system has been successfully implemented, according to observations. [6]


Induction motor scalar control design and implementation are discussed in this work. This technique allows for the control of the frequency and amplitude of the induction motor's stator voltage, with the requirement that the ratio of stator voltage to frequency be maintained constant (V/F or scalar control of induction motor drive). This research gives a comparative study of open loop \sand close loop V/F control induction motor. The introduction of stator voltage derivatives is the basis of the V/F control. For induction motor speed control, simulation is performed in a MATLAB/SIMULINK environment, and results are compared. [7]

## 2.3 Compare and Contrast

There are different ways to control the speed of a three-phase induction motor, such as using a universal bridge or a PID controller. Here is a way to see the similarities and differences between two methods.

Universal Bridge:

A universal bridge is a special circuit that can make an induction motor go faster or slower. There are four switches that connect to the motor's wires. To change how fast the motor goes, we can turn different switches on and off in a certain order to control the flow of electricity in the motor's coils.

Comparison:

The universal bridge control is an easy and cheap way to control the speed of induction motors. The universal bridge method can control speed quickly. It can work at many different speeds.

Contrast:

Universal bridge control is not as precise as PID control as it lacks feedback control, and its performance can vary depending on the load and other factors. It may result in significant power losses due to switching losses and other inefficiencies in the circuit.

PID Controller:

A PID controller is a type of machine that helps to control how fast a motor goes. It does this by using three different things called proportional, integral, and derivative terms. It checks if the motor is going too fast or too slow, and makes changes to make it go at the right speed.

Comparison:

A PID controller provides precise and accurate speed control of induction motors as it has feedback control. PID controllers can be tuned to provide optimal performance, making them suitable for applications that require high precision. It can handle disturbances in the system and bring the motor back to its setpoint.

Contrast:

PID control is more expensive than universal bridge control as it requires additional hardware and software components. It has slower response times as it depends on the time constant of the system. PID controllers have limitations in the range of speeds it can control.

Both universal bridge and PID control methods can work well to control the speed of a three-phase induction motor. You need to think about how exact you need something to be, how much money you want to spend, how fast it needs to go, and how quickly it needs to react before deciding.

## 2.4 Summary

Many studies have been done to find ways to control the speed of a three-phase induction motor using a universal bridge and a PID controller. These studies have looked at different methods to control the motor's speed so that it works well and is accurate.

Changing how often the electricity flows can make an AC motor go faster or slower. You can do this with a special machine called a universal bridge. It can change how much electricity comes out and how fast it comes out. The universal bridge is usually managed by a signal called pulse-width modulation (PWM), which comes from a device called PID controller.

Many researchers have investigated the performance of PID controllers for speed control of induction motors. PID controllers are widely used in industrial applications because they are simple to implement and provide good performance. However, tuning the PID controller parameters can be a challenging task, and many researchers have proposed different tuning methods to optimize the performance of the controller.

Several studies have investigated the use of different types of universal bridges for speed control of induction motors. For example, some researchers have used a single-phase universal bridge, while others have used a three-phase bridge. In addition, some studies have investigated the use of different modulation techniques for controlling the

universal bridge, such as sinusoidal PWM, space vector modulation, and hysteresis current control.

The research shows that using a universal bridge and a PID controller can help make a three-phase induction motor work well by controlling its speed accurately and efficiently. The type of bridge used and how the PID controller is set up can really impact how well the system works. This type of system needs more research to find the best way to design and control it.

# CHAPTER 3

# MATERIALS AND METHODS [OR PROJECT/SYSTEM DESIGN]
# [OR DESIGN PROCEDURE]

## 3.1 Introduction

We will use some computer tools called MATLAB, Simulink, and Simpowersystem to help finish the project well.

## 3.2 Methods and Materials or System Design and Components

## 3.2.1 Asynchronous Machine PU Units

The Asynchronous Machine block creates electric machines that use three phases and can have different types of rotors like winding, single squirrel cage, or double squirrel cage. It can work like a machine that makes electricity (generator) or like a machine that uses fuel to move (engine). The way it works is controlled by whether the mechanical force is positive or negative.

- If Tm is positive, the machine works like a motor.
- If Tm is a minus number, then the machine makes power.

The machine has two main parts: the electrical part and the mechanical part. The electrical part can be described using a math model called a quaternary (or sixth order for some machines) state space model. The mechanical part can be described using a math model called a quadratic system. The first signs in the machine equations show the electrical things in the stator. The stator and rotor are measured in a special way called the "dq frame of reference."
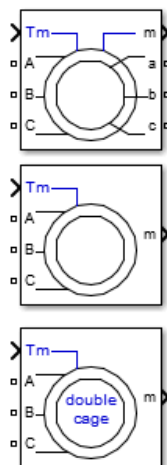


**FIG: Asynchronous Machine**

The indicators used are defined in this table.

| Table of contents | Definition |
|---|---|
| d | number of axes d |
| q | number of axes q |
| r | Number of rotors (wound rotor or single-cage rotor) |
| r1 | Number of cages 1 rotor (double cage) |
| r2 | Number of cage rotor 2 (double cage) |
| s | Number of stators |
| I | Leakage inductance |
| m | Inductor magnetization |

**Electrical system of the rotor winding machine or squirrel cage machine:**
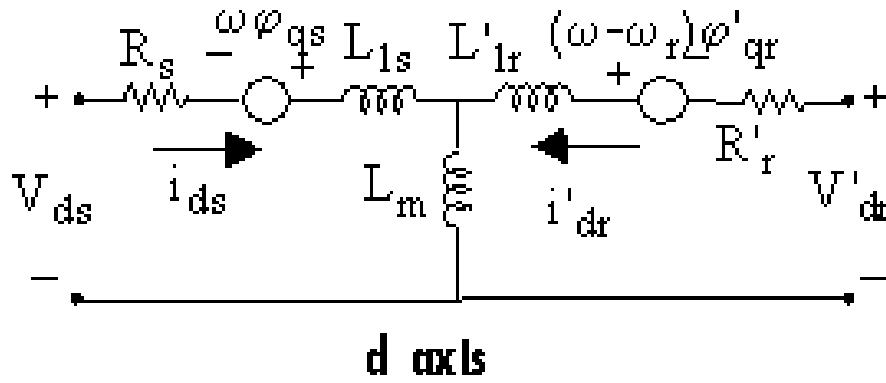


$$q\ axis$$
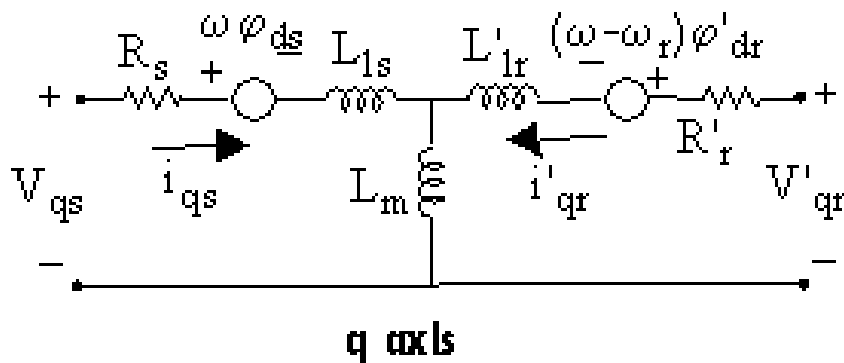
$V_{qs} = R_s i_{qs} + d\varphi_{qs}/dt + \omega\varphi_{ds}$

$V_{ds} = R_s i_{ds} + d\varphi_{ds}/dt - \omega\varphi_{qs}$

$V'_{qr} = R'_r i'_{qr} + d\varphi'_{qr}/dt + (\omega - \omega_r)\varphi'_{dr}$

$V'_{dr} = R'_r i'_{dr} + d\varphi'_{dr}/dt - (\omega - \omega_r)\varphi'_{qr}$

$T_e = 1.5p(\varphi_{ds}i_{qs} - \varphi_{qs}i_{ds})$

d axis

$\omega$ — Angular velocity of the frame of reference

$\omega_r$ — Electric angular velocity

$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr}$

$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr}$

$\varphi'_{qr} = L'_r i'_{qr} + L_m i_{qs}$

$\varphi'_{dr} = L'_r i'_{dr} + L_m i_{ds}$

$L_s = L_{ls} + L_m$

$L'_r = L'_{lr} + L_m$

**Mechanical System**

$$\frac{d}{dt}\omega = \frac{1}{2H}(T_e - F\omega_m - T_m)$$

$$\frac{d}{dt}\theta_m = \omega_m$$

The parameters of the Asynchronous Machine block are defined as follows.

| Specific parameters for single-cage or wound rotor | Definition |
|---|---|
| L`r | Total inductance of the rotor |
| R'r, L'lr | Rotor resistance and leakage inductance |
| V'qr, i'qr | shaft rotor voltage and current q |
| V'dr, I'dr | d. shaft rotor voltage and current |

| φ'qr, φ'dr | Rotor q and shaft flux d |
|---|---|

**Tab Settings**

**Rotor type**

Choose the kind of rotor: Wound (usually used with SI unit), squirrel cage (usually used with pu unit).

**Squirrel cage preset model**

For basic squirrel cage machines, a set of specific numbers for things like horsepower, voltage, frequency and speed is already decided. To do this, choose the Squirrel Cage option for the Rotor Style and click on Apply.

Choose a template to load the electric and mechanical settings into the empty spaces provided. The settings you can choose from do not have a specific saturation level already set.

Choose No (which is already selected) if you don't want to use the pre-made design or if you want to make some changes to it. If you choose a preset format, you can't change the electrical and mechanical settings in the Settings tab of the pop-up box. First, begin with a pre-made model and then adjust the settings of the machine.

- Choose the template you want to use as a starting point.
- Change the starting value of a pre-made template to nothing. This does not make any changes to the machine's settings. By doing that, you are just disconnecting from a specific setting.
- Make the machine do what you want by changing its settings. Then, press the "Apply" button.

**Mechanical input**

- You can choose how fast the machine is rotating or how strong the force pushing it is, and use that as the input for the Simulink® block. Alternatively, you can represent the machine as a hole in a Simscape™ mechanical system.

- Choose Torque Tm (which is already set) to pick the amount of force, either in Nm or pu, and modify the name of the block input to Tm. The speed of the machine depends on how heavy it is (inertia), and the difference between the power going into it (Tm) and the power being produced inside it (Te). In simple terms, when a machine is going forward and torque is positive, it means the engine is running. But if torque is negative, it means the machine is stopping and the generator is working.

- Choose the speed input, speed w, and label it as such. It can be measured in either rad/s or pu. The machine goes fast and we're not paying attention to how heavy it is. By using speed to provide power, we can connect two machines together mechanically. This picture explains how to represent a strong link between two parts in a motor system if we don't account for any resistance in one of the machines. Machine 1's speed is connected to machine's speed. Machine 1 gives mechanical energy to machine 2, which uses it to create electricity. The electricity made by machine 2 then affects the energy used by machine 1. The Kw factor helps us compare two machines that are moving at different speeds (pu or rad/s) and also takes into account the ratio gearbox w2/w1. The KT factor considers how powerful a machine is and how strong its spinning force is. Machine 2's inertia is not important, so we need to add machine 1's J2 measurement to its J1 measurement to get its speed.
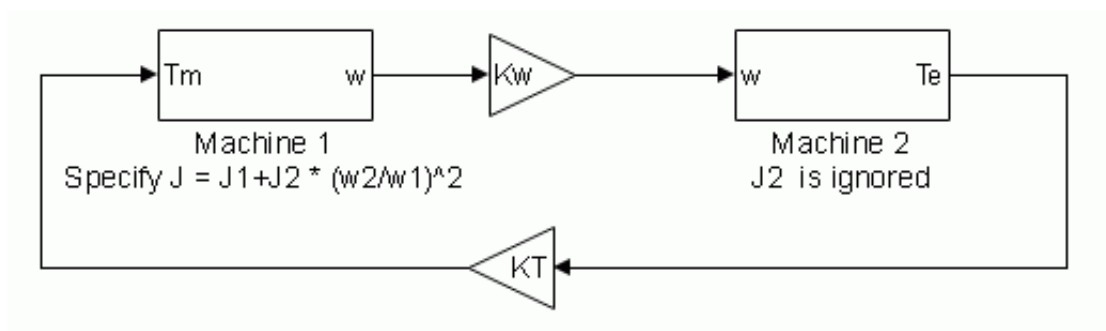


**FIG: Stiff Shaft Interconnection**

Select Mechanical Swing Gate to add a Sim-scape Mechanical Swing Gate to the block allowing the machine shaft to be connected to other Sim-scape blocks that have a Mechanical Swing Gate. The Simulink input shows the power or speed of a machine, and is then taken away.

