Comparative Analysis of the PSO and GA Based on FOC Technique to Control Speed of AC Traction Motor Drive of Electric Train for Ethio-Djibouti Standard Gauge Railway

Mikiyas Dereje Teshome

A Thesis Submitted to

The Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Master's in Electrical Power and Control Engineering (control Engineering)

Office of Graduate Studies

Adama Science and Technology University

June 2022

Adama, Ethiopia

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DECLARATION

I formally declare that on this Master's Thesis, "Comparative Analysis of the PSO and GA Based on FOC Technique to Control Speed of AC Traction Motor Drive of Electric Train for Ethio-Djibouti Standard Gauge Railway" is my original work. This means that it hasn't been submitted to another college or university for the purpose of conferring a diploma, degree, or certificate. This thesis has correctly cited and recognized all information sources utilized.

Mikiyas Dereje Teshome

Name of student	Signature	Date

RECOMMENDATION

I, the thesis advisor, hereby confirm that I have read and understood the updated version of the thesis named "Comparative Analysis of the PSO and GA Based on FOC Technique to Control Speed of AC Traction Motor Drive of Electric Train for Ethio-Djibouti Standard Gauge Railway" prepared under my guidance by Mikiyas Dereje Teshome developed under my supervision and submitted in partial completion of the criteria for the Master of Science in Control Engineering degree. As a result, I urge that the amended version of the thesis be submitted to the department in accordance with the appropriate processes.

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Advisor	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

I, the advisor of the thesis entitled "Comparative Analysis of the PSO and GA Based on FOC Technique to Control Speed of AC Traction Motor Drive of Electric Train for Ethio-Djibouti Standard Gauge Railway" and developed by Mikiyas Dereje Teshome, I hereby attest that the board of examiners' recommendations and suggestions have been suitably integrated into the final version of the thesis.

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We, the undersigned members of the Board of Examiners for Mikiyas Dereje Teshome thesis "Particle Swarm Optimization (PSO) Based FOC Speed Control of AC Traction Motor Drive," have reviewed and evaluated the thesis of Electric Train for Ethio-Djibouti Standard Gauge Railway" and examined the candidate during the open defense. As a result, this letter certifies that the thesis has been approved as partial completion of the Master of Science in Control Engineering degree requirement.

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Finally, approval and acceptance of the thesis are reliant on the Department Graduate Council (DGC) and School Graduate Committee (SGC) submitting the final copy to the Office of Postgraduate Studies (OPGS).

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LIST OF ABBRIVATIONS

AC	Alternating Current
ATO	Automatic Train Operation
DC	Direct Current
DFOC	Direct Filed-Oriented Control
EDR	Ethio-Djibouti Railways
FOC	Field-Oriented Control
GA	Genetic algorithm
ICM	Integrated Communication Monitor
IFOC	Indirect Field-Oriented Control
IEEE	International Electrical and Electronics Engineer
IM	Induction Machine
MMF	Magnetomotive Force
PID	Proportional Integrated Derivative
PSO	Particle Swarm Optimization
PWM	Pulse Width Modulation
RFO	Rotor Flux Oriented
SPWM	Sine Wave Pulse Width Modulation
SVPWM	Space Vector Pulse Width Modulation
VSI	Voltage Source Inverter

LIST OF ACRONYMS

F	Friction coefficient
i_{ar}, i_{br}, i_{cr}	The three-phase stator current components
i_{as}, i_{bs}, i_{cs}	The three-phase stator current components
i_{qm}, i_{dm}	Direct and quadrature component of magnetizing current
i_{qs}, i_{ds}	Direct and quadrature component of stator current
$i_{\alpha s}$, $i_{\beta s}$	Time-variant stator current in fixed two coordinate
I_s	Stator Current
J	Moment of inertia of the motor
Kg	Kilo gram
L_s, L_r, L_m	Per phase stator, rotor, and mutual inductance
P	Number of poles
R_s, R_r	stator and rotor phase resistance for symmetrical IM
T_e	Electromagnetic torque
T_L	Load torque
T_0, T_1, T_2	Space vector pulse width modulator switching duration
V_{ar}, V_{br}, V_{cr}	The three-phase rotor voltage components
V_{as}, V_{ds}, V_{cs}	The three-phase rotor current components
V_{ds}, V_{qs}	Direct and quadrature component of stator current
V_{dr}, V_{qr}	Direct and quadrature components of rotor voltage
λ_{ds}, λ_{qs}	Direct and quadrature components of stator flux
λ_{qm}, λ_{dm}	Direct and quadrature components of air gap flux
λ_r	Rotor flux magnitude aligned with the d axis
θ	field Rotor flux position
ρ	Time derivative operator
ω	Speed of arbitrarily rotating reference frame
ω_m	Motor mechanical speed
ω_r	Electrical speed
ω_s	Synchronous speed

ABSTRACT

In that they are highly effective in reducing traffic congestion, increasing transportation capacity, consuming less energy, and limiting air pollution, rail transport systems play a significant role in public transportation systems. In railway train operation processes safety is the preliminary affair that are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable specially with controlling the speed of train. For ac traction induction motor vector control, a PI (Proportional, and Integral) parameters controller is used. Particle swarm optimization, evolutionary algorithms, and simulated annealing are a few examples of effective tuning methods for PI parameters. This work proposes a scheduling method for an ac traction induction motor speed control that compares PI tuning parameters using the particle swarm optimization algorithm and the genetic algorithm. As a function of the required settling time and motor specifications, the suggested method will calculate the ideal parameters for the current loop, flux loop, and speed loop. The simulation result shows that PSO-PI technique produce 0% overshoot whereas GA-PI produce 3.86% overshoot at a time of train move with 70km/hr. Again PSO-PI control technique produce 0.15 rise time, 0.27 sec for settling with 4.28 steady error. GA-PI produce 0.12 second rise time and 0.189 settling time with 7.72 steady state error. Generally we can conclude from simulation results obtained using Matlab/Simulink showed that the PSO method is superior to GA to come upon steady state.

Keywords:-Particle swarm optimization (PSO) Algorithm, PI Controller, Induction Motor.

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

The reason that indicator motors are so widely used is that they are both inexpensive and durable, being used in everything from domestic appliances to artificial processes like pumps, suckers, and boasters. In the past, induction motors were typically operated at a single speed that depended on the frequency of the main voltage and the number of poles inside the motor. It is far more challenging to control the speed of an induction motor than it is a DC motor since there is no direct current. Similar to how it is with a DC motor, there is a relationship between the motor current and the performing necklace (Adinur et al., 2017). Additionally, in contrast to dc motors, induction motors can be utilized continuously for an extended period of time due to their brushless construction.

The least precious and most extensively spread induction motor is the squirrel pen motor. We aren’t use the current to produce glamorous field from outside the rotor. So that this is the main reason to say induction motor is so robust and not expensive. An ac induction motor's speed can be varied using vector control or field familiarity control techniques is credited with creating the majority of this style. The rotor current controls the flux position in the motor while the stator current on the quadrature axis controls the control in this control fashion scheme. This control fashion scheme was initially developed for high-performance motor operations that are required to operate easily over the full speed range, induce666 full necklace at zero speed, and have high dynamic performance, including. Even said, FOC is losing some of its attraction for lower performance applications because of its advantages in motor size, cost, and power consumption reduction.

Two abecedarian concepts form the foundation of the vector control algorithm. The flux and necklace-producing currents come first. The most straightforward technique to replicate (and run) an induction is to employ two quadrature currents rather than the traditional three phase current supplied to the motor. The direct (id) and quadrature (command) currents are responsible for producing flux and necklace in the motor independently. According to the description, Iq current is in phase with stator flux and Id is at a right angle. Of course, the operational currents and real voltage provided to the motor are in the well-known three-phase configuration. It is also difficult to go from a reference frame that spins independently of the stator flux to one that rotates in lockstep with it. The abecedarian alternative theory of vector control follows from this. An alternate abecedarian idea is the concept of reference frames. The function of a reference frame is to translate a sinusoidal volume in a reference frame spinning at one frequency to a constant value in another reference frame spinning at the same frequency. Classical commensurable integral (PI) regulators may be used to control a sinusoidal volume after it has been translated to a constant value using a well selected reference frame.

The Ethiopian road was erected by the French to grease the transport of wares which preliminarily had to be carried on the tails of creatures. Not only did the Ethiopian road contribute to bring the country out of its centuries-old insulation from the rest of the world but it also played an important part in changing the social relations between the Ethiopian nations. Indeed though the road line had limited transport possibilities because of the hand (950 mm) and enormous differences in position, it came the most important turnpike of Ethiopia for numerous decades. These drives necessitate accurate speed adaptation in a step-less manner over the whole speed range required. The speed control of IM has become easier thanks to thyristors power mills providing a changeable voltage and variable frequency force, making them viable competitors to DC motors. Variable speed drives in the sedulity utilize IM as their drive motors for a variety of reasons, including cargo capacity, smooth speed control over a large range, and the ability to operate in all four quadrants of a speed-choker airplane, among others.

The switch from dc motors to traction induction motors (asynchronous motors) in community transportation, which enables both wheel-by-wheel and mono-motor driving on the axle to accommodate new traction system requirements, notably in low-bottom vehicles. The fundamental benefit of direct driving is that it eliminates the need for a mechanical transmission. Due to the demanding nature of the job, the final bone quickly wears out. Modern light traction systems used in road motorcars (tramways, trolley lines, and sanctum trains) are powered by GTO or IGBT power inverters (pen induction, endless magnet brushless or switched disinclination motors). Over a wide speed range, electronic control can provide both a constant choker and a constant power condition. Traction motors must have high power density and high instantaneous power. Low-speed chokers with high chokers have the following characteristics: quick choker response, high effectiveness throughout a wide speed and choker range, great reliability and robustness, and low cost. A direct drive system, on the other hand, has a number of benefits (Amritha et al., 2018), including no gear energy losses when driving an axle or wheel without requiring any gears. No gear conservation; no gear noise; oil-free drive system; traction motor noise is reduced by using a lower motor speed and inverter feeding. According to recent research, permanent magnet brushless motors are better motors for direct drive traction operations because they are more efficient, more portable, and have better steady-state and dynamic performances at low speeds. The induction motors, however, offer to be (Donar er al., 2020) a good provident outcome, satisfying the need for power and speed for road bus operation through unique design. According to the authors of the research (Charlis et al., 2016), full enclosed induction motors are the best option for the majority of variable-speed operations, whereas direct-drive a.c. induction motors are preferable for other operations. Variable speed drives are commonly used to describe similar loads. These drives necessitate accurate speed adaptation in a step-less manner over the whole speed range required.

In this situation, Not only did the Ethiopian road contribute to bring the country out of its centuries-old insulation from the rest of the world but it also played an important part in changing the social relations between the Ethiopian nations. Indeed though the road line had limited transport possibilities because of the hand (950 mm) and enormous differences in position, it came the most important turnpike of Ethiopia for numerous decades. alternative mechanisms such as a gear and a belt were utilized to reduce the speed, however this medium resulted in power loss. The power electronics switch in inverter fed IM control approximates a normal voltage position by switching the force voltage on and off at regular intervals. Speed control is being employed in a wide range of tasks (illustration process sedulity, hitting ventilating and air exertion, hoist and electrical vehicle). Despite this, because to its multivariable and nonlinear nature, controlling IM is a difficult task. Furthermore, certain of the parameters are time-dependent, such as the stator-rotor collaborative inductance, and some state variables as well as the development of AC motor control propositions analogous to field- In the design, analysis, and control of IM, developing an accurate system model is critical. For both steady-state and flash working circumstances, these models must include the key elements of both the electromagnetic and mechanical systems.

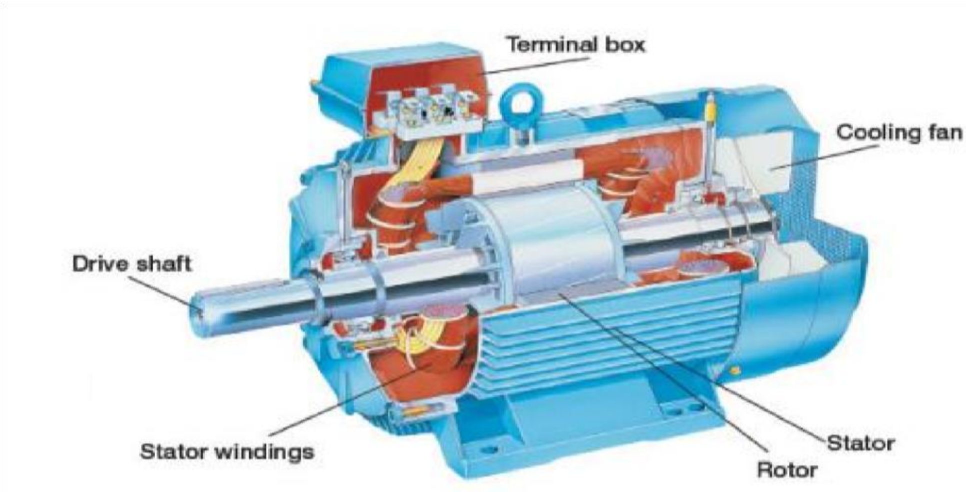


Figure 1. 1 The sectional view of IM (Charlis et al., 2016).

Artificial loads are used to carry out procedures at a variety of favas. Variable speed drives are commonly used to describe similar loads. These drives necessitate accurate speed adaptation in a step-less manner over the whole speed range required. The speed control of IM has become easier thanks to thyristors power mills providing a changeable voltage and variable frequency force, making them viable competitors to DC motors. Variable speed drives in the sedulity utilize IM as their drive motors for a variety of reasons, including cargo capacity, smooth speed control over a large range, and the ability to operate in all four quadrants of a speed-choker airplane, among others. Pulsation range modulator (PWM) switching techniques regulate variable frequency drives. PWM may be done in a variety of methods. In this thesis, the space vector pulsation range (SVPWM) is applied.

1.2. Statement of the problem

In transportation industry train operation primarily need safety for passengers and goods. The basic main thing we get benefits from the electrical train operation is safety, high range of speed operation, minimization of cost and energy, also its reliability and accuracy. As train technology increase from time to time we use ac traction motor on electrical trains. For a decade of years control the speed of ac traction induction motor is not possible. Now a days the three trains which are on operation from labu to nagad (passenger train, maintenance train and freight trains) are using ac traction motor which are faced the problem to control the speed of electrical train. So due to ineffective control of ac traction motor so many damages appear on social life by killing their cows, camels, dogs, sheep and even human beings. This difficulties corrected using FOC control system and analysis by different optimization techniques like pso and GA algorithm to tune PID parameters and get the baste value. It will improve or increase its efficiency, accuracy, and precision of electrical train. The most essential of any train control algorithm is the speed control. The speed will be developed beforehand as an optimization problem with colorful objects similar as energy saving, promptitude, passenger comfort. Grounded on predefined speed, either the motorist or the automatic control in an ATO system will try to follow the commanded speed, although in ATO equipped trains there's still frequently an driver on it for unplanned and emergence situation.

1.3. Objectives of the Study

1.3.1. General Objective

The primary goal of this investigation is comparative analysis of the PSO and GA based on FOC technique to control speed of AC traction motor drive of electrical train for Ethio-Djibouti Standard Gauge Railway.

1.3.2. Specific Objectives

- ✓ To design mathematical modeling of ac induction motor suitable for electrical train.
- ✓ To develop Simulation on MATLAB/SIMULINK and experimental setup for the system on FOC
- ✓ Control speed of ac traction induction motor for electrical train at EDR currently on operation.
- ✓ Design a GA tuned PI to control of ac traction induction motor for the electrical train at EDR.
- ✓ To study characteristics of ac traction motor drive system.
- ✓ To model speed controller of the ac traction motor with field oriented control.

1.4. Scope of the Study

These work will be give attention for analyzing and modeling to regulate the ac's speed traction motor for electrical trains using vector control (field oriented control) method. Again study to improve the performance, drive efficiency, and stability of electrical trains which is operated under EDR by tuning a proposed controller to control speed of passenger train, freight train and maintenance train. I use for simulation MATLAB software.

1.5. Limitation of the Study

A drawback to this study is there is no reference book related to Ethio-Djibouti railway system. The thesis is forced to show only the simulation because to implement in real system I need extra time and cost. Again in this thesis I am not consider performance of electrical train looks like with field weakening (for different flux). When another flux is applied which exceed the reference flux we may not control the speed of ac traction motor for electrical train. So its limited to constant flux producing operation system.

1.6. Motivation of the Study

Now a days, electrical traction trains are used than that of diesel traction train and steam traction train because of it have high range of speed. The ac traction motor in electrical train (passenger train, maintenance train and freight train) have good stability, high speed range. Generally there are varies types of traction motor have been there on the world but ac traction motor is better due to high performance, efficiency, less maintenance, high speed range and etc. A system like this can provide a better reaction to load variations.

1.7. Significance of the Study

Minimization of energy consumption, cost, and Speed range of operation, safety, accuracy, reliability, and decrease air pollution are the basic factor of the electrical operation under EDR. Now a days electrical traction motor are used than other traction motor (diesel and steam traction motor) based on above factors. The train operated under Ethio-Djibouti railways uses ac traction motor. So this thesis is significant to control speed of electrical train based on field oriented control (vector control) technique.

1.8. Organization of the Study

Chapter 1:- This chapter explain about background of the Ethio-Djibouti railway operation and ac traction induction motor of high-speed electrical trains.

Chapter 2:- This chapter reviews the background literature and papers. In addition, the advantages of induction motors over other electric motors are explored, as well as the present control mechanisms for induction motors.

Chapter 3:- delves into the examination of field oriented control model description and the modeling of induction motor drives and the suggested system controller.

Chapter 4:- In this chapter, I am present the result of system I have get on Matlab.

Chapter 5:- under this chapter I am make conclusion and a recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1. Chapter Overview

This chapter examines current developments in an speed control of electrical train locomotives Machine based on vector control techniques that have been used to maintain the ideal of accident specially in Somalia region. The operating temperature, the gap in temperature control schemes, ICM selection for system modeling, and MATLAB control simulation are all covered in the first portion. Then, a review of PID controllers is given, along with relevant research on the suggested controller for electrical train application are reviewed and discussed.

2.2. Electrical Trains

Locomotives having on-board fueled prime movers, such as diesel engines or gas turbines, are categorized as diesel-electric or gas turbine-electric locomotives rather than electric locomotives since the electric generator/motor combination solely serves as a power transmission system. frequently greater than 90%. (not including the inefficiency of generating the electricity). Regenerative braking can increase efficiency by allowing kinetic energy to be captured during braking and utilized to restore power to the line. Modern electric locomotives are equipped with regenerative braking owing to AC motor-inverter drive systems (Donar et al., 2020). Electric locomotives are quieter than diesel locomotives since there is no engine or exhaust noise and less mechanical noise Electric locomotives are simpler to run on the track and require less maintenance since they lack reciprocating parts.

Figure 2. 1 Types of electrical train in EDR (Donar et al., 2020)

2.2.1. Types of electric trains

Now a days, in the world we have three techniques of electrical traction system. Those are:-

Direct Current (DC) traction train:- The most common line voltages for overhead line force systems with direct current have been 1,500 and 3,000. The voltage range for third rail systems is usually 600 to 700 volts. Direct current has the disadvantage of requiring frequent substations and requiring a large and heavy overhead line or third rail. Road traction is made possible by the low-voltage, series-clutch direct current motor, which is very simple to build. In electric and diesel-electric traction systems up to the late 20th century, it was often used. One of the most dc electrical trains are DF4 electric locomotives were developed jointly by CSR Zhuzhou Electric Locomotive Works and CSR Zhuzhou Institute. Its technical parameters are listed below:-

- Purpose: passenger and freight transport
- Rated operating voltage: 15kv
- Service weight: 138t
- Passenger locomotives has 120km/h speed whereas 70km/h for freight locomotive
- Passenger locomotives has 26.3km/h to move continuously and freight locomotives move with 21.9km/h at no disturbance condition.
- For passenger locomotives we use 35,100kg whereas 42,100kg for freight locomotive to apply Starting tractive effort on the locomotives.
- For passenger locomotives we use 25,700kg continuously tractive effort and 30,800kg for freight locomotive
- Wheel base of locomotive: 15,600 mm
- Wheel base of bogie: 3,600 mm
- Distance between bogie pivot centers: 12,000 mm
- Distance between centers of couplers: 21,100 mm
- Traction motor: ZQDR-410

Alternating current (AC) traction train:- alternating current specially have fairly high outflow line voltages (10,000V and above). The high distance between stations necessitates the use of smaller substations, and the lighter overhead current force line that can be used in a similar manner reduces the weight of structures required to support it, which results in a lower cost associated with the longer-term capital costs of electrification. When high-voltage current alternating electricity was first developed. Now a days EDR use ac traction system starting from labu Addis abeba to labu djibouti available interspersing current motors weren't suitable for operation with interspersing current of which is stated the standard marketable or artificial frequentness. It was necessary to use a lower frequency (162/3 hertz in Europe and 25 hertz in the US). The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application. Due to this, either specific railroad power plants had to be used to produce alternating current at the required frequency, or machinery had to be used to convert the commercial frequency to the railroad frequency. Let's take a look at some of the world's greatest traction trains.. One of the most ac electrical trains are SS3 electric locomotives were developed jointly by CSR Zhuzhou Electric Locomotive Works and CSR Zhuzhou Institute. Its technical parameters are listed below:-

- Rated operating voltage: 25kV
- Gauge: 1,435mm
- Maximum running speed: 150km/h
- Axle load: 23t
- Locomotive service weight: 138t
- Minimum radius of curvature negotiable: 125m
- Electric braking mode: secondary resistance braking
- Distance between bogie pivot centers: 15,800mm
- Fixed wheel base of bogie: 4,300mm
- Distance between centers of front and rear couplers: 21,416mm
- Locomotive body width: 3,100mm
- Length of locomotive body underframe: 20,200mm
- Continuous tractive effort: 317.8kN
- Starting tractive effort: 941.8kN
- Total wheel base of locomotive: 37,216mm

Composite traction motor:- The high points of the AC and DC systems are considered using this approach. One type of these systems is single phase to three phase (kando), while the other is single phase to direct current (DC). A single outflow line in a kando system carries a single phase force of 16kv, 50Hz. Through the motor and transformer, In the locomotives, this high voltage is reduced and converted to a three-phase system with the same frequency (Gandin et al., 20018).

