

# **AN ONBOARD FAULT PROGNOSIS AND ISOLATION FOR SMALL BEVs**

A PROJECT REPORT

Submitted by

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**TKM20EEPS09**

to

**the APJ Abdul Kalam Technological University**

in partial fulfillment of the requirements for the award of the Degree

of

**MASTER OF TECHNOLOGY**

in

**POWER SYSTEMS**



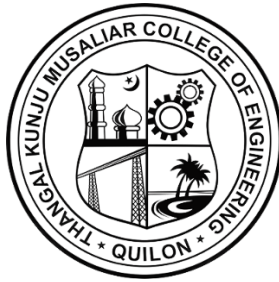
**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**

**T.K.M COLLEGE OF ENGINEERING**

**KOLLAM-5**

**2022**

**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**  
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**CERTIFICATE**

This is to certify that the Project report entitled '**AN ONBOARD FAULT PROGNOSIS AND ISOLATION FOR SMALL BEVs**' submitted by '**MISNA NAVAS**' to the APJ Abdul Kalam Technological University in partial fulfillment of the requirement for the award of the Degree of Master of Technology in Power Systems, Electrical & Electronics Engineering is a bonafide record of the project work carried out by her under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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# ACKNOWLEDGEMENT

I am obediently thankful to **God Almighty**, praise and glory is to Him, for all His uncountable bounties and guidance, without which, this project would have never been a reality.

It is my privilege and pleasure to express my gratitude and indebtedness to **Dr. T Shahul Hameed**, Principal of TKM College of Engineering, and **Dr. Sabeena Beevi K**, Head of the Department, Dept. of EEE, for providing all the required resources for the completion of my project work.

My heartfelt gratitude to **Prof. Shanavas T N**, Associate Professor, PG Coordinator and Internal Supervisor **Prof. Jibi P Mathew**, Asst. Professor , Department of Electrical and Electronics Engineering, for his valuable suggestions and guidance in designing and implementing this project.

I express my thanks to **Prof. Jibi P Mathew**, Asst. Professor, Project Coordinator, Department of Electrical and Electronics Engineering for all help and coordination in completing this project successfully and on time.

I will be failing in duty if I do not acknowledge the authors of the references and other pieces of literature referred to in this project.

I show my extreme gratitude to all Faculty member and Technical staffs in Electrical and Electronics Dept, for providing all the help and necessary facilities to complete the project work and my deep hearted cheers to my parents and all my friends who extended their supportand co-operation towards the successful completion of the project.

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## **ABSTRACT**

A vital component of a battery electric vehicle is the electric propulsion system. Performance degradation in the drive system and, more seriously, a loss of power in the vehicle may result from anomalies in the electric drive system components. An integrated prognosis system for the early isolation and detection of the electric drive system and component failure of small BEVs is proposed in this project. The primary objective of this thesis is to develop a novel technology for prognosis and drive system failure diagnostics, which in turn avoids loss of propulsion and the walk-to-home situation for small BEV customers. Based on available fault statics of BEVs, various faults are ranked and selected lead electrical faults such as stator winding open and short circuit faults to reduce the complexity of the system and to implement in budget small BEVs economically. The novelty of the proposed system is fault diagnosing of the entire electric drive system, that is the BEV battery fault also diagnosing here. The battery health check is related to the ageing of the battery or remaining life period based on battery SOC, voltage, current, and the occurrence of severe degradation in the battery. Detecting the defect at its earliest stage will help to significantly reduce the cost of maintenance.

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# ABBREVIATIONS

PV	:	Photovoltaic
EV	:	Electric vehicle
BEV	:	Battery electric vehicle
ECU	:	Electronic control unit
BDC	:	Bidirectional DC-DC converter
MPPT	:	Maximum power point tracking
P&O	:	Perturb and observe
FOC	:	Field-oriented control
PWM	:	Pulse width modulation
SOC	:	State of charge
SC	:	Short circuit
OC	:	Open circuit
FDD	:	Fault detection and diagnosis
PMSM	:	Permanent magnet synchronous motor
SVPW	:	Space vector pulse width modulation
SE	:	Static eccentricity
DE	:	Dynamic eccentricity

# CHAPTER 1

## INTRODUCTION

### GENERAL BACKGROUND

Battery Electric Vehicle is considered to be one of the widespread sustainable transportation solutions as it is eco-friendlier and more efficient than internal combustion or IC engine. It is not only a solution but also widespread. The need of electrification has become one of the major roles for future automobile development. So, if it is battery or even any other source either hybrid, the electric vehicle or BEV main feature is fault diagnosis. So that if we do the fault diagnosis on the battery electric vehicle (BEV), as a result customers can avoid walk to home situations and loss of propulsions; that is the main motives. So here the main objective is fault diagnosing of BEV.

In this project, a method for prognosing of selected faults of the drive system (motor and inverter) and battery i.e., entire electric drive system including energy source, is proposed. The drive system includes SVPWM inverter controlled/ fed permanent magnet synchronous motor (PMSM) and the fault diagnosis system intakes inverter/ motor parameters.

Comparatively PMSMs are highly efficient, reliable, brushless, less noise, fast, high torque density and give high dynamic performance in both high and low speed of operations. Due to their excellent efficiency and broad constant power speed range, permanent magnet synchronous motors (PMSM) become more suited in applications requiring a wide speed range. In reality, the absence of rotor windings and, consequently, of external stimulation, boosts the PMSM's efficiency and significantly lowers its maintenance costs. A significant use of this type of machine is also encouraged by the decline in permanent magnet prices, particularly in the field of electric car applications. In reality, such a motor is attractive to EV industrial designers due to its tiny volume, low weight, and great reliability. Due to these advantages, PMSM have been used widely in modern electric vehicle drives system. Although since the motor is working at different environmental, terrain, load, speed and torque conditions; it may face much concerns, especially various faults will certainly occur in the motor throughout the course of far continual operations. These faults will affect the reliability of the motor operation and EV as well.

Therefore, it is very important to investigate the different fault occurring in the drive system and recently there are many intelligent fault diagnosis and isolation technique in PMSM drives. As a result, fault diagnosis for PMSM problems is critical because the PMSM has a significant impact on vehicle safety and economic efficiency. The stator winding fault is a common fault that has long piqued the interest of researchers. It is caused by the breakdown of the inter-turn interphase and the main isolation of the motor winding. This internal fault will worsen machine performance by increasing torque ripples. However, such a fault can quickly propagate to the motor stator turn because it generates a large circulating current in the shorted path, resulting in excessive heat. Heat will occasionally cause progressive deterioration and eventual breakdown of winding insulation in the phase of the motor. Since incipient faults also cause power loss and reduced efficiency of system, there is necessity of an effective fault diagnosis and isolation method or system.

To maximize the availability of BEVs, this project proposes an integrated, innovative onboard/integrated prognosis system for early detection and isolation of electric drive system issues (Battery electric vehicle). The integrated fault prognostic strategy attempts to identify the problem, when it is in the initial stage itself, hence improving the system efficiency by lowering the losses in the system. The prognostic algorithm predicts the remaining life of the machine (Motor). The early stages of fault detection and prognosis will improve system perception while the drive system's condition of health is being observed.

## **1.2 THESIS MAIN OBJECTIVES**

The goal is to identify and predict the motor-related issue and determine how long the system, including the battery, will last. The major goal of this thesis study is to create a brand-new technology for prognostic analysis and drive system failure diagnostics. This is based as per statics for choosing the fault kind as electrical fault including stator winding faults open and short circuit; For that the conditions checked here are input over voltage (OV), input over current (OC), and input under voltage (UV); Because too much current in a coil damages the system. Here, taking into account the drive system's health metrics in particular the inter-turn short circuit and open circuit faults that can occur with motor windings. The novel aspect of this thesis is the introduction of the battery's health prediction. Recent literature is unable to determine the likelihood of a problem in a battery. Battery abuse faults are a common electrical problem that affect batteries. These faults are typically categorized as internal, external,

batteries with inadequate connections, overheating incipient defects in batteries, and excessive charging and discharging of batteries, and battery faults that are just beginning.

The framework must account for the following challenges;

- To design an entire drive system fault diagnosis which is done by selecting the fault types as per statics thereby, reduces the parameters as a result complexity can be reduced and easily implemented in small electric vehicle also which is more economical and useful to customers to avoid loss of propulsion and walk from home situations.
- To design a fault prognosis of battery which is based on the check related to the health management of battery considering the aging of battery or remaining life period basis of batteries state of charge (SOC), battery input voltage, battery input current and the occurrence of severity degradation in battery. The major relevance is it will helpful to save the considerable cost on maintenance by identify the fault from initial stage itself.

## **1.1MOTIVATION**

- Fault identification is crucial to ensure the continuity and safety operation of the electric vehicles (EVs).
- In recent years many diagnosis tools are used for the detection of fault in electric drive system but the results obtained from these methods are unreliable.
- Present literatures not diagnosing of whole electric drive system fault.
- It is essential to develop an economic fault prognosing system for small BEVs and Battery operated two wheelers to avoid walk to home situation and to enhance life span of EV with on time maintenance.

## **1.4 ORGANISATION OF THESIS**

There are eight chapters in the thesis. The project's inspiration, goals, and brief introduction are presented in Chapter 1. The project's literature review is covered in Chapter 2. The methodology and application of the proposed system are the main topics of Chapter 3. A brief overview of various failure approaches in permanent magnet synchronous motors is provided in Chapter 4. The complete description and modelling of a permanent magnet synchronous motor are included in Chapter 5. The chapter 6 deals with the design of PMSM, Loss Model, PV array, Boost converter and Battery model. The simulation and findings of the proposed model of fault prognosis in PMSM are covered in Chapter 6. The outcome and analysis are given in Chapter 7. The project's conclusion is provided in Chapter 8.

## CHAPTER 2

# LITERATURE SURVEY

### 2.1 INTRODUCTION

The chapter offers a review of the literature based on the prognostic analysis and failure detection of the complete drive system. The categorization of fault diagnosis methods is offered and is based on numerous studies. In permanent magnet synchronous motors, a number of methods, including demagnetization, structural analysis, and problem diagnostics, have been demonstrated. Additionally, most fault detection techniques are model-based to make it simple to compare faults in electric drives. The three technologies in PMSM are discussed as follows:

**[1] Jiya Zhang, Hengyang Yao, Giargio Rizzoni, “Fault diagnosis for electric drive system of electrified vehicle based on structural analysis” journal of IEEE transaction on vehicular technology, Nov10, 2016**

In the control algorithm develops a systematic model based diagnostic method based on the structural analysis. The structural analysis is a fault detection and isolation strategy which evaluates the systems structural model. This method is possible to determine the analytic fault or redundancy. This methodology is demonstrated in this method; also, effectively determines the sensor fault by model-based fault detection method which compares the measured signal with estimated one which often using diagnostic observer Through the state observer based FDI (fault detection and isolation) technique, it effectively detects the incipient fault, but the isolation of fault is very difficult when the multiple faults occur in such system. In electrified drive system is embedded with several sensors which include current sensor, voltage sensor, speed sensor, etc. might cause serious consequences such as significant torque oscillation and unstable battery voltage The merit of this methodology it efficiently analyst the detectability and property of various fault which occurs in complex system. The further advantage of structural analysis method which is efficiently diagnose fault especially in large complex system to smaller sub-system. This decomposition allows the efficient design of diagnostic algorithm for to easily implemented.

**[2] J. Lee, Y.-J. Jeon, D.-c. Choi, S. Kim, and S. W. Kim, “Demagnetization fault diagnosis method for pmsm of electric vehicle,” in IECON 2013-39th Annual Conference of the IEEE Industrial Electronics Society IEEE, 2013, pp. 2709–2713.**

In this control algorithm develops a model-based strategy for fault detection based on the parameter identification. The most relevant method for parameter estimation is least square method. The least square for fault deionization is an optimal solution to estimate fault in PMSM. This method demonstrates to resolves the demagnetization fault in PMSM. Demagnetization is the property of weaken the magnetization in PMSM; like high temperature stress, physical damage, low output torque, inverse magnetic field and aging which is undesirable to electric drive system. The method is based on the least square method to estimate the magnetic flux linkage in PMSM. It analyses the estimation error; Thereby magnetic flux linkage of PMSM which is proportional to the strength of PMSM So it effectively diagnoses the demagnetizing fault in PMSM; The drawback of this method sometimes it's difficult for the estimation process. and it may be not accurately done the fault analysis in PMSM drive.

**[3] H. Chen, B. Jiang, S. X. Ding, N. Lu, and W. Chen, “Probability-relevant incipient fault detection and diagnosis methodology with applications to electric drive systems,” IEEE Transactions on Control Systems Technology, vol. 27, no. 6, pp. 2766–2773, 2018.**

This method suggested for FDD called FRPCA analysis. This method is illustrated by mathematical and statistical analysis. The objective of this scheme is to develop an FDD method for detecting incipient fault. To illustrate the novel FDD methodology for incipient fault, six data driven method including PCA is implemented also the hypothesis test is consider for to evaluate the fault decision in system This a reliable detection strategy for incipient fault is a necessary part of fault diagnosis and prognosis. This will implicitly analyze the crowding problem caused by incipient fault. FPCA algorithm uses both normal and faulty data and process monitoring for fault analysis. This method consists of two parts; namely fault-relevant and fault-irrelevant part. The part that will present larger variation relative to the normal case under the disturbance of fault is regarded to be more informative for fault detection (called fault-relevant part). It is then separated from the fault-irrelevant part and highlighted for online monitoring which is deemed to be more effective for fault detection. This method provides a detailed insight into the decomposition of the original normal process information from the fault-relevant perspective. The first method suggested for FDD called FRPCA analysis. This method is illustrated by mathematical and statistical analysis. The objective of this scheme is

to develop an FDD method for detecting incipient fault. To illustrate the novel FDD methodology for incipient fault, six data driven method including PCA is implemented also the hypothesis test is consider for to evaluate the fault decision in system. This a reliable detection strategy for incipient fault is a necessary part of fault diagnosis and prognosis. This will implicitly analyze the crowding problem caused by incipient fault. FPCA algorithm uses both normal and faulty data and process monitoring for fault analysis. This method consists of two parts; namely fault-relevant and fault-irrelevant part. The part that will present larger variation relative to the normal case under the disturbance of fault is regarded to be more informative for fault detection (called fault-relevant part). It is then separated from the fault-irrelevant part and highlighted for online monitoring which is deemed to be more effective for fault detection. This method provides a detailed insight into the decomposition of the original normal process information from the fault-relevant perspective.

**[4] E. G. Strangas, S. Aviyente, and S. S. H. Zaidi, "Time–frequency analysis for efficient fault diagnosis and failure prognosis for interior permanent-magnet ac motors," IEEE Transactions on Industrial Electronics, vol. 55, no. 12, pp. 4191–4199, 2018**

This paper presents a comparison of efficient time frequency analysis for using an algorithm for the fault detection and isolation of interior PMSM ac motor. The algorithm consists of four distinct time frequency analysis strategy adopted for the diagnosis and isolation of intermittent fault in drive system. In addition, here this paper proposes an MDA based method to reduce the time frequency feature vector to low dimensional space prior to classification.

**[5] Raphael Peugeot, Stephane Courtine and Jean-Pierre Rognon, "Fault detection and isolation on a PWM inverter by knowledge-based model", IEEE Transaction on industry application, vol.34, no.6, December 2017.**

This method develops a knowledge-based model to detect and isolate fault in a pulse width inverter in a synchronous machine. This is based on the analysis of the current vector trajectory applied the instantaneous frequency in faulty condition. The first approach is based on the analysis of current vector; used to detect and isolates faults in a PWM inverter and current sensor. In this method the transistor and sensor fault have been consider for fault detection and isolation. The second methodology is the instantaneous frequency of the current vector; this approach is very efficient to analyse the transistor fault but the major drawback of this method

is the isolation of faulted transistor is impossible; Also, the first method current vector trajectory is more robust than the second method based on the instantaneous frequency.

**[6] F. Meinguet, P. Sandulescu, X. Kestelyn, and E. Semail, “A method for fault detection and isolation based on the processing of multiple diagnostic indices: application to inverter faults in ac drives,” IEEE transactions on vehicular technology, vol. 62, no. 3, pp. 995–1009, 2019.**

This paper adopted a strategy for fault diagnosis and detection is presented and it applied to the inverter related faults in electric drive system. The algorithm is based on the change detection technique, its feature to detect the more than single fault indices. This fault indices are related on unbalances of the phase current and instantaneous frequency. In addition to change detection algorithm here adopted the CUSUM technique. This technique is highly intelligent method for fault detection in an electric drive system. This proposed strategy is effectively works in different modes of conditions like variable speed, at zero current, flux weakening area also in energy recovery conditions.

**[7] J. Rosero, J. Cusido, A. Garcia, J. Ortega, and L. Romeral, “Broken bearings and eccentricity fault detection for a permanent magnet synchronous motor,” in IECON 2016-32nd Annual Conference on IEEE Industrial Electronics. IEEE, 2016, pp. 964–969.**

This paper presents a study of the broken bearing and eccentricity fault diagnosis in permanent magnet synchronous motor. In this paper introduce a major fault detection in permanent magnet synchronous motor (PMSM); like mechanical faults including static and dynamic irregularities, broken bearing, gear box failure etc. and electrical fault especially stator fault due to the open or shorting of phase windings. Irregularities in connections and weakening of permanent magnet motor. The conclusion is acquired deriving out of analyzing the stator current harmonic spectrum. This paper suggests a stator current spectrum methodology to easily detect the rotor eccentricity fault and broken bearing in permanent magnet synchronous motor (PMSM).

**[8] R. R. Schoen, T. G. Habetler, F. Kamran, and R. Bartfield, “Motor bearing damage detection using stator current monitoring,” IEEE transactions on industry applications, vol. 31, no. 6, pp. 1274–1279**

This paper suggests a motor current spectrum analysis for identifying the bearing damage in electrical machines. In addition to spectrum analysis vibration monitoring of mechanical

bearing frequency is used to detect the faulty conditions. Also, this method effectively diagnoses the presence of internal bearing failure in electrical machines.