The picture below explains how to combine an Ideal Torque Source block from Simscape library to a machine's shaft. This represents the machine in either motor mode or generator mode, depending on the rotor speed being positive.
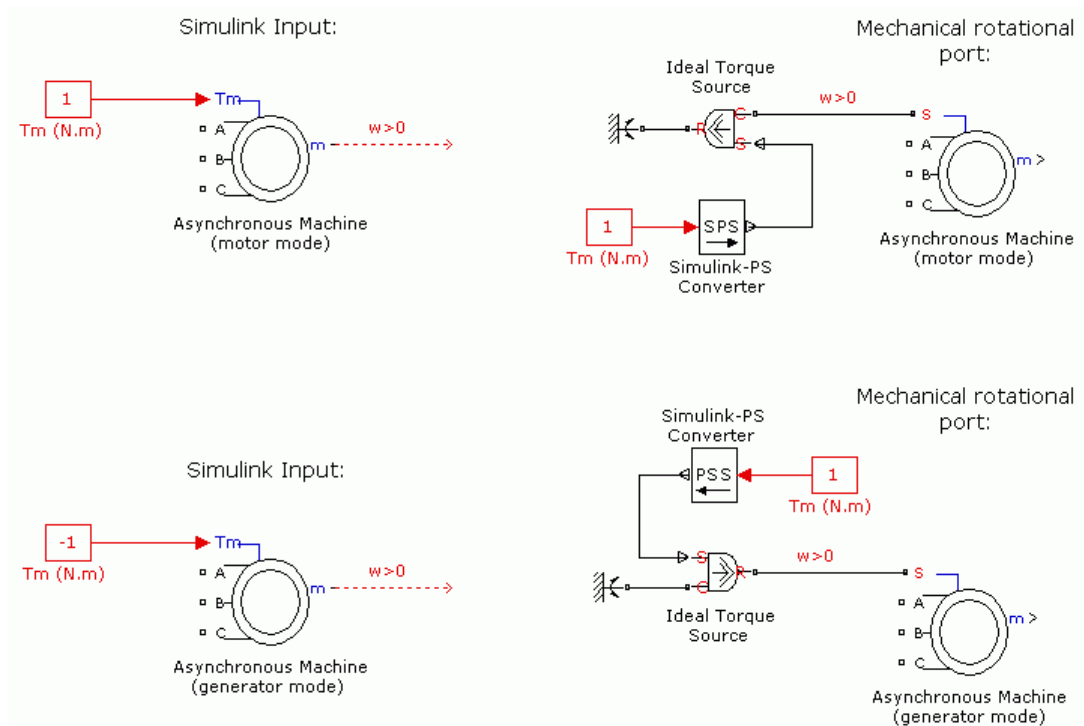


**FIG: Simulink Input and Mechanical Rotational Port**

## 3.2.2 Universal Bridge

The universal bridge block is a useful tool that changes electric power in a helpful way. It has up to six switches that connect together to do this. You can choose which power switch and adapter to use by clicking on the options in the dialog box.

The Common Bridge lets you pretend to use things that change electrical power, like diodes or transistors.

The Common Bridge is an important part for building a device that changes voltage called a two-stage voltage source converter.
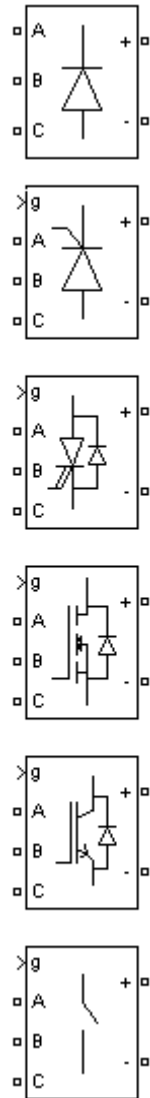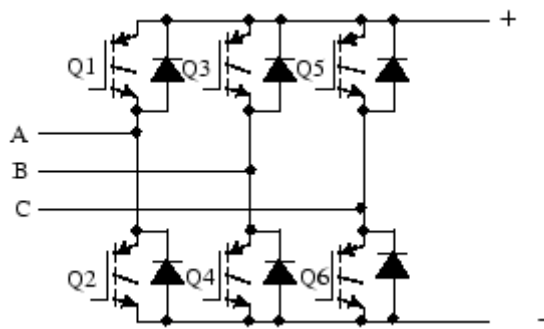
**FIG: Universal Bridge**

If the power electronic device is for natural commutation or forced commutation, the device numbering is different. For naturally commutated three-phase power converters (diodes and thyristors), the numbering follows the natural commutation order.
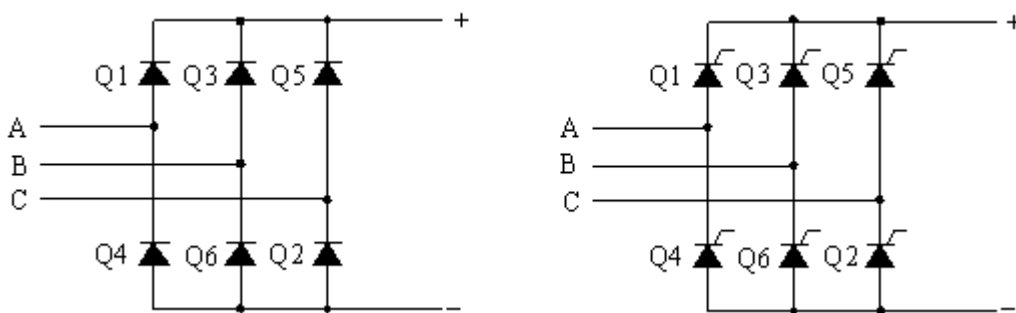


**FIG: Two-Phase Diode and Thyristor Bridge**

**FIG: IGBT-Diode Bridge**

## Parameter

### Number of Bridge Arms

Choose 1 or 2 if you are using a single-phase converter which has either 2 or 4 switching elements. To connect a three-phase converter using 6 switching devices, set it to 3 and place it in a Graetz bridge configuration. "The standard setting is 3."

### Attenuation Resistance Rs

The resistance of a snubber measured in ohms. The standard value is 1e5. To take out the snubbers from the model, just change the Snubber resistance Rs value to infinity.

### Snubber Capacitance Cs

Snubber capacitance is measured in a unit of measurement called "farads" (F). The default setting is infinity. To remove the snubber, set the Cs parameter to 0. If you want a resistive snubber, set the Cs parameter to inf.

If you use the continuous solver, you can turn off the snubbers on power devices by choosing the Disable snubbers option in the Power guide block settings.

If you make your system into separate parts, you can create computer versions of power devices that don't need a lot of extra equipment. To do this, you just need to add a special kind of resistor with a very high resistance. So, the small amount of electricity escaping is not important. A bridge is stable when it has a special support called a resistive damper.

## Electronic device

Choose what kind of power electronics to use for the bridge. The Thyristor is the standard option.

When picking a VSC based on switching function, we use a model that replaces the switches with voltage sources. This helps us understand how the VSC works. The flow of electricity on the DC side right now. This machine uses the same signal as other machines and shows the usual patterns made by the bridge.

If you pick a VSC that's based on the average model, it means that a regular voltage source converter will be used to control the power electronic switches. This type of power electronics is different because it uses a signal called Uref to show the middle amount of voltage made at the ABC parts of the bridge. This model doesn't show harmonics. This can be used for a longer time to keep the same average voltage movement.

Check out Power_sfavg to see how two models compare to a regular sphere using an IGBT or diode device.

## Ron

The resistance inside the chosen device, measured in ohms. The starting value is 01e-3.

## Lon

How much energy can be stored in a diode or thyristor, measured in Henry (H). The starting value is zero. When there is no specific demand, Lon should be set as zero.

## Forward voltage Vf

You can only use this feature if you are using Diodes or Thyristors as your power electronics. Direct voltage, in volts (V), across the terminals of the device when it is conducting. The default value is zero.

## Forward Voltage [Device Vf, Diode Vfd]

This option is only for specific types of electronic equipment called GTO/Diodes or IGBT/Diodes.

The voltage needed to turn on certain electronic devices and their corresponding diodes. The starting value is [0 0].

## Measure

The default value is nothing.

Choose the voltage of the device to measure the voltage between the six terminals of power electronics.

Choose the Device Current to check how much electric flow goes through six power electronic devices. If you use two diodes facing opposite directions, the total current measured includes the current from the switch and both diodes. A positive current means it's going through the forced switch while a negative current means it's going through the diode. If small gadgets are used, the measured electric flow is only the flow that goes through the power control system.

Choose the voltage UAB, UBC, UCA, or UDC to check the voltage of the Common Bridge block's terminals for both AC and DC.

Choose all the electricity powers and flows to check all the electricity powers and flows described for the Common Bridge block.

Put a tool called a multimeter in your model to show the measurements you picked during a computer test. The Multimeter block has a menu that shows what measurements are available. Each measurement has a label and the name of the block.

| Measure | Label |
|---|---|
| Device voltage | Usw1: 0 |
| current branch | Isw1: 12 |
| Terminal voltage | UAB: 100 |

## Entrance and exit

The entrance for a switch that is controlled. The order of the pulses in the gate signal vector is connected to the number of switches in the six circuits in the Description. In diode and thyristor bridges, the order of the pulses matches the way they naturally switch on and off. For other switches that are turned on and off by force, signals are sent to both the upper and lower switches in the A, B, and C phases.

| Topology | Pulse vector input g |
|---|---|
| an arm | [Q1, Q2] |
| two arms | [Q1, Q2, Q3, Q4] |
| three arms | [Q1, Q2, Q3, Q4, Q5, Q6] |

## 3.2.3 PWM Generator (2-Level)

The PWM generator makes pulses for PWM converters that have two levels. The block can operate different types of switches (FET, GTO or IGBT) for three converter types: one with one branch, one with two branches, and one with three branches.

The Uref signal is compared to a triangle signal in a fair way. If the signal we are using to reference is stronger than the main signal, then...

The upper switch is turned on with a strong signal, while the lower switch is turned off with a weak signal.

For controlling one device worldwide, you can pick either unipolar or bipolar PWM modulation. Because of unipolar modulation, every branch can be controlled separately. The second signal is made by changing the first signal to be the opposite way around. By using bipolar modulation, the switches in the second branch are linked to the switches in the first branch and the first arm landing switch, making them all work in sync. Unipolar modulation makes better AC wave patterns, while bipolar modulation creates less varying common mode voltages.

**FIG: PWM Generator (2-Level)**

The picture displays three ways to sample a reference signal called Uref. The way we take measurements is like how a machine makes an electronic signal called PWM. We can take Uref measurements using two common methods. One is to take two samples at the highest and lowest points of the signal, and another option is to take just one sample at the lowest point of the signal. The first way is known as asymmetric sampling or double-edged technique. The second way is called either symmetric sampling or single edge technique.