This three-phase system is also utilized to power the locomotives' three-phase induction traction motors. Science replaces the three-phase system's two outflow lines with a single outflow line, indicating that the system is provident. The single to DC system, which offers a variety of DC series motor and is the most preventive method for single overhead lines, was previously mentioned in the context of ac electrification. The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application. The treatments in this system scale down and convert a single phase 25kv, 50Hz overhead wire system to DC. The DC is provided to the DC drive system to operate the series motor and regulate its speed. (Gandin et al., 2013).

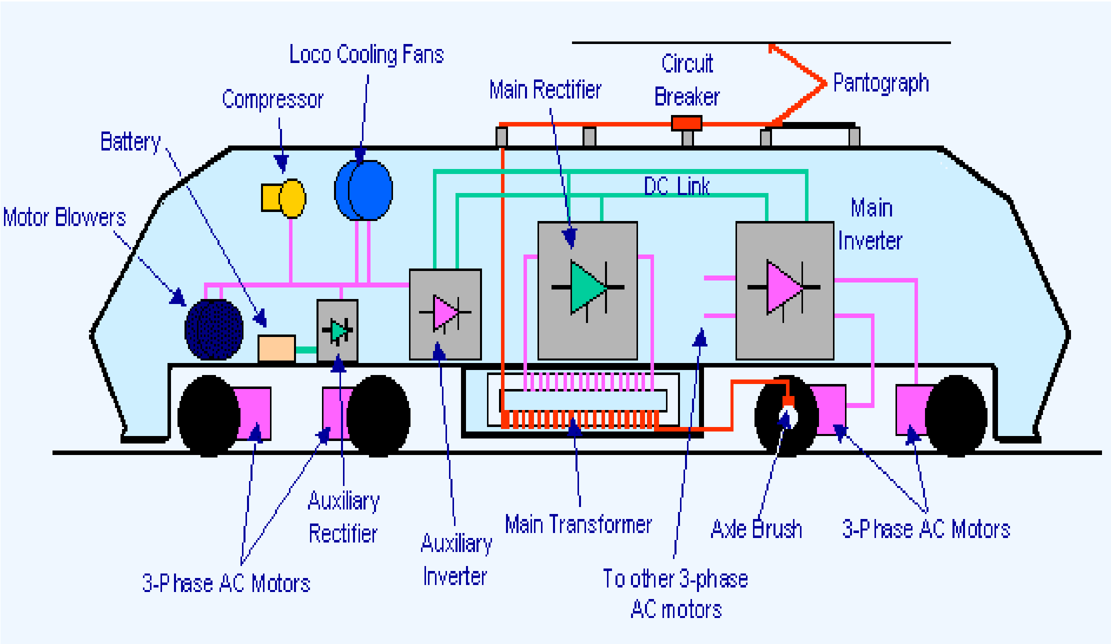


Figure 2. 2 Internal construction of electrical train (Gandin et al., 2013)

2.2.2. Advantages of Electrical Trains

- Electrical locomotives preferred for a variety of reasons, including better efficiency and cheaper maintenance costs. In comparison, they're eerily silent.
- Better speed and acceleration control in the engine.
- Electric locomotives are best adapted for facilitating the movement of people, things, and services between different locations and also more reliable.
- The use of this technology results in a power factor of unity and fewer harmonics.
- For a given weight and volume, the regulated system produces superior results.
- It saves more energy when this technology is used.
- A better tractive impact and a higher amount of stickiness.

2.2.3. Driving Character of Electrical Motor

Drive train of an electrical train can be chosen from different types of motor. To select appropriate type to fulfill all requirements a thorough comparison of motors with respect to the application is needed. The most crucial characteristics of such motors include high reliability, precise electronic controllability of the motor in all aspects, low electromagnetic interface, fault tolerance of the motor drive system, high instant power (high power density), high efficiency, low power consumption, wide speed range with constant power region, low moment of inertia, and torque to size ratio (Hoda et al., 2021). The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application.

Selection of AC or DC motor for electrical train demands consideration of power requirement, voltage and current handling, safety, torque speed characteristics, power to size ratio, maintenance and controllability of each system. Here important feature of each in electrical train environment have been considered. Considering AC IM at a time of starting the magnetic flux produced by stator winding is rotating faster than rotor, causing 100% slip which in turn results high initial current and torque. As the speed of motor increase to rated speed the current decrease and torque increase. In contrast, an induction motor operating at a low speed Torque is greater with a DC motor. Generally speaking, AC IM has less torque and more slip than DC, which has no slip. Due to space constraints, the output power to size ratio of the motors are critical in the design of in-wheel motors for electrical trains. In brushed DC motor the heat which is produced by armature winding is dissipated by the air gap causing increase in the air gap temperature.

2.3. Motor used in electrical train

There are a number of electrical motor which are used in electrical train are listed below:-

2.3.1. Dc Motors

A DC motor is an electric device that converts electrical energy from direct current into mechanical energy. Any electric motor that works on direct current, sometimes known as DC, is a DC motor, according to the definition above. A DC motor has a stator, armature, rotor, and brushes on the commutator. The two magnetic fields within the motor rotate because their polarities are opposite. DC motors are the most basic sort of motor, and they're used in everything from electric razors to vehicle windows. We use dc motor for different application like Drilling machines, washing machine, reciprocating pump, conveyors, electric locomotives, cranes, shear, elevator, and vehicles (karlos et al., 2020). The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application.

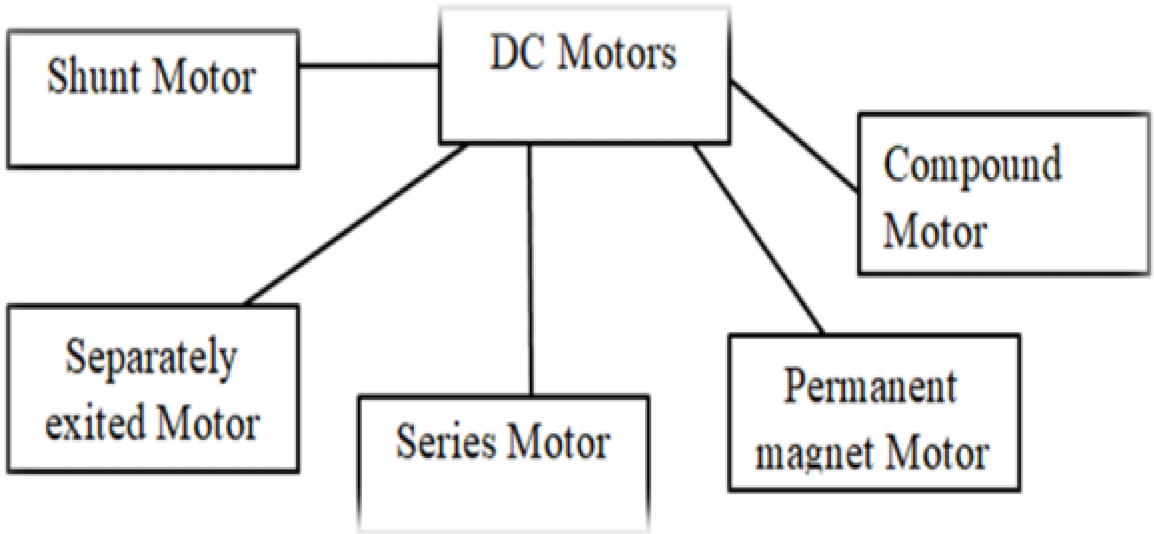


Figure 2. 3 Dc Motor Classification (Karlos et al., 2020).

2.3.2. Ac Motors

An AC motor is a particular kind of motor that uses electromagnetic induction to transform alternating current into mechanical power. An erratic current drives this motor. The two most important passages in an AC motor are the stator and rotor. The motor's rotating component, the rotor, rotates while the stator is stationary. There are single-phase and three-phase AC motor options available. The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application

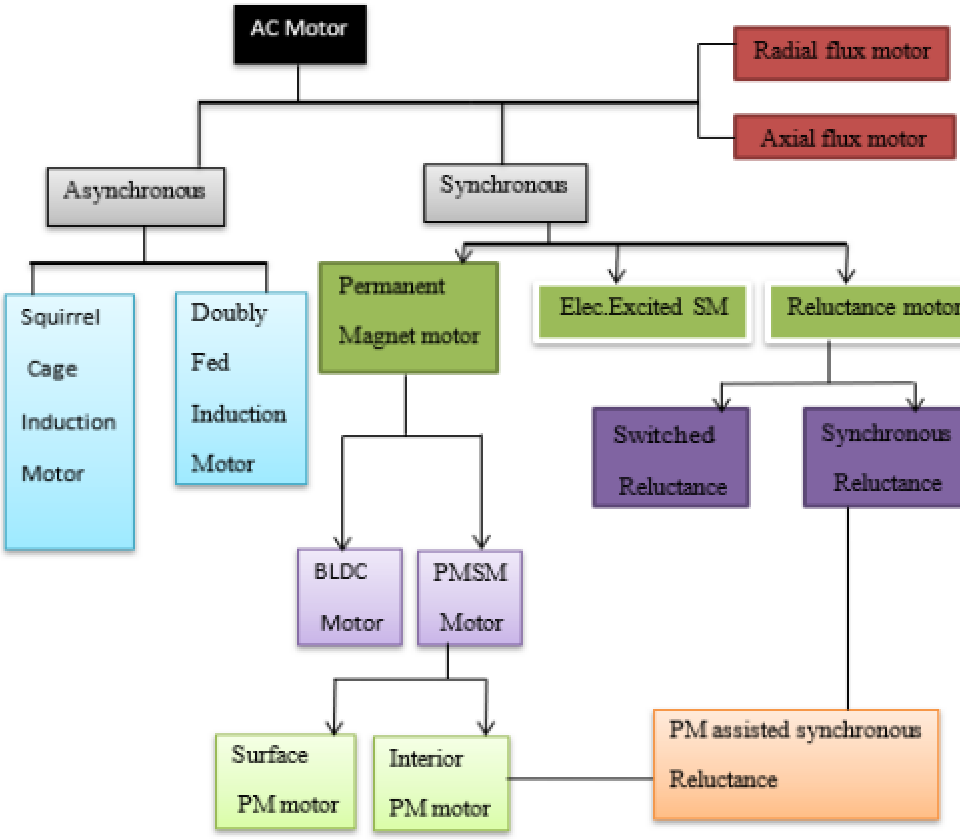


Figure 2. 4 Ac motor classification.

2.3.3. Asynchronous Ac Motor

An induction motor is a device that uses electromagnetic induction to transform ac electric power into mechanical power.

Single-phase induction motors and three-phase induction motors are the two main types of induction motors. The same winding is utilized in an induction machine to produce both AC and DC force flux in the air gap. Coetaneous speed is the rate at which the flux rotates.

Single-phase induction motors and three-phase induction motors are the two main types of induction motors. The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application. The same winding is utilized in an induction machine to produce both AC and DC force flux in the air gap. Coetaneous speed is the rate at which the flux rotates (Mensodin et al., 2010).

Single phase induction motor is usually built at a modest scale (up to 3H.P). In the assiduity, three phase induction motors are the most often utilized AC motors. They have a straightforward restriction and are reliable. It has a low cost, great efficacy, a decent power factor, is dependable, has a tone beginning necklace, and uses very little energy. Three-phase induction motors manage over 90% of the mechanical energy required in the assiduity.

Three phase induction motors are frequently used in the effort to save substantial amounts of energy. Induction motors with a single phase are utilized for low-power conversion. Applications for induction motors include the household, workplace, business, and other sectors.

Figure 2. 5 Induction motor hold together with wheel.

2.3.4. Synchronous Ac Motor

Induction motors are employed in a variety of settings, including the home, business, and industry. A synchronous motor is one that always operates at the same speed. The term "continuous speed" describes the steady pace at which the motor produces the electromotive force. Electrical energy is converted into mechanical energy by a coetaneous motor. The coetaneous motor's major passages are the stator and the motor. The motor's architectural winding is carried by the stator, which becomes immobile. The field winding is carried by the architectural winding. The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application

The rotor rotates as a result of the primary field flow. The salient pole rotor is one of the two methods. The salient pole rotor is used in the coetaneous motor. The rotor pole that is pushed in the direction of the building's windings is referred to as the salient. Sword laminations are used to create the rotor of the coetaneous motor.

The laminations assist in reducing eddy current loss on the motor's winding. In the building of medium and low-speed motors, the substantial pole rotor is extensively used. The high speed is carried by a spherical rotor in the motor (Harfosima et al., 2011).

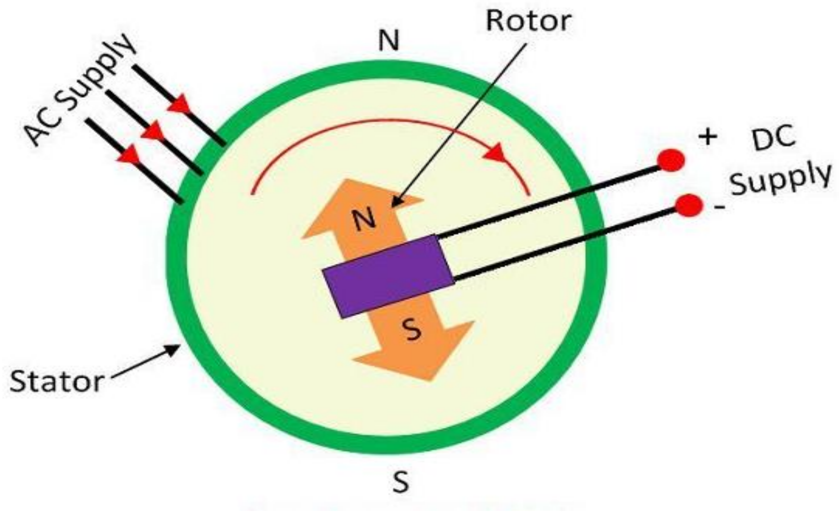


Figure 2. 6 Synchronous motor (Harfosima et al., 2011).

Coetaneous motor is a motor that operates at coetaneous speed, i,e. The rotor's speed is the same as the motor's stator speed. It follows the formula N=NS=120f/P, where Ns is the coetaneous speed and N is the rotor speed. An AC induction motor is an asynchronous motor. The rotor of an asynchronous motor rotates at a lower speed than that of a coetaneous motor.

Selection of AC or DC motor for electrical train demands consideration of power requirement, voltage and current handling, safety, torque speed characteristics, power to size ratio, maintenance and controllability of each system. Here important feature of each in electrical train environment have been considered. Considering AC IM at a time of starting the magnetic flux produced by stator winding is rotating faster than rotor, causing 100% slip which in turn results high initial current and torque. As the speed of motor increase to rated speed the current decrease and torque increase

The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application. The motor uses a high-speed cylindrical rotor to do this. When the rotor and stator of a motor rotate at the same speed, the motor is said to be synchronous. It is calculated using the equation N = NS = 120f/P, where N is the rotor speed and Ns is the synchronous speed.

An AC Induction motor is an asynchronous motor. The rotor of an asynchronous motor rotates at a lower speed than a synchronous motor's rotor.

2.3.5. Performance Comparisons of Motor

The common comparison of ac induction motor with dc motor and other ac motors are discussed in this section. The ability for ac traction induction motor drive are superior compared to DC and other motors for electrical train application. Because of its numerous advantages which are listed below:-

- Low initial cost
- Low maintenance cost
- Simplicity
- There is no restriction on tractive effort owing to wheel-rail adhesion.
- There are no centrifugal forces that limit maximum speed.
- A higher power-to-weight ratio is achieved.
- There is no rotor overheating since the motor runs repeatedly across the cold rotor plate, leaving the hot rotor section behind.

2.4. Space Vector Modulation (SVPWM)

Voltage source inverters have a lot of experience with variable speed IM drives. Pulsation range modulation is used to regulate these variable speed drives. The modulating signal in the SVPWM system is treated as a single unit termed reference voltage. The switching signals may be directly induced using the space vector in SVPWM. Six of the vectors have non-zero bulks, whereas the other two are vectors of zero length (Trzynadlowsk et al., 2019). Assume a reference voltage Vref is provided to the IM as shown in figure (2.8). If Vref is not identical to one of the basis vectors, it must still be addressed using these eight vectors. The SVPWM fashion's ideal is to use the eight switching patterns to compare the reference vector Vref. There are two forms of PWM: sine swell pulsation range modulation (SPWM) and sine swell pulsation range modulation (SVPWM). In sine swell PWM, one signal is a reference sinusoidal swell Vref and the other is a triangular carrier swell Vcar (Sargon et al., 2021).

SVPWM system treats the modulating signal as a single unit called reference voltage. In SVPWM it is possible to induce the switching signals directly using the space vector. Six vector of them have non-zero bulks, while the other two are zero length vectors. Pertaining to suppose a reference voltage Vref is to be applied to the IM. Still, it must be approached using these eight vectors, if Vref is not identical to one of the base vectors. Here important feature of each in electrical train environment have been considered. Considering AC IM at a time of starting the magnetic flux produced by stator winding is rotating faster than rotor, causing 100% slip which in turn results high initial current and torque. As the speed of motor increase to rated speed the current decrease and torque increase

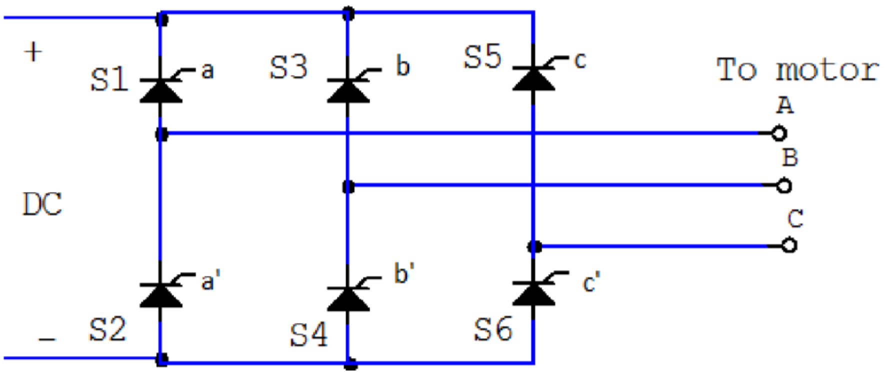


Figure 2. 7 PWM inverter using a three-phase voltage source (Manadin et al., 2013).

A comparator is used to compare the moment values of the Vref and Vcar signals to trigger the SVWM. The affair of the PWM signal is high ("on") when Vref is lower than Vcar. The affair of the PWM signal is low ("off") when Vref is lower than Vcar. Specific switching sequence known as SVPWM. The modulating signal in the SVPWM system is treated as a single unit termed reference voltage. The switching signals may be directly induced using the space vector in SVPWM. Six of the vectors have non-zero bulks, whereas the other two are vectors of zero length (Trzynadlowsk et al., 2019). Assume a reference voltage Vref is provided to the IM as shown in figure (2.8). If Vref is not identical to one of the basis vectors, it must still be addressed using these eight vectors. The SVPWM fashion's ideal is to use the eight switching patterns to compare the reference vector Vref.

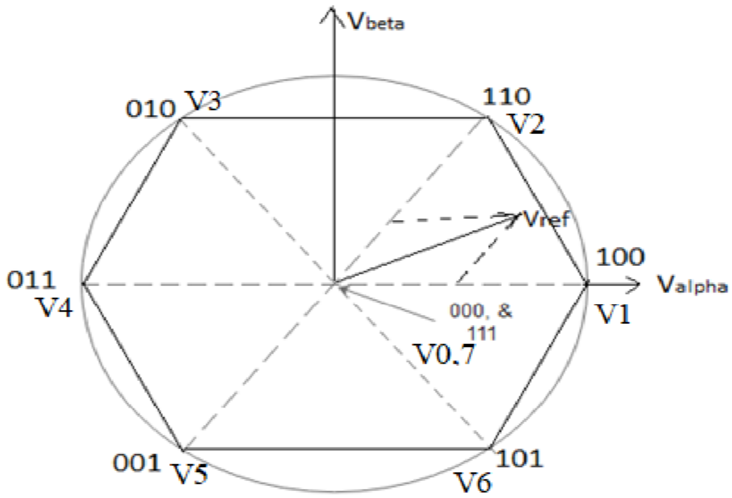


Figure 2. 8 Rotating reference voltage Vref within a hexagon (Trzynadlowsk et al., 2019).

They are easily calculated once the upper power transistor's nations are known. The accompanying table shows the affair phase voltage and line to line voltage in terms of DC-link Vdc for the eight different switch configurations.