**[9] J. R. Stack, T. G. Habetler, and R. G. Harley, “Fault classification and fault signature production for rolling element bearings in electric machines,” IEEE Transactions on Industry Applications, vol. 40, no. 3, pp. 735–739, 2014**

This paper suggests an innovative strategy to classifying the bearing fault. The classification of bearing fault is based on the location of fault which is inner race or outer race fault. This is very effective technique for monitoring the bearing damage in electrical machine. Most rolling element bearing condition monitoring techniques are designed to detect the four characteristic fault frequencies. This has resulted in the widespread practice of categorizing bearing faults based on fault location (i.e., inner race, outer race, ball, or cage fault). While it is necessary to be able to detect the four characteristic fault frequencies, this approach ignores another important class of faults that occur in many industrial settings. This study introduces the concept of classifying bearing faults as single-point defects or generalized roughness. These classes categorize bearing faults based on the types of fault signatures produced rather than the physical location of the fault. Single-point defects produce four predictable characteristic fault frequencies, whereas generalized roughness faults produce unpredictable broadband changes in machine vibration and stator current.

**[10] S. Moon, H. Jeong, H. Lee, and S. W. Kim, “Interturn short fault diagnosis in a PMSM by voltage and current residual analysis with the faulty winding model,” IEEE Transactions on Energy Conversion, vol. 33, no. 1, pp. 190–198, 2017**

This paper proposes a model-based method for detecting interturn short circuit faults in permanent magnet synchronous motors (PMSM). The fault diagnosis is based on the residual current vector, which allows for the precise diagnosis of an inter turn short circuit fault in the stator phase winding. Because an interturn short fault (ISF) in a permanent-magnet synchronous machine (PMSM) reduces energy efficiency and may cause other issues, PMSM fault diagnosis must be precise. To analyse the fault, a faulty-winding model (FWM) is introduced; the model describes a relationship between the voltage decrease of the faulty winding and fault characteristics such as fault resistance and fault turn ratio. We propose a fault index (FI) based on the model to indicate the severity of the ISF. Because the ISF induces residual components in both voltage and current, the proposed method made use of those

components in conjunction with the FWM. To estimate the FI and diagnose the ISF of PMSMs, the least squares (LS) method is used.

## CHAPTER 3

### METHODOLOGY

#### 3.1 INTRODUCTION

The classification of faults in PMSM is covered in this chapter. Also includes a description of the controller used and the proposed prognosis approach of motor-related fault analysis.

#### 3.2 FAULTS CHARACTERIZATION

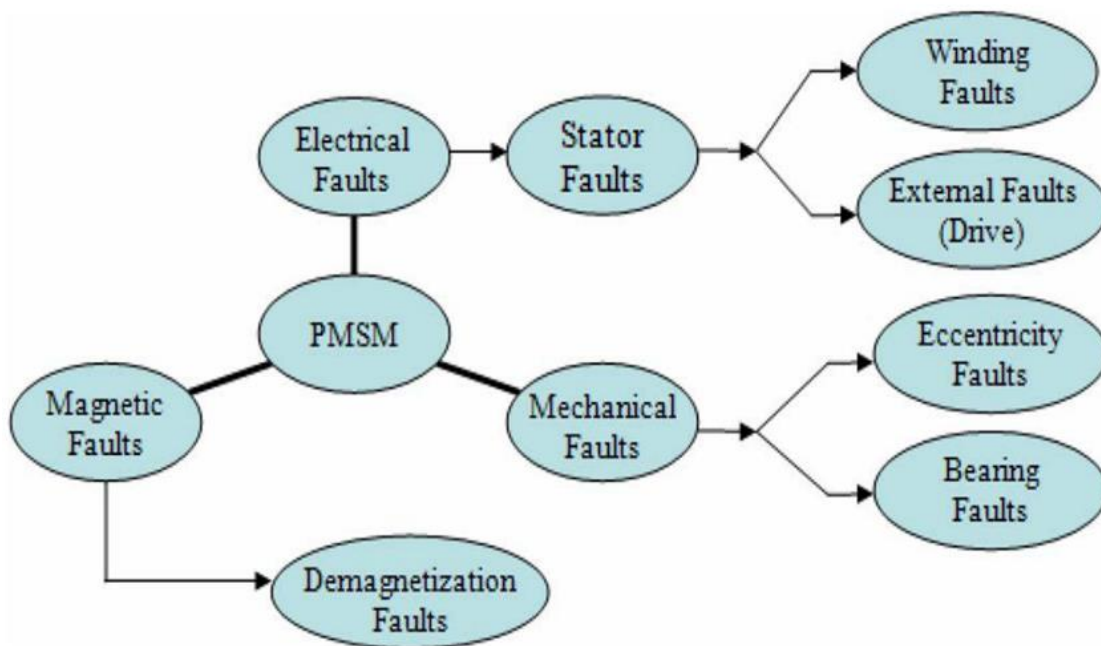


Fig 3.1 classification of fault

The uses for electrical machines have greatly expanded during the past few years. As a result, the amount of energy needed to drive the motor is also rising quickly every day. But due to limited constant supply of energy and poor efficiency of at present electrical motors, there is need of more advance and energy efficient motors to fulfill above said problems. And nearest so far answer to this is permanent magnet synchronous motor (PMSM). Unlike rotor wound synchronous motor in permanent magnet synchronous motor the field winding is completely replaced with permanent magnets. Therefore, energy required for field winding for excitation is completely eliminated. Which means permanent magnet synchronous motor is superior to other motors in terms of higher efficiency, high power to volume ratio (power density) and high

torque to current ratio. Permanent magnet synchronous motors (PMSMs) are widely used in different industries. So, protection of these motors against different faults is necessary. Faults in PMSMs are classified into magnetic, electrical and mechanical faults. However, 80% of the mechanical faults lead to the eccentricity. Therefore, the eccentricity fault should be accurately diagnosed in PMSMs. A round rotor synchronous motor under dynamic eccentricity (DE) has been modelled by winding function method. However, to maximize the applications of PMSM we need to study various faults associated with PMSM, and classify them in proper way, so that we can check them prior that leads to dangerous accidents.

The advantages of PMSM over other motors. Some of these advantages are given below.

### **Advantages of PMSM**

- Large ratio of torque to inertia.
- High power density.
- Strong dynamic reaction
- High efficiency resulting in machine size decrease.
- Extended service life
- Operation that is silent
- A large power factors
- A high weight to power ratio
- A high ratio of torque to inertia
- High air-gap flux density
- Broader speed spectrums
- More favorable speed-to-torque characteristics
- Less expensive upkeep
- Ruggedness and simplicity

Predominately, according to the nature of the fault common faults of the PMSM can be classified as electrical, mechanical and magnetic fault.

#### **3.2.1 Electrical fault**

An electrical fault is an abnormal condition and it mainly occurs due to the equipment failure, poor electrical connections, short circuit of stator phase winding, insulation failures, open circuit faults etc. Electrical issues typically entail faulty grounding, short circuits in the stator

phase windings, and open circuits throughout the entire phase. 38% of all motor failures are caused by faulty stator. The most frequent defect in PMSM is the inter-turn short circuit of the stator windings. The stator winding insulation system in the motor may fail as the running duration rises as a result of insulation wear, overheating, or overload, leading to a short-circuit defect between the stator turns. A short-circuit fault is challenging because it generates a strong circulating current and a lot of heat in the shorted channel. Since it can quickly spread into more stator windings and damage more wire insulation as a result, if it is not found and fixed in a timely manner, it could result in demagnetization, phase-to-phase faults, and even phase-to-ground faults. One of the phases may open-circuit due to a failing internal stator winding, however drive system issues are frequently to blame for this. It can result in significant mechanical vibrations of the motor and huge electromagnetic torque fluctuations. Without prompt repairs, starting and operating the problem PMSM might cause additional damage and perhaps the collapse of the entire system. Electrical motor winding damage and bearing issues account for about 80% of electrical motor failures. Among the various faults in PMSM; the most recurrent is stator winding interturn faults which is mainly due to the insulation failures. Undersized motors, variable speed drives (VSD), inadequate cooling at low speeds, variations in the load on the motor, such as equipment that is jammed, and warm environmental conditions can all cause overheating. Insulation breakdown, which results in burned windings, indicates a short-circuit either inside the motor or within the circuit that supplies power to the motor. This short-circuit can be brought on by overheating, overloads, or overvoltage.

Due to the breakdown of stator winding insulation system normally the interturn fault is an initial fault of short circuit fault. Thereby, those issues may be some reasons for happening the destruction in an ac machine. The electrical faults include inter turn short circuit fault. When the magnetic attraction between the stator and rotor is unevenly distributed around the motor's perimeter, electrical unbalance results. As a result, there is a mechanical unbalance due to the shaft deflecting as it turns. An electrical failure, such as an open stator or rotor winding, an open bar or ring in a squirrel cage motor, or shorted field coils in a synchronous motor, is typically indicated by an electrical unbalance. Electrical unbalance is also caused by an uneven air gap, typically from severely worn sleeve bearings. Noise often does not cause harm but can be an indicator of motor issues. However, vibration frequently goes hand in hand with noise. There are several ways that vibration can harm. Windings are frequently shaken loose, and the insulation is mechanically harmed by cracking, flaking, or abrasion of the substance. Vibration

can also result in lead wire brittleness due to excessive movement and brush sparking at commutators or current collecting rings.

Finally, vibration can hasten bearing failure by pounding out-of-round balls in sleeve bearings or loosening housings inside shells. Anytime a running motor exhibits noise or vibration, the cause needs to be quickly identified and fixed. What appears to be the noise's or vibration's obvious cause could instead be a sign of something else.

- Inter-turn short circuit fault
- Drive and winding fault

## **INTER-TURN SHORT CIRCUIT FAULT**

Different factors, such as extreme temperature fluctuations and high voltage rates brought on by PWM (pulse width modulation) inverter feed, reduce the insulation of winding turns. The inter-turn short circuit is the result of this insulation degradation in the end. Short circuits between turns reduce the number of active turns in the affected phase, which results in a lower electromotive force. Unbalanced satiric flux results from this. Additionally, it produces a current loop, commonly known as a short-circuit loop. The current running in this loop has the potential to be quite significant, causing permanent harm to the entire system. Early discovery of this defect is crucial since it may result in the entire destruction of the phase, which would have a negative impact on the machine's performance. Insulation breakdown between a coil's individual windings can result in inter-turn short-circuits, which can then spread to the entire coil and even to nearby coils. Mechanical stress, overcurrent, or thermal impact are all potential causes of insulation damage. Additionally, inter-turn short-circuits can result in an asymmetrical magnetic field, which can generate vibration and higher harmonics in a torque waveform, both of which can have a substantial impact on system performance. The procedure outlined above may make it possible to halt the motor, which could result in high production costs.

## **DRIVE AND WINDING FAULT**

When a motor is subjected to unfavorable operating circumstances, whether electrical, mechanical, or environmental, the life of a three-phase stator winding can be drastically reduced. Fig 3.2 illustrates stator problems that result from insulation breakdown in stator windings.

Turn-to-turn, coil-to-coil, phase-to-phase, open circuit fault, coil-to-ground fault, and phase-to-ground fault are the different types of these faults. Figure 3.2 depicts the defects already described. A decrease in rotor velocity is connected to a significant turn-to-turn defect. About 35 to 40 percent of motor failures are caused by the insulation and core of the stator windings. According to common consensus, insulation breakdown in a number of stator coil turns within a single phase causes the majority of stator winding-related failures. "Stator turn fault" is the name given to this kind of error reduced. The winding failures seen here are typical of what might occur in these situations. A symmetric three-phase AC machine has a stator turn defect because a shorted turn allows a high current to pass and produce a lot of heat. Motor failure may result from the heat that is inversely proportional to the square of the circulating current. results in the drive's operation being stopped. An error in the stator winding caused by a short-circuited turn in a permanent magnet synchronous motor can be found by monitoring the second-order harmonic components in the q-axis current through harmonic analysis.

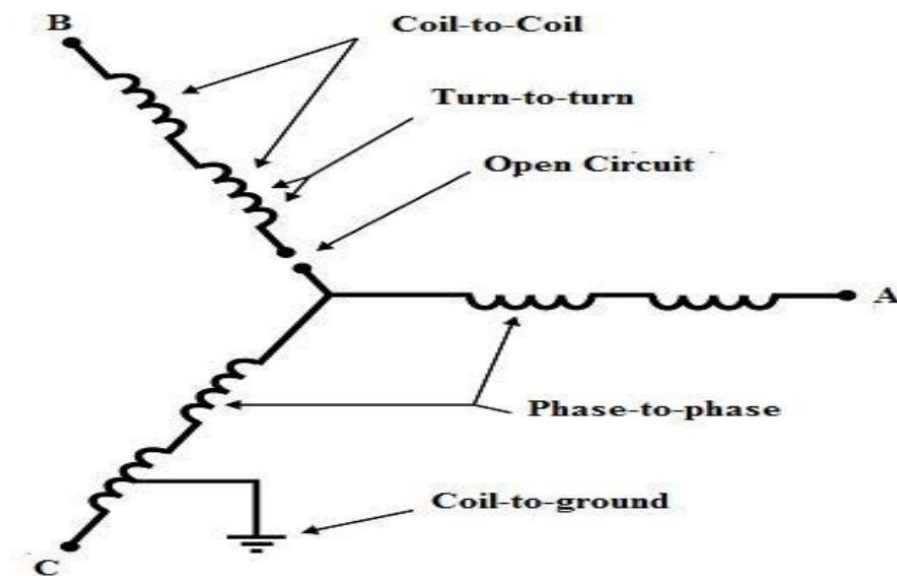


Fig 3.2 Stator Winding Faults

### 3.2.2 Mechanical fault

The most significant motor failure is related to mechanical faults. Mechanical faults which are about 40-50 % of all motor fault mainly involve,

- Bearing fault
- Eccentricity Fault

- Damage to magnet
- Bearing fault etc.

Nearly 40–50% of all motor defects are caused by bearing faults, which can also be caused by shaft misalignment, insufficient lubrication, overload, corrosion, and other factors. Notably, even following routine use, bearings eventually become worn out. A piece of metal breaks off and leaves a little pit or flaking as the fatigue fracture spreads from beneath the metal surface to the surface. As a result, the bearing will sustain damage and eventually fail. The bearing may have a cage defect, an inner raceway fault, an outer raceway problem, or a ball fault. Other problems, such as air gap eccentricity, increased friction, and inter-turn short-circuit fault, can also be brought on by the bearing deterioration. The main reason for occurring bearing faults are environmental mechanical vibrations, overload conditions, corrosion, poor lubrications, corrosion, and so on.

The uneven air gap between the rotor and the stator is referred to as an eccentricity defect. The centerline of the shaft deviates consistently from the stator's center when static eccentricity takes place. When dynamic eccentricity takes place, the minimum air gap distance rotates along with the rotor. These two phenomena frequently occur in the real world, which causes mixed eccentricity. Eccentricity defects can result in more vibration, noise, rippled torque, and other problems. Additionally, when the eccentric fault worsens, it will generate friction between the stator and the rotor, harm the stator or rotor core, and impair the motor's ability to run normally. Eccentricity faults involve static eccentricity (SE), Dynamic eccentricity (DE), and mixed eccentricity (ME). This may occur due to manufacturing imperfections like unbalanced mass, shaft bow, and bearing tolerance. Eccentricity faults may occur due to the inaccurate positioning of the rotor, bearing wear, stator core movement, shaft deflections, also due to additional vibrations, noise, ripple, and so on. The major bearing faults are due to improper lubrications; if the wrong lubricant is used or if the bearing has been exposed to much excess temperatures that may lead the lubricant to degrade. A warped mounting, bent shaft, an unbalanced rotor, loose pieces on the rotor, or faulty bearings are the main reasons of mechanical unbalance. The fan striking the frame, the shroud, or outside items inside the shroud can also produce noise. Determine the cause of the bearing failure if the bearings are faulty as indicated by excessive bearing noise.

### 3.2.3 Magnetic fault

The magnetic faults related with generation, and distribution of magnetic field lines. Antiparallel crossing magnetic field lines demagnetize each other and leads to irregular distribution of magnetic flux, this fault is referred as diamagnetic fault. The magnetic fault in permanent magnet synchronous motor includes demagnetization of permanent magnet. The demagnetization fault is a particular PMSM fault. Demagnetization of permanent magnets in the PMSM can occur for a variety of reasons, including damage to the magnet, high temperatures, huge stator currents, large short-circuit currents caused by inverter or stator failures, and ageing of the magnet itself. Armature reflexes are the main culprit of this error. The stator current creates a reverse magnetic field that constantly opposes the magnetic field of the permanent magnet during a PMSM's normal operation. This resistance will eventually result in the permanent magnet demagnetizing over the course of prolonged use. It is fully demagnetized when this demagnetization covers the entire magnetic pole. Additionally, the partial magnetic pole and partial demagnetization are equivalent. Some studies claim that when the PMSM-specific demagnetization defect arises, flux linkage ripples will cause the torque to be insufficient, leading the current to increase in order to supply the necessary torque. This will increase the temperature and intensify the demagnetization in turn. Additionally, the torque variation will cause irregular vibration and acoustic disturbance. They can impair motor performance and efficiency and negatively impact the PMSM's normal operation.

### **DEMAGNETISATION OF PERMANENT MAGNET**

The magnetic defect of demagnetization is one of the faults seen in PMSMs. High loads or an armature reaction that happens during the abrupt transition from a permanent situation to a static one can cause demagnetization faults, which are particularly common. Additionally, magnetic fields in the opposite direction that emerge from currents flowing through stator windings in stationary state and high temperatures that happen in winding failures are what create demagnetization fault. Numerous stresses are also placed on the rotor. Strong temperatures, field weakening operation, and high short-circuit currents can demagnetize one or more rotor poles. The magnets' residual induction level is thereby permanently reduced. Centrifugal force or manufacturing flaws can also break one magnet. A demagnetized pole like that induces less voltage into the windings. This throws off the magnetic flux of the rotor. Contrary to inter-turn short-circuit, every phase experiences the same consequence. Effective

differentiation between one fault and another will be possible thanks to this disparity. Demagnetization faults in PMSMs typically result from conditions like loads that demand high starting torques, fixture reaction during the quick transition from a transient state to a stationary state, magnetic fields in the opposite directions caused by currents flowing through stator coils in static state, and high temperatures experienced during winding faults. The fluxes created by the magnets lead to irreversible losses, which reduce the motor's efficiency.