## Reference signal sampling technique

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Regular sampling - Symmetrical (single edge)
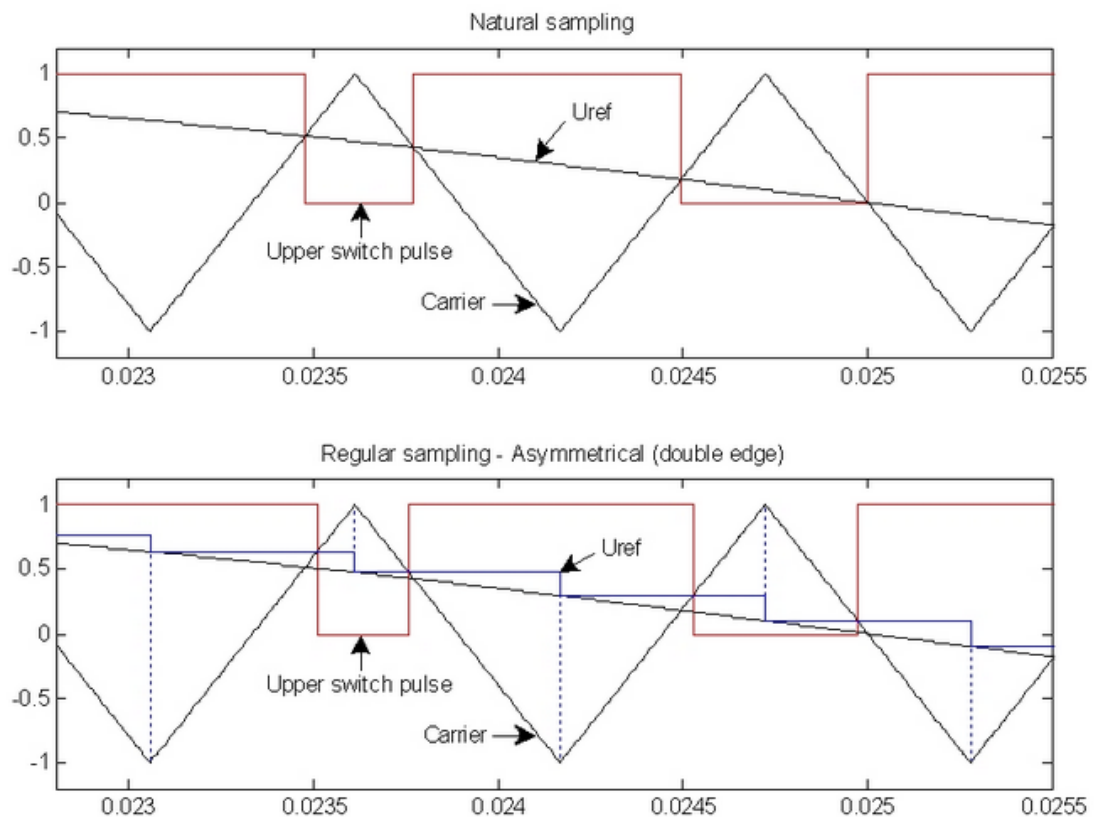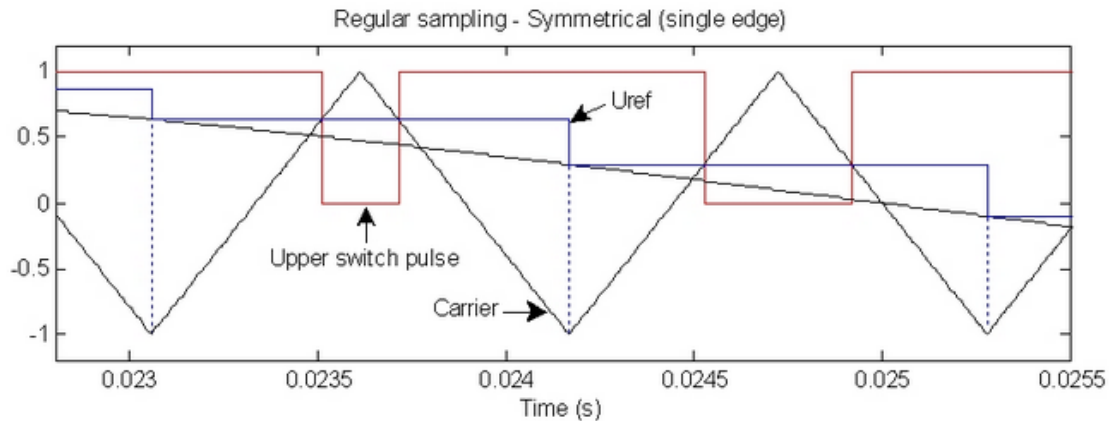
## Parameters

## Generator type

Please tell us how many pulses you want to create. If you draw more handles, you'll make more pulses with the block.

Choose Single-Phase Half-Bridge (2 Pulse) to turn on the automatic switching part of the single-phase half-bridge converter. Pressing button 1 turns on the top thing, and pressing button 2 turns on the bottom thing.

Choose the Single-Phase Bridge (4 Pulses) to make the self-switching feature work in the single-phase bridge converter. After that, four beats/pulses are made. Pulses 1 and 3 turn on the top devices in the first and second sections. The device works when impulses 2 and 4 are turned on.

Choose Single-Phase Global Modulation - Bipolar (4-Pulse) Modulation to turn on devices that can switch themselves for single-phase full-wave bridge converters. 4 beats are made. "When we send signals (called pulses) 1 and 3, it turns on the devices at the top of the first and second parts." Signals 2 and 4 turn on the device underneath. Pulses one and four are the same. Pulses two and three are exactly the same.

Choose a 3-phase bridge (which has 6 pulses) to activate the self-switching feature of the 3-phase converter bridge. The 1st, 3rd, and 5th pulses make the devices at the top of the 1st, 2nd, and 3rd branches work. The lower device turns on when signals 2, 4, and 6 are received.

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## Service provider: how it works

When Asynchronous mode is on, the Frequency setting controls how fast the signal goes.

When you choose to synchronize, the carrier signal matches an outside signal (input weight), and the carrier frequency changes based on the Switching Ratio setting.

## Service Provider: Frequency (Hz)

Tells you how many times per second the delta carrier signal is sent. The starting value is 1350. This setting is only available when the mode is set to No Sync.

## Service Provider: Initial phase (degrees)

Tell me, in degrees, where the carrier starts from. The starting number is ninety. When a triangle starts in the middle and goes up, it has a value of 90 degrees.

You can only see this parameter if the Operating Mode is set to No Synchronization.

## Service provider: min and max value

Tell us the lowest and highest points of the signal that looks like a triangle. The starting value is set to [-1 1].

The ratio between the frequency of the signal that controls the electronic switch and the frequency of the output signal.

Tell me how often the triangular carrier signal happens (Fc).

The value of Fc is determined by multiplying the switching ratio with the frequency of the output voltage.

The starting number is 27. You can only use this feature if you choose the Sync option in the Operation Mode setting.

### Reference Signal: Sampling Technique

Tell us how we sample the reference signal: using Natural (the usual way), Smooth Asymmetrical (twice the edges), or Smooth Symmetrical (once the edge).

If you decide to use convenience sampling, the time when you take samples needs to be a whole number that fits evenly into how often you are taking samples. For sampling that is uneven, the time between samples is half of the frequency at which the signal being sampled is transmitted. For sampling that is even, the time between samples is equal to the frequency at which the signal is transmitted.

### Reference Signal: Internally Generated Reference Signal

The block makes a signal that can be used for reference when chosen. The usual setting has been taken away. If it's not chosen, an outside signal is used to create pulses. You can only use this feature when you choose Unsynchronized mode.

### Reference Signal: Modulation Index

To control the strength of the main part of the voltage that comes out of the converter, you need to tell it how much to change the amplitude. The amount of modulation must not be too much or too little, and it should be between 0 and 1. The starting value is 0.8. This option is only there when you choose to make an Internal reference signal.

### Reference Signal: Frequency (Hz)

This text is saying that it determines how often the power goes out from the converter. The starting or normal value is sixty. This feature is only available if you choose the option to create a signal that is modulated internally.

### Reference Signal: Phase (degrees)

To control the phase of the base part of the converter's output voltage, use this parameter. The starting value is none or nothing. You can only use this setting if you've chosen to create a modulated signal internally.

## Sampling time

Tell me how often to take a sample by giving me the number of seconds between each one. Make it zero to use a continuous block. The starting value is nothing. If you pick the regular way of taking samples, the time between each one needs to be a whole number of the time it takes for one sample. The time between samples is different for asymmetric and symmetric sampling - asymmetric is half the carrier frequency and symmetric is the carrier frequency.

## Display Measurement Port

Tick the box to include Simulink® results to the block. The result shows the main signal used to create the pulses and a sample of another signal. The previous setting has been erased.

## Entrance and exit

## Uref

The vector reference signal creates the pulses that come out. You can only see the things you type if the system is not making its own sound. When you use this block to power a single-phase converter, connect it to a single-phase sine wave signal. If you are using the PWM generator block to power a three-phase converter phase bridge converter, connect it to a three-phase sine wave signal. The Uref size should be between negative 1 and positive 1 for the block to work correctly.

## wt

We use an outside signal to make sure our communication is in sync. The input port in Simulink won't show when Executive Mode's Service Provider is set to No Synchronization.

**p**

The result has signals that turn on electronic switches in converters with one, two or three prongs.

**m**

The measurement result shows the signal used to make the pulse and the reference signal that was tested. This port will only show up if you choose the Display measurement port.

| Sampling Time | Specified in the Sampling Time parameter Continuous if Sampling time = 0 |
|---|---|
| Scalar expansion | No |
| dimensionalized | No |

## 3.2.4 Controlled voltage source

The Controlled Voltage Source block changes a signal in Simulink® to make it act like a battery. The amount of electricity made is changed by the information that comes in.
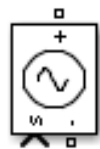


**FIG: Controlled Voltage Source**

You can start the Controlled Voltage Source square with a specific AC or DC voltage. When starting the simulation, connect the Simulink input to a signal that starts as either a sine wave or DC waveform, depending on the initial value.

### Initialize

The option that is automatically chosen is called "default." If you choose this option, it will start the Controlled Voltage Source block with the starting voltage, phase, and frequency that you set.

### Source type

If you don't choose "Initialize," you can't use the "Source Type" option.

Type of energy supply. Choose AC (which is the usual setting) to start the Controlled Voltage Source block with an electrical current source that produces an alternating current. Pick DC to start the control voltage source block with a steady voltage.

### Initial amplitude

You can't use this thing if the starting thing is turned off. The starting power in volts (V) for the source. The starting point is zero.

### Initial phase

First step of setting up the source in degrees. This means that when you start, you begin with nothing. You can't use the Initial Phase setting when you set the Source Type to DC.

### Initial frequency

The first sound frequency created by a device, measured in hertz (Hz). The starting point is zero. The option to set the starting frequency is not shown when DC is selected as the power source.

### Measured value

The starting option is nothing. Choose the voltage you want to measure by using the Controlled Voltage Source block. Add a tool called "multimeter" to your project so you can see the important numbers while it's running. In the box for Available

Measurements in the Multimeter block, you can see labels that tell you what each measurement is for, followed by the name of the block.

| measurement | label |
|---|---|
| Voltage | Usrc: 100 |

## 3.2.5 PID Controller

Include controllers (PID, PI, PD, P or I) in your Simulink® model to make it work continuously or at specific intervals. The PID controller can have its settings adjusted either by someone or by the machine. If you want to make tuning happen by itself, you need this software called Simulink Control Design™.