Voltage vectors	**Switching state**			**Phase voltage**			**Line to line voltage**		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V0	0	0	0	0	0	0	0	0	0
V1	1	0	0	$\frac{2}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	V_{dc}	0	$-V_{dc}$
V2	1	1	0	$\frac{1}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	$-\frac{2}{3}V_{dc}$	0	V_{dc}	$-V_{dc}$
V3	0	1	0	$-\frac{1}{3}V_{dc}$	$\frac{2}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$	$-V_{dc}$	V_{dc}	0
V4	0	1	1	$-\frac{2}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	$-V_{dc}$	0	V_{dc}
V5	0	0	1	$-\frac{1}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$	$\frac{2}{3}V_{dc}$	0	$-V_{dc}$	V_{dc}
V6	1	0	1	$\frac{1}{3}V_{dc}$	$-\frac{2}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	V_{dc}	$-V_{dc}$	0
V7	1	1	1	0	0	0	0	0	0

Table 2. 1 SVPWM Output Voltage Waveform

The modulating signal in the SVPWM system is treated as a single unit termed reference voltage. The switching signals may be directly induced using the space vector in SVPWM. Six of the vectors have non-zero bulks, whereas the other two are vectors of zero length. Assume a reference voltage Vref is provided to the IM as shown. If Vref is not identical to one of the basis vectors, it must still be addressed using these eight vectors. The SVPWM fashion's ideal is to use the eight switching patterns to compare the reference vector Vref. Switching time is calculated where V1 and V2 are two conterminous base vectors and two conterminous base vectors, respectively, and vref is an arbitrary reference voltage demanded to be approached as the two conterminous base voltages by confirming the switching time of the switching device using vector principle.

T0 = (1 − (r1 r2))

T1 = r1T

T2 = r2T

Where $r_1 = \sqrt{3}\,\frac{V_{ref}}{V_{DC}}\sin(60 - \theta)$

$$r_2 = \sqrt{3}\,\frac{V_{ref}}{V_{DC}}\sin(\theta)$$

If T is too tiny, the PWM signal will more closely resemble the original signal.

T0 Duration of zero vectors

The durations of V1 and V2 are T1 and T2, respectively.

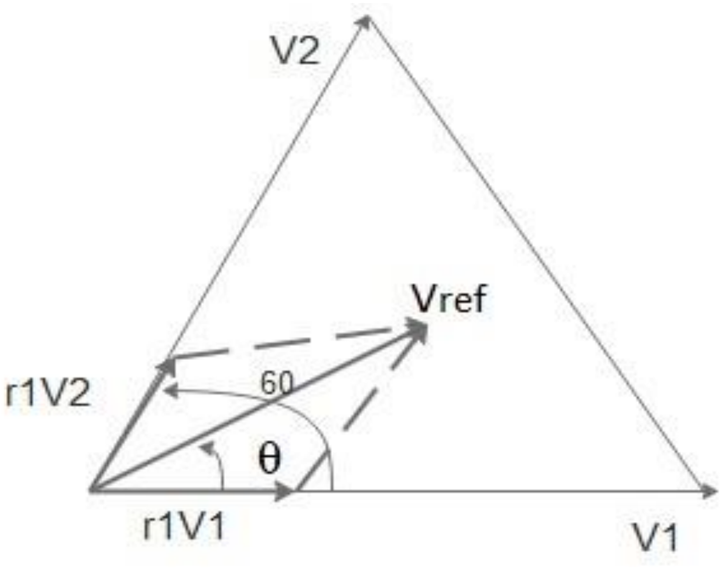


Figure 2. 9 SVPWM Switching Time (Munashir 2000).

The following are the key benefits of SVPWM-generated gate palpitation.

- Wide direct modulation range
- Lower switching loss
- Lower total harmonious deformation in the diapason of the switching waveform
- Fairly easy perpetration

SVPWM consists of two main parts

- The switching vectors are chosen and
- Calculation of the vector interval

2.5. Inverters for ac Drives (DC-AC)

Circuits called inverters change alternating current (ac) from direct current (dc) at a certain voltage and frequency. The inversion, in more technical terms, converts electric power from a dc source to a weight. Inverters come in two main categories: voltage source inverters (VSI) and current source inverters (CSI) (CSI). In VSI, the dc source's impedance is low or non-existent. To put it another way, the input terminal of a VSI is a stiff dc voltage source. A CSI, on the other hand, gets pliable current from a stiff dc current source, which has a high impedance. In VSIs that employ thyristors, forced commutation is usually necessary. To manage the on/off of VSIs constructed of GTOs, power transistors, power MOSFETs, or IGBTs, tone communication with base or gate drive signals is employed (Sersuma 2020).

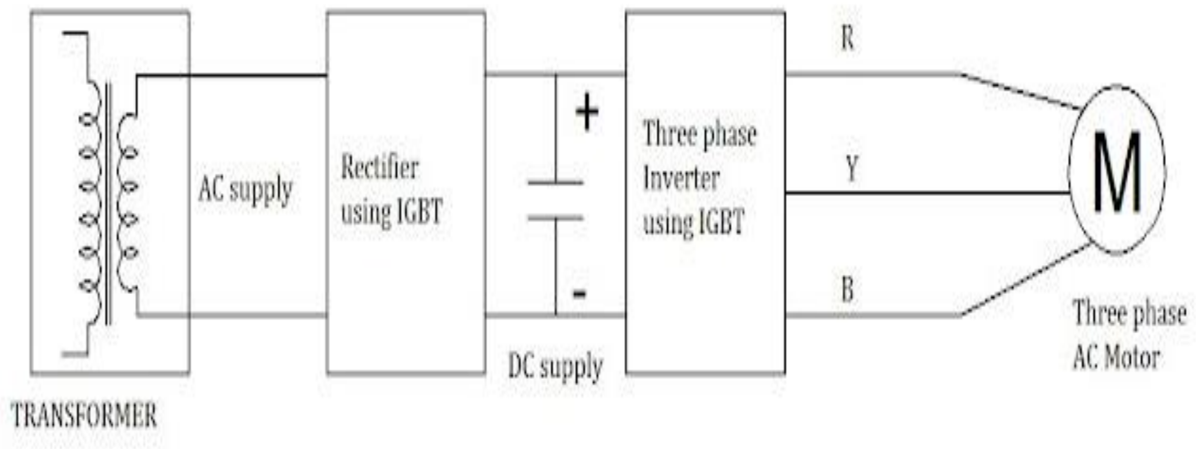


Figure 2. 10 Tree-phase inverter in electrical train (Sersuma et al., 2020).

2.6. PSO (Particle Swarm Optimization) Algorithm

In complex and multi-peak challenges, PSO offers superior results. The PSO computation is extremely rapid, simple, and uncomplicated to get and execute. It also has a limited number of settings that may be changed. When the look space is large, can calculate the best esteem with molecular contact, but when the look space is little, its merging speed becomes extremely modest, near to the global ideal. When it deals with a large and complicated data collection, it also looks to be lacking in quality. As previously stated, a few PSO variants have been developed to address this problem (Vanclis 2018).

The PSO algorithm's pseudo code may be seen below.

Initialize parameter
Initialize randomly position (xi)
Initialize randomly velocity (Vi)
Set pbest and gbest in particle
While (t < final iterations)
Calculate fitness value of new particle xi using objective function (ITAE)
If xi is best than pbest
Set xi as pbest
end
If xi is best than gbest
Set xi as gbest
end
for i: No. Population
Update (x_i) and (Vi) of particle by using equation Error! Reference source not found. and Error! Reference source not found.
end
t=t+1
end

2.7. Genetic Algorithm

The genetic algorithm employs natural selection, the mechanism that propels evolutionary processes, to solve limited and unconstrained optimization problems. Two main features of the genetic algorithm:

- A design's significance is evaluated by the fitness function; a greater fitness value denotes a more potent design. A fitness function may be defined using a variety of techniques.
- A chromosome or chromosomes can have their programming changed from generation to generation via a genetic operator called crossover. Crossover is a term used to describe sexual reproduction. To produce superior offspring, two strings are randomly chosen from the mating pool to cross over.

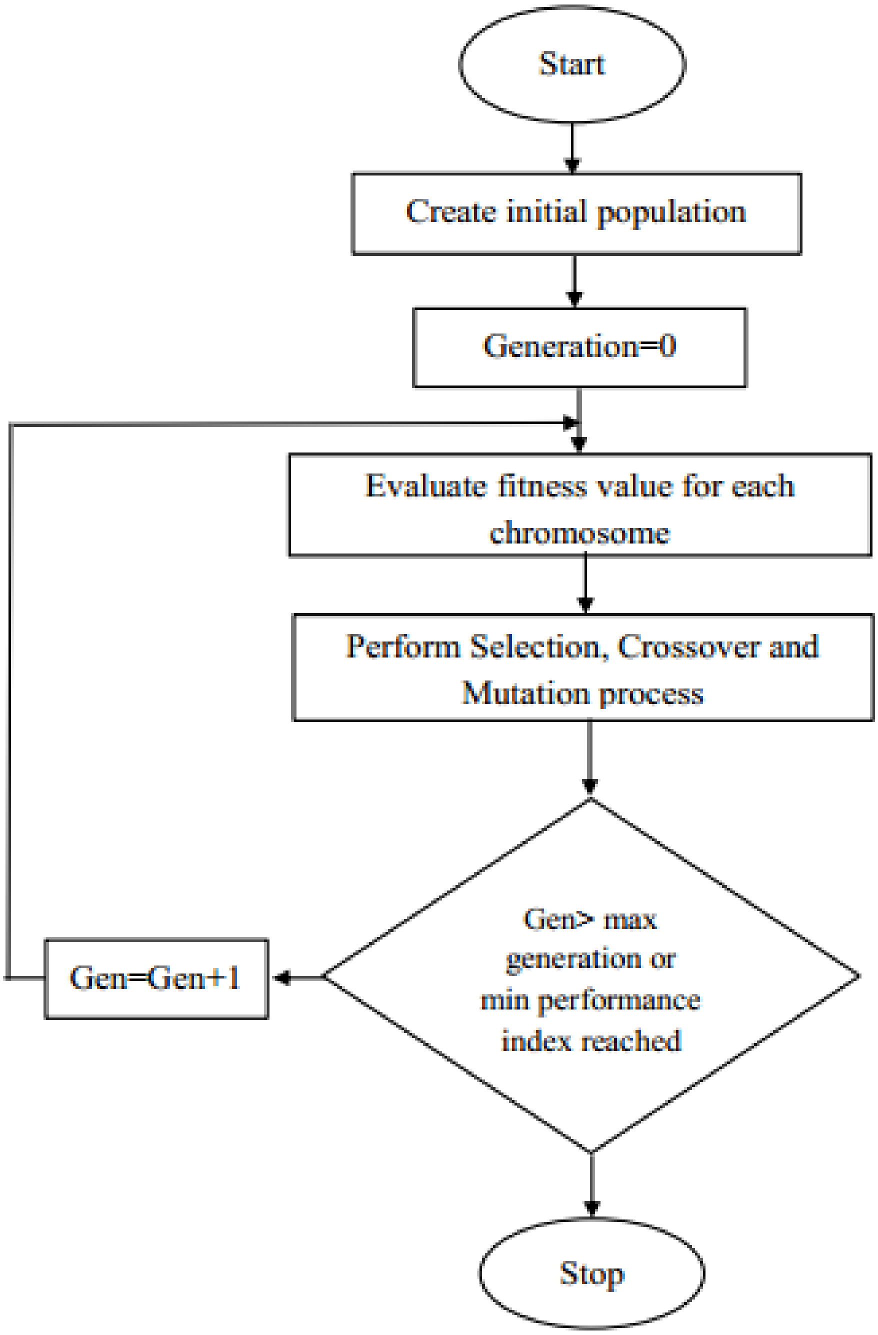


Figure 2. 11 Genetic algorithm architecture

Initialize parameter

Create initial population

While (t < Max number of iterations)

Calculate the value of fitness for individual in the population using (ITAE)

For i: max iteration

Select individuals for the new population –selection

Perform cross-over operation

Perform mutation of individual

Evaluate individuals

Replace old population with the new one

end

t=t+1

end

The system's whole response is computed and optimized using GA for each PID control parameter value and starting fitness value of integral absolute error (IAE). This technique will be repeated every generation until the best fitness value is reached at the end of the generation.

Genetic algorithm	
GA Property	value
Population Size	50
Maximum number of generation	60
Mutation Probability	0.1
Lower boundary	[0 0 0]
Upper boundary	[50 50 50]

Table 2. 2 Parameter setting of genetic algorithm optimization

2.8. Related work

There you have it – phase traction. Because of its simple design and longevity, IM is known as the loafer of artificial and home motor operations. There are several types of IM that have attracted the interest of researchers, and several control systems have advocated using IM in variable speed drive operations. The ac traction IM control strategy's performance may be divided into two categories: scalar control and vector control (Parsin et al., 2002). Changing the force frequency factor stator voltage is a basic IM control mechanism. In many high performance motion drive applications. An induction motor, a power electronic device, and a controller make up the three essential parts of a system. Review of the state-of-the-art in motor loss reduction and speed sensor-less control. The current issues with induction motor drive system deployment are listed.

Full digital control-based AC drives have attained the status of a mature technology. The goal of ongoing research is to detach the speed sensor from the machine shaft without compromising the dynamic performance of the drive control system. Some people have tried reworking the induction machine to address these issues (Jansen et al, 1994a). The dynamic and stationary performance of this speed control system is poor. This system also has a considerable power loss due to slide. Because the speed is near to coterminous, changing the stator frequency provides an excellent speed control mechanism for traction IM. The rotor circuit's operational slip and slip power loss are both minimal. Even yet, this speed control mechanism necessitates the use of a frequency motor, which is expensive. Controlling the current using a slip.

Over the past 20 years, there has been a lot of research done on how to estimate the induction machine's flux and speed. In the past, a unique sensing component, such as Hall-effect sensors positioned in the air gap, was used to monitor the rotor flux. This approach has the benefit that variations in temperature and flux level do not appreciably influence the extra needed parameters. The drawback of this approach is the high cost and specialized installation and maintenance required for flux sensors. Vector control and v/f control both require frequency motors. Both voltage and frequency fluctuated with v/f control, while the rate remained fixed. Provide acceptable flash results (Nasedor et al., 2019). Scalar control refers to control systems that simply regulate the amount and frequency of stator current and voltage. A vector or FOC system is used to create a fast and exact choker response for a high performance AC traction IM drive. FOC's universality is based on the prediction of stator current putrefying in chokers and flux generating elements (Mensodin et al., 2019). As a result, it allows for independent flux and choker control. Different field exposures exist. Stator- flux field exposures and rotor- flux field exposures are the most prevalent field exposures (Ongish et al., 2008). The first field – acquainted control is rotor flux field acquainted control, which is accomplished by aligning the rotor flux on the rotating reference frame's d-axis.

It is obvious that the cost, reliability, and maintenance requirements of control systems using mechanical speed sensors are higher. The aforementioned drawbacks are eliminated by induction motor control methods without speed sensors. This is the reason why many studies are now focusing on the sensorless speed control of the induction motor industry. The most popular method for sensorless speed control of induction motors nowadays is field oriented control. The fundamental benefit of this approach is independence in torque and flux control (Quang, et al., 2008).

Direct system on field acquainted control, the first FOC, uses direct seeing of the air gap flux vector by employing various dimension methods such as air gap hall sensors, seeing coils, or other dimension methods. Although this system is mostly immune to variation since it relies on feedback control and direct observation of the regulated variable, it is nevertheless troublesome because it necessitates new writing, which adds expense and complexity to the drive (Harfosima et al., 2011). Mounting the seeing device in the air gap might be tricky. The other sort of field-acquainted control is circular field-acquainted control, which eliminates flux seeing bias by ciphering the relevant motor slip frequency to acquire the requested flux position using known motor performance. Because it is easier to implement than direct field-acquainted control, this approach is quite common. In reference, sensorless control was presented, in which the speed and/or position sensors are not present (Hukra et al., 2021). The speed and flux vector are computed online from the voltage and current dimensions in sensorless control. The expense of driving will be reduced in the future.

Even in transient regimes, the induction motor's independent torque and flux regulation offers great precision and quick dynamic speed response. Because it is straightforward to apply and a very reliable approach. Sensorless speed control is especially necessary when fresh wiring is impossible owing to temperature, sudden contract, and other factors. In reference, an indirect field-acquainted control of IM without the need of a current sensor was also presented (Basnet et al., 2018). No current sensors are required in this control method. However, because there is no voltage or current feedback, the drive's performance may suffer as a result of parameter divagation/mismatch and disturbance. Multitudinous controllers were proposed in IM FOC (fuzzy control, neutral network, inheritable algorithm, adaptive control, SMC, neuro-fuzzy control, and multitudinous others). The IFOC system is proposed in this thesis because of its great performance.

CHAPTER 3

MODELLING AND PARAMETERS ESTIMATION

Measured data, model correction plans, and parameter estimation via genetic algorithms and particle swarm optimization are all used in the estimate of model parameters. The calculated model is validated using the normalized-root-mean-square error (NRMSE) % fitting.

3.1. Materials

The following software tools are used in this thesis work: MATLAB 2019b for simulation, signal conditioner, microcontroller, a specially designed data logger, WassGrill-ICM, and step signal generator for experimental setup. Again in Microsoft office, the block diagram is created using Microsoft visio.

3.2. Methods

Figure 3.1 depicts the strategy used in this thesis to complete the required goal. The articles and literatures that are closely connected. Because ac traction motors are more efficient and easier to maintain than dc motors, they are commonly employed in electrical trains. So, electrical train that uses power from overhead system that comes from power substation supported ac traction motor is discussed during this research. Motor specification of ac traction motor for electrical trains have taken from the manufacturing company. The acquired data is theoretically and visually examined in order to construct system modeling. The maximum power needs of an electrical train is calculated using dynamics modeling. The ac traction motor speed control drive is designed using inverter commutation approaches that support the electrical train.

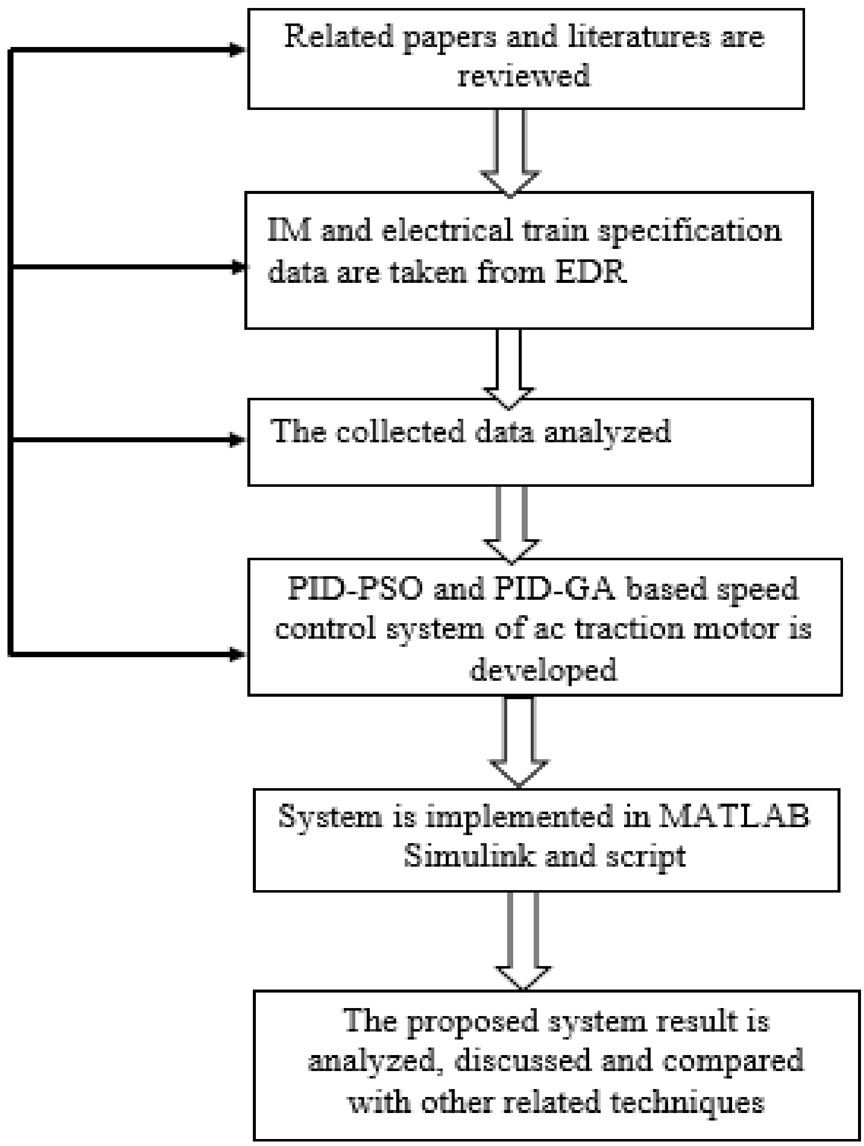


Figure 3. 1 A block representation of the research process.

3.3. Analysis of Electrical Train System Development

The pantograph is a current-gathering system for overhead lines. The locomotive obtains current from the overhead wire through this pantograph. Pantographs are maintained up by compressed air pressure to link to the overhead wire. It's also designed to collapse in the event of an obstacle, and it can be manually lowered to shield the locomotive from the above wire.

A circuit breaker is an electrical restraining device. It is used to isolate the locomotive from the principal power force flowing from the pantograph when a problem occurs.

Axle Encounter- The pantograph helps link phase or line captains, whereas axle encounters help connect neutral captains. The pantograph collects electricity from the load line and returns it to the locomotive through the axel encounter.

Step-down motor voltage: The locomotive in a kando system is driven by a single phase force of 16kv or 25kv at 50 Hz. As a consequence, the high voltage is reduced using a step down motor. A tap changer is also included with this motor.