### 3.3 TYPICAL MODEL OF DRIVE SYSTEM

As shown in fig3.3, basic electric drive system in a battery oriented electric vehicle which inverts the DC voltage to AC. It mainly consists of units like DC link, three phase inverter, an electric motor (PMSM), Resolver and a motor controller unit. As shown as figure; the function of an inverter is the conversion of ac power is used to drive the motor. Here the motor type is PMSM (Permanent magnet synchronous motor). The purpose of resolver to senses the motor position  $\theta_r$  and it provides the feedback to the controller unit. The motor controller which regulates the supplied power by the inverter to motor. The three-phase inverter comprised of the six power switches, the on and off state of these power switches controlled by switching command generated by controller unit. The output voltage of the inverter is controlled to proper value such that the electric motor generates the desired output. Here the motor type is PMSM (Permanent magnet synchronous motor). The purpose of resolver to senses the motor position  $\theta_r$  and it provides the feedback to the controller unit. The motor controller which regulates the supplied power by the inverter to motor.

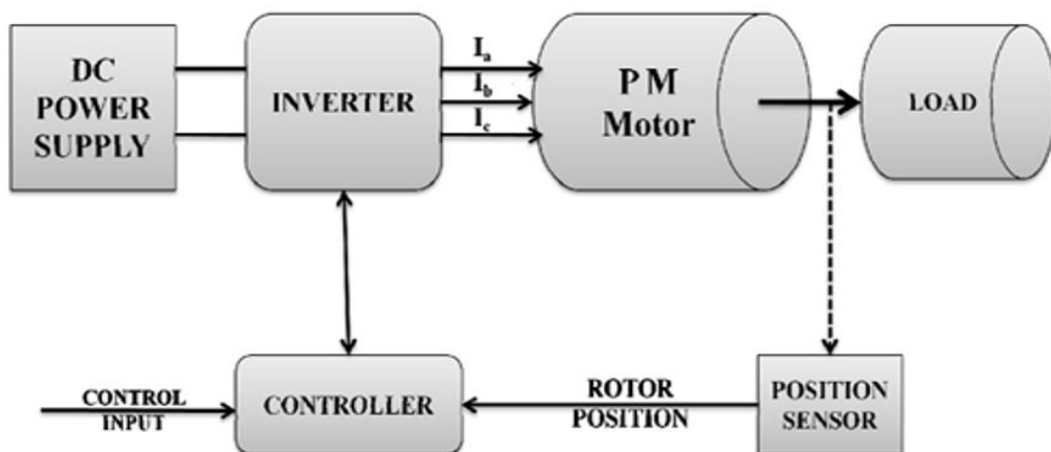


Fig 3.3 Schematic of electric drive system in BEV

### 3.4 EQUIVALENT CIRCUIT OF PMSM

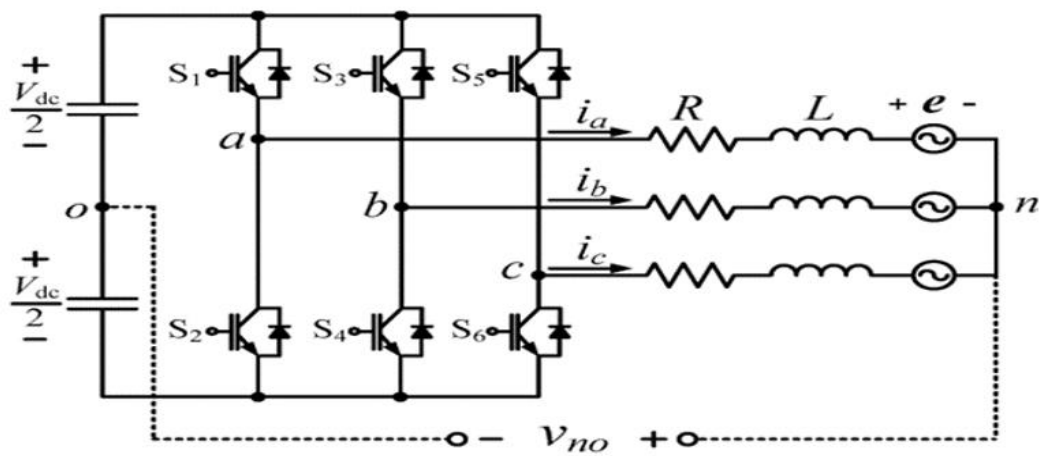


Fig 3.4 Electric drive system circuit

As shown in fig 3.4, The three-phase inverter comprised of the six power switches, the on and off state of these power switches are regulated by the switching command generated electronics switches are used. The switch is selected on the basis of its power capacity and switching. Table 3.1 shown below illustrates power devices and their switching capabilities by motor control unit. The output voltage of the inverter is controlled to proper value such that the electric motor generates the desired output. For inverter power electronics switches are used. The switch is selected on the basis of its power capacity and switching. Table 3.1 shown below illustrates power devices and their switching capabilities.

DEVICE	POWER CAPACITY	SWITCH SPEED
IGBT	MEDIUM	MEDIUM
MOSFET	LOW	HIGH
GTO	HIGH	LOW
BJT	MEDIUM	MEDIUM

Table 3.1 Power Device and its switching capability

### 3.5 PROPOSED METHOD OF FAULT DETECTION IN PMSM

The proposed methodology suggested for fault detection and diagnosis in permanent magnet synchronous motor (PMSM) is prognostic analysis. The ‘Prognostic’ term defines the prediction of remaining life of a system. It is a hierarchical approach to ensure accurate prognosis and to analyses the healthy condition of electric drive system for fault detection and diagnosis. The prognostic strategy identifies the faulty condition like short circuit, open circuit from initial stage itself and it is very effective diagnosis method for fault detection and analysis.

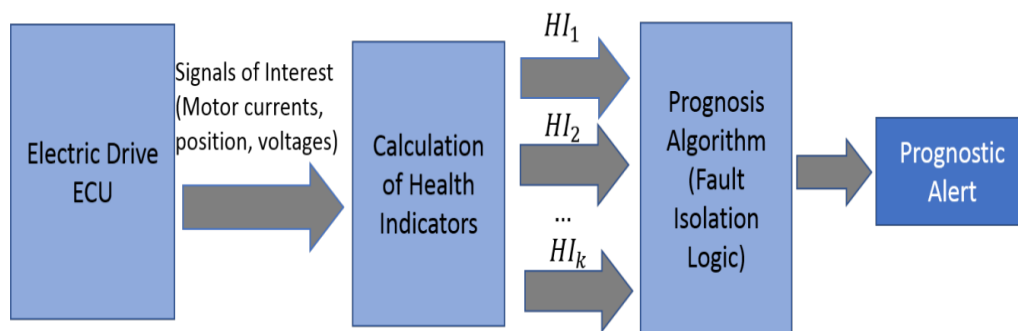


Fig 3.5 System description for prognostic framework

In this paper, the prognostic framework for electric drive system is described by Fig 3.5 As can be seen, there are two major steps in this framework.

- Calculating the health indicator from the required signals of interest including sensor measurement, controller inputs.
- Prognostic algorithm for decision making and to generates the prognostic results.

The objective of this proposed model is to detect and diagnose the faults in permanent magnet synchronous motor (PMSM). First of all, to detect the fault So that there is ECU (Electronic control unit); which is kept in electric drive as shown in fig 3.5. The function of ECU is calculating health indicator. For that; there need required signals which is the signals of interest. The signals of interest collected from ECU like reference q-axis current  $i_q$  and the reference d axis current from the motor (PMSM) controller input, three phase sensor current measurement, inverter input source and so on. Then, the health indicator calculation module HI calculates multiple health indicator  $HI_1, HI_2, HI_3 \dots HI_n$  based on the signals of interest. Here the fault

which is developed manually to the system and to check whether the system is in faulty or healthy condition. The faulty condition can check using the prognostic algorithm. The prognostic algorithm is a hierarchical procedure, The algorithm first collecting the input data from inverter input source .First of all, it checks that the working system is in condition or not. For that the algorithm first detect that if there is a performance degradation in the entire drive system by looking at the system level indication then goes into the component level. To diagnose the component faulty level; the component fault level is the state of health (SOH) value. A model developed in that algorithm sets a pre-fault or threshold value for comparison purpose for checking that the system is in faulty or not faulty condition; By comparing the input value with pre-fault values. If the input value is greater than the threshold value, the system is in healthy condition. The input value is lower than the threshold data; the system is in faulty condition; the pre-fault data's is taken from the real time data set.

### 3.6 CLASSIFICATION OF FAULT TO BE DETECTED

In accordance to this table shown in Table3.2 here to identify the fault type, as well as the circumstance surrounding that specific detecting fault. The motor electrical defect, which may be an electrical or a stator winding issue, is the first sort of fault to be found. The leakage current in the winding core is detected here, and the fault is identified ahead of time. In this instance, no faulty circumstances, short circuit faults, or open circuit faults are found. Input overvoltage, input undervoltage, and input current are the circumstances that are examined here.

FAULT TYPE	FAULT TO DETECT	FAULT STATUS
ELECTRICAL FAULT	SHORT CIRCUIT FAULT	INPUT OVER VOLTAGE INPUT UNDER VOLTAGE INPUT OVER CURRENT NO FAULT CONDITION
	Three phase faults	
	Phase-Phase fault	
	Phase-earth fault	
	OPEN CIRCUIT FAULT	
	Single phase OC fault	
	Two phase OC fault	
Three phase OC fault		

Table 3.2 Classification of electrical fault

<b>FAULT TYPE</b>	<b>PARAMETERS TO BE MEASURED</b>
BATTERY FAULT BASED ON DEGRADATION, LIFE CYCLE	Battery state of charge (SOC) of battery Battery voltage (V) Battery current (I)

Table 3.3 Battery life based on state of charge (SOC)

According to the table shown as Table 3.3 it is based on a check related to battery health management, taking into account battery ageing or remaining life period based on battery state of charge (SOC), battery input voltage, battery input current, and the occurrence of severity degradation in battery.

### 3.7 CONTROL ALGORITHM OF PROPOSED METHODOLOGY

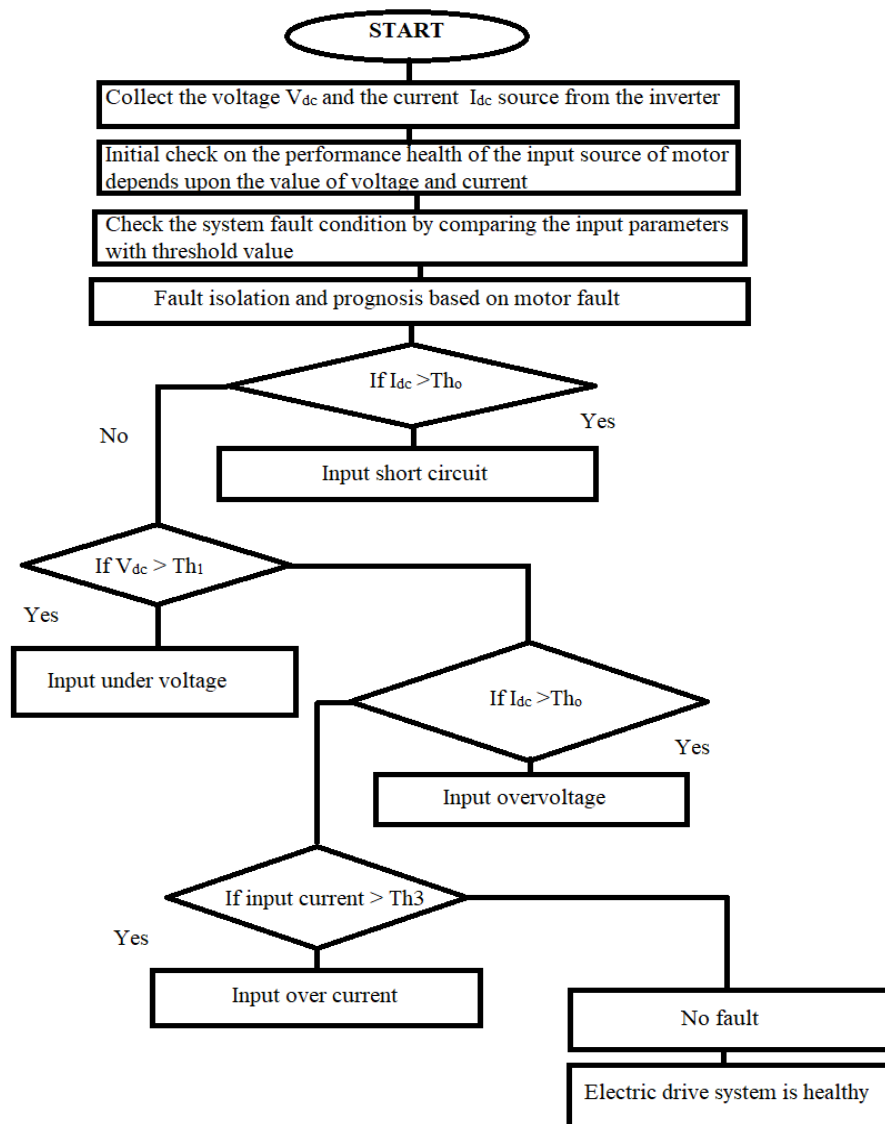


Fig 3.6 Prognostic algorithm of initial motor winding fault analysis

Here, the initial step is to determine the fault analysis of electric drive system. Here the voltage  $V_1$  and current  $I_1$  input as taken from the input source of inverter. The input values introduced here is then compared with the threshold or pre-fault value so as to check the performance i.e., whether there is any fault or not. The first stage in this process to collect the dc input source voltage and current from the inverter. These two parameters are the basis of motor health assessment. Fault detection is done by comparing these two input parameters with threshold values. Fault detection and isolation is done on the basis of degree of severity of fault in motor.

For this first check the input current is greater than threshold value. If the condition is satisfied, we can identify as now system has a chance of short circuit. If the condition is false move on to the next condition., here the input source voltage is compared with the threshold value, if it is greater than threshold value the system has over voltage. If the condition is false then move on to next condition. For this is compared to another threshold value, here the input current is compared with next threshold value, if the condition is satisfied the system has the chances of input over current. If the condition is false, we can conclude that the system is healthy condition, there is no fault.

## CHAPTER 4

### DIFFERENT FAULT ANALYSIS TECHNIQUES IN PMSM

#### 4.1 INTRODUCTION

The chapter describes strategic procedures based on the fault detection and diagnosis analysis. Based on various researches; the categorization of common approaches for fault detection are listed, including model-based fault diagnosis, data-driven intelligent diagnostic method, Observer-based method, Hardware-based method, History-based method.

#### 4.2 STRATEGY FOR FAULT DETECTION AND DIAGNOSIS (FDD)

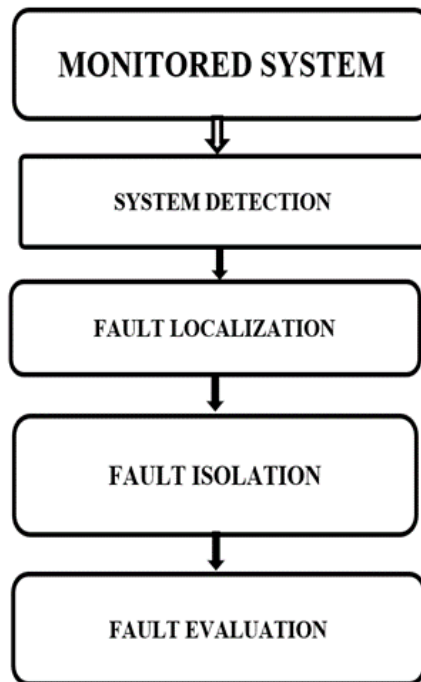


Fig 4.1 Fault detection and diagnosis procedure

The above fig.4.1 illustrates the different steps of fault diagnosis procedure which includes fault detection, localization and identification. Whenever the fault is to be detected; the next step is localization which identifies the exact location of the particular fault according to degree of severity. Localization of fault is very difficult in case of multiple faults occur at same time. After the step of localization next step is estimation of fault. During estimating, finds out the nature and size of fault. Finally, the decision has to be taken whether faulty condition or not.

## **4.3 CATEGORISATION OF FAULT DIAGNOSTIC TECHNIQUES**

The classification of FDI (Fault diagnosis and isolation) methods are classified as

- MODEL BASED FAULT ANALYSIS TECHNIQUE
- DATA-DRIVEN BASED FAULT ANALYSIS TECHNIQUE
- SIGNAL BASED FAULT DIAGNOSIS TECHNIQUE
- HARDWARE BASED FAULT ANALYSIS TECHNIQUE
- HISTORY BASED FAULT ANALYSIS TECHNIQUE
- OBSERVER BASED FAULT ANALYSIS TECHNIQUE

### **4.3.1 DATA-DRIVEN BASED FAULT ANALYSIS TECHNIQUE**

Data-driven approach is one of the efficient methods for fault detection in permanent magnet synchronous motor (PMSM). This method works out as per the spectrum analysis. This technique effectively diagnoses the incipient fault in the electrical system due to the imbalance occur in system caused by the electrical or mechanical fault. This method does not rely on mathematical model yet are capable of detecting the process malfunction. Instead of developing mathematical model for comparing the performance to check the faulty conditions.

The Algorithms used in conventional artificial intelligence rely on prior information. For instance, the fuzzy logic (FL) rule base may be built on the knowledge of specialists regarding PMSM defects. There have lately been many data-driven intelligent diagnosis algorithms proposed as a result of research in artificial intelligence and machine learning. Some statistical techniques used in feature excision for fault identification, such as principal component analysis (PCA) and independent component analysis (ICA), are included in basic data-driven methodologies. The defect type and severity of the motor, however, can be automatically determined by the input data based on the provided training data thanks to data-driven intelligent diagnosis algorithms. Neural networks, support vector machines, sparse representation, deep learning, and other techniques make up the majority of these techniques.

### 4.3.2 MODEL BASED FAULT ANALYSIS TECHNIQUE

This model-based approach is very efficient for diagnosing the multiple faults in electric drive system. This method develops a model which requires a pre-knowledge of system dynamics to check the performance analysis of the system by comparing the actual value and estimated torque. The system faulty condition can check when the estimated torque is equal to the actual torque.

The idea behind the model-based fault diagnosis method is to create a motor model with a specific issue based on physical principles, and then compare the model's projected output with the output that was actually observed to see if the motor has the fault. The actual model itself can be used to simulate different diagnostic techniques. The motor model must be quite accurate for this method to work because it can pierce the physical laws and internal workings of motor defects. Analytical mathematical models, magnetic equivalent circuit (MEC) models, and digital simulation models are among the frequently employed models. The fundamental mathematical models of the healthy three-phase and multiphase PMSMs in the ABC reference frame have been developed. Some variables in the voltage equation and the magnetic equation will change when the inter-turn short circuit occurs in phase an of the motor. The motor model can be changed by including the short circuit's resistance and inductance. The and dq reference frames also established a similar motor model. The electrical equivalent circuit (EEC), which is quick but less precise, provides the basis for this concept. It is restricted to the examination of the inter-turn short circuit fault as a result.