The PID Controller block gives a result by adding together the input signal, the signal over time, and the change in the signal. Weights are numbers that are used to adjust how much importance is given to different parts of a calculation. The three types of weights are called proportional, integral, and derivative. First-order poles are used to filter or smooth out differential action.
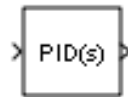


**FIG: PID Controller**

You can change the settings of the PID Controller block.

- What type of controller is being used? It could be PID, PI, PD, P or I.
- What kind of controller do you need? Is it parallel or ideal?
- The time domain refers to either a continuous or a limited set of time values.
- Starting requirements and triggers for starting over.

The device has a limit on how much output it can give, and it automatically stops itself from going over that limit to prevent any damage or errors.

We want to make sure that our control system can smoothly transition between different control modes and use multiple control loops at the same time, so we need to track the signals carefully.

In a normal setup, the PID Controller block is used in the front part of the feedback system.
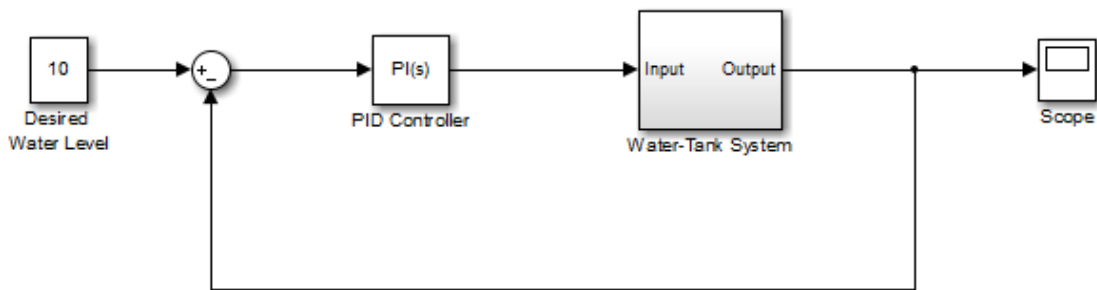


**FIG: PID Controller (2 DOF) Block Reference**

The block usually gets a signal called the error. This signal is the difference between the desired signal and the actual outcome. If you want to change how much importance to give to a certain desired value in a system with two inputs, you can check out the PID Controller (2 DOF) block reference page.

You can create code to make controllers in Simulink with different types of data, including those that use fixed numbers. You need two types of software (Simulink Coder and Fixed-Point Designer) to create and use specialized computer code.

To see how to use the PID Controller block in different situations, check out the Simulink examples.

- A way to control windup using a type of controller called a PID controller.
- A smooth transition between manually controlling something and using a computer program to control it.

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## Data type support

The PID controller block can work with real-world signals that have numbers in them. These numbers can be any type that Simulink software can understand, including fixed-point numbers. To learn more about data types that Simulink supports, check out the Simulink documentation.

## Parameter

This table shows the settings you can adjust in the PID Controller block by clicking on the block parameters dialog box.

| Task | Parameters |
|---|---|
| Select the controller shape and type. | - main menu controller form<br>- controller |
| Select discrete time or continuous time. | - time range<br>- sample time |
| Select the integration method (discrete time). | - integral method<br>- Filter method |
| Set and tune controller gains. | - Source of controller parameters on the Main tab<br>- Proportional (P) on the main menu<br>- Integral (I) on the main menu<br>- Main Menu Derivation (D)<br>- Filter factor (N) in main menu<br>- Use filtered derivatives on the Main tab. |
| Set the initial conditions for the integrator and filter. | - Initial conditions Source in Main tab |

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| | |
|---|---|
| | - Integrator Initial condition in Main tab<br>- Filter Initial condition in Main tab<br>- Initial condition setting (command line only)<br>- External reset in Main tab<br>- Ignore reset when linearizing in Main tab |
| Limit block output. | - Limit output in PID Advanced tab<br>- Lower saturation limit in PID Advanced tab<br>- Upper saturation limit in PID Advanced tab<br>- Ignore saturation when linearizing in PID Advanced tab |
| Configure anti-windup mechanism (when you limit block output). | - Anti-windup method in PID Advanced tab<br>- Back-calculation gain (Kb) in PID Advanced tab |
| Enable signal tracking. | - Enable tracking mode in PID Advanced tab<br>- Tracking gain (Kt) in PID Advanced tab |
| Configure data types. | - Parameter data type in Data Type Attributes tab<br>- Product output data type in Data Type Attributes tab<br>- Summation output data type in Data Type Attributes tab |

| | |
|---|---|
| | • Accumulator data type in Data Type Attributes tab<br>• Integrator output data type in Data Type Attributes tab<br>• Filter output data type in Data Type Attributes tab<br>• Saturation output data type in Data Type Attributes tab<br>• Lock output data type setting against changes by the fixed-point tools in Data Type Attributes tab<br>• Saturate on integer overflow in Data Type Attributes tab<br>• Integer rounding mode in Data Type Attributes tab |
| Configure block for code generation. | • State name in State Attributes tab<br>• State names must resolve to Simulink signal objects on the State Attributes tab.<br>• Storage class for code generation in Status Attributes tab<br>• Code Generation Storage Type Modifiers in Status Attributes Tab |

## Convert PID Controller from Standard to Parallel Form

Change a certain type of controller, called pidstd, into another format called parallel form.

The Standard PID form is a way to describe how a controller works using some specific values: Kp, Ti, Td, and N. You can change a standard controller to a parallel controller using the PID command. Let's look at this typical controller.

## Setting

## Parallel (default)

Select a controller type that adds up proportional, integral, and derivative actions based on the separate settings for P, I, and D. The number N decides where the differentiation filter points will be located. The way a machine controls something using a parallel PID controller can be described in a formula called a "transfer function."

$$C_{par}(s) = [P + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{N+s}\right)]$$

The transfer function for parallel PID controllers that work in intervals is written in a particular way.

$$C_{par}(z) = P + Ia(z) + D\left(\frac{N}{1+Nb(z)}\right)$$

The place where we decide (for a specific time called Ts) using two methods: the integrator method and the filter method.

| | Forward Euler method | Backward Euler method | Trapezoidal method |
|---|---|---|---|
| a(z) (Determined by integral method) | $\dfrac{T_s}{z-1}$ | $\dfrac{T_s z}{z-1}$ | $\dfrac{T_s z + 1}{2z - 1}$ |
| b(z) (Determined by filtering method) | $\dfrac{T_s}{z-1}$ | $\dfrac{T_s z}{z-1}$ | $\dfrac{T_s z + 1}{2z - 1}$ |

The controller transfer function for the current settings is displayed in the block dialog.

## Parallel PID controller
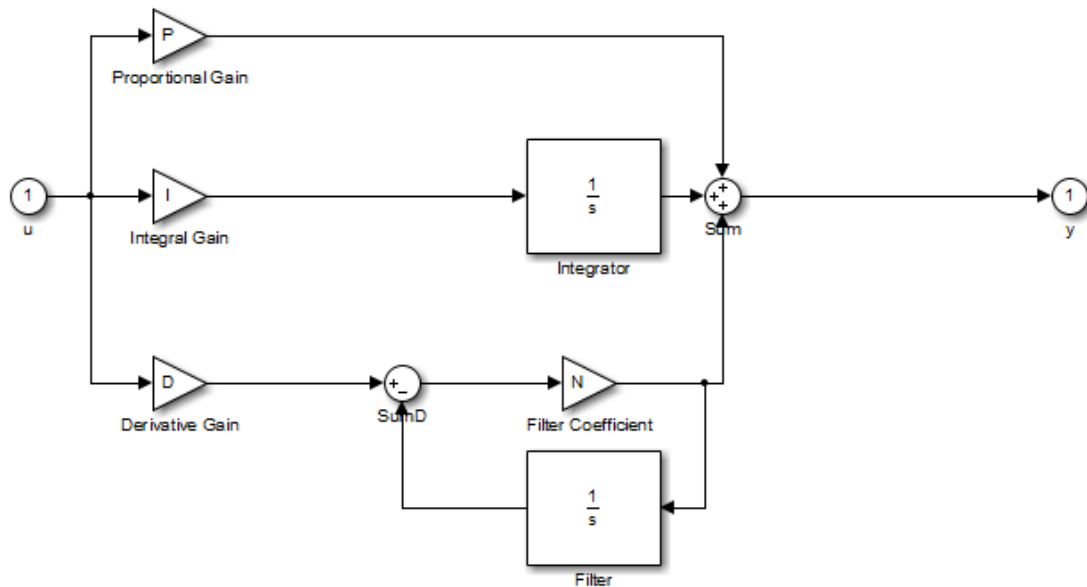


**FIG: Parallel PID controller**

## Ideal

Pick a controller form where the proportional gain P affects the total of all actions combined. The transfer function is like the one in parallel shape, but P increases or decreases all the parts in it. The transfer function of an ideal PID controller that works continuously over time can be expressed as follows:

$$C_{par}(s) = [P + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{N+s}\right)]$$

For a discrete-time ideal PID controller, the transfer function is:

$$C_{par}(z) = P + Ia(z) + D\left(\frac{N}{1+Nb(z)}\right)$$

The integrator method helps find a value for a(z), while the filter method helps find a value for b(z) in the parallel controller form.

An ideal PID controller is a type of device that helps control a system's behavior. It uses three components to do this: proportional control, integral control, and derivative control. The goal of an ideal PID controller is to quickly and accurately adjust the system to meet the desired outcome.
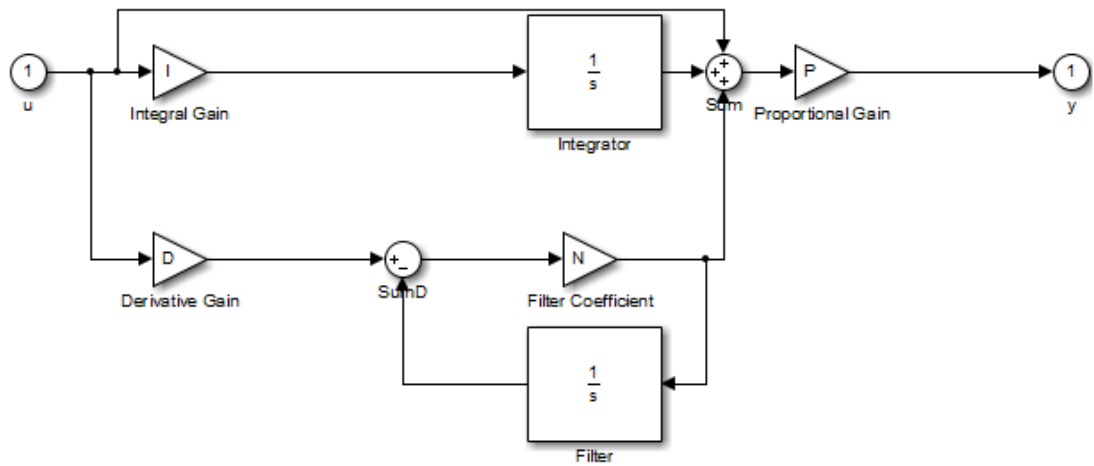
**FIG: Ideal PID Controller**

## Controller

Specifies the type of control.

## Setting

## PID (default)

Implement controllers with proportional, integral, and derivative actions.

## PID

Use tools that control things in a way that depends on how far they are from an ideal value and how long they have been away from that value.

## PD

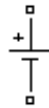Create a device that uses a method called proportional and derivative action.

## P

Create a controller that adjusts its output in proportion to the input.

**I**

Create a single controller to manage all actions.

## 3.2.6 DC Voltage Source

The DC Voltage Source picture represents a perfect DC battery. A "+" sign on a terminal means it's a positive one.



**FIG: DC Voltage Source**

You can adjust the power level whenever you want while using the simulation.

## Parameter

## Amplitude

The size of the source's electrical signal measured in volts. The starting point is 100.