A rectifier is a device that transforms single-phase AC electricity from a motor into direct current (DC). Because they carry a substantial amount of current and electrical power, SCRs, IGBTs, and other similar devices are widely used in this therapy.

Sludge: Two propellants are used, as seen in the diagram below. There's a DC sludge that's used to filter the DC affair of the treatment.

The DC force is converted with this single phase to three converter (three phase AC force is utilized to run the three phase induction motor). High-carrying SCRs and IGBTs are commonly used in this inverter circuit.

The speed, necklace, acceleration, and other characteristics of a three-phase motor are controlled by a motor controller.

A traction motor, in general, is a mechanism that allows you to pull anything.

In current locomotive systems, three-phase asynchronous motors or induction motors are employed. Induction motors, among other things, provide superb speed control, regenerative braking, and quick acceleration.

The locomotive system also uses a single phase inverter to power the light, sucker, AC sockets, cooling suckers, and battery bowl, among other things. This single phase inverter is likewise powered by the main therapy.

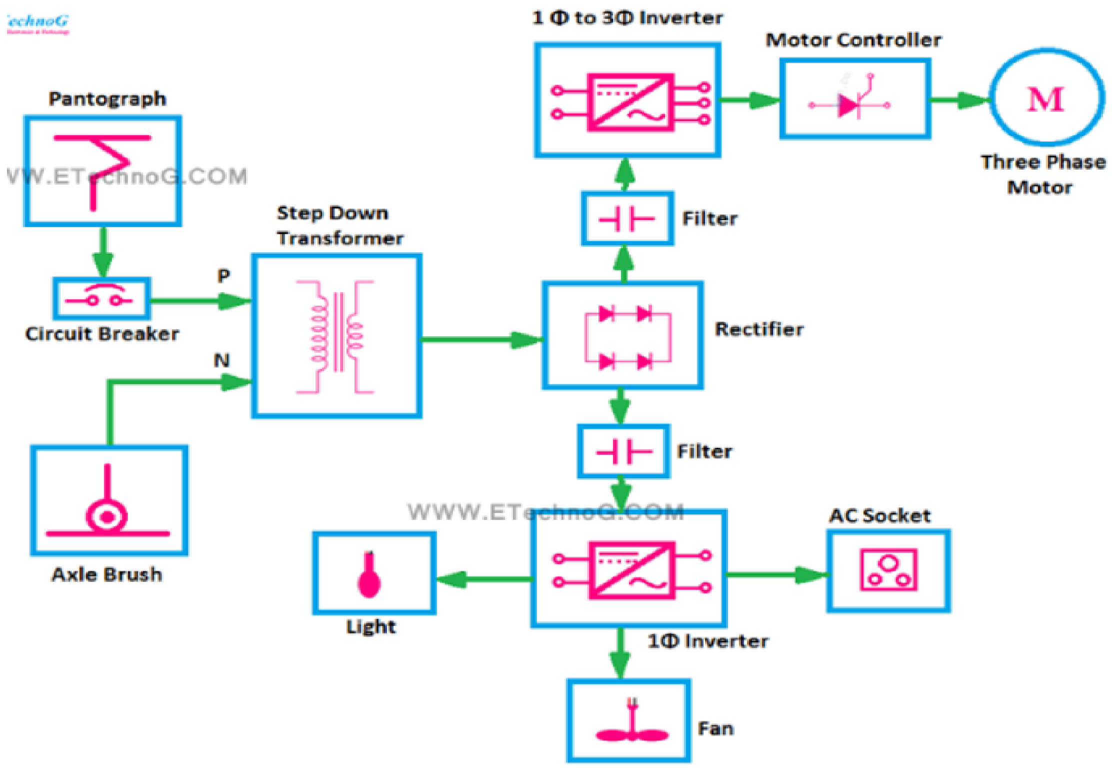


Figure 3. 2 Electrical locomotives traction system block diagram

3.4. Modelling of AC Traction Induction Motor

A conventional control system design requires a precise mathematical model. The PID controller settings will be determined using the fine model reflecting plant dynamics. The space vector form of the voltage equations is used to create the AC IM model. The model is meant to have ideally symmetrical IM with direct glamorous circuit features in the first chapter. The development of a good system model is crucial in the design, analysis, and control of ac traction IM. These models have to take into account the fundamental properties of mechanical and electromagnetic systems for both steady-state and flash operation. In general, IM modeling in ac traction

1. There is no magnetic saturation, which means the inductance is unaffected by the current position
2. There is no saliency effect, thus inductance isn't affected by where you are.
3. The stator and rotor windings are arranged to generate a sinusoidal MMF distribution, therefore spatial MMF is insignificant.
4. There's no fringing of the glamorous circuit
5. Eddy current and hysteresis goods are negligible, and

6. Livery air gap

IM voltage equation is produced using the differential equations below. [11], [26].

$$V_{qdos} = R_S i_{qdos} + \omega\lambda_{dqs} + \frac{d}{dt}\lambda_{qdos} \quad (3.1)$$

$$V_{qdor} = Rri_{qdor} + (\omega - \omega_r)\lambda_{dqr} + \frac{d}{dt}\lambda_{qdor} \quad (3.2)$$

Where $[fqdos]^T = [fqs\ fds\ fos]$

$[fqdor]^T = [fqr\ fdr\ for]$

The voltage equations above in expanded rewritten as

$$V_{qs} = Rsiqs + \omega\lambda ds + \rho\lambda qs \quad (3.3\ a)$$

$$Vds = Rsids - \omega\lambda qs + \rho\lambda ds \quad (3.3\ b)$$

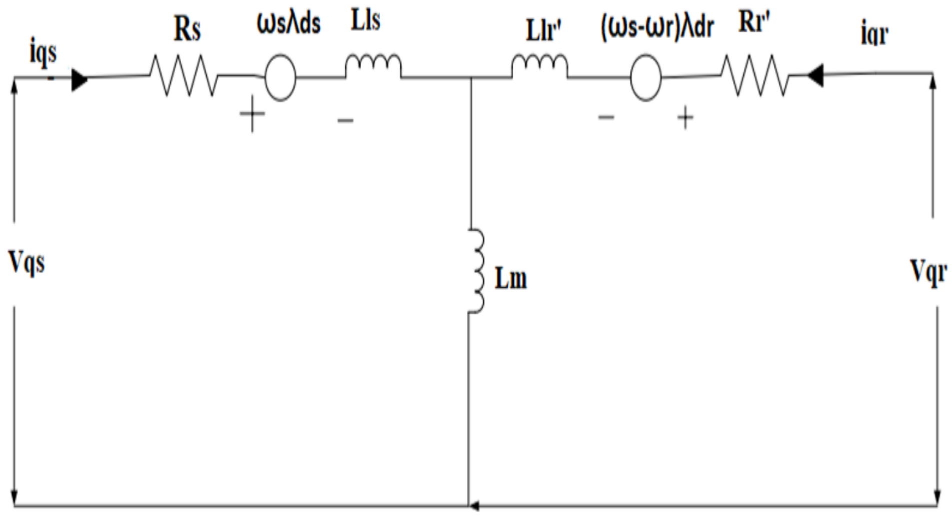
$$Vos = Rsios + \rho\lambda os \quad (3.3\ c)$$

$$V_{qr} = R_r i_{qr} + (\omega - \omega_r)\lambda'_{dr} + \rho\lambda_{dr} \quad (3.3d)$$

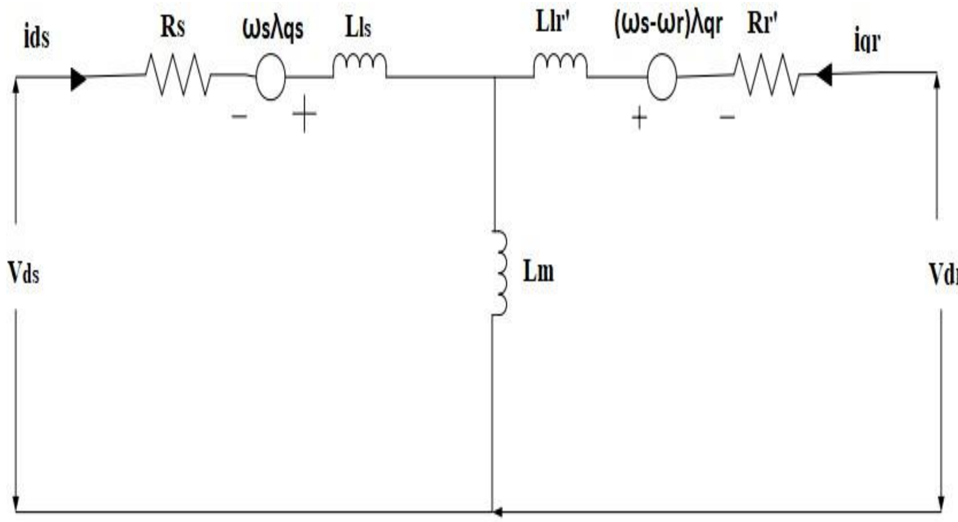
$$V_{dr} = R_r i_{dr} - (\omega - \omega_r)\lambda'_{qr} + \rho\lambda dr \quad (3.3e)$$

$$V_{or} = R_r i_{or} + \rho\lambda'_{or} \quad (3.3f)$$

The original circuit representation of the model in the coetaneous reference frame is illustrated in figure (3.1a and 3.1 b) using the following equations.



a) a) q-axis circuit representation



b) d- axis circuit representation

Figure 3. 3 IM original circuit in the coetaneous reference frame

If you have the expression for the flux relation, you can finish the voltage equation. The formulae for the flow equation are as follows.

$$\begin{bmatrix}\lambda_{qdos}\\ \lambda_{qdor}\end{bmatrix} = \begin{bmatrix} K_s L_s (K_s)^{-1} & K_s L'_{sr}(K_r)^{-1} \\ K_r (L_{sr})^T (K_s)^{-1} & K_r L'_r (K_r)^{-1}\end{bmatrix}\begin{bmatrix} i_{qdos}\\ i_{qdor}\end{bmatrix} \quad (3.4)$$

The equation for the flow was reduced as indicated in equation (3.5) below for this disquisition using symmetrical IM.

$$\begin{bmatrix}\lambda_{qdos}\\ \lambda'_{qdor}\end{bmatrix} = \begin{bmatrix} \begin{pmatrix} L_{ls}+L_m & 0 & 0\\ 0 & L_{ls}+L_m & 0\\ 0 & 0 & L_{ls}\end{pmatrix} & \begin{pmatrix} L_m & 0 & 0\\ 0 & L_m & 0\\ 0 & 0 & 0\end{pmatrix} \\ \begin{pmatrix} L_m & 0 & 0\\ 0 & L_m & 0\\ 0 & 0 & 0\end{pmatrix} & \begin{pmatrix} L'_{lr}+L_m & 0 & 0\\ 0 & L'_{lr}+L_m & 0\\ 0 & 0 & L'_{lr}\end{pmatrix}\end{bmatrix}\begin{bmatrix} i_{qdos}\\ i'_{qdor}\end{bmatrix} \quad (3.5)$$

Also the flux equation in the expanded form will be as below

$\lambda_{qs} = L_{ls} i_{qs} + L_m(i_{qs} + i'_{qr})$ (3.6 a)

λds = Llsids Lm (ids i ′ dr) (3.6 b)

$\lambda os = L_{ls} i_{os}$ (3.6 c)

$\lambda'_{qr} = L'_{lr} i'_{qr} + L_m(i_{qs} + i'_{qr})$ (3.6 d)

$\lambda'_{dr} = L_{ls} i'_{dr} + L_m(i_{ds} + i'_{dr})$ (3.6 e)

$\lambda'_{or} = L'_{lr} i'_{or}$ (3.6 f)

To anatomize balanced or symmetrical IM situations, a stationary or synchronously rotating reference frame is often used. The voltage equation supplied in the coterminous reference frame is preferred when a linearized model of ac traction IM is required in the study and development of a transfer function. This thesis research also uses a continuous reference frame for the reasons described below.

By just letting the speed to run, a continuous reference model will emerge. The linearized fine model will be used to develop the PID regulator. For a synchronously rotating frame, an IM model with mixed stator current and rotor flux as state variables is appropriate. Count (idr, iqr, ds qs) and describe the system using (dr, qr, ids, and commands) as state variables. It has the benefits of quantifiable affair quantities (stator currents) and a low computing load. The electromagnetic choker relation and the matrix equation are shown below. Also, this model is suitable for rotor flux exposure can be quantified analytically by this model. For pen type, the rotor winding is shorted and for crack type, the rotor circuit stations are open and accessible to add an external resistor to gain the demanded choker- speed characteristics and after adding the demanded resister, it needs to be shorted. Therefore both pen and crack rotor type IM rotor circuit is short- circumvented at running. Thus, equation (3.3 d) and (3.3 e) rewritten as follows.

$$0 = R_r i_{qr} + (\omega - \omega r)\lambda'_{dr} + \rho\lambda'_{qr} \qquad (3.7\ a)$$

$$0 = R_r i_{dr} - (\omega - \omega r)\lambda'_{qr} + \rho\lambda'_{dr} \qquad (3.7\ b)$$

Where = the time secondary driver the flux equation (3.6 a) – (3.6 f) rewritten as

$$\lambda_{qs} = L_s i_{qs} + L_m i'_{qr} \qquad (3.8\ a)$$

λds = Lsids Lmi ′ dr (3.8 b)

$$\lambda'_{qr} = L'_r i'_{qr} + L_m i_{qs} \qquad (3.8\ c)$$

$$\lambda'_{dr} = L'_r i'_{dr} + L_m i_{ds} \qquad (3.8\ d)$$

Where Ls = Lls + Lm and $L'_r = L'_{ls} + L'm$

From 3.8 c and 3.8 d we've

$$i'_{qr} = \frac{1}{L'r}(\lambda'_{qr} - L_m i_{qs}) \qquad (3.9\ a)$$

$$i'_{dr} = \frac{1}{L'_r}(\lambda'_{dr} - L_m i_{ds}) \qquad (3.9\ b)$$

Substitute equation3.9 a and3.9 b into3.7 a and3.7 b we gain the following differential equations.

$$\frac{d\lambda'_{qr}}{dt} = -\frac{R_r}{L_r}\lambda'_{qr} + \frac{L_m R_r}{L_r} i_{qs} - (\omega - \omega_r)\lambda'_{dr} \qquad (3.10\ a)$$

$$\frac{d\lambda'_{dr}}{dt} = -\frac{R_r}{L_r}\lambda'_{dr} + \frac{L_m R_r}{L_r} i_{ds} - (\omega - \omega_r)\lambda'_{qr} \qquad (3.10\ b)$$

When we change equations 3.9 a and 3.9 b to 3.8 a and 3.8 b, we get

$$\lambda_{qs} = L_s i_{qs} + L_m(\frac{1}{L'_r}(\lambda'_{qr} - L_m i_{qs})) \qquad (3.11\ a)$$

$$\lambda_{ds} = L_s i_{ds} + L_m(\frac{1}{L'_r}(\lambda'_{dr} - L_m i_{ds})) \qquad (3.11\ b)$$

We may extract the following equations by substituting equations 3.11 a and 3.11 b into equations 3.3 a and 3.4 b.

$$\frac{di_{ds}}{dt} = -\gamma i_{ds} + \omega i_{qs} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_{qr} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_{dr} + \frac{1}{L_s \sigma}V_{ds} \qquad (3.12\ a)$$

$$\lambda_{ds} = L_s i_{ds} + L_m(\frac{1}{L'_r}(\lambda'_{dr} - L_m i_{ds})) \qquad (3.12\ b)$$

An IM's mechanical equation is provided by equation (3.13)

$$\frac{Jd\omega_m}{dt} = T_e - T_l \qquad (3.13)$$

With $T_e = \frac{3PL_m}{4L'_r}\left(\lambda'_{dr} i_{qs} - \lambda'_{qr} i_{ds}\right)$ [16] [27] [25]

Then $\frac{d\omega_m}{dt} = \frac{1}{J}\left(\frac{3PL_m}{4L'_r}\left(\lambda'_{dr} i_{qs} - \lambda'_{qr} i_{ds}\right) - \left(F\omega_m + T_L + T_d\right)\right)$ (3.14)

Also the fine model that can represent ac traction IM roughly well in the arbitrary reference frame is given by.

$$\frac{d\omega_m}{dt} = \frac{1}{J}\left(\frac{3PL_m}{4L'_r}\left(\lambda'_{dr} i_{qs} - \lambda'_{qr} i_{ds}\right) - \left(F\omega_m + T_L + T_d\right)\right) \qquad (3.15\ a)$$

$$\frac{di_{ds}}{dt} = -\gamma i_{ds} + \omega i_{qs} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_{qr} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_{dr} + \frac{1}{L_s \sigma}Vds \qquad (3.15\ b)$$

$$\frac{di_{qs}}{dt} = -\gamma i_{qs} - \omega i_{ds} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_{dr} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_{qr} + \frac{1}{L_s \sigma}V_{ds} \qquad (3.15\ c)$$

$$\frac{d\lambda'_{qr}}{dt} = -\frac{R_r}{L_r}\lambda'_{qr} + \frac{L_m R_r}{L_r}i_{qs} - (\omega - \omega_r)\lambda'_{dr} \qquad (3.15\ d)$$

$$\frac{d\lambda'_{dr}}{dt} = -\frac{R_r}{L_r}\lambda'_{dr} + \frac{L_m R_r}{L_r}i_{ds} - (\omega - \omega_r)\lambda'_{qr} \qquad (3.15\ e)$$

Where wr and we generate an ac traction IM model in a synchronously rotating frame by setting the reference frame's speed equal to the coetaneous speed, as shown in equation. (3.16a-3.16 e).

$$\frac{d\omega_m}{dt} = \frac{1}{J}\left(\frac{3PL_m}{4L'_r}\left(\lambda'_{dr} i_{qs} - \lambda'_{qr} i_{ds}\right) - \left(F\omega_m + T_L + T_d\right)\right) \qquad (3.16\ a)$$

$$\frac{di_{ds}}{dt} = -\gamma i_{ds} + \omega_s i_{qs} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_{qr} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_{dr} + \frac{1}{L_s \sigma}Vds \qquad (3.16\ b)$$

$$\frac{di_{qs}}{dt} = -\gamma i_{qs} - \omega_s i_{ds} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_{dr} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_{qr} + \frac{1}{L_s \sigma}V_{ds} \qquad (3.16\ c)$$

$$\frac{d\lambda'_{qr}}{dt} = -\frac{R_r}{L_r}\lambda'_{qr} + \frac{L_m R_r}{L_r} i_{qs} - (\omega_s - \omega_r)\lambda'_{dr} \quad (3.16\ d)$$

$$\frac{d\lambda'_{dr}}{dt} = -\frac{R_r}{L_r}\lambda'_{dr} + \frac{L_m R_r}{L_r} i_{ds} - (\omega_s - \omega_r)\lambda'_{qr} \quad (3.16\ e)$$

3.5. Controller Design

The vector control approach for regulating the speed of an ac traction motor is based on two important aspects. The first step is to decouple the flux from the current-producing choker [9]. Instead of applying three phase currents to an ac traction induction motor, two quadrature currents may be used to regulate it simply. Direct axis and quadrature axis are the two instructions in the motor that are responsible for producing flux and torque independently. That is, iq is parallel to the stator flow while id is perpendicular to it. Of course, the actual voltages and operational currents supplied to the motor are in the renowned three-phase system. It is also difficult to go from a stationary reference frame to one that spins in lockstep with the stator flux. This leads to a new abecedarian vector control theory. This is a proposition that is founded on a frame of reference. A different abecedarian idea is the reference frames proposal. In general, there are two methods for controlling an ac traction motor for an electrical train: the scalar technique and the vector way.

3.5.1. Vector Control

Vector control refers to the methods for regulating an ac traction motor by adjusting the amplitude, frequency, and phase of the voltage and/or current inputs. The vector control approach may be divided into two categories once again.

- ✓ Field oriented control
- ✓ Direct torque

We've been employing an electrical DC drive system for a decade, even though it's less trustworthy and dependable than an AC drive system due to the simple and precise command and control structure. AC drives are frequently more expensive, but they are far more dependable and are equipped with complex modern ways. Because it is manufactured without a slip ring or commutators, the induction motor is a relatively affordable and durable machine. These advantages encouraged the development of electrical drive systems that employ an induction motor as the selecting element for all aspects of starting, braking, speed reversal, and speed shifting, among other things.

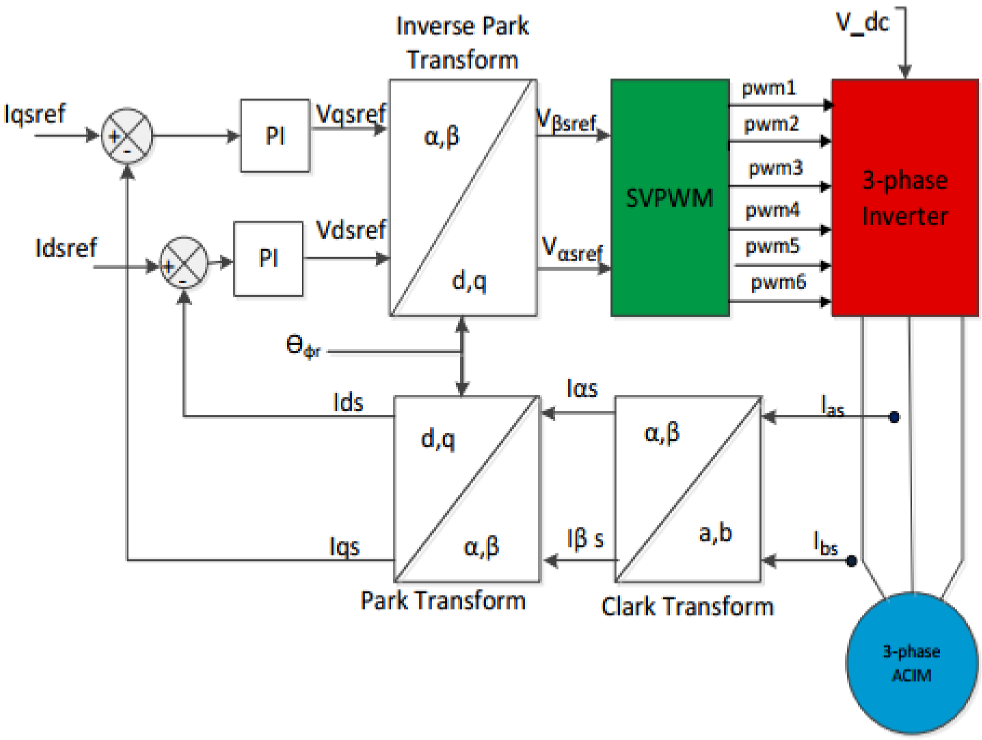


Figure 3. 4 Basic scheme of FOC (Rasfiner et al., 2055).