Some researchers also employ the MEC model for the identification of electrical defects since it may be used as a field-based analytical tool to study discrete winding distributions, stator slots, and the like. By resolving the MEC equations, it is possible to calculate the magnetic fluxes in all branches and potentials in this model. Though less accurate than the digital simulation models, which were the most frequently used models in the defect diagnosis of PMSM, such as the finite element model, the MEC models have more accuracy than the EEC models (FEM). In order to demonstrate a link between FEM and MEC, some researchers have tried. For practically all PMSM problems, including the inter-turn short circuit, eccentricity, and demagnetization, FEM has been widely applied. This is because different types of mechanical failure can be represented using finite element field calculations, which can take both physical and geometrical information into consideration. Compared to an analytical model

with linear parameters, the finite element model can simulate machine data with greater accuracy. It has the highest accuracy and the largest computational cost when compared to other models.

### **4.3.3 SIGNAL BASED FAULT DIAGNOSIS METHOD**

Signal based strategy analyze the fault symptoms in the real signal which acquires from system parameter like frequency, current, voltage, vibration so on. While in a normal state, the acquired signal corresponds to certain frequency, amplitudes and ripple but in the faulty states this indicator differs from the normal state. Through signal-based methodology (SBM), it helps to identify the fault as if present or not in the system The SBM methods are classified as time domain, frequency domain, and time or frequency domain. Electrical and mechanical components are combined in the motor. Therefore, complex fault behaviors may develop when faults exist. Along with non-electrical quantities like heat, sound, light, gas, radiation, vibration, and so on, there are electrical quantities like voltage, frequency, current, and power. One of the often-employed techniques for defect identification is the processing of the signals collected from the motor. These techniques may recognize the behavior of faults and extract fault characteristics from the signals, which primarily include current, vibration, and other characteristics. Numerous researchers have explored motor current signal analysis (MCSA), and some have merged various signals to create a PMSM fault diagnosis system.

### **4.3.4 HISTORY BASED METHODOLOGY**

A model-based strategy is used in history-based fault diagnosis. Additionally, this approach works with non-linear systems. This approach uses no mathematical model at all. This model, which mathematically connects measurable input to measured output data, was developed using a known and measured input and output process. This defect diagnostic method's central idea is to create a model that mathematically connects measured input to measured output. Generally speaking, this technique can be categorized as FL, neural network, clustering, self-organizing map (SOM), statistical method, expert system, and pattern recognition.

### **4.3.5 HARDWARE BASED METHODOLOGY**

The hardware-based fault diagnosis method which do not deploy a mathematical model. In general, the hardware- based fault diagnosis method is classified as hardware redundancy, voting techniques, special hardware, limit checking and frequency analysis.

#### **4.3.6 OBSERVER BASED FAULT ANALYSIS TECHNIQUE**

The observer-based fault analysis technique which is a classical method adopted in permanent magnet synchronous motor (PMSM). In observer-based approach the fault diagnosis procedure is takes place through two process like residual generation and residual evaluation. The function of residual generation is to generates residual signal by comparing the process output with estimate produced by the observer. Observer based method is mostly applied technique in model-based approach for fault diagnosis in electrical system.

## **CHAPTER 5**

# **MODELLING AND FIELD ORIENTED CONTROL OF PMSM**

### **5.1 INTRODUCTION**

This chapters deals with the detailed modelling of permanent magnet synchronous motor. Field oriented control of PMSM using PI controller is discussed. The modelling of PMSM is done in two ways; in order to analyses the faulty condition in motor.

Firstly, modelling of electric motor on the basis of d-q reference frame; the synchronous reference frame is a d-q reference frame. Here three phase variables are required to transform two phase variables. The three-phase current, voltage, magnetic flux is transformed into two phase reference frames comprised of current, voltage and magnetic flux are transformed into two phase reference frames comprised of rotating d-q axis. By using d-q reference, the system can explain via from equation1 to 12.

#### **5.1.1 EQUIVALENT CIRCUIT IN PMSM**

The equivalent circuitry model of Permanent magnet synchronous motor is necessary for the study and simulation of motor. The stator equivalent circuit is implemented to develop the transformation of three phase stationary reference frame to two phase rotational reference frame in d and q axis. The conventional electrical circuit model of PMSM is illustrated in fig 5.1. The d- and q-axis equivalent circuit model of PMSM are demonstrated in Fig 5.1.1 and 5.1.2, here  $R_s$  is the winding resistance,  $L_s$  represents the synchronous inductance. The permanent magnet synchronous motor which is excited by permanent magnet (PM); and the permanent magnet flux is expressed as flux linkage  $\lambda$ . To realize the vector control of PMSM, it is essential to transform the three-phase stationary reference frame to two-phase rotational reference frame as shown in fig 5.1.a& 5.1.b.

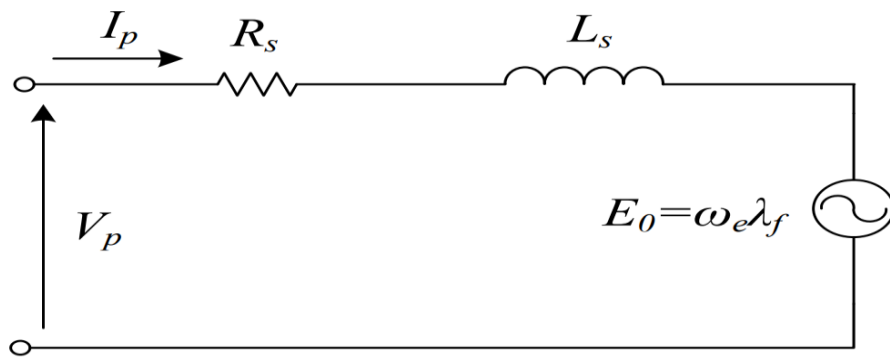


Fig 5.1 Conventional equivalent circuit model of PMSM

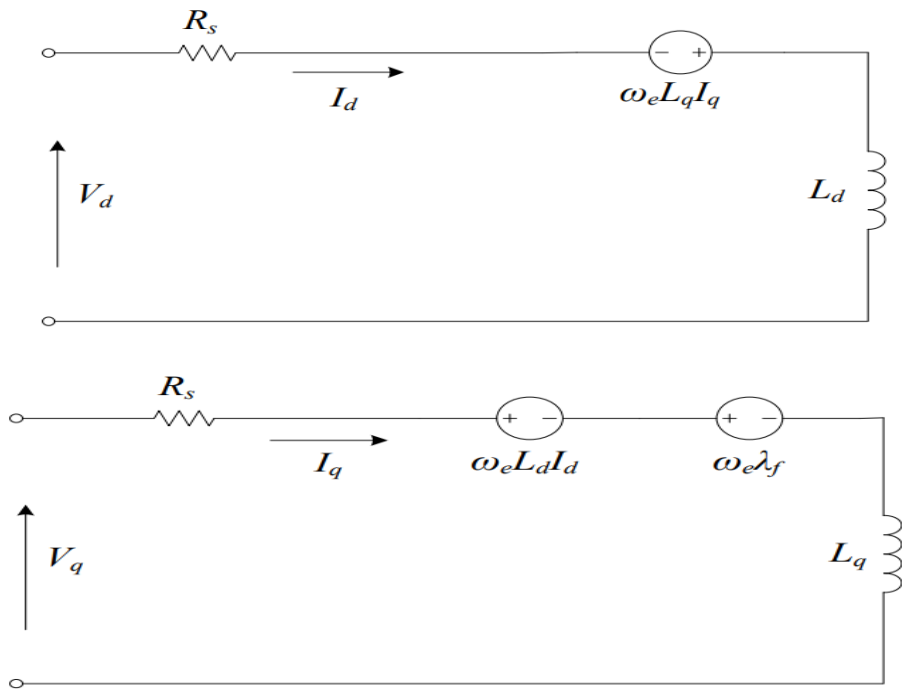


Fig 5.1.a & 5.1.b Conventional d and q axis equivalent circuit model of PMSM

By using d-q reference, the system can explain via from equation 1 to 12.

Transformation equation of PMSM,

$$V_d = \frac{2}{3} (\cos\theta \times V_a) + (\cos(\theta - 120) \times V_b) + (\cos(\theta + 120) \times V_c) \dots \dots \dots (1)$$

$$V_q = \frac{2}{3} (\sin\theta \times V_a) + (\sin(\theta - 120) \times V_b) + (\sin(\theta + 120) \times V_c) \dots \dots \dots (2)$$

Stator voltage in q-axis;

$$V_q = r_s i_q \frac{d\lambda_q}{dt} + \omega_e \lambda_d \dots \dots \dots (3)$$

Stator voltage in d-axis

$$V_d = r_s i_d \frac{d\lambda_d}{dt} + \omega_e \lambda_q \dots \dots \dots (4)$$

Stator flux in q-axis

$$\lambda_q = L_q I_q \dots \dots \dots (5)$$

Stator flux in d-axis

$$\lambda_d = L_d I_d + \lambda_m \dots \dots \dots (6)$$

Stator current in d-axis

$$I_d = \frac{\lambda_d - \lambda_m}{L_d} \dots \dots \dots (7)$$

Stator current in q-axis

$$I_q = \frac{\lambda_q}{L_q} \dots \dots \dots (8)$$

The developed motor torque is given by,

$$T_e = \frac{3}{2} \frac{p}{2} (\lambda_d I_q - \lambda_q I_d) \dots \dots \dots (9)$$

Electromagnetic torque,

$$T_e = T_l + B_{wm} + J \frac{d\omega_m}{dt} \dots \dots \dots (10)$$

$J$  is the inertia of motor,  $B$  is the viscous coefficient,  $T_e$  is the electrical torque developed by motor.  $T_l$  is the load torque.

Solving rotor mechanical speed from above equation

$$W_m = \int \frac{T_e - T_l - B\omega_m}{J} dt \dots \dots \dots (11)$$

And,

$$W_m = \omega_r \frac{2}{p} \dots \dots \dots (12)$$

## 5.2 FIELD ORIENTED CONTROL OF PMSM

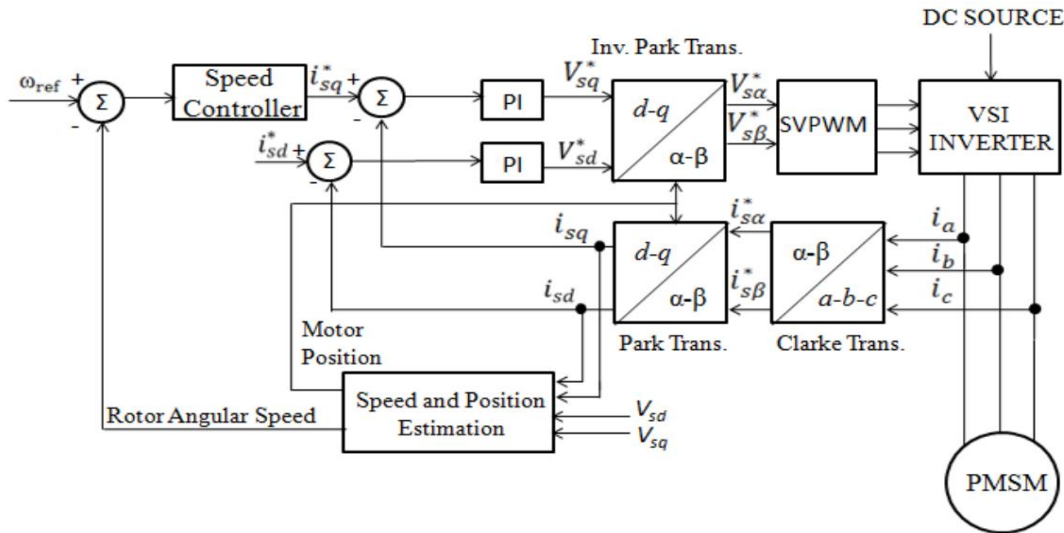


Fig 5.2 Field oriented control of FOC control of PMSM using PI controller

Field oriented control is one of the most relevant techniques used in permanent magnet synchronous motor. The field-oriented control is most salient variation of vector control methods. The main intent of the FOC method is to regulates the magnetic flux and torque over controlling the d and q components of the stator current. The privilege of this technique is fast in response and little ripple in addition high efficiency, wide speed range via field weakening, independent control of torque and flux, transformation of a complex and coupled ac model into linear system. The framework of this technique will accomplish through the direct and quadrature axis component of current regulators and speed controller.

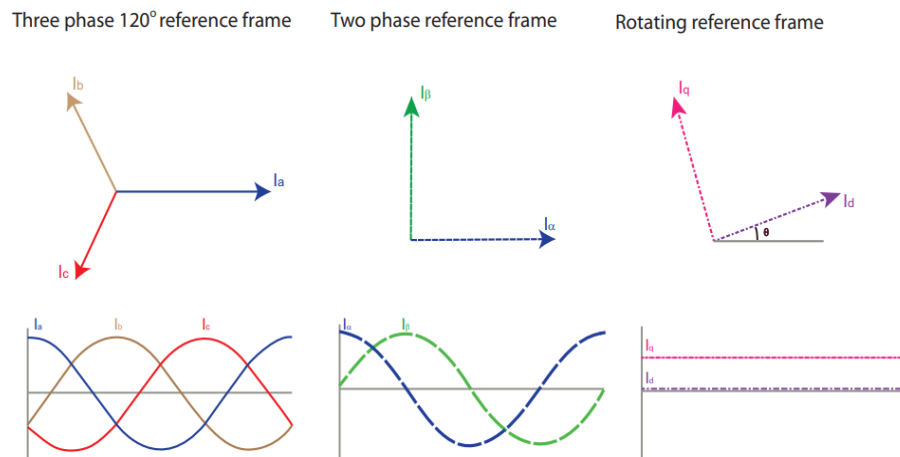


Fig 5.3 Transformation and reference frame

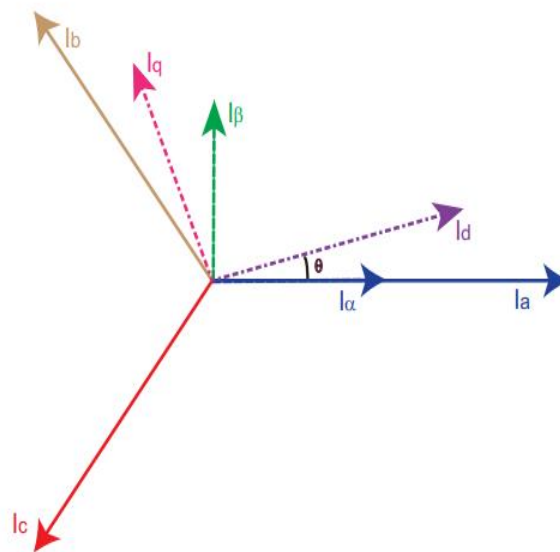


Fig 5.4 Combined Vector Representation of All Transformed Quantities

FOC technique involves three reference frames and acquires transformations from one to the other;

1. Stator reference frame (a,b,c) in which the a,b,c are co-planar, at 120 degrees to each other.
2. An orthogonal reference frame (αβ) in the same plane as the stator

reference frame in which the angle between the two axes is 90 degrees instead of 120 degrees. The axis is aligned with axis in the second frame.

3. Rotor reference frame (dq), in which the d axis is along the N and S poles or along the flux vector.

### 5.2.1 TRANSFORMATION

The elements  $I_q$  and  $I_d$  in FOC are related to the rotatable reference frame. As a result, to convert the recorded stator currents to the two-axis spinning dq rotor reference frame, they must first be translated from the three-phase time variant stator reference frame. Two steps can be taken to accomplish this, as indicated in Fig 5.5.

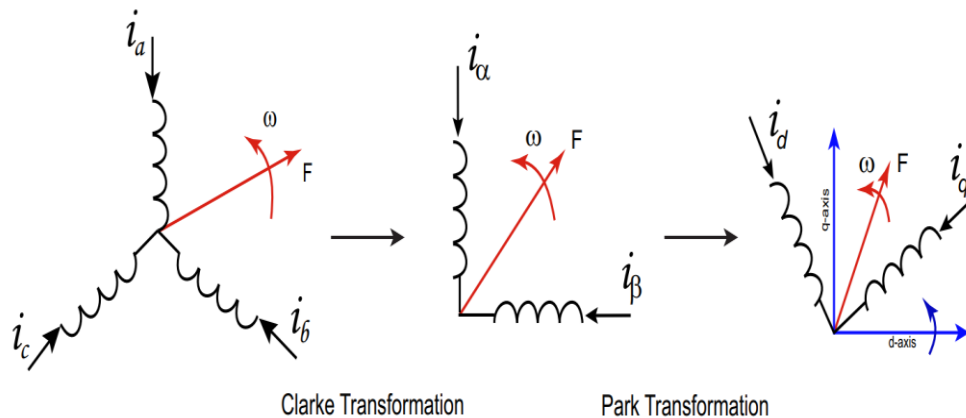


Fig 5.5 Clark and park transformation

The transformation from the 3-phase 120-degree reference frame to two axis orthogonal reference frame is known as Clarke transform. Similarly, the transformation from two axis orthogonal reference frame to the two-axis rotating reference frame is known as Park transform.