## Measured value

Choose the voltage to find out how much electricity is flowing in and out of the DC voltage source. The starting value is zero.

Put a tool called "multimeter" in your model to show certain information while it's running. The box in the Multimeter block shows options for measurements. Each option has a name and a label to identify it.

| measurement | label |
|---|---|
| Voltage | usrc: 100 |

## 3.3 Design Specifications. Standards and Constraints

## 3.3.1 Open-Loop Induction Motor Control

AC motors can be controlled with a method called open-loop control, which is also known as scalar or Volts/Hz control. This is a simple technique that doesn't need information from a motor. To keep the stator's force steady, make the strength of the power source's waves match how quickly they move.
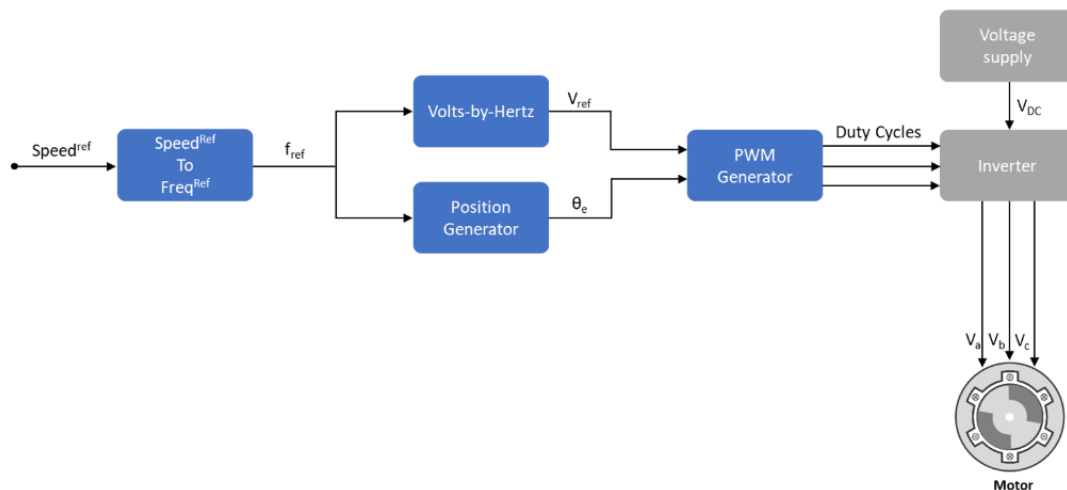


**FIG: Open-Loop and Closed-Loop Control**

This picture shows a type of control system called open-loop control. A device called a PWM voltage-fed inverter is powered by a DC power supply to create the electricity. To control, the system doesn't use signals to give information back. Find out how often the electricity in the stator changes based on how fast something is spinning. To keep the flow steady, the system picks a voltage size that matches the ratio of how much voltage there should be compared to how often it happens.

$$\lambda_m \propto V_{s/f_s}$$

Where:

- The rated strength of the motor's magnetic field measured in *Wb* is called $\lambda m$.

- $V_s$ is the AC motor stator voltage in volts.

- $f_s$ is the frequency (Hz) of the AC motor stator voltage.

The way an AC motor moves is called the speed, and we use a system called open-loop to measure it.

$$Speed(rpm) = \frac{(60 \times fs)}{p}$$

Where:

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- *Speed(rpm)* means how fast the AC motor is moving.
- The frequency of the electricity going into an AC motor is called "fs" and is measured in hertz (Hz).
- p is the pole log number of the motor.

Using the above formula, we can determine the frequency of the reference voltage for the desired speed (specific machine).

$$f^{ref} = (p \times RPM^{ref}) / 60$$

The frequency creates the voltage used as a reference for the inverter's pulse width modulation. Calculate the voltage strength while keeping the number of volts per second the same.

$$V^{ref} = \left(\frac{V_{rated}}{f_{rated}}\right) \times f^{ref}$$

Control systems that don't use feedback consider Vrated as the starting point, usually as 1PU or 100% duty cycle, when using a certain way to express the system. If you use a certain way of controlling electrical signals (either sine wave or spatial vector), you might get more power than usual. To overcome the problem of stator resistance voltage decreasing at lower speeds, the system requires a minimum increase in voltage (either 15% or 25% of the normal voltage rating).

If we don't need to worry about moving things quickly, we can use a simple method called "open-loop control" to solve the problem. Open-loop motor control cannot adjust for outside influences that might change the speed of a motor. The control system cannot fix the difference between the engine speeds that are wanted and the ones that are actually happening all by itself.

## 3.3.2 Closed-Loop Induction Motor Control

The comments from the machine are used to control things in a closed-loop management system. Closed-loop motor control means controlling a motor by monitoring its position and current state. The control device changes the electricity that

goes to the motor and uses signals to make sure the motor works at a certain level.
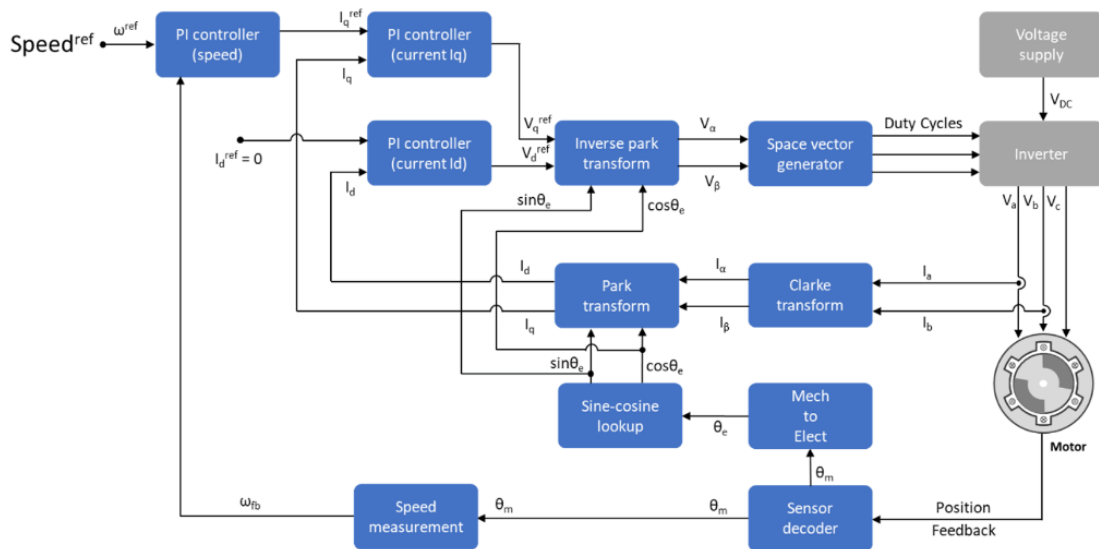


**FIG: Closed-Loop Induction Motor Control**

A way to control motors is called field-oriented control, which is also called vector control or FOC. The FOC method is used to control how fast or slow a motor move and where it stops. This way of doing things gives great control over how fast and strong something moves. To use FOC, we need to convert the current from the stationary frame to the rotor flux frame.

In FOC, we often use different ways to control speed or strength. Less work is done using the position control mode. The engine control system keeps an eye on how much power is needed for most vehicles to move forward. When using speed control mode, the motor controller monitors a target speed and adjusts the amount of force being used to maintain that speed. The governor is part of the inside system that controls the position.

In order to make the FOC algorithm, you need to know where the rotor and current location are at all times. The sensor can tell us where the rotor is and how it's moving. Instead of using real sensor data, you can use approximated response values for your measurements.

We use feedback on the position and current of the machine to control it better. We make adjustments to its governor and current regulator, as well as how often the inverter turns on and off. This makes sure that the motor works properly and any changes it makes will be corrected.

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## Open loop to closed loop transition

Sometimes you need to use open-loop control to turn on the motor. When the motor is working well enough, the control system switches to a different mode called closed-loop control.

An index pulse is a signal that helps switch a motor from being controlled indirectly to being controlled directly in a position sensing system that uses a quadrature encoder.

The motor starts slowly without using a sensor to know where it is, at only 10% of its normal speed. The control system changes the way it works when the reference switch goes above 10% of the normal speed. It goes from working in one way to working in a different way. The PID controller starts over again like the original output to smoothly change from not being controlled to being controlled.

## 3.4 System Analysis or Design Analysis

Here we use DC voltage source as our main power source in open loop operation.
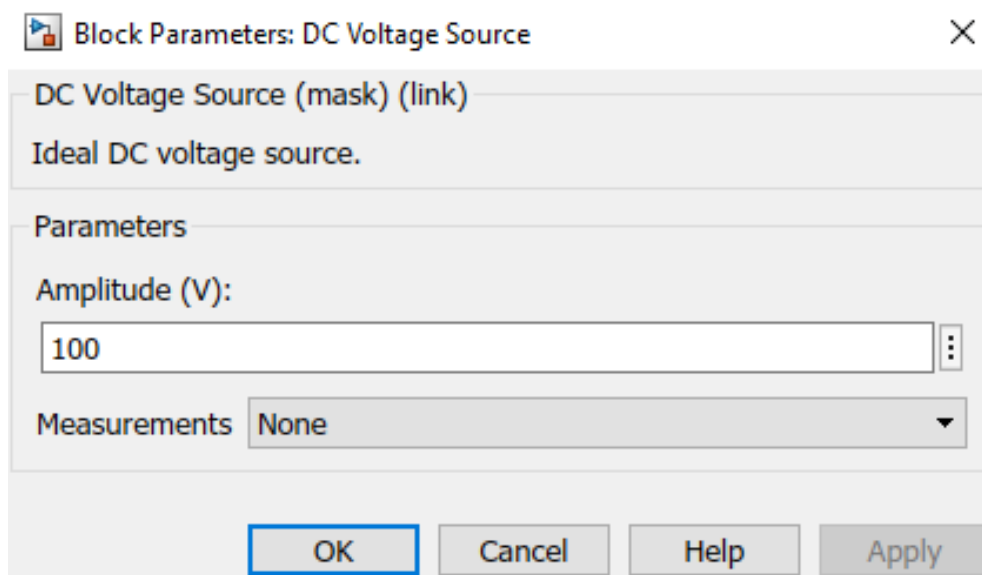


DC voltage converted into AC power through universal bridge (IGBT-Diode) and universal bridge (IGBT-Diode) switch timing controlled by PWM Generator (Level-2).