Selection of AC or DC motor for electrical train demands consideration of power requirement, voltage and current handling, safety, torque speed characteristics, power to size ratio, maintenance and controllability of each system. Here important feature of each in electrical train environment have been considered. Considering AC IM at a time of starting the magnetic flux produced by stator winding is rotating faster than rotor, causing 100% slip which in turn results high initial current and torque. As the speed of motor increase to rated speed the current decrease and torque increase

In recent years, "vector control," an unique control mechanism for AC motors, has arisen as a vital component in the problem of IM drives' dynamic performance. With vector control, you may drive an IM in the same way as a single-agitated DC motor and get the same degree of dynamic performance. The vector technique to control speed of ac traction motor can be applicable over a wide range of speed. In this method the stator current is decoupled in to two axis which are direct axis and quadrature axis one is responsible for production of motor and another one is responsible for rotor flux. As we have mentioned on the above in vector control technique both magnitude and phase must be controlled these leads that for speed control of induction motor scalar is inferior to vector method.

The control issue is restated in order to operate on the control of a DC motor. The control issue is restated as vector control to operate on the control of a DC motor. Speed control across a wide range, accurate speed regulation, quick dynamic reaction, and operating above base speed are all advantages of vector control. For variable frequence driving, IM runs below the synchronous speed indicated by; this coetaneous speed may be increased by reducing the frequence such that the motor still runs below the new synchronous speed but above the nameplate base speed.

Indirect field-oriented control (IFOC) and direct field-oriented control (DFOC) are two forms of field-oriented control for IM drives (DFOC). The rotor flux vector is either measured using a flux sensor positioned in the air gap or approximated using voltage calculations based on the IM parameters in the DFOC method. Nonetheless, in the case of IFOC, the rotor flow vector is calculated utilizing (current models) with the rotor speed/position dimension. Because it can work fluently throughout the speed ranges from zero to high-speed field fading in the unrestricted-circle mode, IFOC is the more often employed of the two methods. The introductory difference is on the rotor flux position determination strategy.

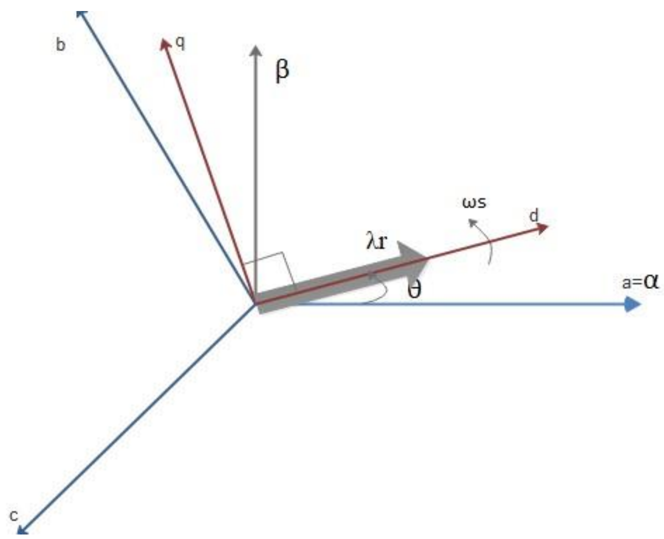


Figure 3. 5 Vector illustration in the stationary and rotating reference frame (Amritha et al., 2018).

$$\frac{d\omega_m}{dt} = \frac{1}{J}\left(\frac{3PL_m}{4L'_r}\left(\lambda'_r i_{qs}\right) - \left(F\omega_m + T_L + T_d\right)\right) \quad (3.17\ a)$$

$$\frac{di_{ds}}{dt} = -\gamma i_{ds} + \omega_s i_{qs} + \frac{L_m R_r}{L_s L_r^2 \sigma}\lambda'_r + \frac{1}{L_s\sigma}Vds \quad (3.17\ b)$$

$$\frac{di_{qs}}{dt} = -\gamma i_{qs} - \omega_s i_{ds} + \frac{\omega_r L_m}{L_m L_r \sigma}\lambda'_r + \frac{1}{L_s\sigma}V_{ds} \quad (3.17\ c)$$

$$\frac{d\lambda'_r}{dt} = -\frac{R_r}{L_r}\lambda'_r + \frac{L_m R_r}{L_r} i_{ds} \quad (3.17\ d)$$

3.5.2. Reference Frame Proposition

There are potentially three common reference frames for converting a (alpha beta) (Amritha et al., 2018).

1. Reference frame fixed on the rotor (R.H. Park)
2. Reference frame rotating in coetaneous speed (G. Kron)
3. Stationary reference frame (H.C. Stanley)

Preliminarily these reference frames are treated and anatomized independently but now a general reference frame that contains all reference frames in one is introduced which is called an arbitrary. All reference frames may be uprooted from the arbitrary reference frame by setting the applicable reference frame speed to w= 0 for a stationary reference frame, w= ws for a synchronously revolving reference frame, and wr for a rotor fixed reference frame.

3.5.3. Vector Transformation

Fqdos = Ksfabcs (3.20)

Where [fabcs] ^{T} = [fa fbs fcs], and

[fqdos] ^{T} = [fqs fds fos]

Then,

$$K_s = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2}{3}\pi) & \cos(\theta + \frac{2}{3}\pi) \\ \sin(\theta) & \sin(\theta - \frac{2}{3}\pi) & \sin(\theta + \frac{2}{3}\pi) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Ks = a vector metamorphosis matrix conserving breadth.

The relationship between reference frames is shown in figure (3.7).

3.5.3.1 ABC-to-αβ (Clark Transformation)

The Clark transformation converts a three-phase stator volume (in this example, stator current) to a stationary two-dimensional signal that varies over time. The Clark transform is given mathematically by

$$[i_{\alpha\beta os}] = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}[i_{abcs}]f_{qdos} = K_s f_{abcs} \qquad (3.21)$$

Equation 3.21 can be written in expanded form as below in equation 3.22a and equation 3.22b

$$i_{\alpha s} = \frac{2}{3}i_{as} - \frac{1}{3}i_{bs} - \frac{1}{3}i_{cs} \qquad (3.22a)$$

$$i_{\beta s} = \frac{1}{\sqrt{3}}i_{as} + \frac{2}{\sqrt{3}}i_{bs} \qquad (3.22b)$$

Using the fact, (ias + ibs + ics = 0) we get the following equation

$$i\alpha s = ias \qquad (3.24a)$$

$$i_{\beta s} = \frac{1}{\sqrt{3}}i_{as} + \frac{2}{\sqrt{3}}i_{bs} \qquad (3.25b)$$

3.5.3.2. αβ-to-dq (Park Transformation)

The park transformation converts a two-dimensional time-varying signal into a rotating two-dimensional time-steady signal. We get the following equation when we resolve to the dq reference frame.

$$iqs = -i\alpha s \sin(\theta_{field}) + i\beta s\cos(\theta_{field}) \qquad (3.26a)$$

$$ids = i\alpha s \cos(\theta_{field}) + i\beta s \sin(\theta_{field}) \qquad (3.26b)$$

3.5.3.3. Inverse Park Transform (dq-to-αβ)

In order to design the system, an SVPWM is employed. The duty cycle of the six switching biases in the inverter is calculated using a space vector notion in an SVPWM. As a result, for SVPWM to work, the rotating time-steady Vdq must be transformed into a fixed time-varying voltage, V.

$$V\alpha s = Vds \cos(\theta field) - Vqs \sin(\theta field) \qquad (3.27a)$$

$$V\beta s = Vds \sin(\theta field)\ Vqs \cos \theta field \qquad (3.28b)$$

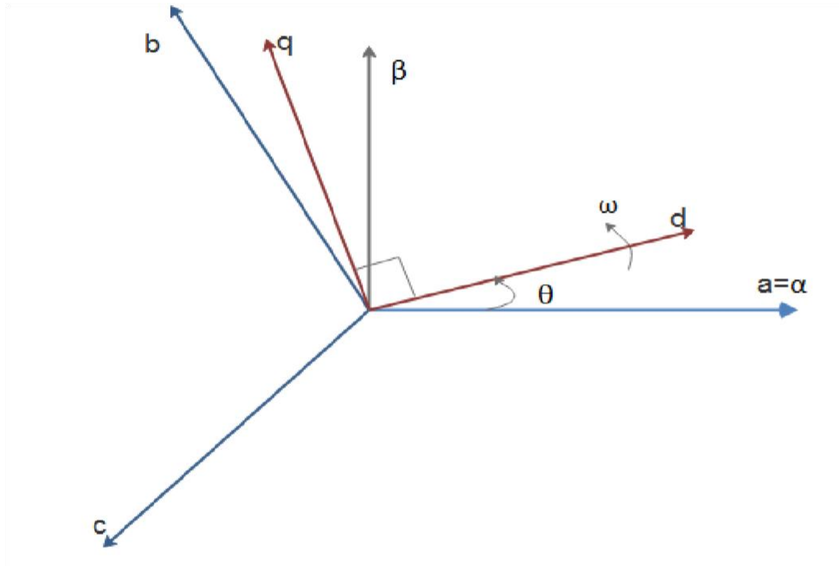


Figure 3. 6 Relationship between different reference frames (Mogribe et al., 2017).

3.6. PID Control

PID control algorithms are used to govern feedback closed loop systems. The major reason for the importance of feedback loops is that they allow systems to reach a collection point independent of disturbances or variations in features of any kind. In a complex system, the. The following is a step-by-step guide on building a PID controller. The proportional (P), integral (I), and derivative (D) controls are displayed in Figure 3.8's block diagram. The system S will be managed by the controller C, whose efficiency is determined by the controller.

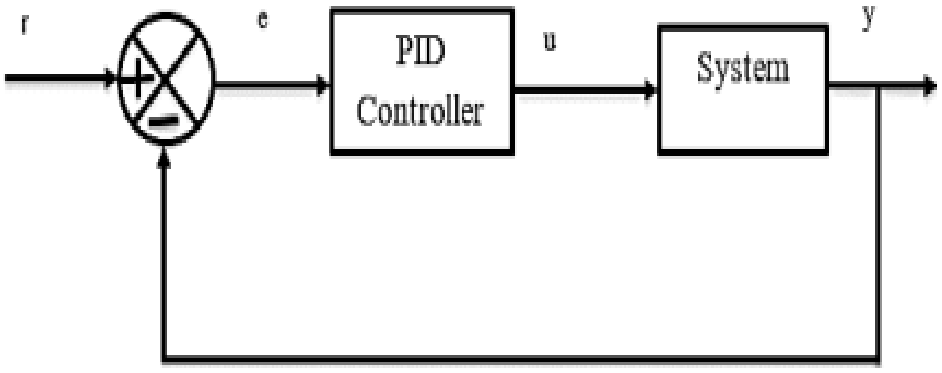


Figure 3. 7 Feedback control loop, block diagram.

The series and parallel structures are the most prevalent, while hybrid versions of the series and parallel structures exist in some cases. Consider figure 3.8, where e represents the sample error, which is defined as the difference between the specified input value R and the specific output value Y. PID control algorithms are used to govern feedback closed loop systems. The major reason for the importance of feedback loops is that they allow systems to reach a collection point independent of disturbances or variations in features of any kind. The error signal will be forwarded to the controller in a closed-loop system, and the controller will conduct integral and derivative computations on it.

To improve flash response performance, the stoner modifies the relative weights of each route. Equation gives the control affair for a PID control method (3.29)

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)d\tau + k_d \frac{de(t)}{dt} \qquad 3.29$$

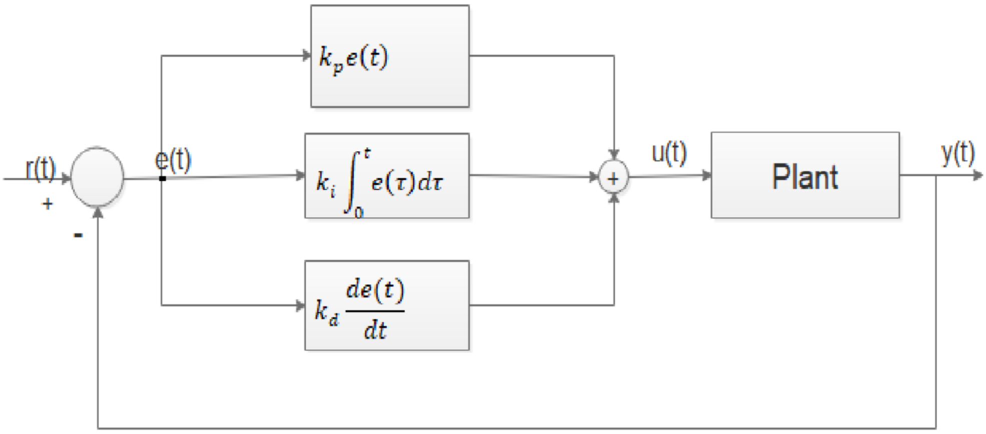


Figure 3. 8 PID control structure [(Munashir et al., 2000)]

CHAPTER 4

Result and Discussion

4.1. Introduction

The main objective of this thesis was using foc method to get the best settling time performance for speed of ac traction IM. This section compares the Pso-based and genetic algorithms for tuning PID outcomes to achieve for various scenarios using MATLAB/SIMULINK simulation. As indicated in the picture below, the simulation for speed management of an ac traction induction motor was created in Mat Lab/Simulink R2020a using components from the Power Systems Block set. Different sub-functional blocks, such as FOC, PID controller blocks, Coordinate Transformation blocks, and SVPWM block, are included in the overall system simulation block. With a genetic algorithm tuned PID and a PSO tuned PID controller, the system is simulated for the speed response of an ac traction motor at 1000 rpm.

4.2. Results

Based on the problem of ac traction IM control the following criteria's are used to evaluate the performance of the designed PSO based and GA based of the system.

- When train go with constant speed at load and no load condition.
- When train go with different speed at load and no load condition.
- When the train go the upward slope road with different speed at load and no load condition.

4.2.1. PSO and GA based PID Speed Controller results for AC Traction Motor

A good controller in a feedback control system is one whose output tracks or follows the reference signal with a transient response specification that is acceptable (settling time, overshoot, steady-state error, etc.). The Simulink model of overall ac traction induction motor with field-oriented control system is developed in MATLAB software to investigate and analyzed the performance of desired ac traction motor then tune PID with PSO and GA to get best performance of the system. Following that, the Simulink model and simulation results of the overall drive system constructed for these two situations (load and no load condition) with the field-oriented control system are explained.

Case I When train go with different speed at load condition

As seen from the result initial the train was moving with 20 rad/s but after 1 sec the speed was increase to 70 rad/sec. when the train moving at low speed (20 rad/sec) PSO tuned PID parameters show good performance with 0% overshoot but GA have no good performance.

Where, as for 70rad/sec both results good performance with have overshoot. Again when we compare the selling time at low speed both shows good performance where, as for high speed PSO have good performance than GA. In Figure 4.1, It is the outcome of improving the settings of the PID controller with particles swarm optimization (PSO) and genetic algorithm to achieve the intended and measured or real speed of an AC traction induction motor (GA). Figure 4.1 shows that When the Kp Ki Kd (9.86 12.52 0) parameters of a PID controller are changed using PSO and have 0% overshoot, 0% settling time, and 0.28 sec rising time, the real or measured speed of an ac traction motor follows the intended speed trajectory exactly. Using a genetic algorithm, the parameters Kp Ki Kd (40.23 26.14 0) are obtained.

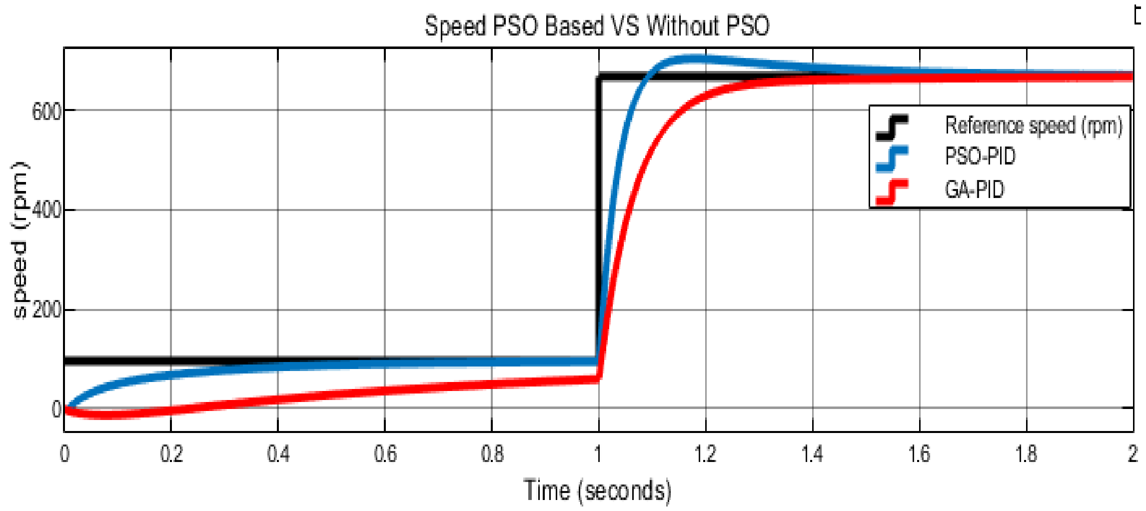


Figure 4. 1 speed of train for PSO and GA based at load condition.

Furthermore, on the above figure the blue one is the result for PSO and the red one is result for GA. When this system was resulted it pass through different process. As show in figure 4.2 the three phase voltage is applied to ac traction motor.

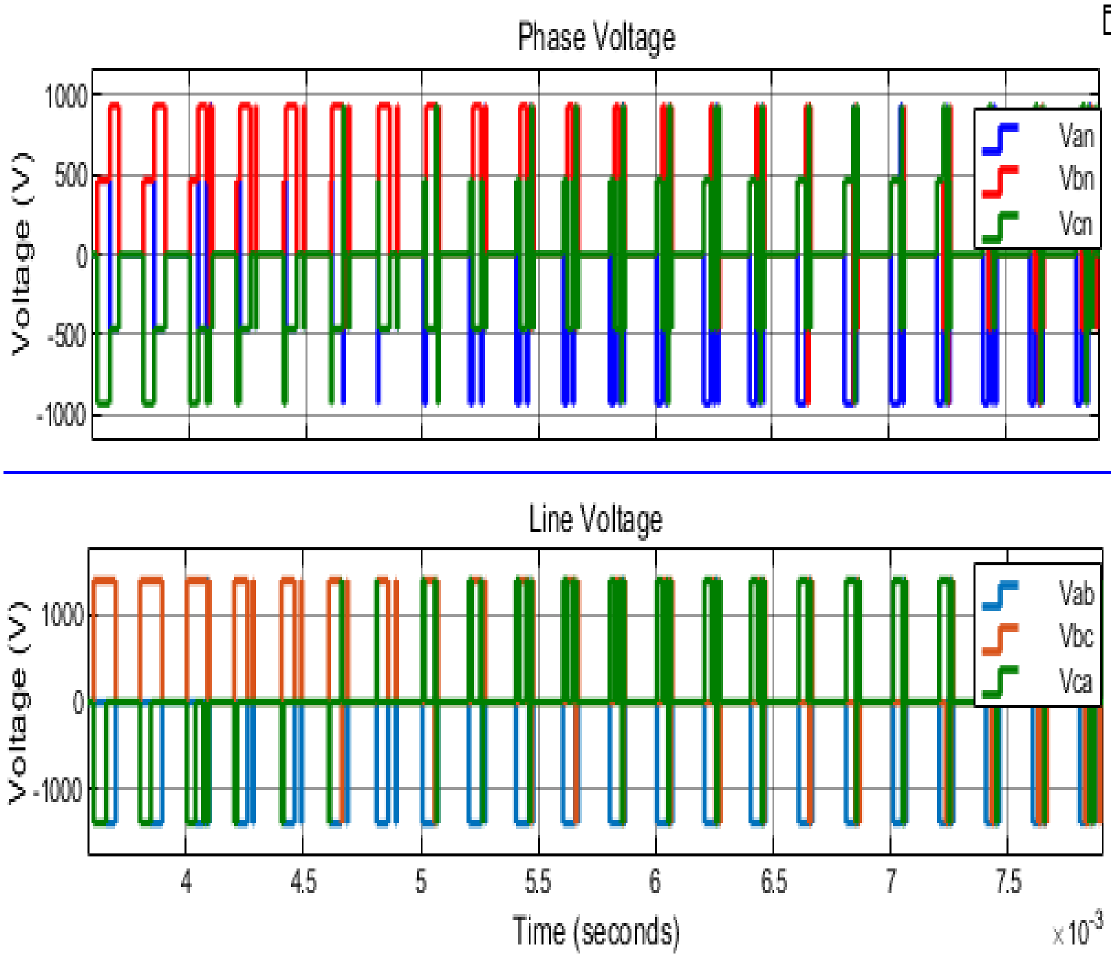


Figure 4. 2 phase and line voltage applied to ac traction motor.