### 5.2.2 CLARKE TRANSFORMATION

The measured motor currents are first translated from the 3-phase reference frame to the two -axis orthogonal reference frame. The transform is expressed by the following equations.

$$I_{\alpha} = I_a$$

$$I_{\beta} = \frac{I_a + 2I_b}{\sqrt{3}}$$

Where,  $I_a + I_b + I_c = 0$

### 5.2.3 PARK TRANSFORMATION

The two-axis orthogonal stationary reference frame quantities are then transformed to rotating reference frame quantities. The transform is expressed by the following equations.

$$I_d = I_\alpha \cos\theta + I_\beta \sin\theta$$

$$I_q = I_\beta \cos\theta + I_\alpha \sin\theta$$

### 5.2.4 INVERSE PARK TRANSFORMATION

Now the outputs of the PI controllers provide the voltage components in the rotating reference frame. Thus, an inverse of the previous process has to be applied to get the reference voltage waveforms in stationary reference frame. At first, the quantities in rotating reference frame are transformed to two axis orthogonal stationary reference frame using Inverse Park transformation. The Inverse Park transformation is expressed by the following equations.

$$v_\alpha = v_d \cos\theta + V_q \sin\theta$$

$$V_\beta = V_q \cos\theta + v_d \sin\theta$$

### 5.2.5 INVERSE CLARKE TRANSFORMATION

The transformation from two axis orthogonal stationary reference frame to the three-phase stator stationary reference frame, is accomplished using the inverse Clarke transformation. The inverse Clarke transformation is expressed by the following equations.

$$V_a = V_\alpha$$

$$V_b = -v_\alpha + \sqrt{3} \cdot V_\beta / 2$$

$$V_c = -v_\alpha - \sqrt{3} V_\beta / 2$$

### 5.3 LOSS MODELLING OF PMSM

The electric drive can be modelled as,

$$P_{em,out} = P_{dc,inv} - P_{loss,inv} \dots \dots \dots (1)$$

$P_{em,out}$  is the power output from motor;  $P_{dc}$  is the inverter input power from dc source,  $P_{loss,inv}$  is the losses in inverter,  $P_{loss,motor}$  is the losses in motor.

$$P_{em,out} = T_{em} * W_{em} \dots \dots \dots (2)$$

$T_{em}$  is the magnetic torque,  $W_{em}$  is the motor mechanical speed; The  $P_{dc,inv}$  which can written as shown in below equation

$$P_{dc,inv} = V_{dc} * I_{dc} \dots \dots \dots (3)$$

$V_{dc}$  is the inverter dc voltage and  $I_{dc}$  is the inverter dc current.

$$P_{loss,inv} = K_2 I_s^2 + K_1 i_s + K_0 \dots \dots \dots (4)$$

$P_{loss,inv}$  is the inverter loss; k is constant.

## CHAPTER 6

### DESIGN AND MODELLING

#### 6.1 INTRODUCTION

This chapter discusses the design of a permanent magnet synchronous motor, the loss model, and the motor parameter selection and loss model specification. This chapter also covers PV array, Boost converter, and battery modelling. It includes a DC-DC converter, a battery electrolyzer controller, and information about the PV array parameters and EV battery specifications.

#### 6.2 DESIGN SPECIFICATION AND GIVEN INFORMATION OF PMSM

SL.NO	PARAMETERS	SPECIFICATIONS
1.	Rated speed	1500 rpm
2.	Rated torque	10 Nm
3.	Rated power	1.57 kW
4.	Stator resistance	1.2 ohm
5.	d-axis inductance $L_d$	5.7 mh
6.	q-axis inductance $L_q$	12.5 mh
7.	Magnetic flux linkage $\lambda_m$	123m web/time
8.	No: of poles	4
9.	Moment of inertia	0.0001584 $kgm^2$
10.	Friction of coefficient	$3.276 \times 10^{-5} N.s.m$
11.	Frequency	50 Hz

Table 6.1 Parameter specification of PMSM

The permanent magnet synchronous motor's specifications are shown in figure 6.1. Here, a 1.57 kW motor with a 1500 rpm speed was chosen. High power rating motor design is necessary for traction applications. Only the necessary power is required for two-wheelers but high power will be reflected in three- or four-wheelers.

The power rating of motor can be calculated; as per the known value torque and angular velocity

### 6.2.1 POWER RATING OF MOTOR

$$\begin{aligned} P &= T \times \omega \\ &= T \times \frac{2\pi N}{60} \\ &= 10 \times \frac{2 \times \pi \times 1500}{60} \\ &= 1.57 \text{ kW} \end{aligned}$$

The motor speed can be calculated basis of frequency and number of poles.

Speed of motor,

$$\begin{aligned} N_s &= \frac{120 f}{p} \\ &= \frac{120 \times 50}{4} \\ &= 1500 \text{ rpm} \end{aligned}$$

### 6.3 DESIGN OF LOSS MODEL OF MOTOR

Inverter dc voltage,

$$V_{dc} = 650 \text{ volt (V)}$$

Inverter dc current,

$$I_{dc} = 0.0184 \text{ Amp (A)}$$

Inverter output power,

$$P_{dc_{inv}} = V_{dc} \times I_{dc}$$

$$= 650 \times 0.0184$$

$$= 12.1 \text{ W}$$

Inverter loss can be simplified as a function of the total stator current,

$$P_{loss_{inv}} = K_2 i_s^2 + k_1 i_s + K_0$$

$K_1, K_2, K_0$  are constant

$$= 2.5 \times (1 \cdot 2)^2 + 2.5 \times (1.2) + 2.5$$

$$= 9.1 \text{ Watt (W)}$$

Here, a simulation of the system with an integrated battery model has been modelled. Through a PV array and DC-DC converter, the battery model is integrated into the system. Between the boost converter and inverter lies the battery model. Therefore, the design of the PV array and converter is crucial (DC-DC converter).

## 6.4 DESIGN OF PV SYSTEM

Open circuit voltage  $V_{oc} = 66.66$

Short circuit current = 6.14

PV voltage,

$V_{pv} = \text{Open circuit voltage} \times \text{Number of panels in series}$

$$= 66.66 \times 3$$

$$= 200 \text{ volts (V)}$$

PV voltage = 200 volt (V)

PV power,

PV power = maximum power  $\times$  number of panels

$$= 300 \times 6$$

$$= 1.8 \text{ kW}$$

## 6.5 DESIGN OF BOOST CONVERTER

Input voltage  $V_{in} = V_{pv} = 200$  volt (V)

$$\begin{aligned} \text{Output current, } &= \frac{P_{out}}{V_{out}} \\ &= \frac{1.8 \text{ kw}}{650} \\ &= 2.76 \text{ amp} \end{aligned}$$

$$\begin{aligned} \text{Input current, input } &= \frac{P}{V_{out}} \\ &= \frac{1800}{200} \\ &= 9 \text{ Amp (A)} \end{aligned}$$

$$\begin{aligned} \text{Duty ratio } &= \frac{V_o - V_{in}}{V_o} \\ &= \frac{650 - 200}{650} \\ &= 0.6 \end{aligned}$$

Assume 20 % of current ripple

$$\begin{aligned} \Delta I_L &= 0.2 \times I_{out} \times \frac{V_{out}}{V_{in}} \\ &= 0.2 \times 2.76 \times \frac{650}{200} \end{aligned}$$

$$\Delta I_L = 1.8 \text{ Amp (A)}$$

$$\begin{aligned} \text{Inductance, } L &= \frac{V_{in} (V_{out} - V_{in})}{V_{out} \times \Delta I_L \times F_S} \\ &= \frac{200 (650 - 200)}{650 \times 1.8 \times (10 \times 10^3)} \\ &= 6.83 \text{ milli Hendry (mh)} \end{aligned}$$

Boost inductance,  $L = 6.83$  mh

$$\begin{aligned} \text{Capacitance, } C &= I_0 \times \frac{D}{f_s \times \Delta V_{out}} \\ &= 2.76 \times \frac{0.6}{(10 \times 10^3) \times 0.05 \times 650} \\ &= 12.9 \mu F \end{aligned}$$

## 6.6 BATTERY MODEL DESIGN

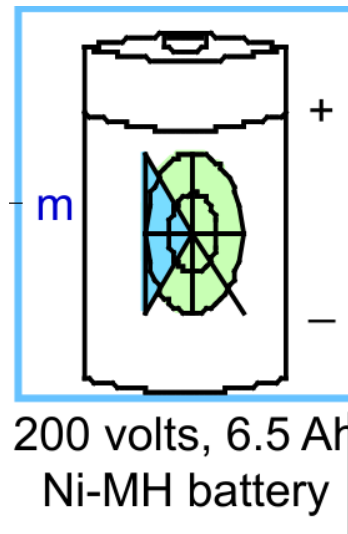


Figure 6.1 Nickel-Metal hydride battery

### 6.6.1 SPECIFICATION OF BATTERY

SL.NO	PARAMETER	SPECIFICATIONS
1	Nominal voltage	200 volts (V)
2	Battery current	6.5 Ah
3	Battery power	1300W
4	Initial State of charge %	60%
5	Response time	30 sec

Table 6.2 Specification of battery parameter

## 6.6.2 RATED CAPACITY OF BATTERY

Battery type: Nickel metal hydride

Battery voltage,  $B_v = 200\text{V}$

Battery current,  $B_i = 6.5$  Ampere hour (Ah)

Power capacity of battery,

$$\begin{aligned} B_p &= B_v \times B_i \\ &= 200 \times 6.5 \\ &= 1300 \text{ watt (W)} \end{aligned}$$

The battery controller is design via PI controller using trial and error method,

The value of propositional constant  $K_p = 2$

The value of integral constant  $k_i = 120$

## CHAPTER 7

### SIMULATION AND RESULT

#### 7.1 Simulation of PMSM (synchronous motor) with field-oriented control (FOC)

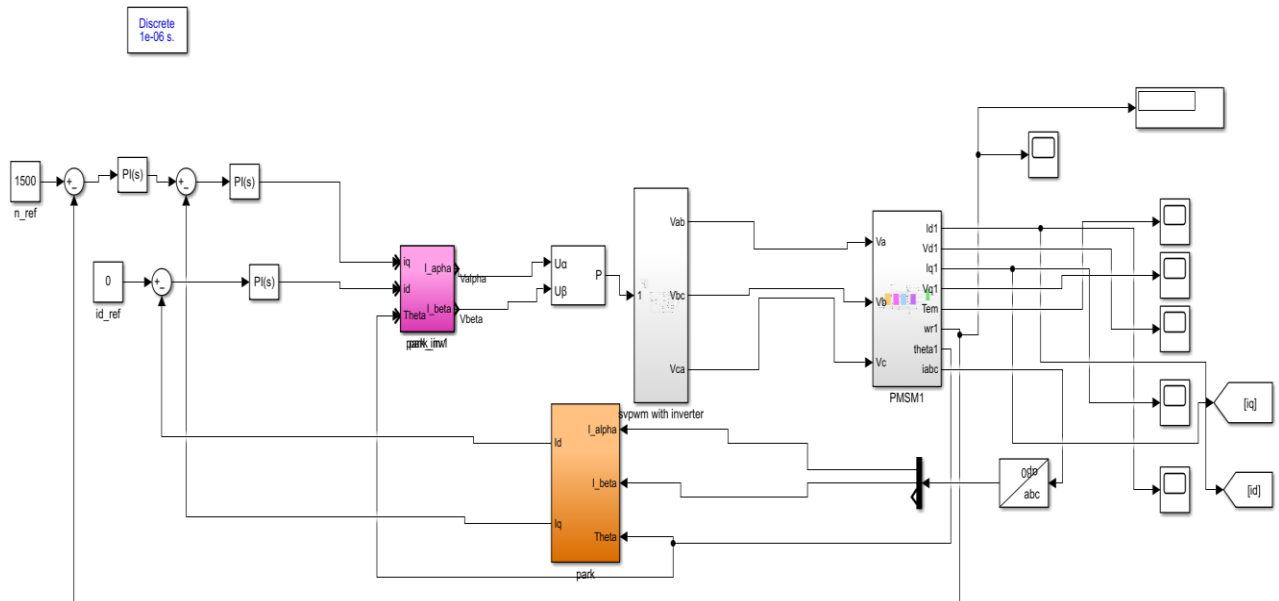


Fig 7.1 Simulation of PMSM with FOC by using PI controller

The fig 7.1 illustrates the simulation model of synchronous AC motor with field-oriented control (FOC) by using PI controller. Here using 1500 rpm motor, load torque given is 10Nm. In next an inverter is integrated to the motor; the pulse given to the inverter through SVPWM. The last stage of field-oriented control uses a technique called space vector pulse width modulation (SVPWM) to choose the pulse width modulated signal for the inverter switch and provide the desired three-phase voltage for the motor. In this case, field-oriented control serves as a speed controller or a PI controller.

The input pulse is the inverters input-1. This pulse was captured using SVPWM. Next, to SVPWM block which has three inputs as  $V_\alpha$ ,  $V_\beta$ , P. The P is just a pulse, and when this pulse is given to inverter input as a result, six pulses  $Vg_1$ ,  $Vg_2$ ,  $Vg_3$ ,  $Vg_4$ ,  $Vg_5$  and  $Vg_6$  are obtained. The inverter will function with the aid of these pulses, and the appropriate  $V_\alpha$ ,  $V_\beta$  is quickly

founded. This  $V_\alpha, V_\beta$  is given as output. A demuxer is fixed as the corresponding  $\alpha, \beta$  is split into one output  $\alpha$ , one output  $\beta$  and zero. The next step to convert  $\alpha, \beta$  to d,q by using Park transformation.

Following the motor controller section, The reference speed on the motor controller is 1500rpm. In this case, a PI controller is being used. The PI controller is also referred to as the speed controller. The output is the reference q-axis current  $i_q^*$ , denoted as PI (S). The d axis current  $i_d$  and reference d axis current i.e.,  $i_{d_{ref}}=0$  is fed to the second PI controller here. This output is given to park inverse. Consequently, obtain  $V_d$  and  $V_q$ . This  $V_d, V_q$  will again undergo an inverse park transformation to become  $\alpha, \beta$  and this  $\alpha, \beta$  is then provided as a space vector (PWM). Here  $V_\alpha, V_\beta$  are provided as input for SVPWM. The system will operate based on the pulse received from SVPWM. As an illustration, if the reference motor speed  $W_r$  is 1000 and the original motor speed  $W_{r1}$  is 2000, the difference between the two speeds is provided to the PI controller, which changes the error to zero, and thus always results in the desired motor output.

### 7.1.1 SIMULATION OF INVERTER

The simulation model of the inverter is seen in Fig 7.2. The inverter's function is to convert DC to AC. For instance, let's say we need to offer a dc voltage of 500. The conversion of dc to ac is required when using a permanent magnet synchronous ac motor in order for the motor to Inverter input 1 will receive the pulse from SVPWM directly, and it will be divided into six pulses (vg1, vg2, vg3, vg4, vg5, vg6) that will be supplied to Inverter 6 Mosfet.

$V_\alpha, V_\beta$  voltage serves as the SVPWM input; this voltage develops pulses and activates the associated six mosfet in the inverter. The voltage measurement block comes next. The motor phase voltages must be determined here.  $V_{ab}, V_{bc}, V_{ac}$  are discovered from a, b, c phase voltages. function. Here, the inverter's supply voltage is 500, and it is connected to six mosfet.

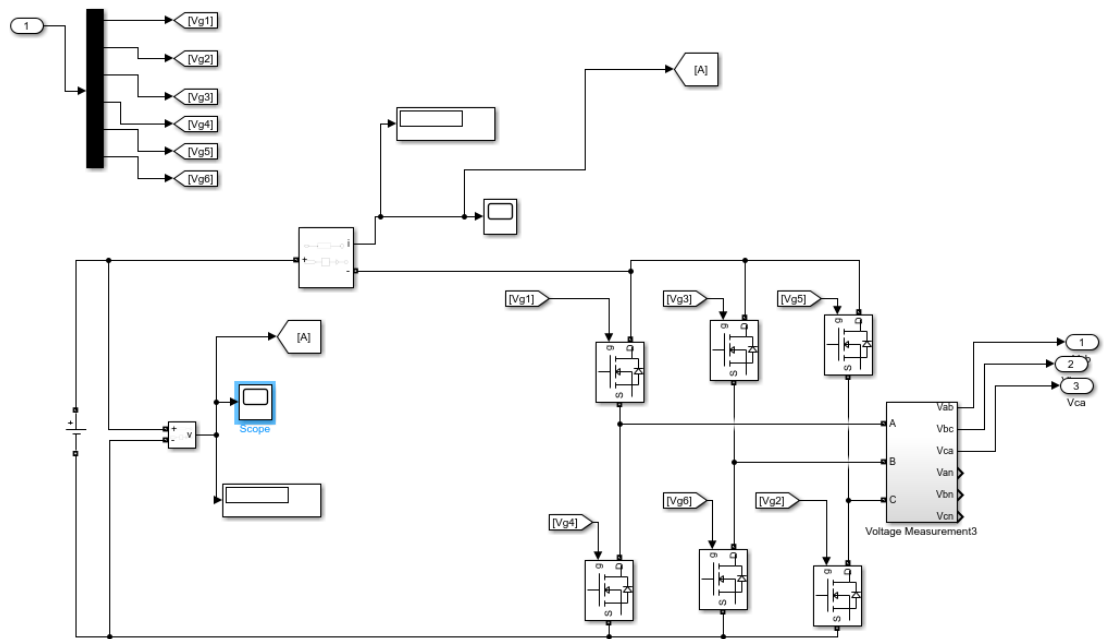


Fig 7.2 Simulation of inverter fed synchronous motor drive

**SUB-SYSTEM OF MOTOR**

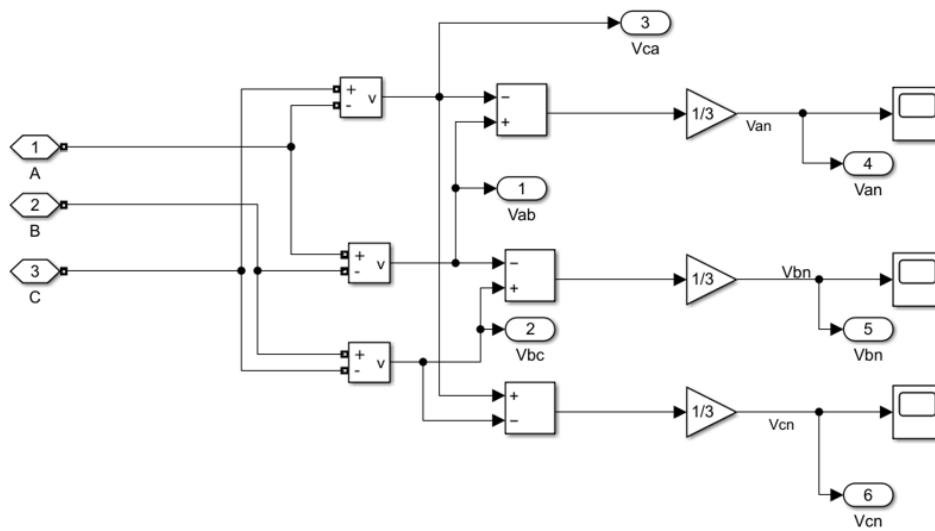


Fig 7.3 Subsystem of synchronous motor

Determine the line voltages  $V_{an}$ ,  $V_{bn}$ ,  $V_{cn}$  using the subsystem in the voltage measurement block. Obtaining the line voltage from the result of equation from this subsystem.