After controlling of PWM Generator (Level-2) and universal bridge (IGBT-Diode) we get AC power supply and we provide that power to Asynchronous Machine PU Units.
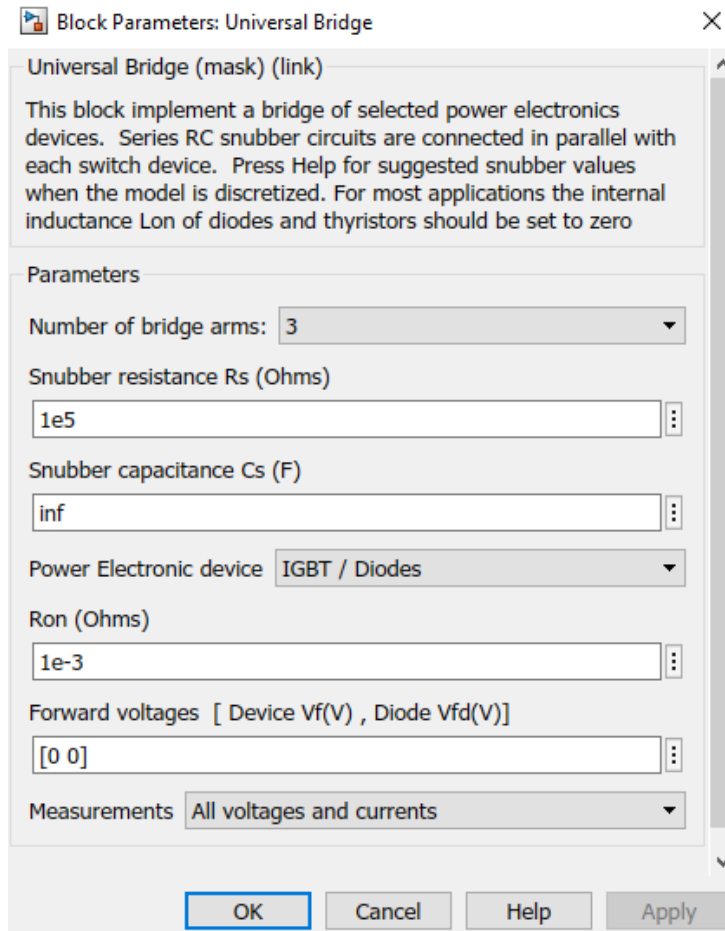
As we provide power to Asynchronous Machine PU Units, so it starts rotating and we collect our desire result from scope.
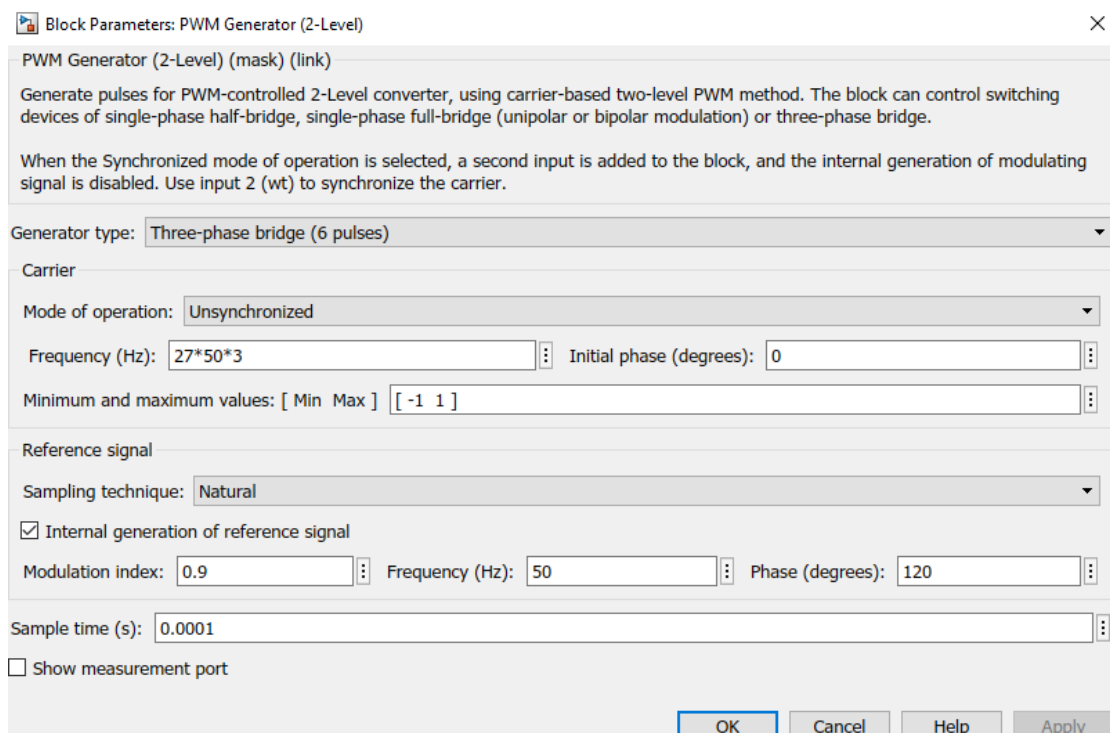
On the other hand, we use Controlled voltage source as our main DC power source in close loop operation.
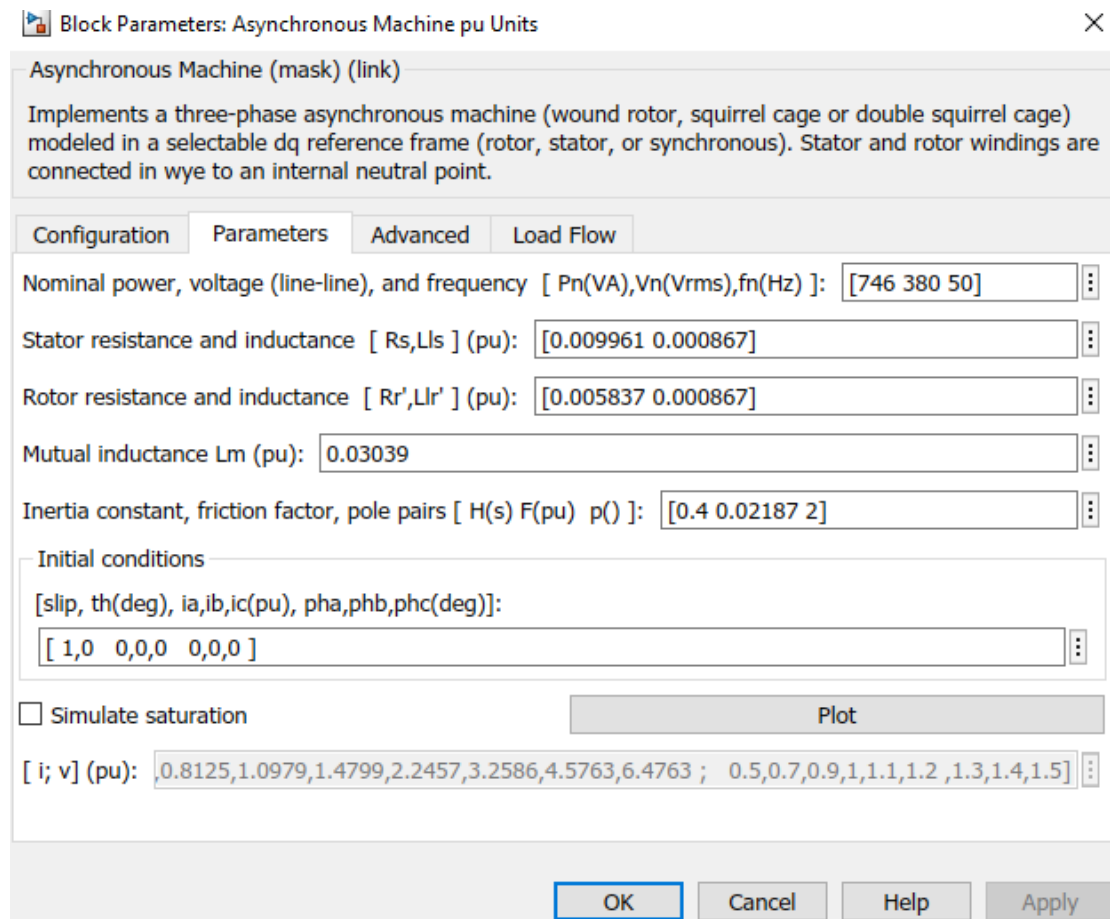


Same as open loop operation DC voltage converted into AC power through universal bridge (IGBT-Diode)

and universal bridge (IGBT-Diode) switch timing controlled by PWM Generator (Level-2).

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After controlling of PWM Generator (Level-2) and universal bridge (IGBT-Diode) we get AC power supply and we provide that power to Asynchronous Machine PU Units.



In this case we use PID Controller as feedback system from Asynchronous Machine PU Units to Controlled voltage source.
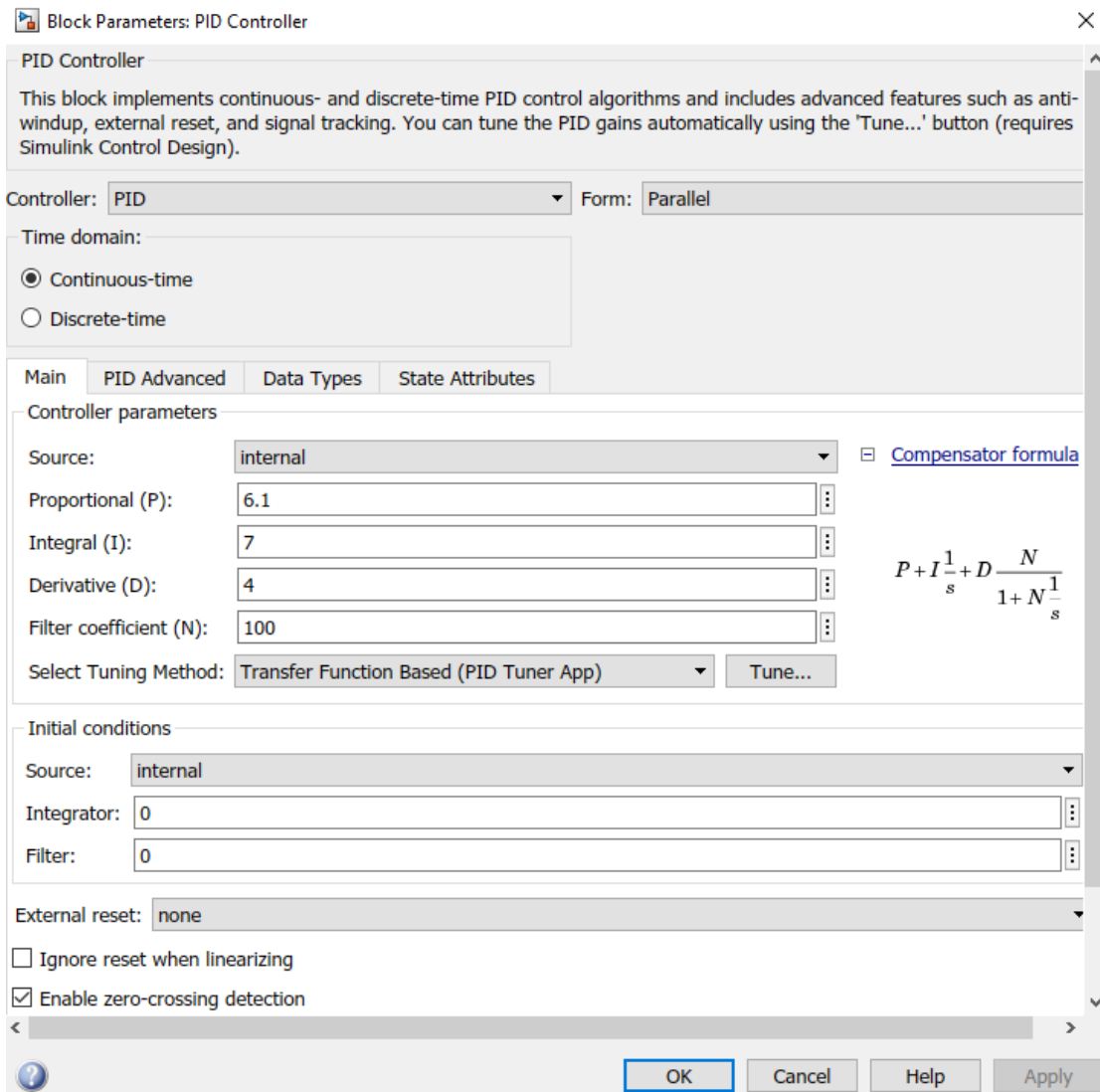
Now PID Controller continually measure this systems feedback and control our full system and provide us best output through Asynchronous Machine PU Units.