Then after three phase voltage is applied the ac traction motor produce or develop three phase stator current (isa, isb, isc). This stator current was show in the below figure.

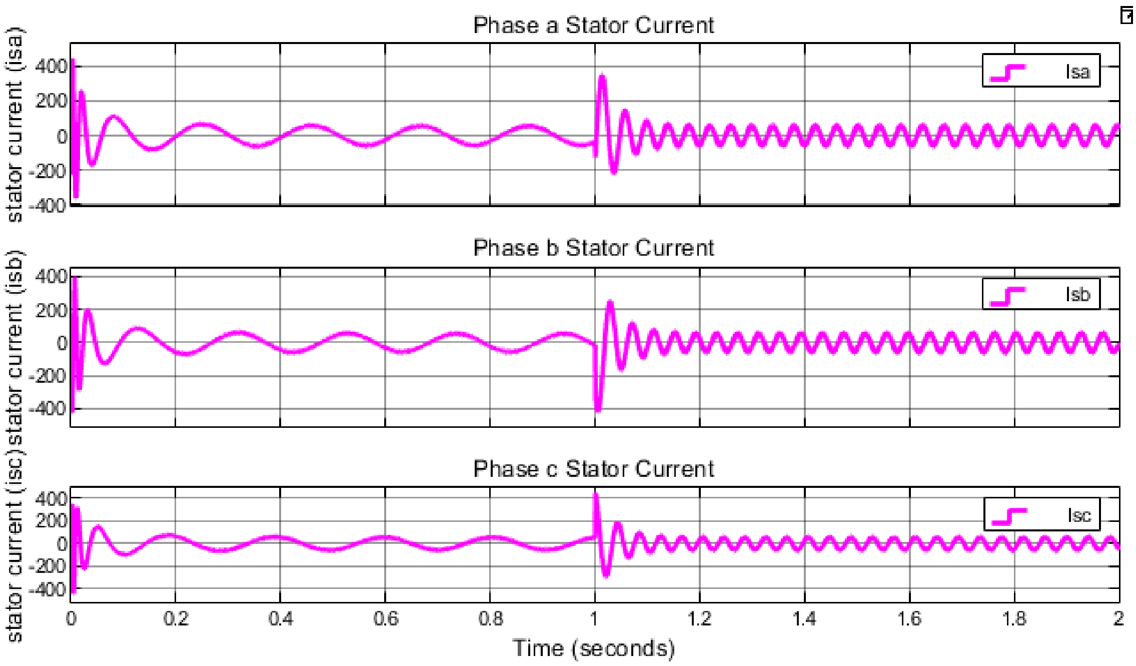


Figure 4. 3 stator current of traction motor at load condition

The produced three phase current converted to alpha and beta using forward clarck transformation and from alpha-beta to d-q axis (park transformation) then we get output as below figure 4.4 and figure 4.5 respectively.

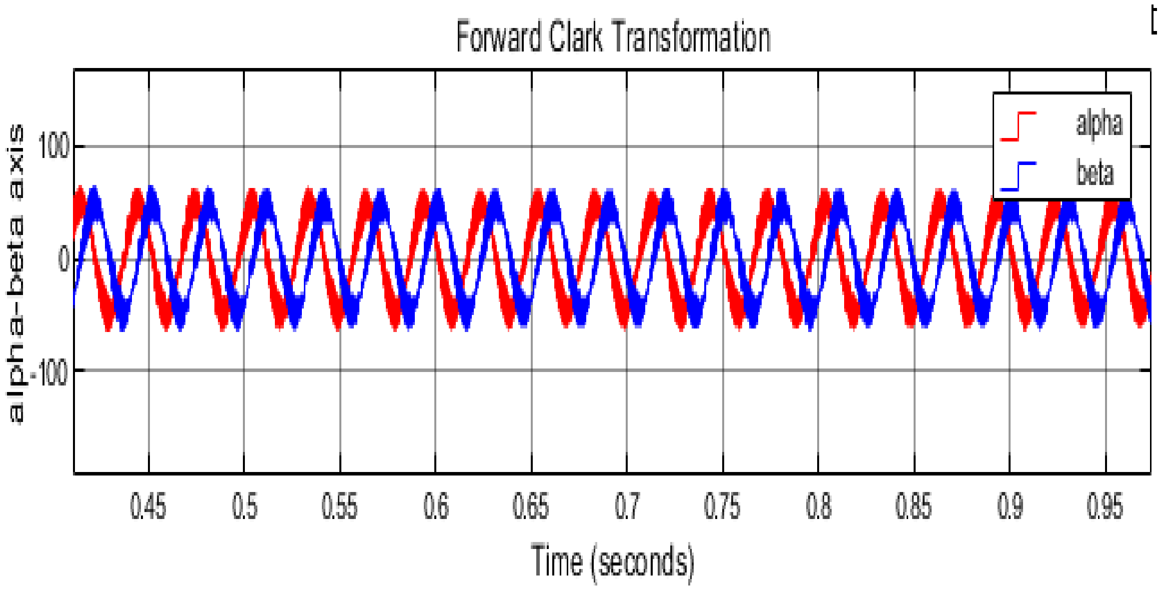


Figure 4. 4 Forward Clark transformation.

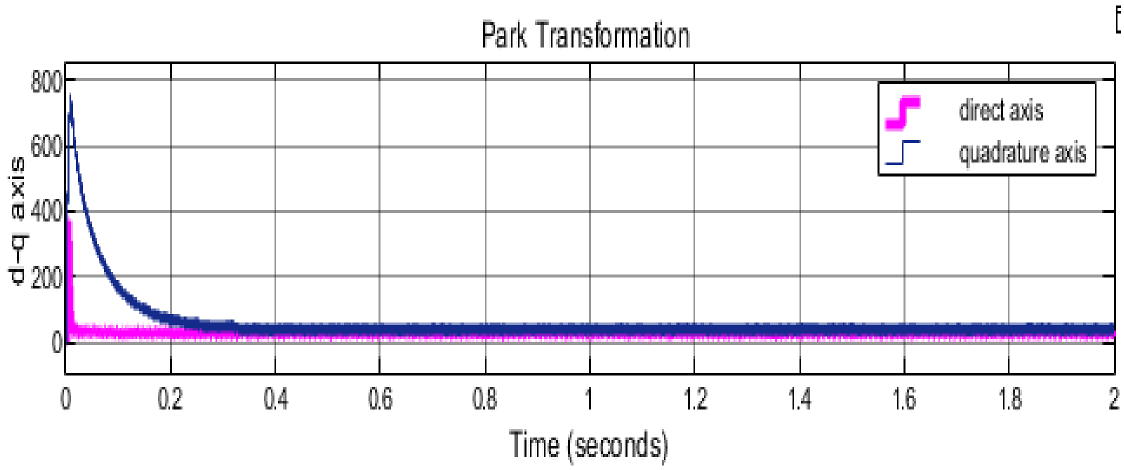


Figure 4. 5 Forward park transformation.

Finally the produced torque when the electrical train move with different speed at load condition shown on the below figure 4.6

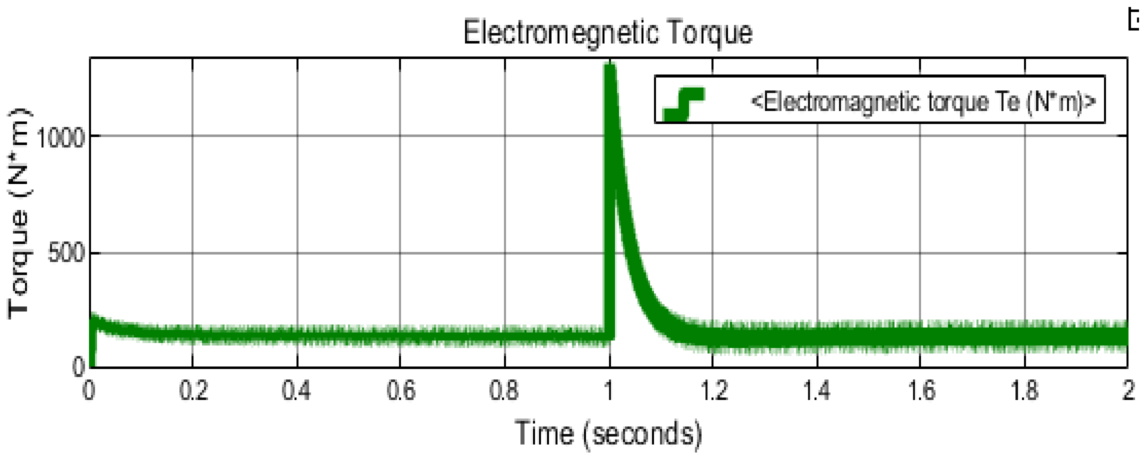


Figure 4. 6 Torque produced of ac traction motor at load condition

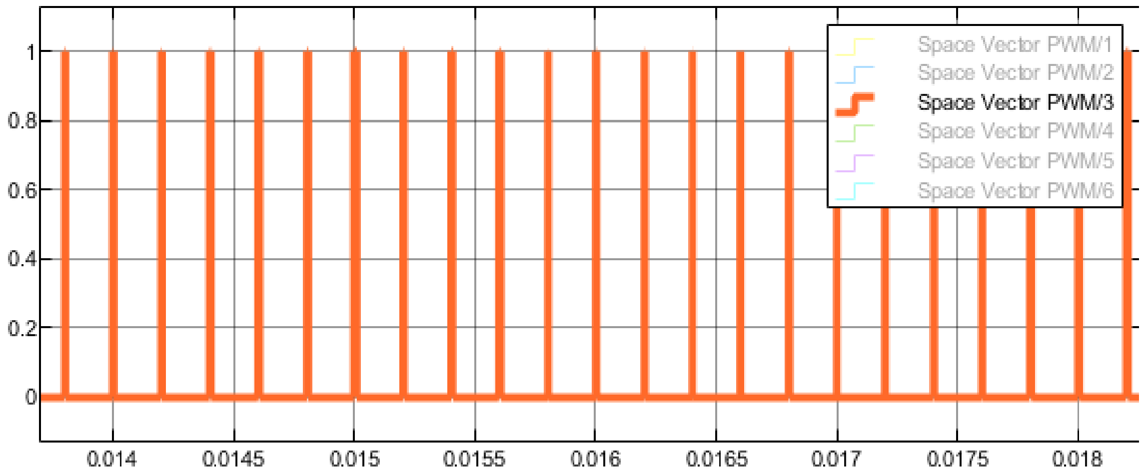


Figure 4. 7 signal gate for inverter at space vector pwm three

Case II When train go with different speed at no load condition

As seen from the result initial the train was moving with 20 rad/s but after 1 sec the speed was increase to 70 rad/sec. when the train moving at low speed (20 rad/sec) both PSO and GA tuned PID parameters show good performance with 0% overshoot. Where, as for 70rad/sec results good performance. Again when we compare the selling time at low speed both shows good performance where, as for high speed GA have good performance than PSO. The torque and stator current produced also listed in the below figure 4.8 and figure 4.9 respectively.

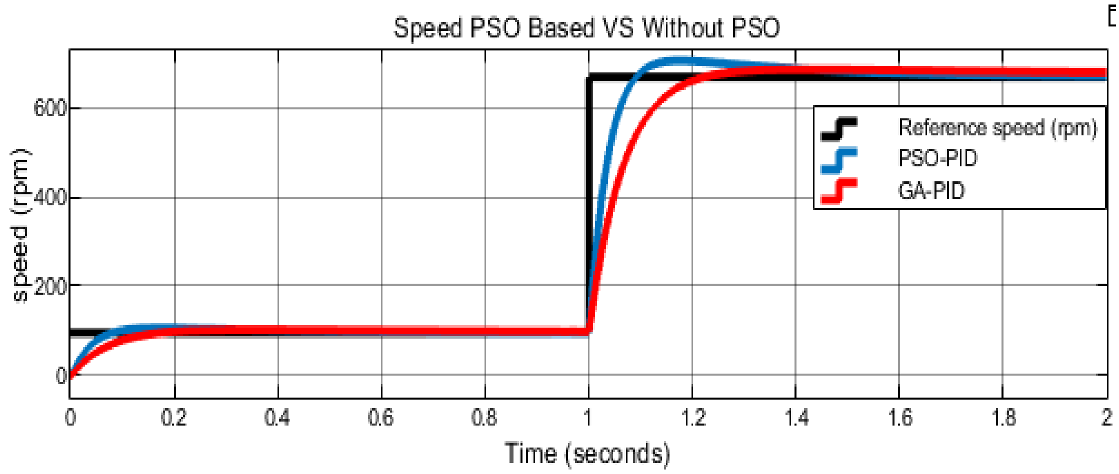


Figure 4. 8 speed of train for PSO and GA based for no load condition.

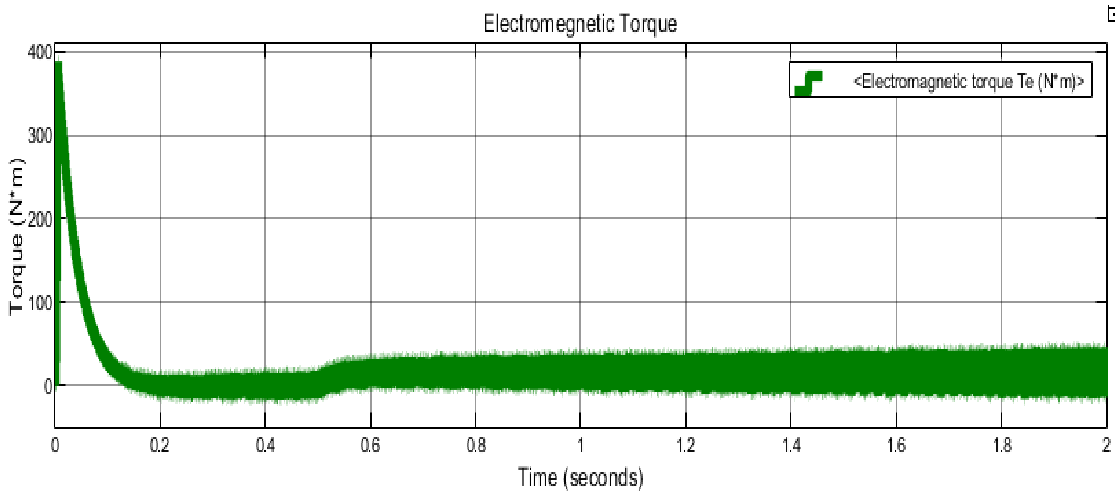


Figure 4. 9 Output torque produced of train for different speed at no load.

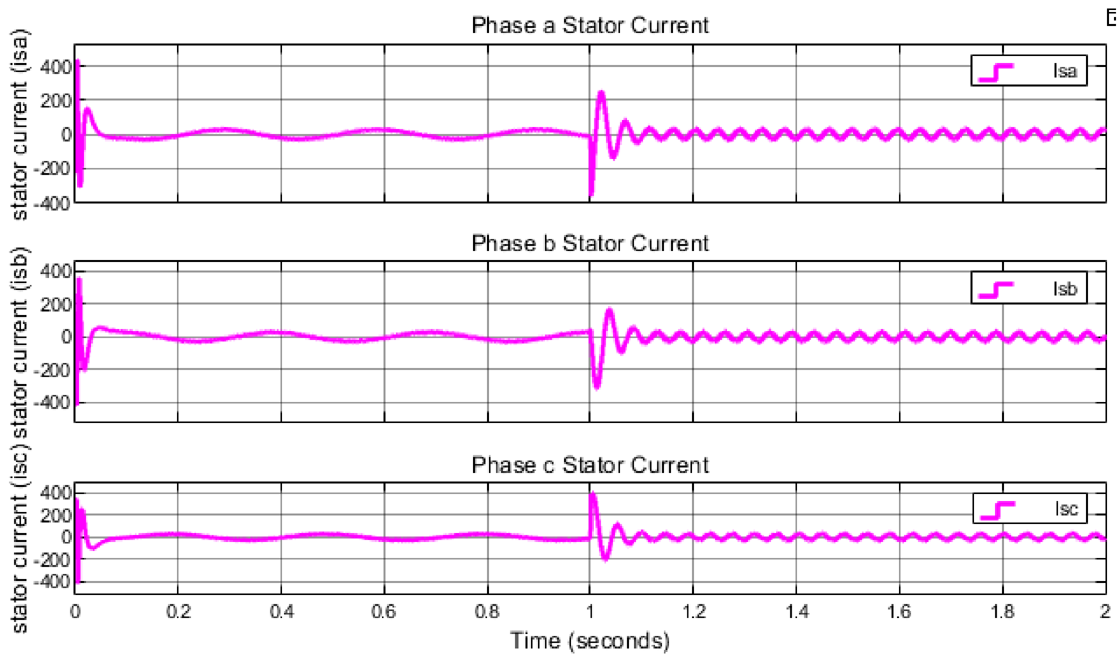


Figure 4. 10 Stator current of traction motor for different speed at no load condition

Case III When train move upward road at no load condition

As we have seen in the below figure 4.10 let when the train move between two adjacent station have upward road with no load condition. Initial the train was move with 20 rad/sec until 0.5 sec. then upward road is start. Even if both PSO and GA good performance GA is inferior to PSO to control speed of ac traction motor for no load condition. Again we can see that the torque produced by the motor, three phase stator current, phase voltage and line voltage in figure 4.11, figure 4.12, figure 4.13 respectively. On the below figure 4.10 the blue color is the result for PSO and the red one is result for GA.

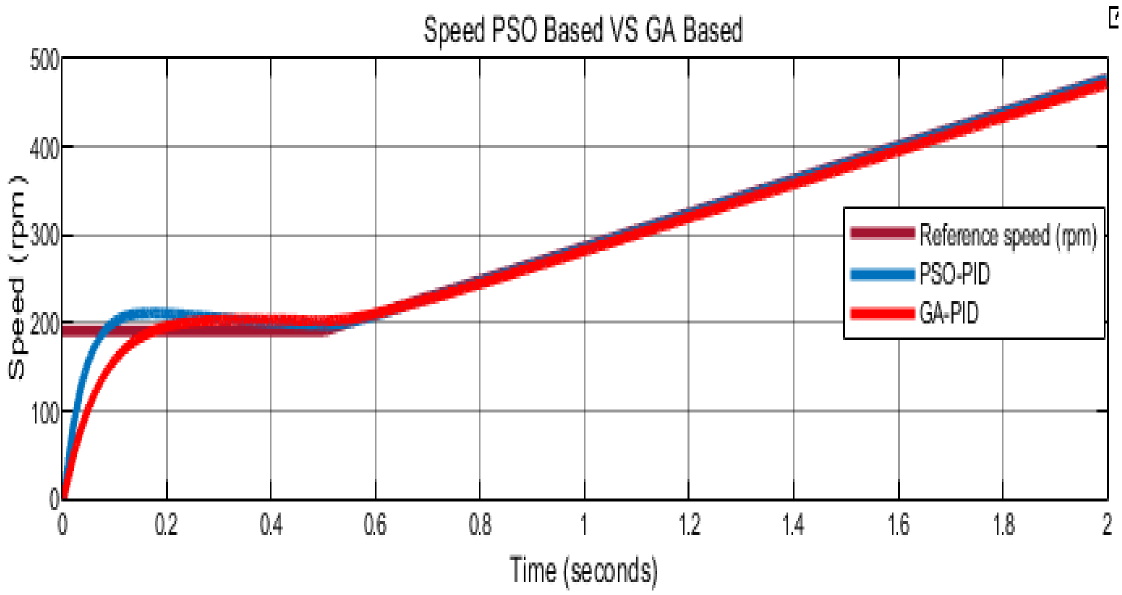


Figure 4. 11 PSO and GA based when train move upward road at no load condition

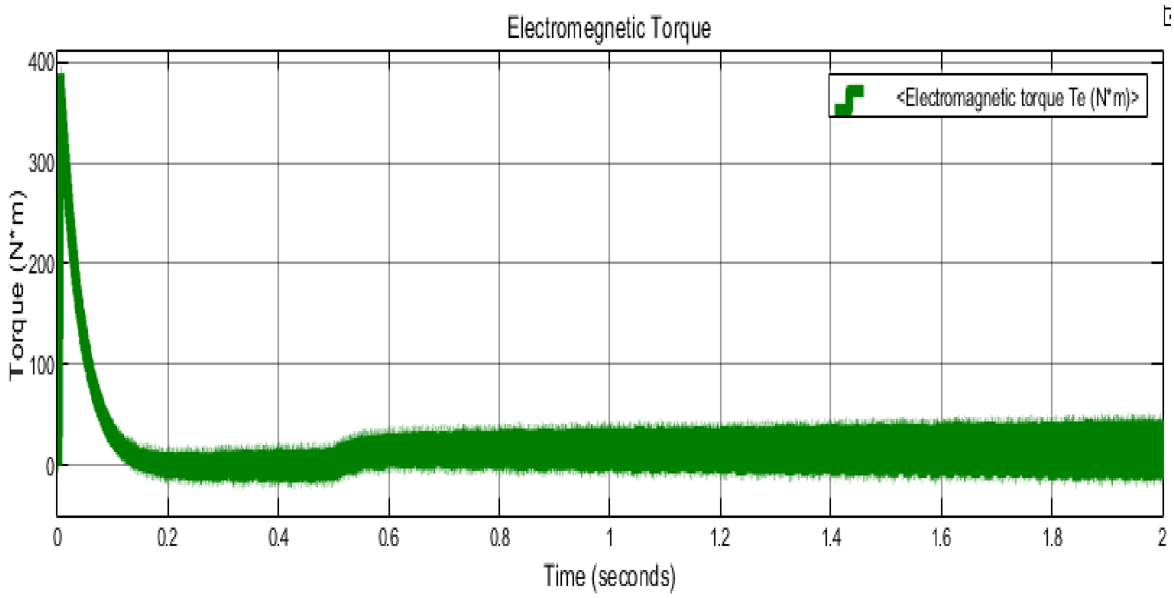


Figure 4. 12 Torque produced when train move upward road at no load condition

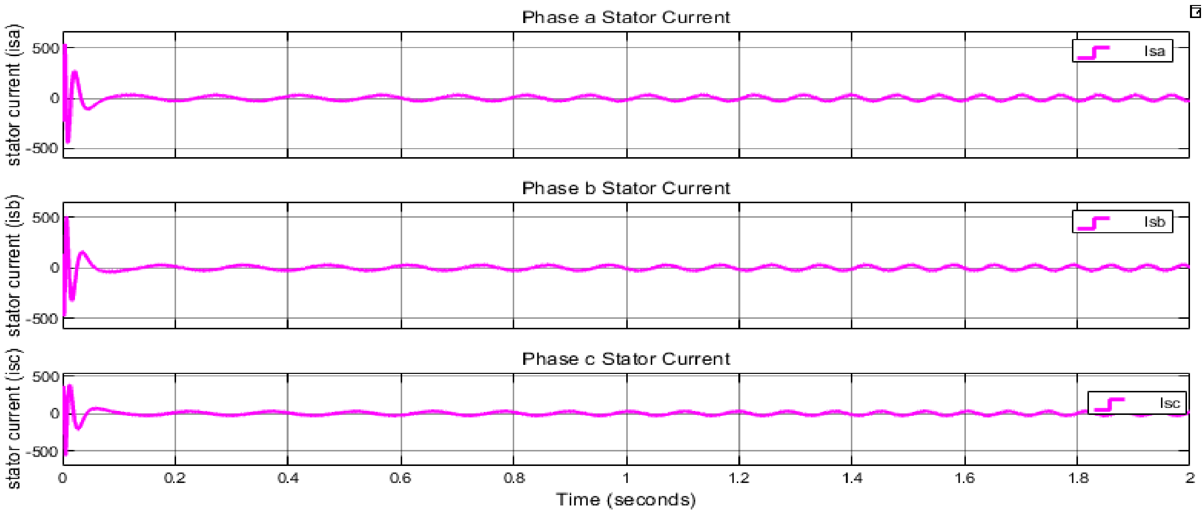


Figure 4. 13 Three phase stator current when train move upward at no load condition