$$V_{an} = \frac{1}{3} (V_{ab} - V_{ca} )$$

$$V_{bn} = \frac{1}{3} (V_{bc} - V_{ab} )$$

$$V_{cn} = \frac{1}{3} ( V_{ca} - V_{bc} )$$

### 7.1.2 SIMULATION OF PMSM

The diagram below depicts the overall simulation of a PMSM motor. The a, b, c to d-q transformation comes first.  $V_a, V_b, V_c$  are converted to d-q quantities here.  $V_d$  and  $V_q$  are the results of this transformation. Specifically, voltage in the d axis and voltage in the q axis. Find the flux in the d-q axis using these voltages i.e.,  $\lambda_d$  and  $\lambda_q$ . Find the  $i_d$  and  $i_q$  or the d and q axis current, using these two outputs. By, using equations.

$$I_d = \frac{\lambda_d - \lambda_m}{L_d}$$

$$I_q = \frac{\lambda_q}{L_q}$$

Find the mechanical torque equation and mechanical angular velocity, i.e.,  $T_{em}$  and  $W_{em}$  from this. Here we get the angular speed  $W_{em}$  in rad/sec and then convert it to rpm using the formula  $W_r = p/2 W_{em}$

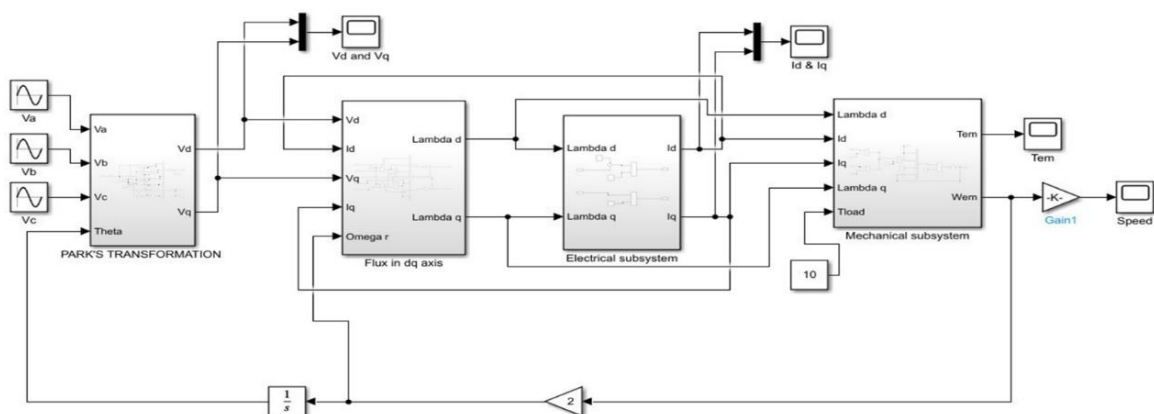


Fig 7.4 Simulation of PMSM

## SIMULATION OF PMSM (Sub-system of Park transformation)

The following stage to convert the system into a synchronous frame is the park transformation. Making computations significantly simpler is the primary goal of transforming the three-phase instantaneous voltages and currents into the synchronously rotating reference dq frame. The second benefit is that it enables the system operator to independently manage the active (d-axis) and reactive (q-axis) components of the currents.

The Fig 7.6 depicts the subsystem created by solving the park transformation equations which is,

Park transformation equation;

$$I_d = I_\alpha \cos\theta + I_\beta \sin\theta$$

$$I_q = -I_\alpha \sin\theta + I_\beta \cos\theta$$

In park transformation, transforming  $\alpha, \beta$  to d,q and obtaining is  $i_d, i_q$  through this output . In motor simulation, there is a thorough explanation. The fig 7.5 depict the conversion of  $\alpha, \beta$  ----- d, q through park transformation

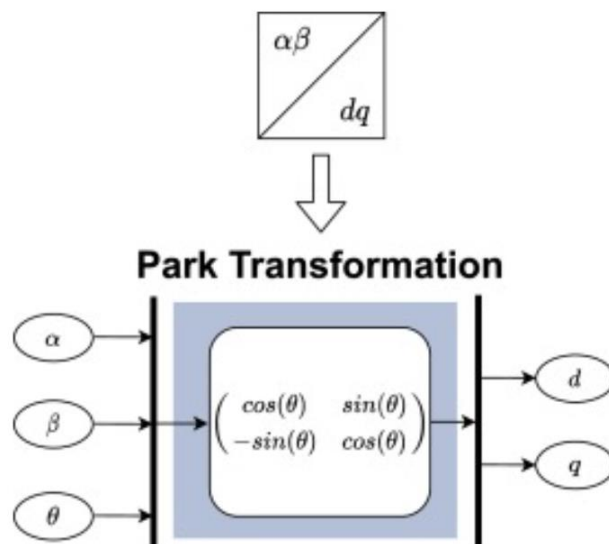


Fig 7.5  $\alpha, \beta$  to d, q transformation via park transformation

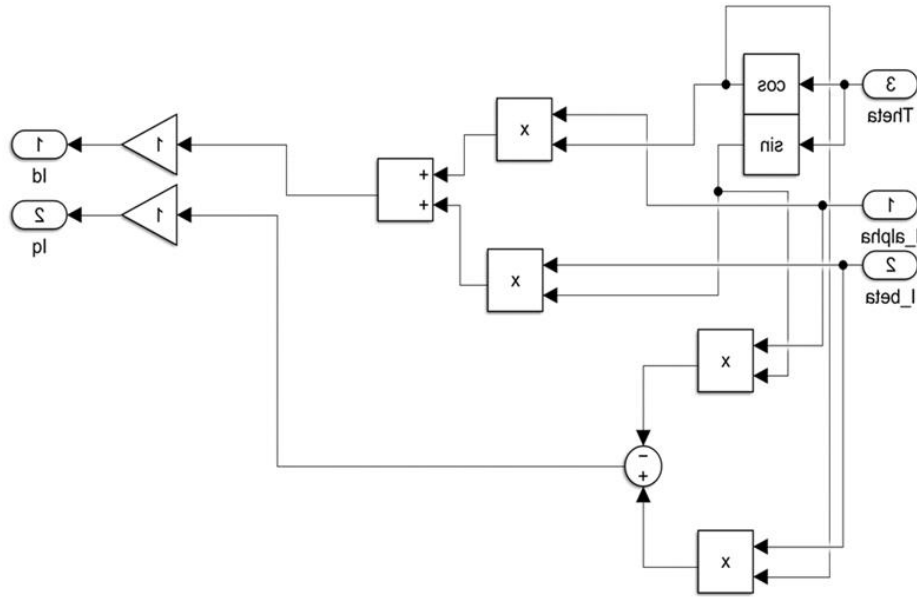


Fig 7.6 Subsystem of park transformation in synchronous AC motor

### SIMULATION OF PMSM (Synchronous motor sub-system of inverse park transformation)

The Inverse Park Transform block transforms time-domain direct, quadrature, and zero components in a rotating reference frame to three-phase system components in an abc reference frame. The inverse park transformation subsystem is shown in Fig. 7.7, which was created by formulating the inverse park transformation equation which is,

Inverse Park transformation equation,

$$I_\alpha = I_d \cos\theta - I_q \sin\theta$$

$$I_\beta = I_d \sin\theta + I_q \cos\theta$$

Inverse park transformation is a transform of  $d, q$  to  $\alpha, \beta$  using this output result as  $I_\alpha$  and  $I_\beta$ .

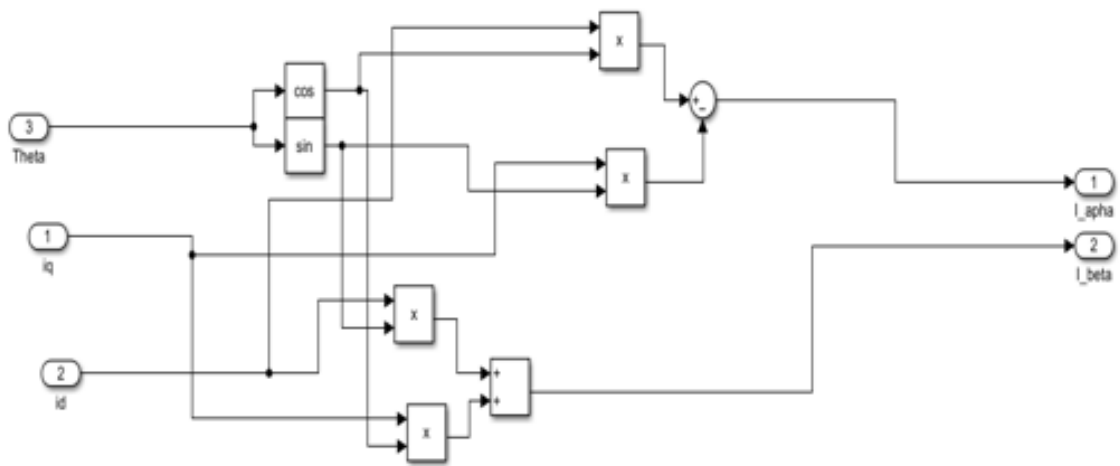


Fig 7.7 Sub-system of inverse park transformation

## 7.2 RESULTS

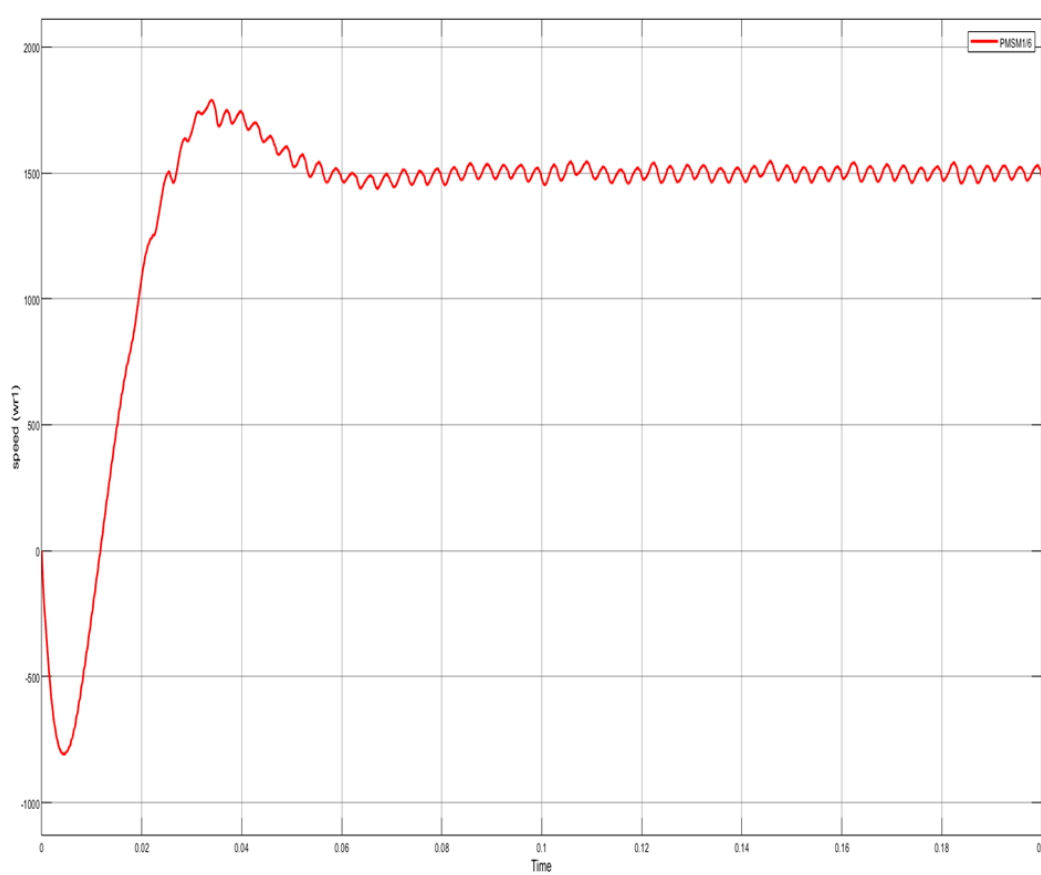


Fig 7.8 Speed-time Chara of motor

This illustrates the closed-loop speed Chara of PMSM. 1500 rpm is listed as the reference speed in this case. where the controller is utilised to design so that the desired output of 1500 rpm came about.

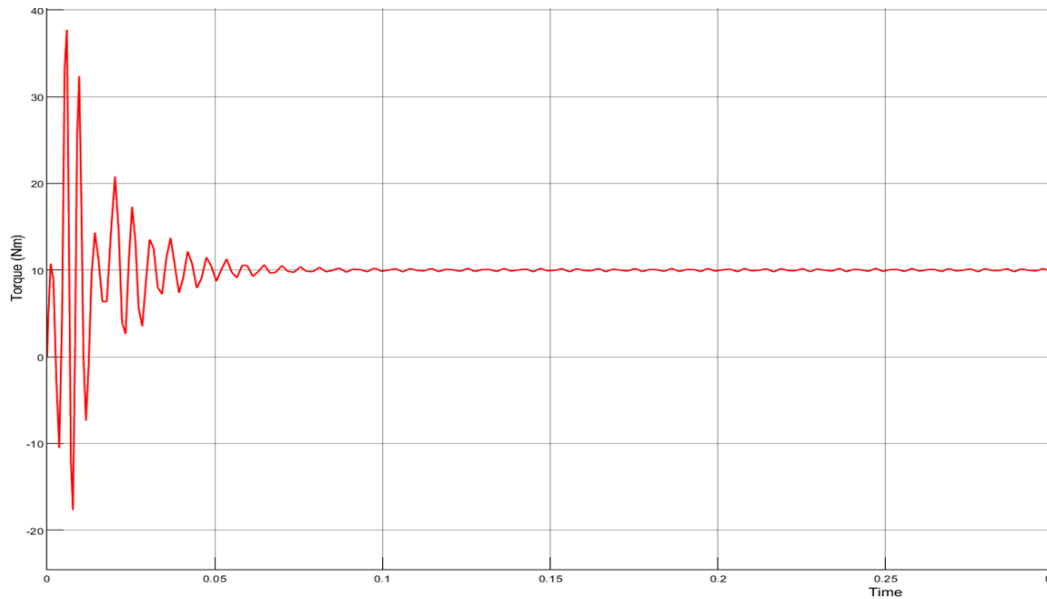


Fig 7.9 Response of electromagnetic torque

The response of electromagnetic torque is depicted in fig 6.9. The rated load torque is 10 Nm, and the electromagnetic torque also achieves the rated value.

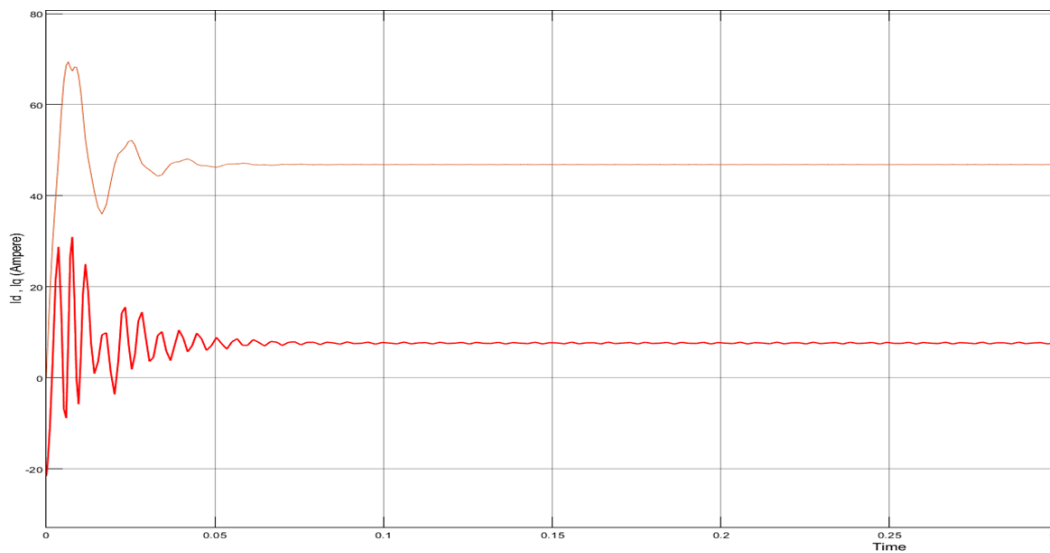


Fig 7.10 Id-Iq Chara of PMSM

Third fig 7.10 illustrate the id-iq characteristic of motor. Iq is 45A and Id is 15 A.

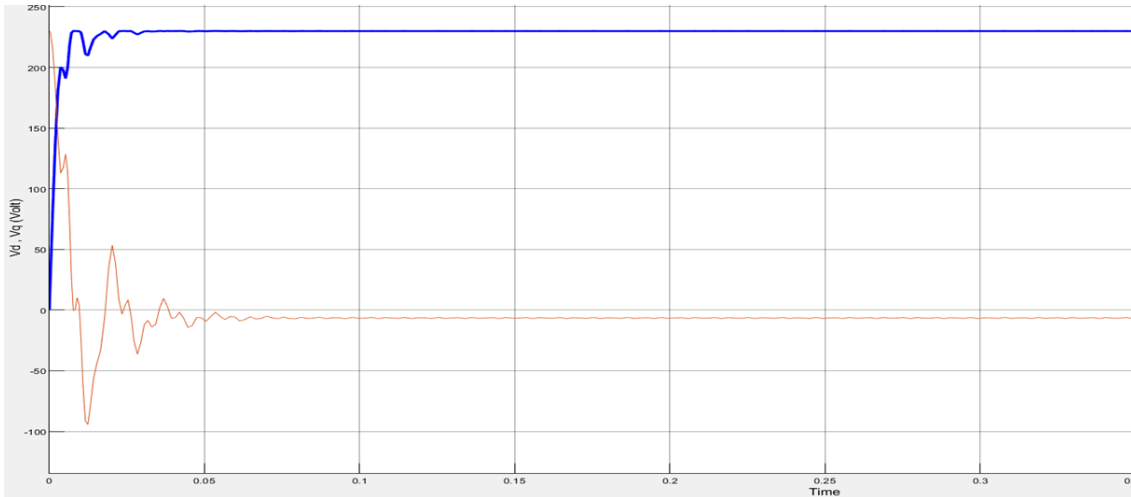


Fig 7.11 Voltage- Time chara of motor

### 7.3 SIMULATION OF PROPOSED SYSTEM

The first portion takes into consideration the motor simulation using the suggested system's simulation schematic. Previously, throughout the session, it was thoroughly discussed. The loss model equations that were integrated from the motor's output are likewise covered in the second section. The control algorithm part is checked in the third section, and its conditions have been discussed in terms of fault analysis and control algorithm flow chart in the previous session.