## 3.5 Simulation/Experimental Setup [or Implementation]

Simulink is a tool to help people design and test different types of models and simulations. It makes it easier to test and check computer systems, keeps testing going, creates computer code without human input, plays out what would happen in real life with embedded systems, and helps design embedded systems. Simulink provides tools to make computer models of things and test them out. You can change the tools to fit your needs. You can send your simulation results to MATLAB and use its tools to complete your research. Simulink is a computer tool used in control and signal processing to help design simulations and models.
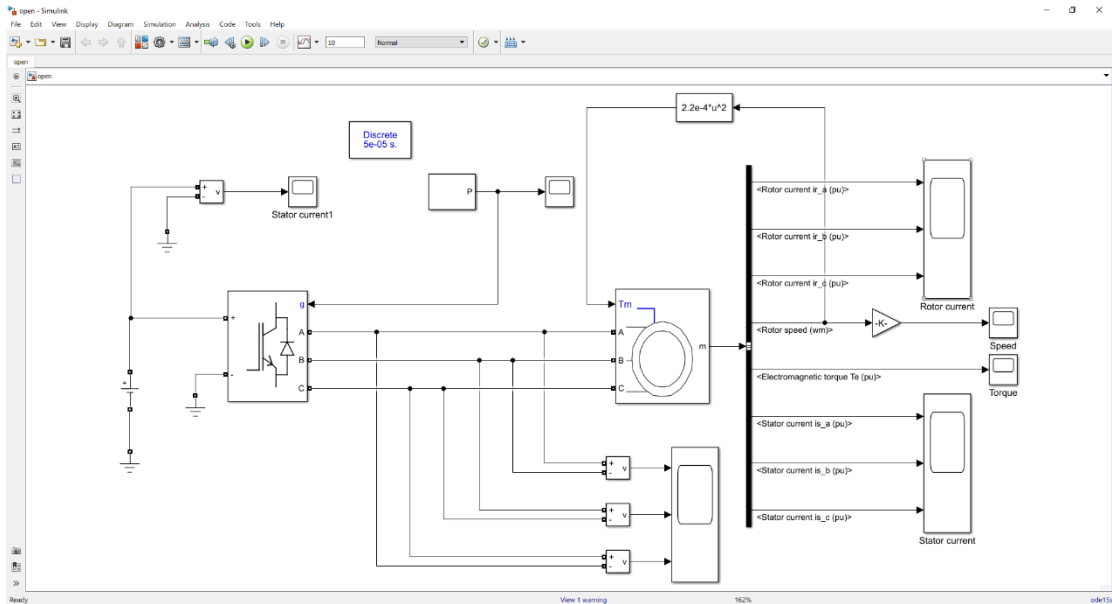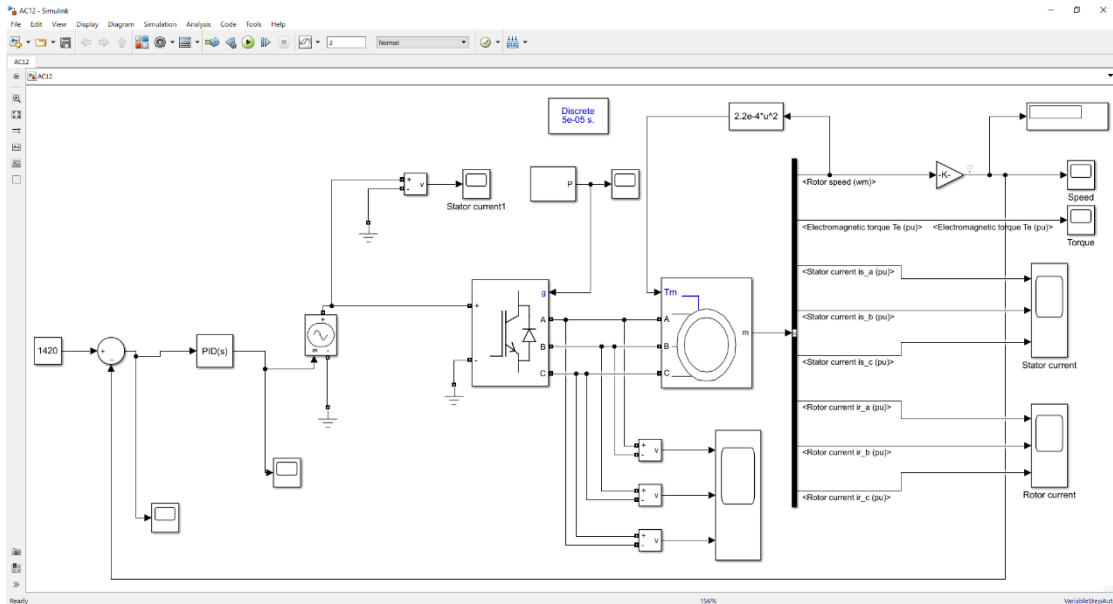
**FIG: Open Loop Simulation.**

Our system has two main sources of power: the DC Voltage Source and the Controlled Voltage Source. They supply electrical energy in the form of DC (Direct Current) to our system. We can start the Controlled Voltage Source with a certain AC or DC voltage. Connect the Simulink input to a flag. This flag should begin as a sine wave or DC waveform, depending on its initial value when the simulation starts and stay the same throughout the simulation.

We set the power input for our system and turn on the electronic device called universal bridge. The universal bridge block is a tool that can change electricity by using up to six switches in a flexible way. We chose to switch between two types of electrical devices to change direct current (DC) energy into alternating current (AC) energy.

We have to change the Universal Bridge's switching time using a device called PWM generating block (IGBT-Diode). Two different levels. The PWM generator makes signals for PWM converters using two levels. The block can operate single-phase half-bridges with one branch, single-phase global bridges with two branches, or three-phase bridges with three branches to drive switches (FET, GTO, or IGBT) for the three distinct types of converters.

**FIG: Closed Loop Simulation.**

Since we now have a three-phase AC power supply, we give the Asynchronous Machine PU Units this power. Three-phase asynchronous machines are constructed using the Asynchronous Machine block. (Winding Rotor, Single Squirrel Cage). It can run in engine or generator mode. The mechanical torque's sign controls the mode of action. The machine functions as a generator or a motor depending on whether Tm is positive or negative. As soon as Tm is set to positive, the asynchronous machine's PU units begin to rotate and serve as a motor, allowing us to gather the desired output.

The PID Controller comes last. The resulting output of the PID Controller block is determined through a linear combination of the input signal, its integral, and derivative, each of which is weighed accordingly. Parallel connections between PID Controller and Asynchronous Machine PU Unit output and voltage input signal are made. The PID Controller serves as a feedback system, and the output of the Asynchronous Machine PU Unit powers the system's main power source. PID Controller continuously calculates the output of the asynchronous machine PU units, measures it, and controls the entire system to produce the best output.

## 3.6 Summary

The utilization of a universal bridge alongside a PID controller represents a common method for regulating the operational speed of a three-phase induction motor. This

practice involves the application of specific techniques and materials to achieve optimal motor speed management.

Materials: The system requires a three-phase induction motor, a universal bridge circuit, a pulse-width modulation (PWM) generator, a phase-locked loop (PLL) circuit, and a PID controller.

Universal Bridge Circuit: The universal bridge circuit consists of four power switches that are arranged in a full-bridge configuration. In order to alter the frequency and voltage of the alternating current (AC) power supply delivered to the induction motor, switches are controlled through pulse width modulation (PWM) techniques.

The Phase-Locked Loop (PLL) is utilized to generate a reference signal that is synchronized with the frequency of the AC supply. The phase-locked loop (PLL) generates a signal which serves to control and adjust the frequency of the output voltage. This is accomplished through the comparison of the AC supply frequency with a reference frequency.

Pulse Width Modulation (PWM) is a technique utilized to regulate the amplitude of the output voltage. The voltage amplitude is modified by adjusting the duty cycle of the PWM signal.

The PID controller is responsible for regulating the speed of the induction motor. The controller facilitates the provision of a control signal that alters the frequency and voltage of the output signal through a feedback mechanism based on the disparity between the reference speed and the actual speed of the motor as the input parameter.

In a closed-loop control system, the output of the motor is routed back to the controller to achieve complete control over the system. In order to maintain optimal motor velocity, adjustments are made to the output voltage and frequency through utilization of feedback signals.

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# CHAPTER 4
# RESULTS AND DISCUSSIONS

## 4.1 Results/ Observations

The simulation results are generated utilizing the Matlab/Simulink software tools. Furthermore, detailed data pertaining to the line voltage, phase voltage, and line current of the induction motor is provided alongside the graphical representation of its speed and torque, which is presented in subsequent figures.

## 4.1.1 Results Open Loop System
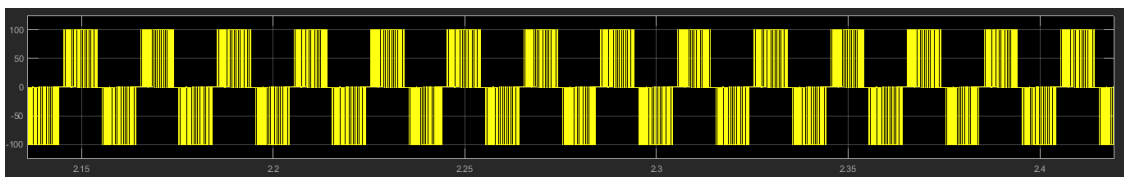


**Figure 6. Line voltage output of universal bridge**

In this figure, the inverter output voltage value is 100V AC. Induction motors use this voltage as Operation with nominal voltage.
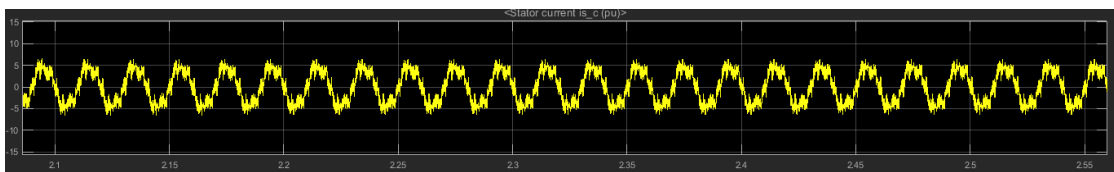