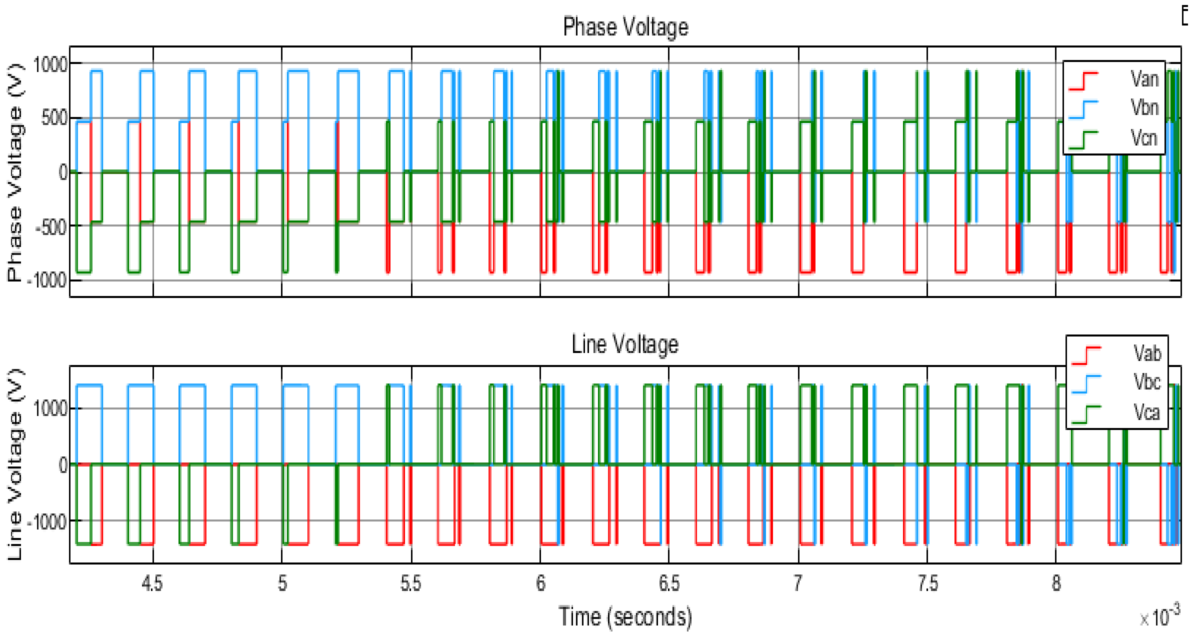


Figure 4. 14 phase and line voltage when train move upward road at load condition

Case Iv When train move upward road at load condition

As we have seen in the below figure 4.14 let when the train move between two adjacent station have upward road with load condition. Initial the train was move with 20 rad/sec until 0.5 sec. then upward road is start. Here PSO have good performance over GA to control speed of ac traction motor for load condition. Again we can see that the torque produced by the motor, three phase stator current, in figure 4.15, figure 4.16, respectively. On the below figure 4.14 the blue color is the result for PSO and the red one is result for GA.

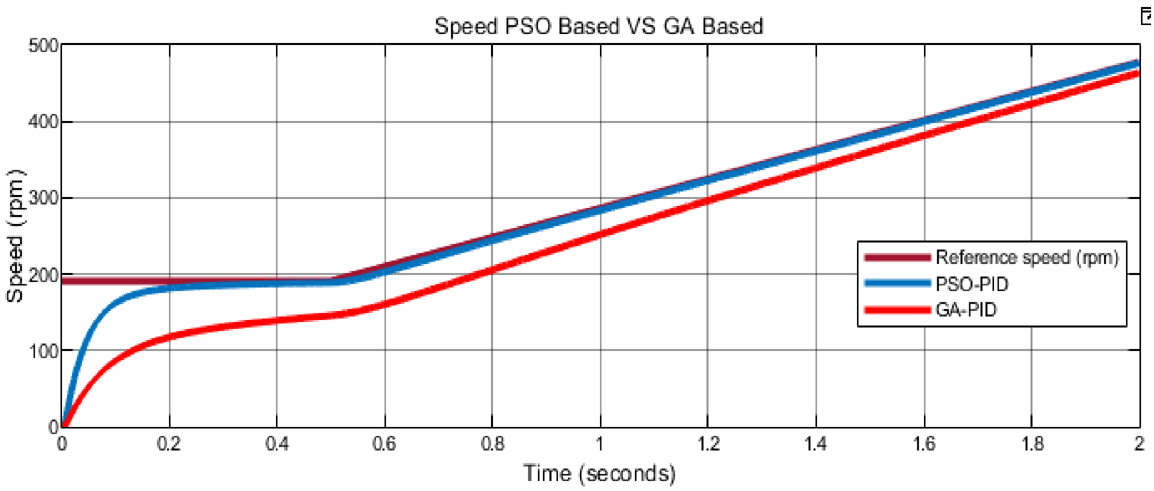


Figure 4. 15 PSO and GA based when train move upward road at load condition

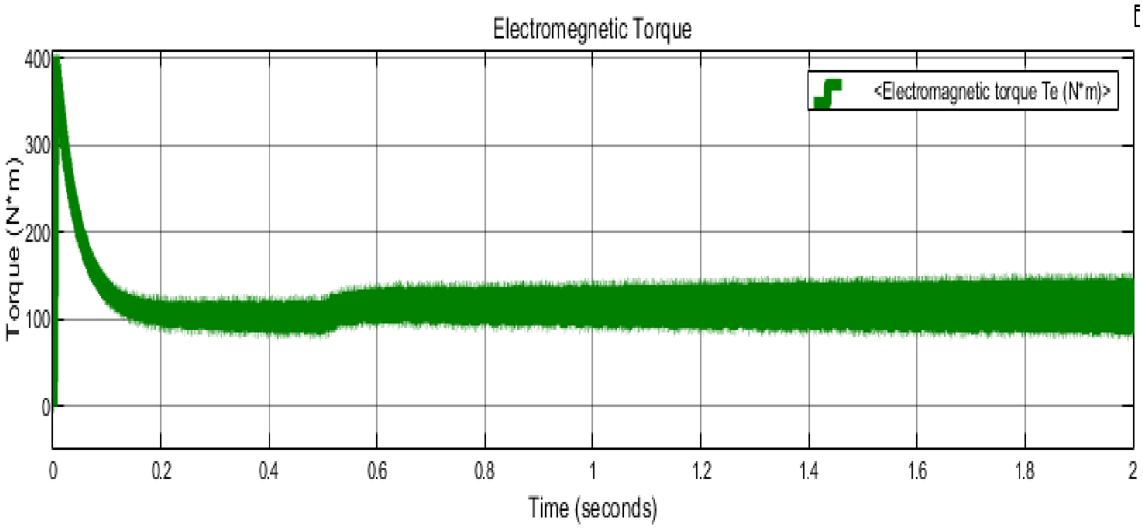


Figure 4. 16 Torque produced when train move upward road at load condition

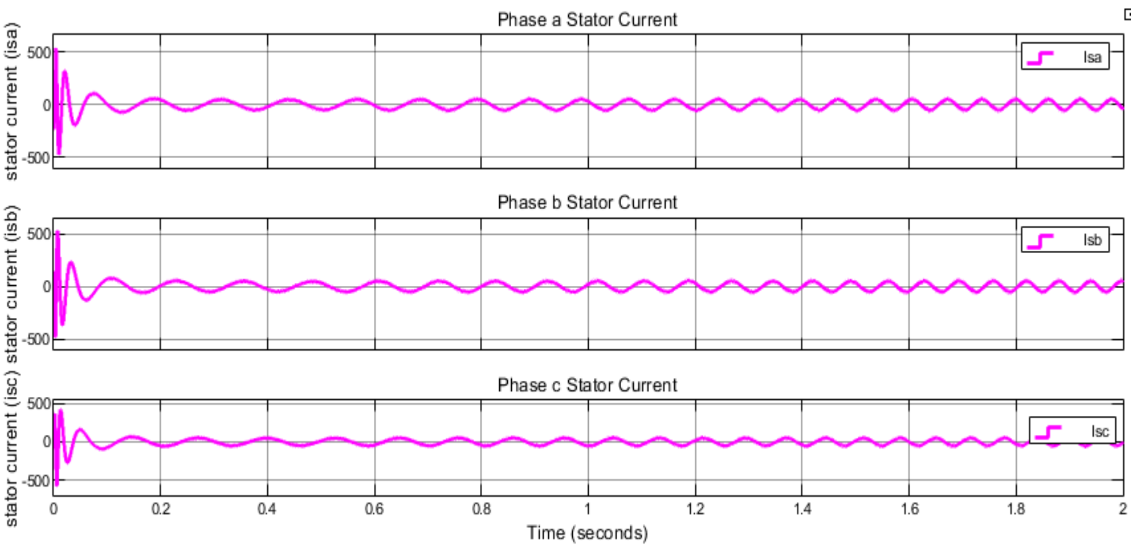


Figure 4. 17 Three phase stator current when train move upward at load condition

On the above figure (4.10_4.16) all of the results comes when the train move upward road (track). Means that if the train goes between two station initially with speed of 20 rad/sec until 0.5 sec then because of the trail have upward slope for both case (with load and without load condition) is looks like what I have shown on the above. As the result show that pso based speed control of traction motor is have good steady state response than other. So in general from the above figure we can understand the proposed method to control speed of traction motor touch its target.

Case V when train go with different speed at load condition

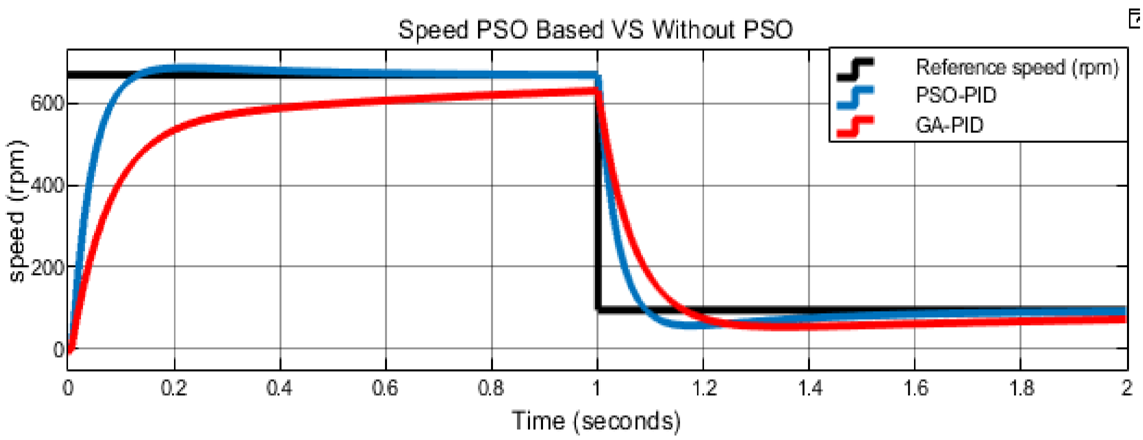


Figure 4. 18 PSO and GA based speed control when train move down rail.

Case VI when train go with different speed at no load condition

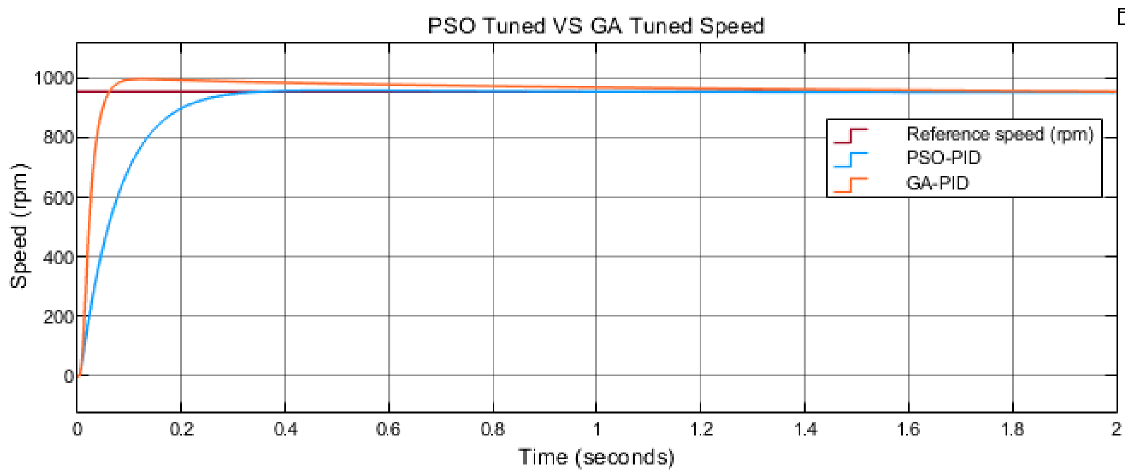


Figure 4. 19 PSO and GA based when train move at maximum speed.

As we have seen the result from above figure 10.17 when the train move with maximum speed (950 rpm) the settling time of PSO is 0.27sec which lower than GA having 0.57 sec settling time. Where, as the rise time for GA 0.03 sec is lower than PSO which have 0.15 rise time. Again for PSO 0% overshoot but GA have 0.24% overshoot

5. Conclusion and Future Work

5.1. Conclusion

In this thesis, a comparative analysis of pso and GA for control speed of traction IM using FOC technique has been done. So based on the output we can judge which is best or have high efficiency by compare the transient response. Again under these thesis we are covered mathematical model and Simulink part of the electrical train. PSO-PID controller and GA-PID controller to control speed. If anyone have no knowledge how PSO and GA are used to tune its so difficult for the first time. Especially in design part we must have the mathematical model if we need to tune the system using PSO and GA algorithm. In general, from the result, one can say from the result GA is inferior to based PSO. In the PSO case, speed of response has no undershot, and overshoot but GA have more overshoot and undershoot and also less in robust than PSO. Again when we compare PSO and GA at low speed the efficiency of traction motor which is tuned by using PSO is superior than GA tuned algorithm. As we have seen from the output PSO have 0% overshot and stable firstly.

5.2. Future work

The following is a research idea for the future. This thesis compares the effects of PSO with the effects of PSO without PSO. Both PSO-based and non-PSO control have their benefits and drawbacks. Even while PSO outperforms tuning without it, it is difficult to develop; it needs specialist knowledge and can lead to blunders. As a result, in order to integrate the benefits of a variety of controllers, future research will focus on hybrid PSO-GA, Fuzzy, hybrid Fuzzy-PID, ANFIS, and Fuzzy SMC. Because the comparison in this thesis is centered on performance, another study area is to look at the power consumption of different controllers.

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APPENDIX

APPENDIX A:

IM SIMULINK MODEL

The SIMULINK model of IM is shown below

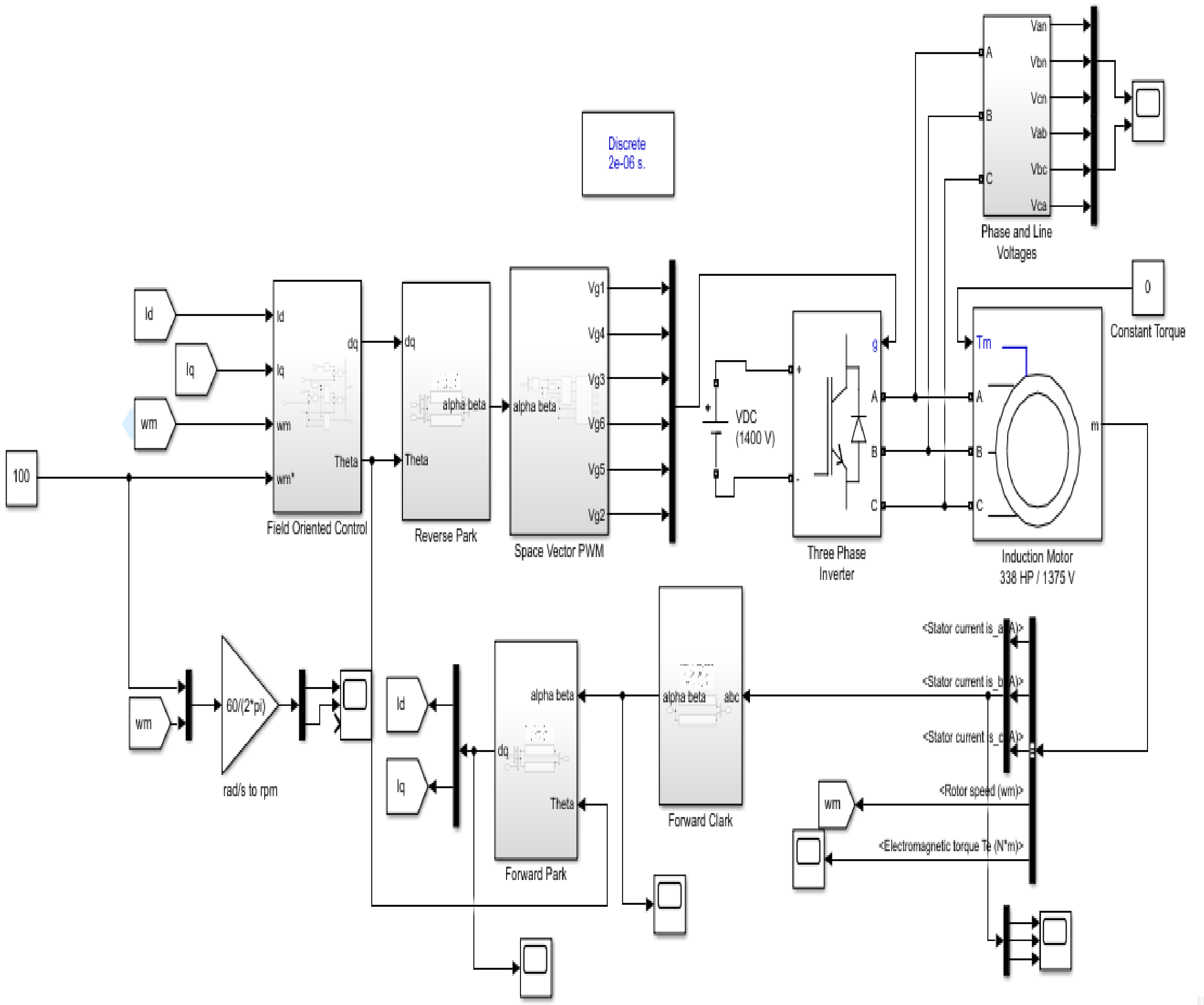


Figure A. 1 Overall system Simulink model

The SIMULINK model of each subsystem is depicted below

a) FOC Block

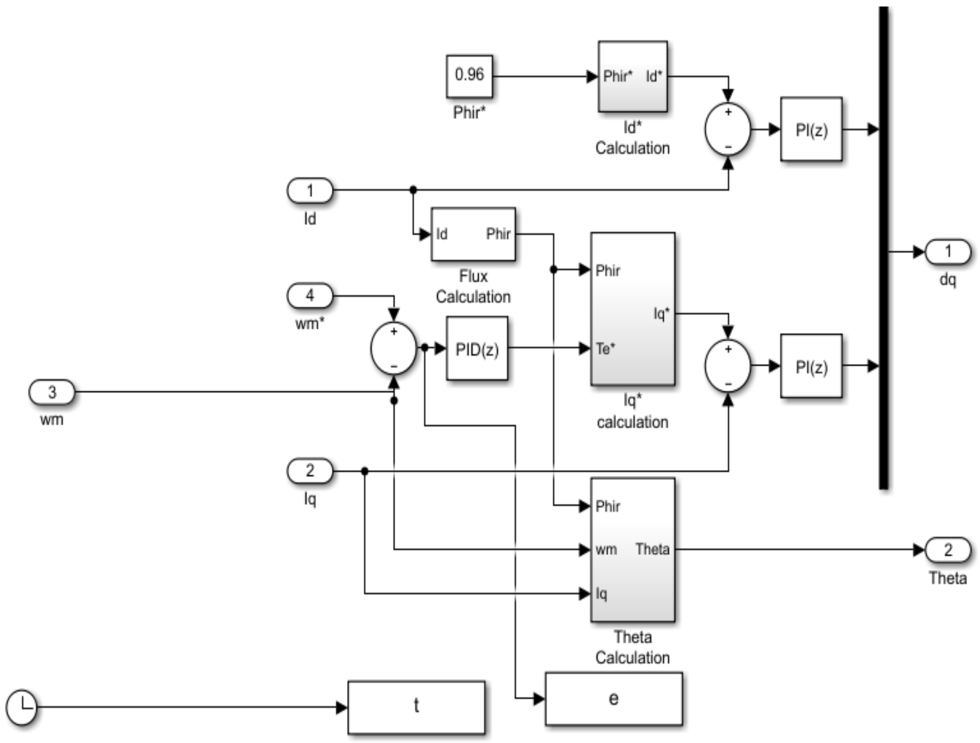


Figure A. 2 FOC block diagram for both PSO and GA

b) Svpwm block

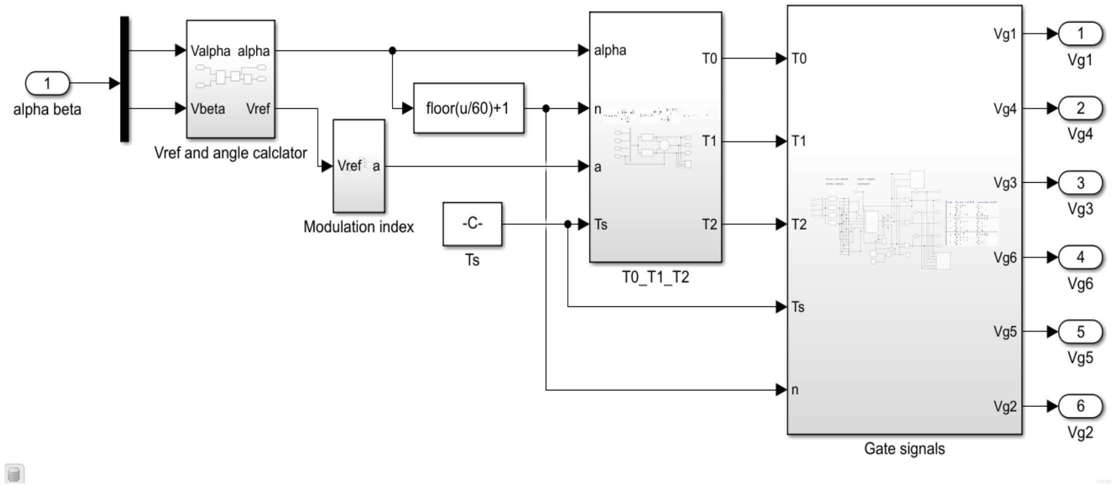


Figure A. 3 Block diagram of svpwm

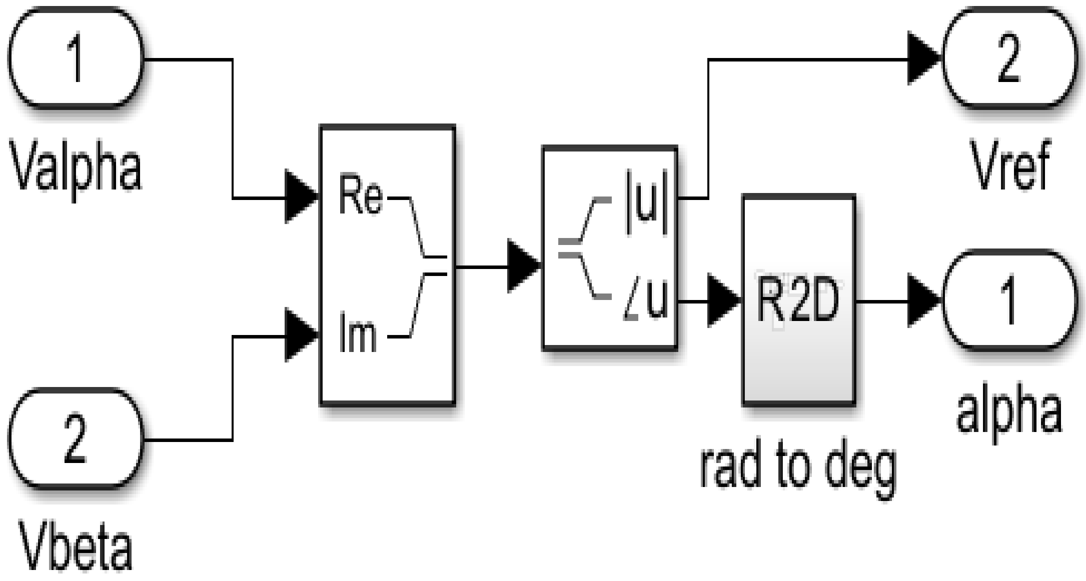


Figure A. 4 Vref and angle calculator

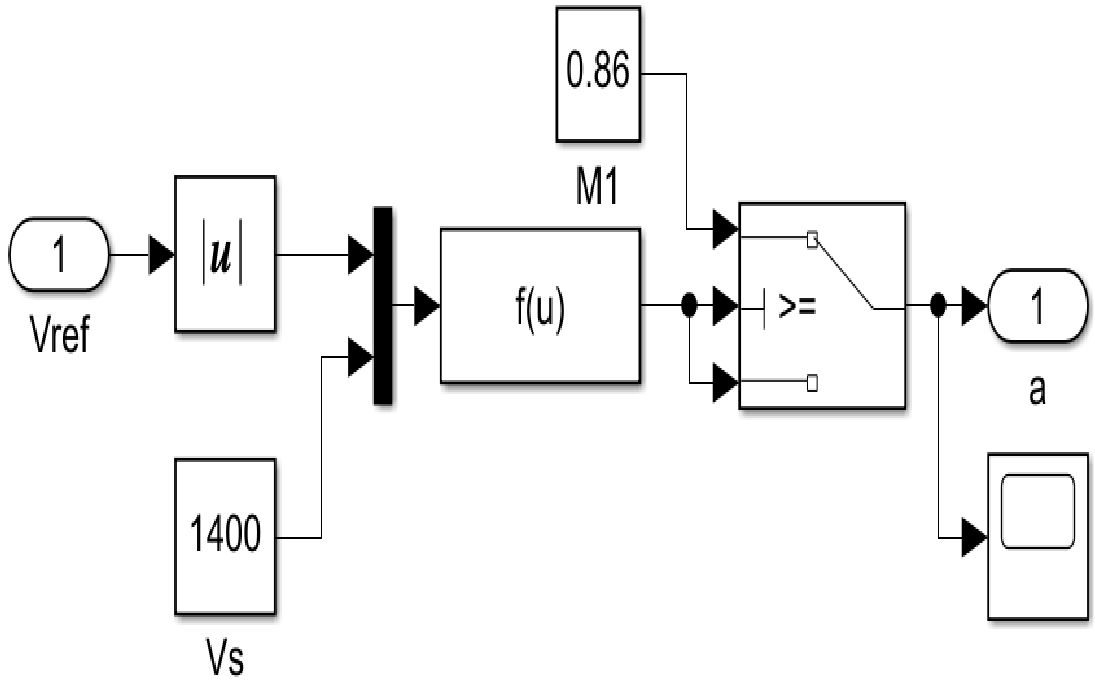


Figure A. 5 Modulation index

$$T1 = a.Ts\frac{\sin\left(\frac{n\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \qquad T2 = a.Ts\frac{\sin\left(\alpha - \frac{(n-1)\pi}{3}\right)}{\sin\left(\frac{\pi}{3}\right)} \qquad T0 = Ts - T1 - T2$$

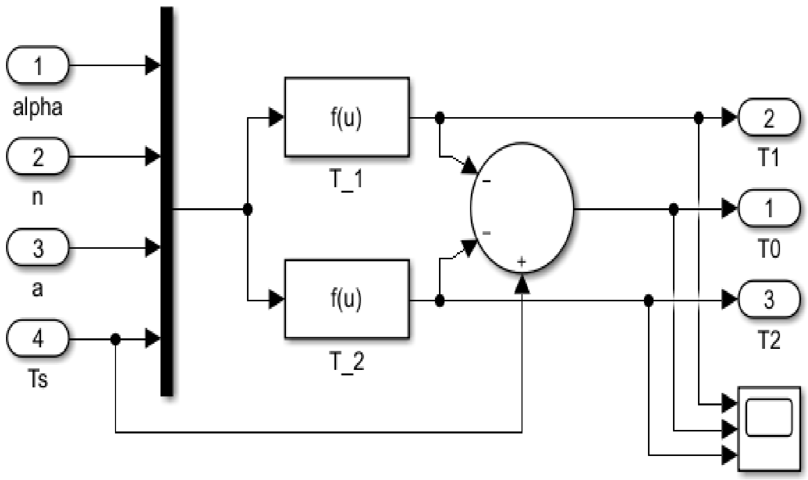


Figure A. 6 Calculate period

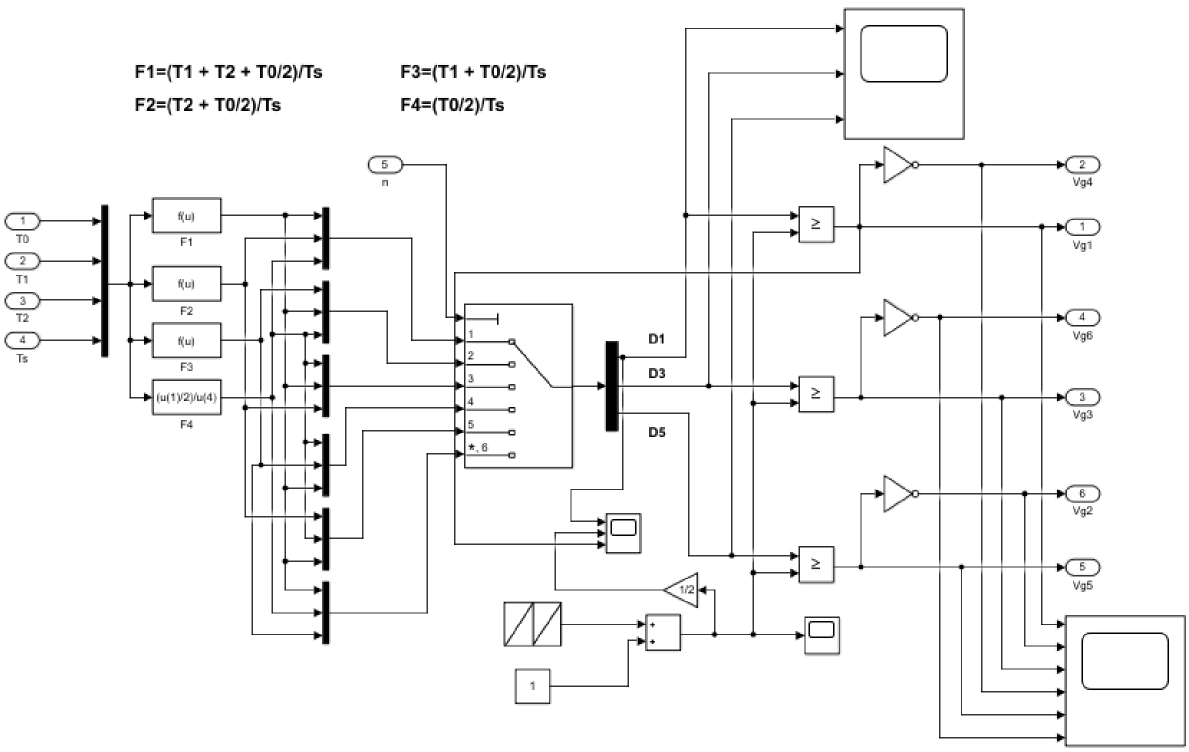


Figure A. 7 Block diagram of gate signal in svpwm

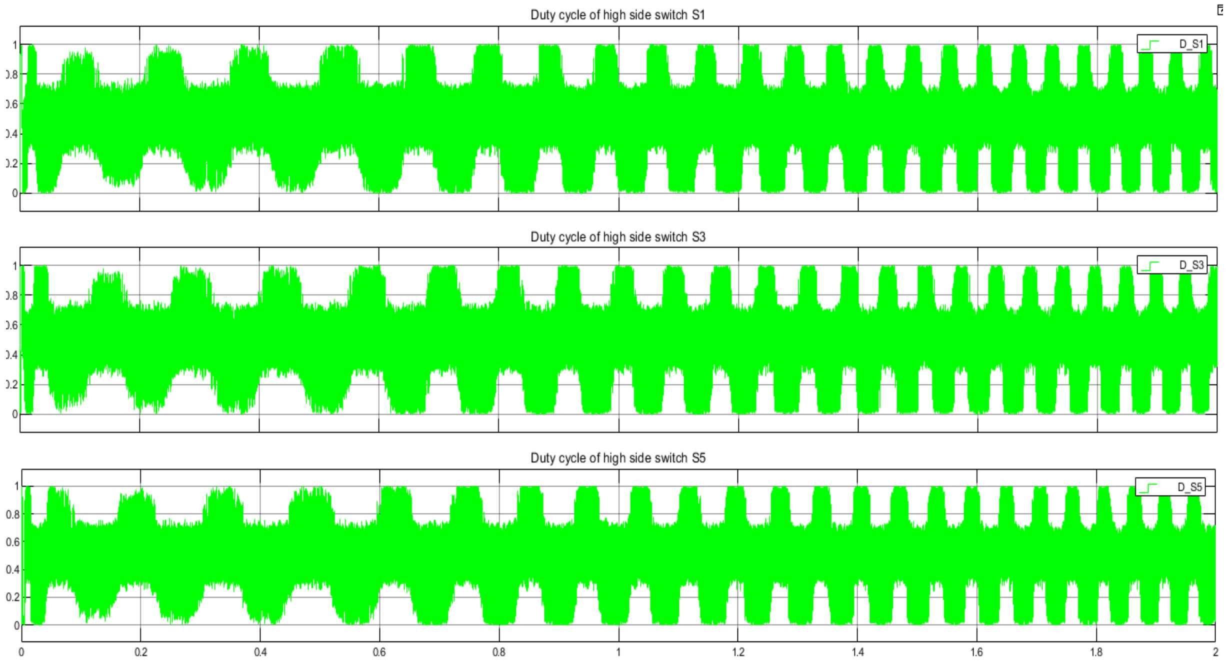


Figure A. 8 Output signal in svpwm

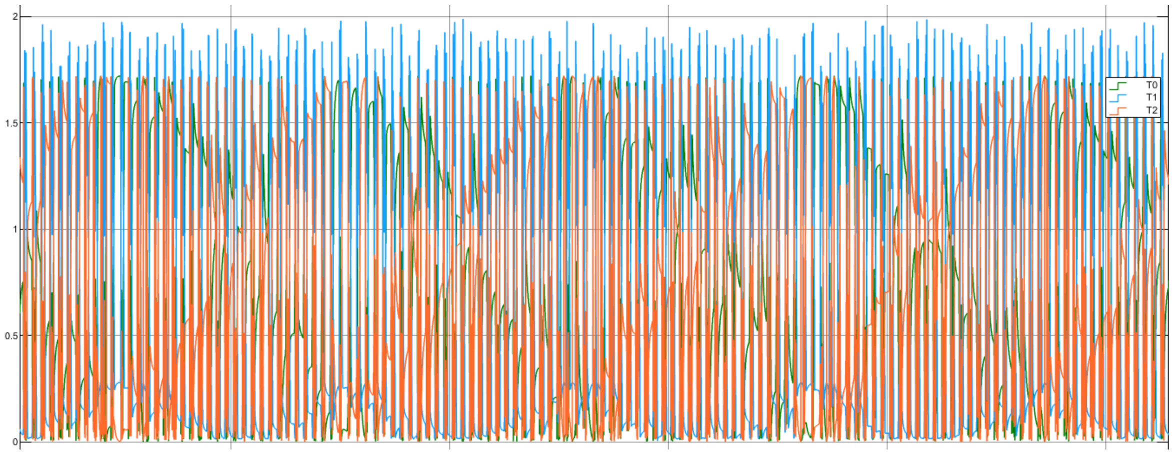


Figure A. 9 Output signal switching time of the system

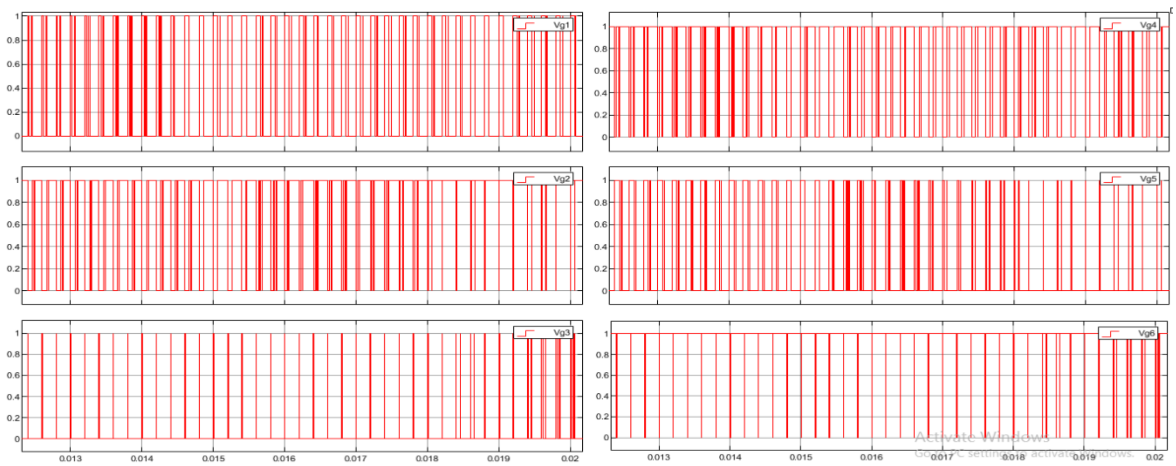
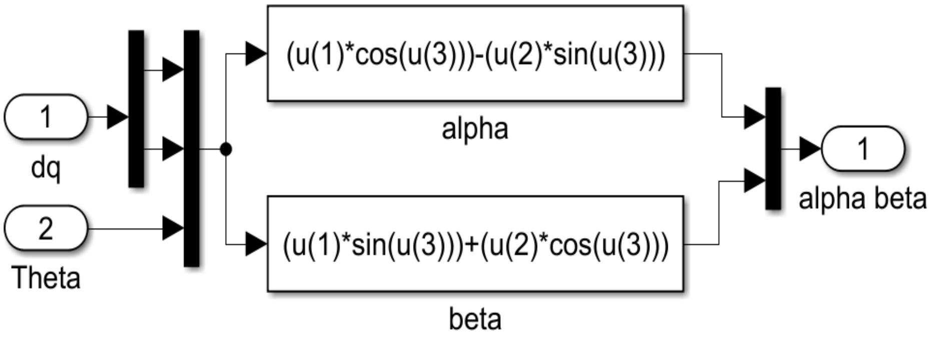


Figure A. 10 Output gate signal of the system.

c) Reverse Park and Forward Park Transformation



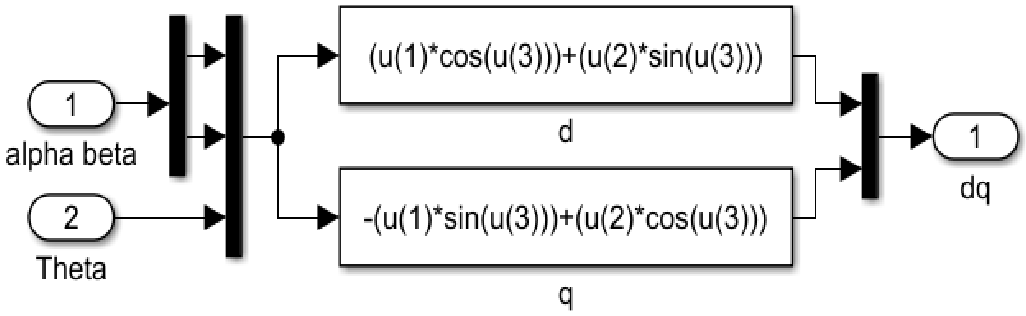


Figure A. 11 Block diagram for Reverse Park and Forward Park Transformation