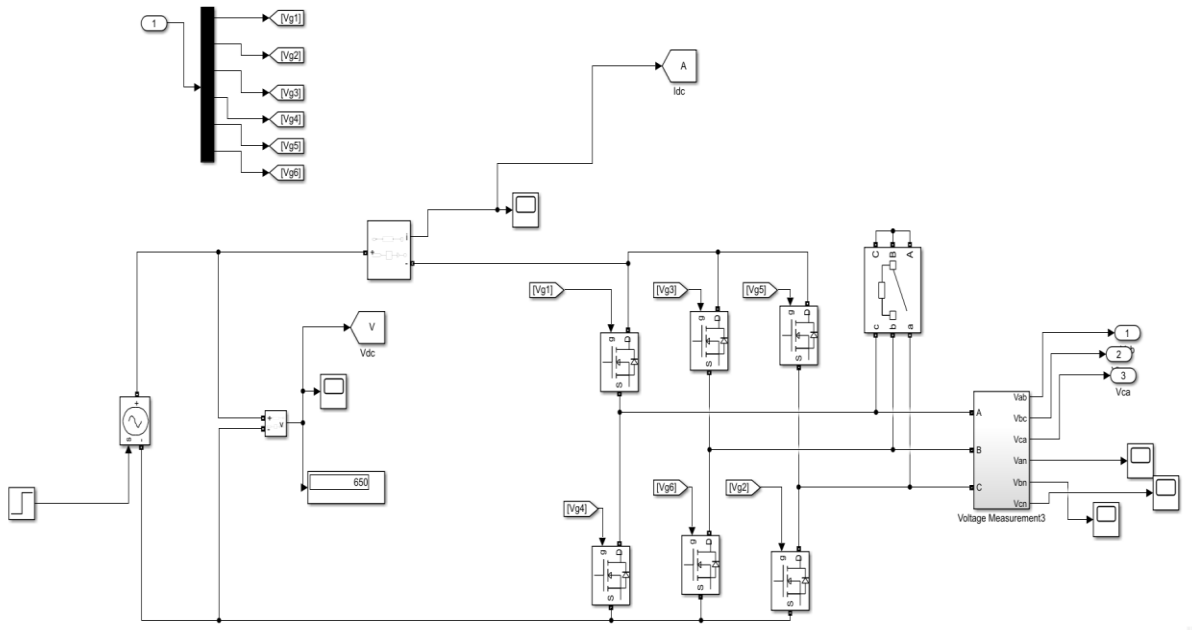


Fig 7.13 Simulation of modified inverter

### 7.4 RESULTS

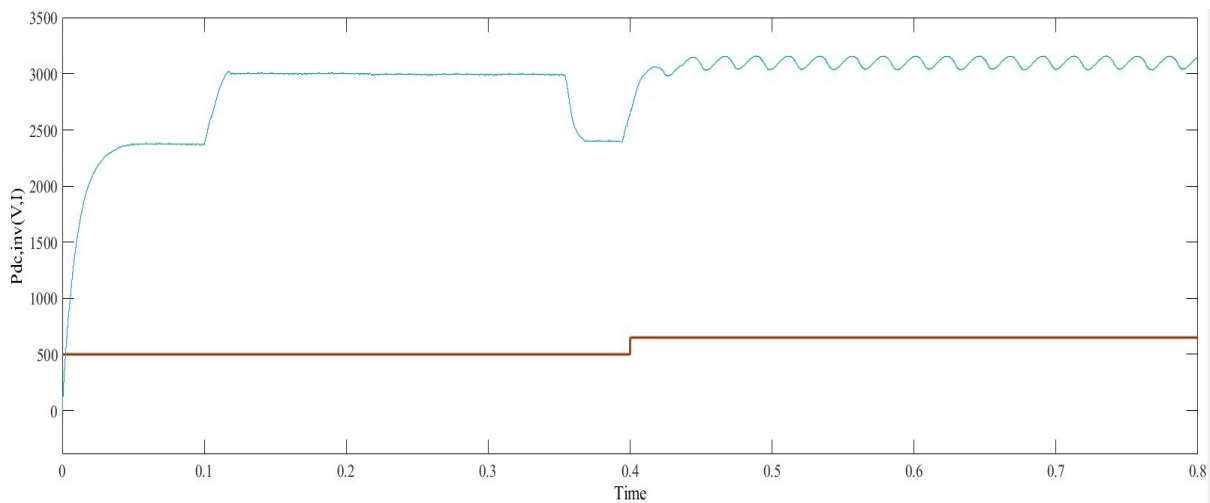


Fig 7.14 Power curve (Output power) of system

The above fig 7.14 shows the output power curve for the system. Here we used to give step input voltage of about 500-650 Volt as input. When say about time sequence, from 0-0.4 sec, it reaches the initial value i.e., 500volt but after 0.4 sec, reaches the final value i.e., 650 volts. From that moment of time, starts the current variation and this leads to system short circuit (SC). And finally, this current variation result to occur fault within the system.

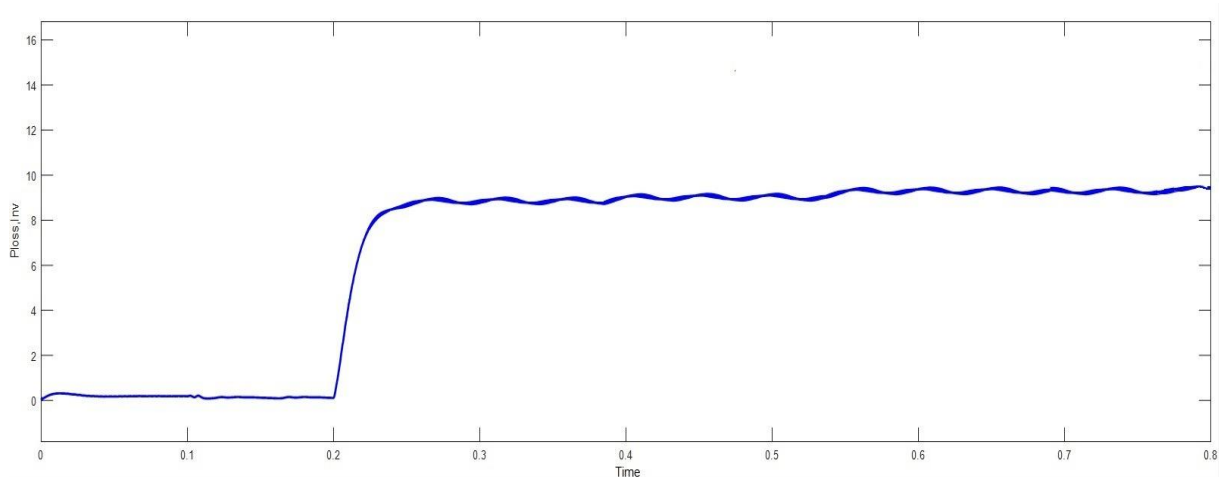


Fig 7.15 Power loss of system

The fig 7.15 shows the power loss curve for the system. Here shows the power loss variation that is created on satisfying the faulty condition as per the time sequence. From the graph, it is clear that the loss comparatively less at 0.2 second. But after 0.2 second, the graph shows an increment representing a considerable amount of loss. For each condition being satisfied fault become moderate to severe accordingly with respect to time. That is, for each time sequence, there will be corresponding fault condition for which power loss should be calculated.

## 7.5 SIMULATION OF PROPOSED SYSTEM WITH INTEGRATED BATTERY MODEL

Here the proposed model is integrating with battery model. Initially the input PV array and DC-DC converter is connected to inverter. Here the DC-DC converter is used as boost converter. The temperature and irradiance are given as the input of PV array where we get low dc voltage as output. Then the output of PV panel is then connected to DC-DC boost converter. Maximum power tracking is done using perturb and observe (P&O) and the output is duty D it is given as the pulse of boost converter. The output of converter is fed to battery model. This battery model is connected parallel to both inverter and converter. Here P&O algorithm based MPPT control technique is used to design the bi-directional converter.

Nickel-metal-hydride type battery is utilised for this purpose having 200V and a capacity of 6.8Ah. Initially the battery is charged at a level of 60%. Battery electrolyte controller is used here for the control purpose of battery system. Design is based on PI controller. Battery measure certain parameters such as current, voltage and SOC (State of charge). S1, S2 which is fed from

battery electrolyte controller and voltage from boost converter IGBT is given as the input of battery module. Here we get the output of battery in terms of battery power (voltage, current) and state of charge (SOC). The main aim of using boost converter in this system to avoid the reverse condition of battery and maintain the charging and discharging of battery.

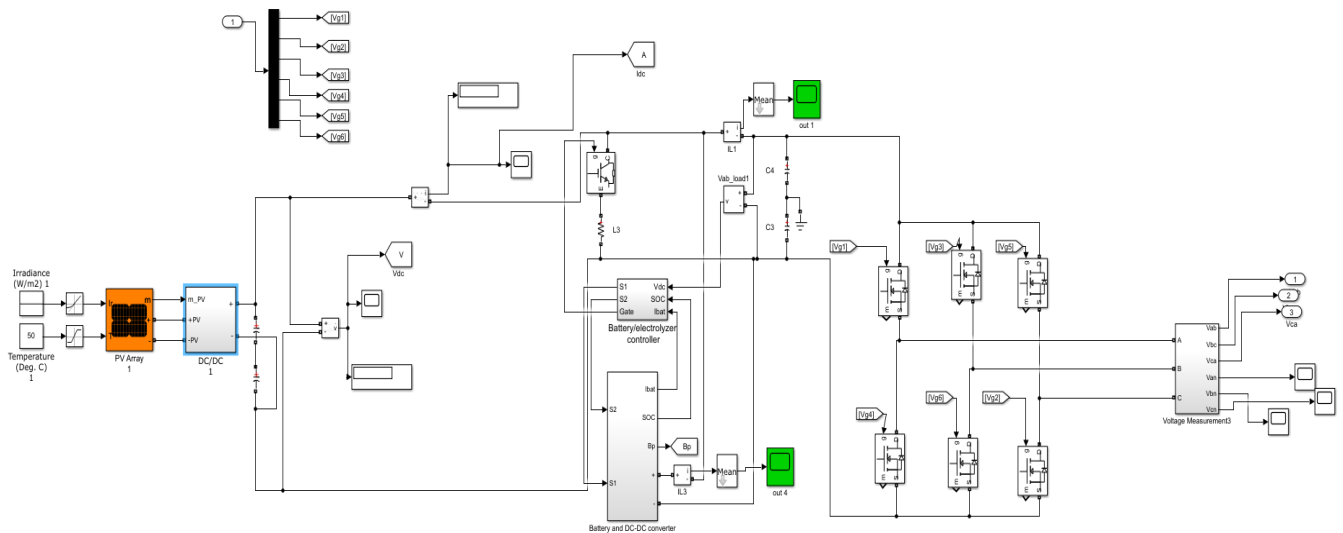


Fig 7.16 Simulation of proposed system with integrated battery model

### 7.5.1 SIMULATION OF BOOST CONVERTER

Here the design of Boost converter is depicted as fig shown in 7.17. Here the input voltage and current from PV array is introduced and given to P&O algorithm which runs as per the input voltage and current. Duty D condition is obtained as output and it is stored in P&O. After a delay, an output is obtained at the boost converter. When it comes to boost converter both delay and A is taken as input. The positive and negative voltage of PV panel is linked to both inductance and capacitance it is given as the input of boost converter. The unit delay output and source getting from this pv circuit is used for the design of boost converter. The input current and voltage from the pv array is fed to MPPT control. The P&O algorithm is processed according to the voltage and current and update the duty cycle D accordingly. The DC current and power is calculated from the boost converter. This output is called as 1 and 4.

$$\text{Power} = V_a \times I_a$$

$$\text{DC current} = \frac{V_a \times I_a}{V_{dc}}$$

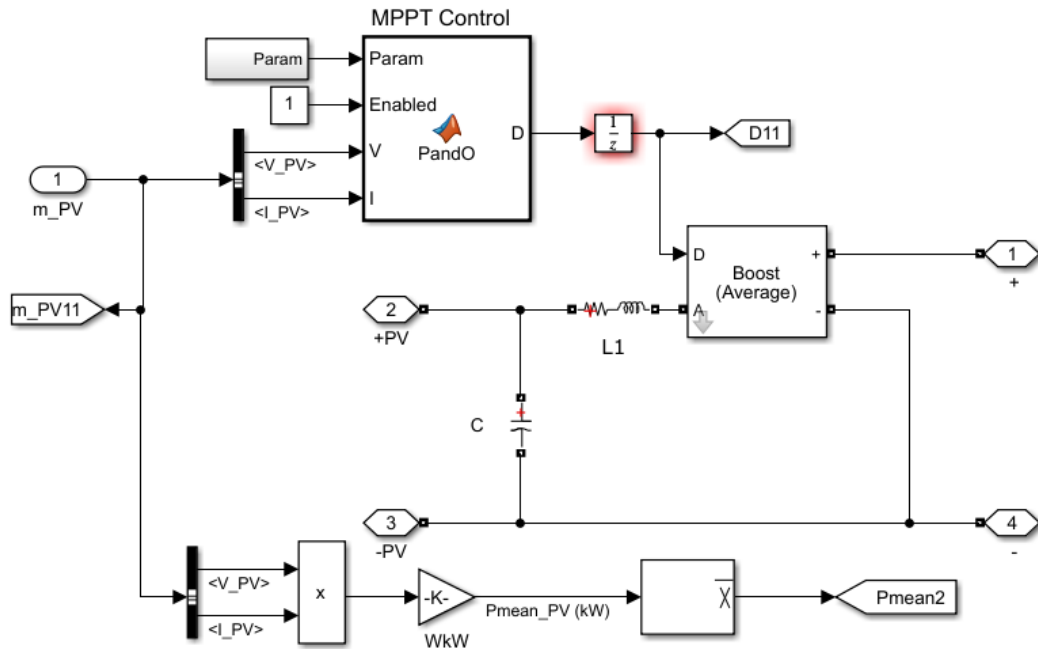


Fig 7.17 Simulation of boost converter

## 7.5.2 SIMULATION OF BATTERY CONTROLLER

This fig 7.18 shows the battery controller section. Battery controller is the control technique of battery electrolyser. The battery type is designed on the basis of some conditions. Here error is given to the PI controller by comparing the input dc voltage and a constant voltage.

Battery electrolyser controller is designed based on the PI. The error is compensated on the basis of PI control and resultant output will get based on the state of charge (SOC) of battery condition. If this condition is satisfied the output will get through S2. Here S1, S2 is the input of the battery. The battery and converter are work based on the condition of S1 and S2.

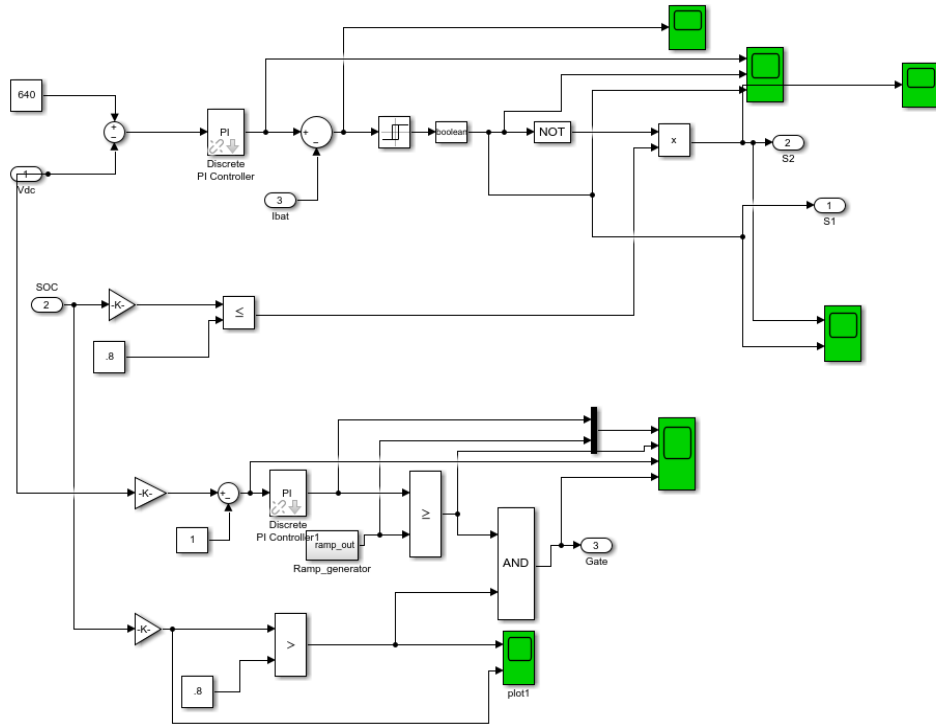


Fig 7.18 Simulation of battery electrolyte controller

### 7.5.3 SIMULATION OF BATTERY MODEL

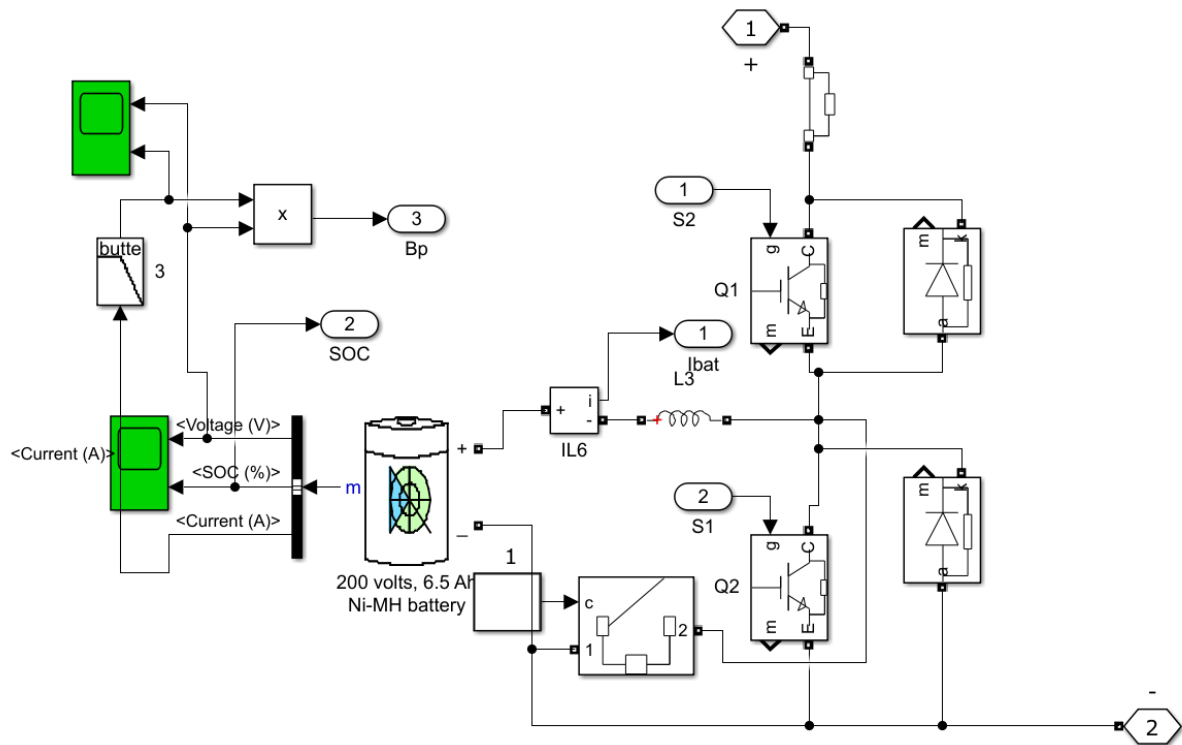


Fig 7.19 Simulation of battery model

Here the fig 7.19 depict the design of battery model. Here using a nickel metal hydride type battery; rating of 200 voltage (V), rated capacity of 6.8Ah, initial state of charge 60%. This battery is integrated in between of three phase inverter and DC-DC converter of proposed system. By using this battery, we can measure certain parameters like state of charge (SOC), current and even voltage also. The trigger input of converter is S1 and S2. The faulty condition of this battery model is tested in the time sequence of 0.8 seconds by manually developing the system fault. The fault condition is checked as same for both motor and battery. If the fault occurs at 0.8 second the system will get short circuited.