**Figure 7. Stator current of induction motor**

The stator current of the induction motor is measured to be 6 amperes. "The operational phases exhibit identical current utilization." Induction motors are regarded as being balanced under load.
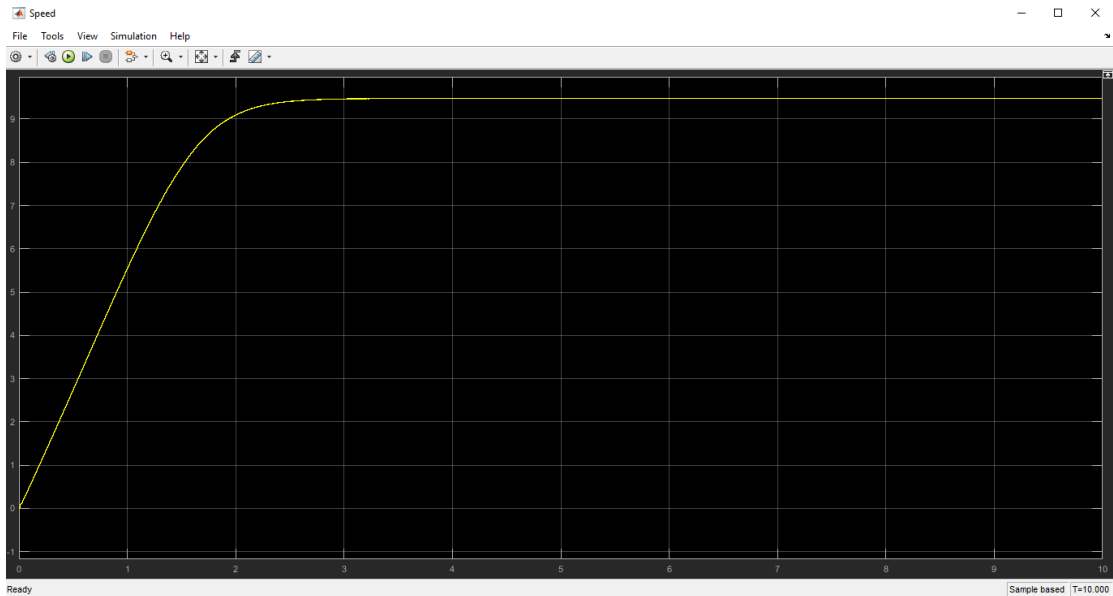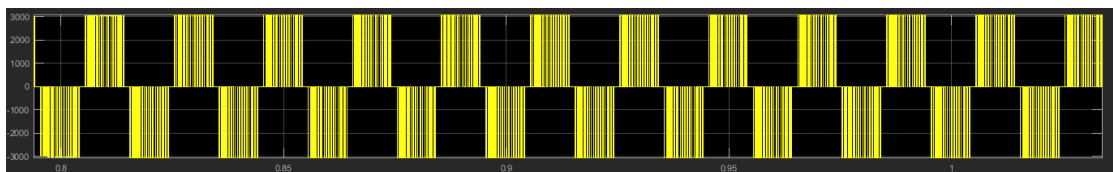
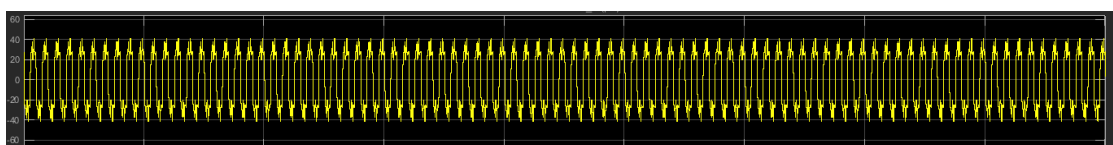**Figure 8. Rpm output of induction motor**

The constant speed of the induction motor observed in the given figure is 9.6 revolutions per minute (rpm). The figure presented illustrates a system that operates in a closed-loop configuration. The open-loop system exhibits a rise time (tr) of 2.8 seconds, a delay time (td) of 0.85 seconds, a peak time (tp) of 2.8 seconds, and a steady-state time (ts) of 2.9 seconds in its response.

## 4.1.2 Results of Closed Loop System



**Figure 9. Line voltage output of universal bridge**

This picture shows that the inverter makes 300 volts of electricity. Induction motors need this electricity when they are working as they should.



**Figure 10. Stator current of induction motor**

The current going through the stator of the induction motor is 40 amps. Each step uses the same amount of electricity. Balanced loads are machines called induction motors.
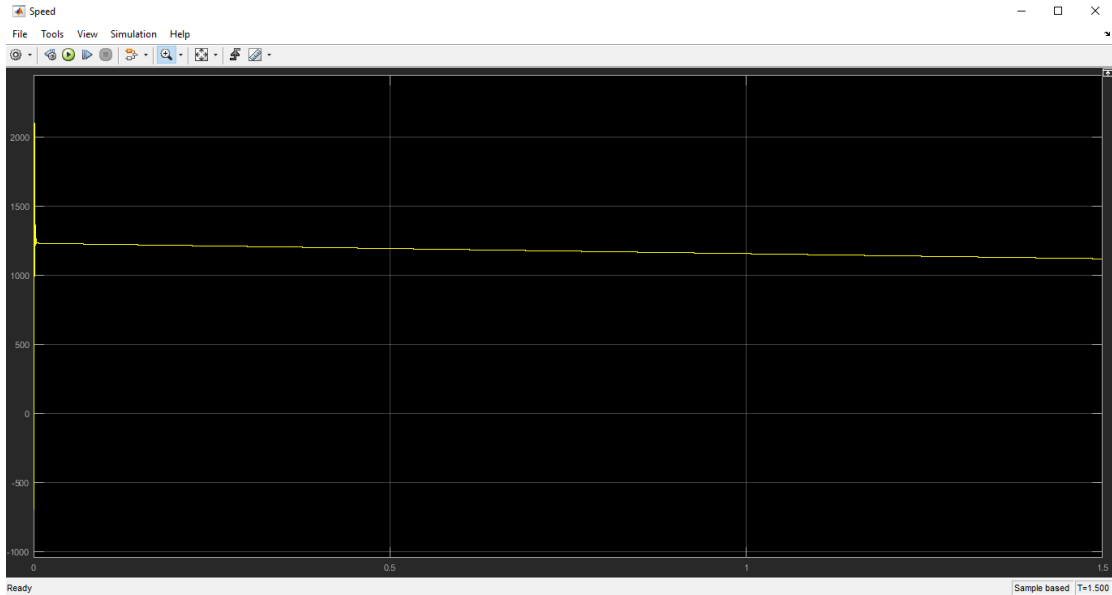


**Figure 11. Rpm output of induction motor**

The induction motor always spins at 1121 times per minute. The reaction of a system that monitors and adjusts itself based on feedback. This picture shows it. The control loop system takes a little bit of time to start working (0.005 seconds) and there is a delay (0.003 seconds) before it reacts to changes. It reaches its highest point (peak) in 0.0025 seconds and then becomes steady (maintains a constant output) in 0.006 seconds.

## 4.2 Discussions

Simpowersystem and MATLAB have been used to do simulations. The simulation results show that utilizing a PID controller and universal bridge to regulate an induction motor results in a better response than doing so without one. Whereas it takes 2.9 seconds for an open loop system 2.9 seconds to reach steady state speed, it only takes 0.006 seconds for a closed loop system to 0.006 seconds. This means that a type of controller called PID was used, which made things happen faster than if a different controller had been used. After running all the simulations, we can say that the suggested system does a decent job of controlling the induction motor's speed.

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# CHAPTER 5
# PROJECT MANAGEMENT

## 5.1 Task, Schedule and Milestones

In this experiment, we exerted much effort to achieve our objective, the force-cast load. Our supervisor instructed us to accomplish our ideal objective. In this experiment, we predicted the load using fuzzy logic. We obtained temperature and previous load data from our residence for this purpose. For the implementation of fuzzy logic, the time, temperature, and prior load are supplied to generate a load forecast.

## 5.2 Resources and Cost Management

In this experiment, we have use laptop computer and MATLAB/Simulink software. Which is free of cost. So, we don't have to worry about budget and cost management.

## 5.3 Lesson Learned

We have mostly gained technical knowledge from the controlling aspect of this experiment. The biggest challenge was keeping the speed of the asynchronous machine PU unit constant, which we overcame by using a PID controller.

However, the Universal Bridge must regulate the timing of its switches, which we do with the support of a PWM generator (Level 2). Overall, this project taught us about control.

# CHAPTER 6
# IMPACT ASSESSMENT OF THE PROJECT

## 6.1 Economical, Societal and Global Impact

The three most expensive components we used in this project were the battery, PID controller, and motor (asynchronous machine PU units). Additionally, we make use of electronic parts like the universal bridge, the PWM generator, and the regulated voltage source. Generally, all of our parts are affordable; none of them are overpriced compared to their usefulness.

That brings us one step closer to accomplishing our financial goals. Several types of growth should be blended for the good of our society. There will be job opportunities as a result of the adoption of this technology. It makes up for the loss of energy that the national economy needs.

## 6.2 Environmental and Ethical Issues

Like any other electrical device, it has environmental and ethical issues associated with its manufacturing, operation, and disposal.

Environmental Issues:

- Energy Consumption: Three-phase induction motors are highly efficient, but they still consume a significant amount of energy. This high energy consumption contributes to the depletion of fossil fuels, which are non-renewable resources.

- Pollution: The production of three-phase induction motors involves the use of various toxic substances, including lead, mercury, and cadmium. These substances can contaminate soil and water resources when not disposed of properly, leading to environmental pollution.

- E-waste: Three-phase induction motors have a long lifespan, but eventually, they become obsolete and are replaced. Disposing of these motors in landfills can lead to the accumulation of electronic waste, which can release toxic substances into the environment.

- Ethical Issues: Human Rights Violations: The mining of minerals used in the production of three-phase induction motors, such as copper and aluminum, is often associated with human rights violations. Workers in these mines are often exposed to unsafe working conditions and low wages.

- Conflict Minerals: Some of the minerals used in the production of three-phase induction motors, such as tantalum, tin, and tungsten, are referred to as conflict minerals. These minerals are often mined in war-torn areas, and their trade can fuel conflict and human rights abuses.

- Labor Rights Violations: The production of three-phase induction motors involves assembly lines where workers are often exposed to harsh working conditions and low wages. These labor rights violations can have a negative impact on the well-being of the workers and their families.

In conclusion, three-phase induction motors play a significant role in modern technology, but their manufacturing, operation, and disposal have environmental and ethical issues that need to be addressed. We should use less energy, use more renewable energy, and dispose of electronic waste correctly. Additionally, companies should be held accountable for their supply chains to ensure that they do not contribute to human rights abuses and labor rights violations.

# CHAPTER 7
# CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

Induction motors, which possess three-phases, are commonly utilized for converting electrical energy to mechanical energy. The employment of three-phase induction motors dominates the power consumption in industrial settings. When operating under light loads, these motors' efficiency and power factor are poor. In order to reduce the consumption of electric energy, ensuring high power factors and efficiency for these motors is imperative. This can be done by using the method suggested in this thesis, which involves a PID controller to control our operating system, when we need a higher power factor for light load or heavy loads in order to operate it efficiently. When maximizing the efficiency at light loads, we consider how the proposed technique would affect several motor properties, including stator current, output power, reactive power, rotor speed, and others. We also go into greater detail on the three-phase induction motor's equivalent circuit and mathematical analysis, and we use SIMULINK models to figure out what the circuit parameters should be.

A new study found that a motor doesn't work as well when it's not carrying much weight. But, as more weight is added, the motor starts working better. This happens at different levels of electricity flow but when the motor's rotor is moving at the same speed. When we keep the motor at a constant speed that works best with the PID controller, the motor can work really well with a certain amount of force. This is better than using regular PID control for a heavier load.

Also, it should be noted that using the suggested method results in a lower stator current and apparent power relative to standard operation. This essentially lowers the cost of electricity. Moreover, when motor efficiency rises, overall motor losses fall, extending the lifetime of the motor.

MATLAB and Simulink were used to run pretend tests. The experiment showed that using a PID controller and universal bridge to control an induction motor works better than not using them. It takes longer for an open loop system to reach a steady speed (0.9 seconds) than a closed loop system (0.2 seconds). This shows that the PID controller made a faster

response than if there wasn't one. After trying it out, we can say that the recommended system works well for keeping the induction motor at the right speed.

## 7.2 New Skills and Experiences Learned

We had never used MATLAB before, so we learned how to utilize it as well as how to build subsystems. Working on this project has resulted in a wealth of new experiences. We can now regulate PWM Gen and Universal Bridge, manage PID Controllers, obtain flawless results from Asynchronous Machine PU Units, for example, and work on any MATLAB/Simulink project with ease. We had a very pleasant experience, which helped us improve our abilities and learn how to produce results.

## 7.3 Future Recommendations

We have worked in MATLAB and Simulink on the Three-Phase Induction Motor Speed Control Using Universal Bridge and PID Controller. The PID Controlling and Universal Bridge sections of both the open loop and closed loop systems must be improved if the system is to be improved. Moreover, the timing component of the PWM generator has to be improved, both in the open-loop and closed-loop sections.

Generally, controlling the speed of a three-phase induction motor with a universal bridge and PID controller may be a valuable approach to managing the motor's speed under a variety of working circumstances. The PID controller provides accurate and stable control of the motor speed, while the universal bridge allows for flexible and efficient control of the motor voltage and frequency.

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# APPENDIX A
# TURNITIN REPORT

## Turnitin Originality Report

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