This model consists of two IGBT and diodes for the protection and it avoids the reverse condition of battery. Breakers are introduced for the safety of the components. Before even the fault occurs, breakers help to switch off the system so as to prevent the whole system components. Moreover, they not even allow the fault existence further more. Here an inductor is also used because the variation is depended upon load. In case of battery condition here the inductor current is passed through the positive side of battery. That is the output current of battery  $I_{bat}$  is measured on the basis of inductor current.

## 7.6 RESULTS

When the battery model is integrated to proposed system, the input given are PV input regarding solar and input motor speed of 1500 rpm. The variation within the above mentioned two inputs may used to diagnose the fault within the system. This can be represented through a waveform depicted different malfunction conditions such as short circuit condition, input over voltage, input under voltage, open circuit condition like wise.

The below fig 7.20 depict the plot showing graph between voltage and time. In this system three forms of faulty condition are checked. The combined effect of faulty conditions namely short circuit (SC), Open circuit (OC), and no faulty condition are checked.

A slight variation at its initial stage represents the open circuit fault. Open circuit fault occurs during a time interval from 0 - 0.1second. During the time interval from 0.1sec-0.8sec, voltage stays constant which represent no faulty condition. After 0.8 second, there saw a dip in case of voltage variation.; and that particular point represent system short circuit. During system short circuit (SC), three conditions should be checked namely Over voltage (OV), Under voltage (UV), and over current (OC). Rectification of these fault were discussed via algorithm.

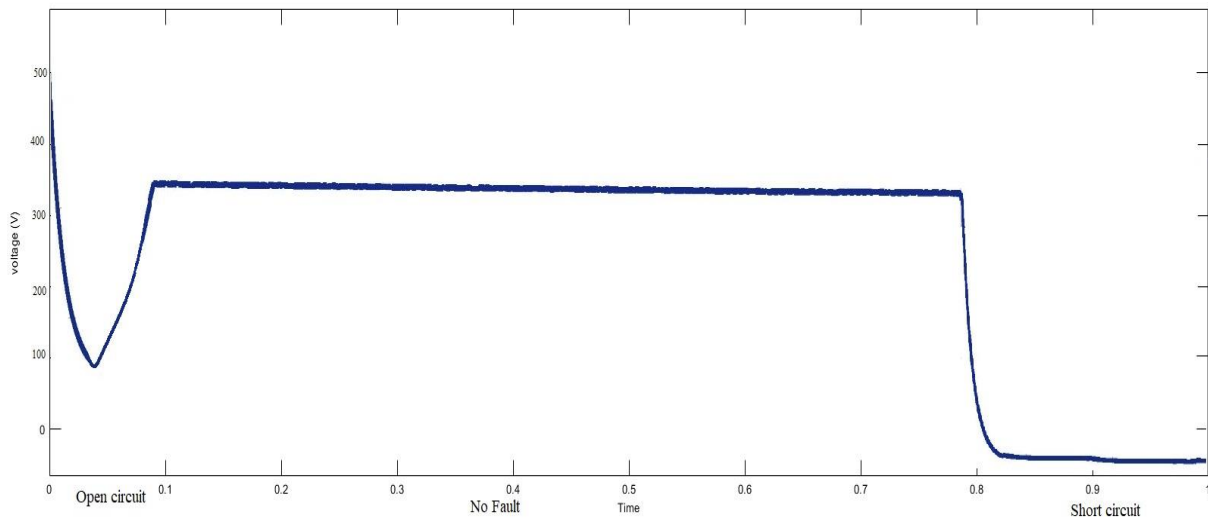


Fig 7.20 Different faulty conditions in integrated proposed system

### 7.6.1 VISUALISATION DIFFERENT MODES OF FAULTY CONDITIONS

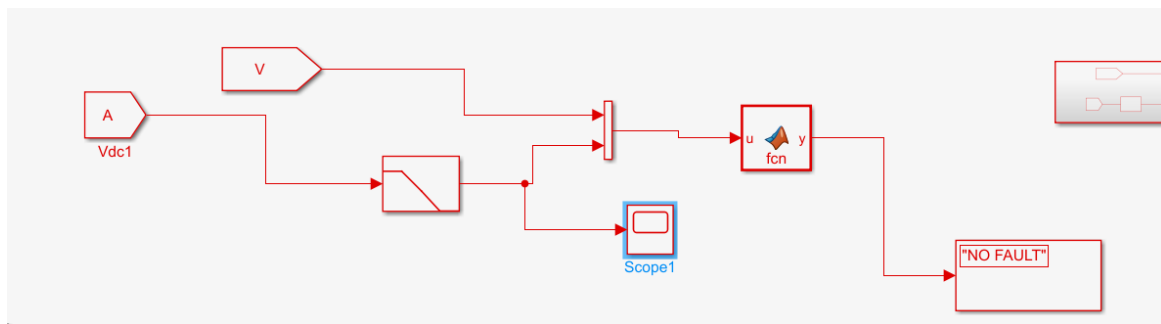


Fig 7.21 Display visualisation of 'NO-FAULT' CONDITION

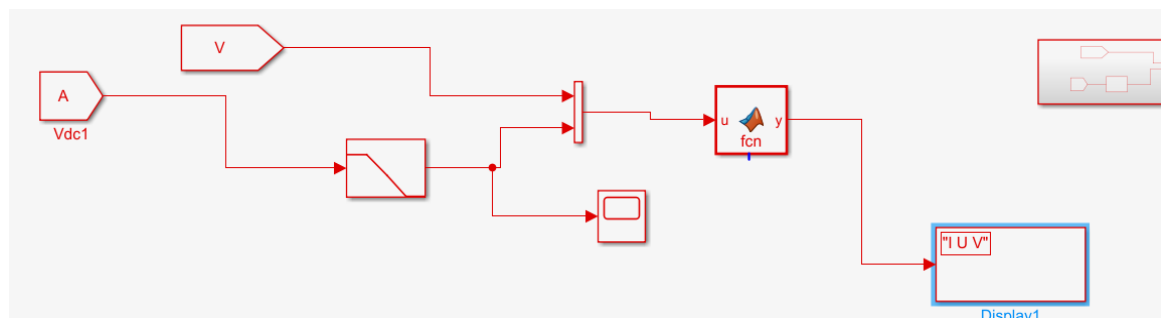


Fig 7.22 Display visualisation for short circuit condition of "UNDER VOLTAGE"

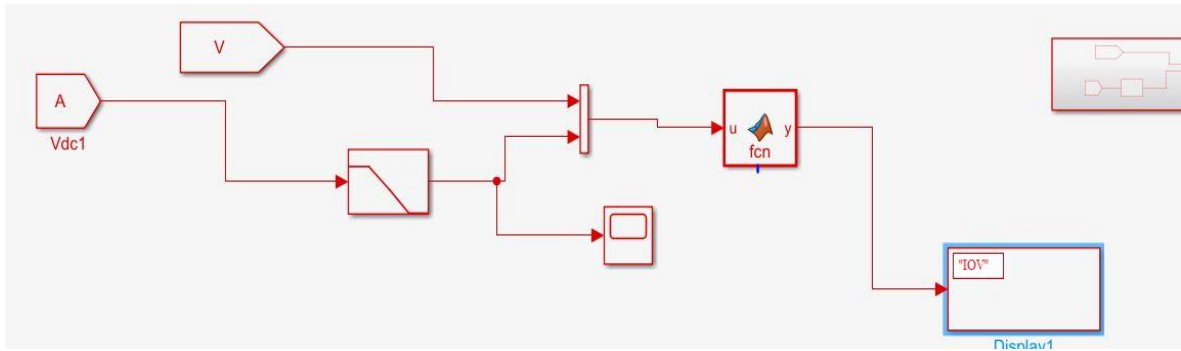


Fig 7.23 Display visualisation for Short circuit condition of 'INPUT OVERVOLTAGE'

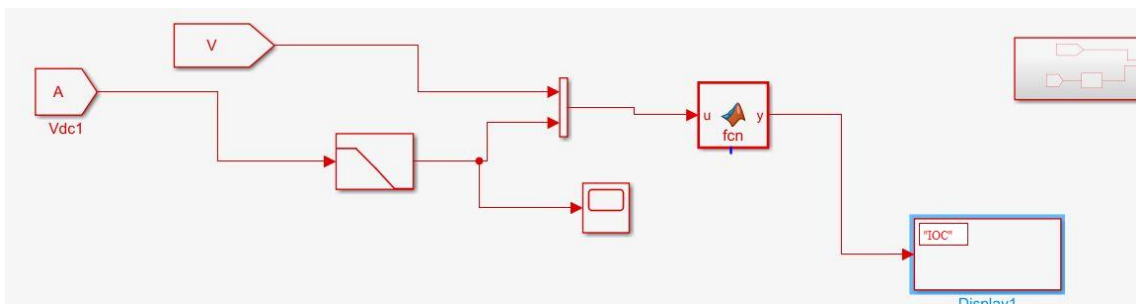


Fig 7.24 Display visualisation for Short circuit condition of 'INPUT OVERCURRENT'

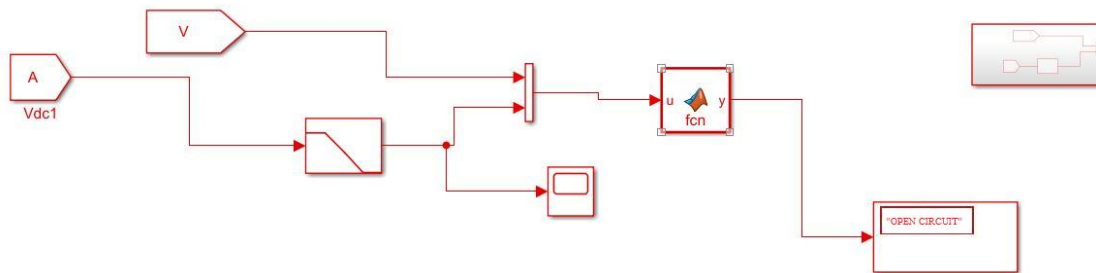


Fig 7.25 Display visualisation of 'OPEN CIRCUIT' Condition (OC)

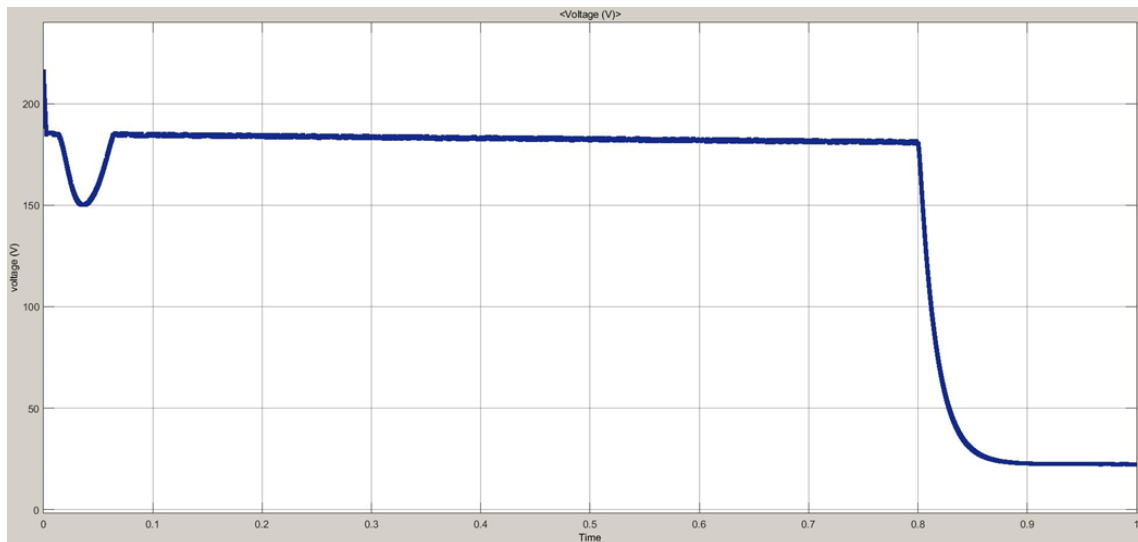


Fig 7.26 Output voltage of battery

The battery's output voltage waveform is depicted in Fig 7.26. The battery has a 200-volt dc voltage. Here, the voltage starts off at 200 volts, then changes slightly to be constant between 0.1 and 0.8, indicating that the system is fault-free. When the voltage dips after 0.8 seconds, it indicates that the system has experienced a short circuit at that specific moment

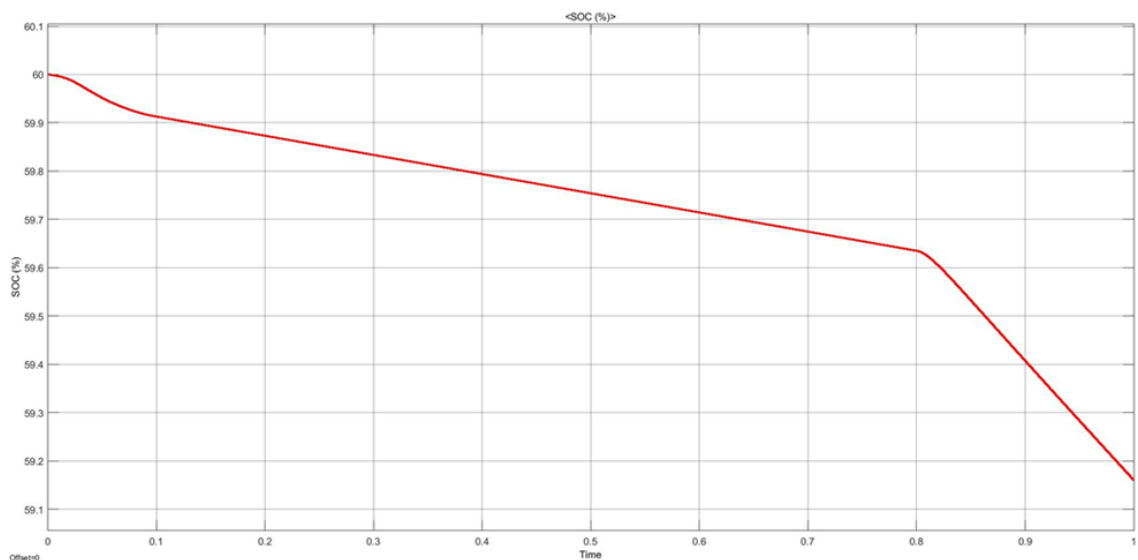


Fig 7.27 State of charge (SOC) of battery

The graph depicts the battery's deviation in state of charge. Battery degradation is common nowadays. The battery used here is a nickel metal hydride battery with a 60% initial charge. The battery state of charge evolves over time. It first changes from 60 to 50, then to zero at the end of use.

Based on the SOC parameter, we can see that it is not going to a stable state condition; instead, it is transitioning from a stable to an unstable state, and it is decreasing day by day. If the SOC is decreasing, it is reducing the voltage and affecting the current, which is why the SOC is decreasing. Here, the SOC factor is clear, and the maximum SOC parameter is 80% based on the current and voltage parameters. If the SOC is stable, it is also acceptable if the current and voltage are in a stable state.

## **CHAPTER 8**

# **CONCLUSION**

An essential component of battery electric vehicles is the electric driving system (BEVs). Anomalies in the electric drive system components may cause a decline in drive system performance and, more gravely, a loss of vehicle power. Here is a presentation of an integrated prognosis system for the fast detection and isolation of faults in the electric motor system and its components. Here proposes, a method for predicting specific drive system problems, including the energy source, battery, and drive system (motor and inverter), is provided. The problem detection system receives inverter/motor parameters from the drive system's SVPWM inverter-controlled/fed permanent magnet synchronous motor (PMSM). This thesis' main objective is to develop a novel technology for drive system failure diagnostics and prognostic analysis. Here, fault diagnosis is carried out based on statics for selecting the fault type as electrical fault, including stator winding faults, open circuit, and short circuit, thereby reducing the parameters and making it easier to implement in small electric vehicles, which are more cost-effective and helpful to customers in preventing loss of propulsion and situations where they must walk home. Additionally, this article suggests an innovation in battery's fault prognosis based on a check of the battery's health management, which takes into account the battery's age or remaining life period based on its state of charge (SOC), battery input voltage, battery input current, and the occurrence of severe degradation in the battery. By detecting the problem at its earliest stage, this will assist save a significant amount on maintenance.

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