“SIMULATION AND IMPLEMENTATION OF DSP BASED EXCIATION CONTROL SYSTEM FOR SYNCHORNOUS MOTOR”

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING

(POWER APPARATUS & SYSTEMS)

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CERTIFICATE

This is to certify that the Major Project Report entitled **"Simulation and Implementation of DSP based Excitation Control system for Synchronous Motor"** submitted by **Mr. Swapnil N. Jani (07MEE005)** towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Power Apparatus & Systems** of **Nirma University of Science and Technology** is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Swapnil Jani

ABSTRACT

Today industrial facilities pay great attention to energy conservation programs. Efficient electrical energy usage is becoming more of a concern than in the past and electrical energy costs play an important role in overall facility expenses. Power factor (PF) improvement is an important opportunity to save energy and improve reliability of the electrical system in industrial facilities. Induction motors are widely used in industrial production processes. Use of an induction motor will result in increased lagging power factor. If not, the result is the penalty of larger kVA burdens to the interconnected system. PF improvement using capacitor banks and VAR compensators have been implemented widely in the industry. Depending on the loading conditions and number of online units synchronous machines can substantially improve PF and voltage levels of a plant with a controllability not readily replicated with static capacitors. Traditional methods of PF improvement lack overall supervision and monitoring of the overall system. There is no dynamic control and/or feedback from system electrical parameters to optimize PF correction process. In addition, industrial facilities employing significant synchronous motor loads often do not take advantage of their ability to provide VAR compensation.

The synchronous machine, with the aid of an intelligent excitation controller, can control power factor to reduce the plant reactive loading to the connected system. Final simulation has been done using PSIM software. It is shown that unity power factor and also power factor regulation achieved by proposed control strategy. The proposed control algorithm including the whole system control is implemented on a low cost, fixed-point DSP TMS320F2811. Different modes like power factor control and var operation are also provided. Simulation of the proposed topology is given Thus, This digital excitation control system is not only use for the power factor regulation but also controls starting, synchronizing, and protection of collector-ring and brushless type synchronous motors. Typical protections are also included in this excitation system.

LIST OF FIGURES

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NOMENCLATURE

Rs	Stator winding resistance R, in Ohm.
Ls	Stator leakage inductance, in H
Ldm	d-axis magnetizing inductance, in H
Lqm	q-axis magnetizing inductance, in H
Rf	Field winding resistance, in Ohm
Lfl	Field winding leakage inductance, in H
Rdr	Rotor damping cage d-axis resistance, in Ohm
Ldrl	Rotor damping cage d-axis leakage inductance, in H
Rqr	Rotor damping cage q-axis resistance, in Ohm
Lqr	Rotor damping cage q-axis leakage inductance, in H
Ns/Nf	Stator-field winding effective turns ratio
Tc	Torque constant, in N*m
W	speed in rpm
Vf	Field Voltage
If	Field Current

ABBREVIATION

DSP	Digital Signal processor
PF	Power factor
DC	Direct current
AC	Alternating current
PI	Proportional-plus- Integral
ZOH	Zero Order Hold
VAR	Reactive power
EMF	Electro Motive force

CONTENTS

CHAPTER - 1:
INTRODUCTION

1.1 GENERAL:

Motors are electromagnetic devices used to convert electrical energy into useful mechanical work. There are **two major** classifications of ac motors:

(1) Induction motors that are electrically connected to the ac power source. Through electromagnetic coupling, the rotor and the stator fields interact, creating rotation without any other power source.

(2) Synchronous motors that have fixed stator windings that are electrically connected to the ac supply with a separate source of excitation connected to a field winding on the rotating shaft. Magnetic flux links the two windings when the motor is operating at synchronous speed.

Induction motors can be started and accelerated to steady state running condition simply by applying ac power to the fixed stator windings of the motor, but synchronous motors can neither start nor run without special attention because the net torque on the rotor of a Synchronous machine is zero unless the rotor winding is rotating at nearly synchronous speed with appropriate excitation applied to the moving winding. For this reason, various arrangements have been devised for starting synchronous motors and for providing excitation to the field winding at the appropriate time in the starting sequence. When the synchronous motor is operating at synchronous speed, it is possible to alter the power factor of the ac system supplying power to the motor by varying the excitation supplied to the motor field.

Induction motors are often the choice for various industrial production processes. Use of an induction motor, however, will result in increased lagging power factor burdens in the plant. This burden often must be corrected by adding capacitors. If not, the result is the penalty of larger kVA burdens to the interconnected system. For low speed applications, synchronous motors may be a better choice when equipped with accessories that offer power factor.

Large synchronous machines are used in all major industries.

✓ **Specific applications include:**

- Fans
- Pumps

- Compressors
- Metal rolling mills
- Grinding mills
- Mine hoists
- Pulp & paper refiners
- Small hydro generators
- Marine propulsion
- Gas & steam turbine generators

✓ **Advantages of the synchronous motor:**

The initial cost of a synchronous motor is more than that of a conventional AC induction motor due to the expense of the wound rotor and synchronizing circuitry. These initial costs are often off-set by:

- Precise speed regulation makes the synchronous motor an ideal choice for certain industrial processes and as a prime mover for generators.
- Synchronous motors have speed / torque characteristics which are ideally suited for direct drive of large horsepower, low-rpm loads such as reciprocating compressors.
- Synchronous motors operate at an improved power factor, thereby improving overall system power factor and eliminating or reducing utility power factor penalties. An improved power factor also reduces the system voltage drop and the voltage drop at the motor terminals.

1.2 PROJECT DEFINITIONS AND OBJECTIVE

In this Digital excitation system, D.C. field excitation using thyristors based rectifier, which is controlled by DSP based control card, carried out control. As load changes the excitation will be also change automatically with improved power factor. Also Speed of the motor should not fall down as load changes. In this system the necessary protections are also considered in designing. These Protections are Over Voltage, over current, Under/Over Frequency, DC Field current loss, Power factor protection (Pullout Fault), Motor Trip Temperature (Thermal Protection), Incomplete Sequence. All these protections are provided by DSP based card. For that different control logic is implemented in DSP based card. Transient Response should be in millisecond so that whole the system will not stop if load changes suddenly.

This Excitation system control functions for starting synchronous motors include accurate sensing of motor speed and rotor angle, allowing the unit to apply excitation at optimum speed and angle. This permits closer matching of the motor to the load. Optimum application of excitation also reduces power system disturbance, which occurs when the motor goes through a complete slip cycle with the field energized. In addition, the Excitation system can take advantage of the extended stall time of a reduced voltage start. It also responds with the proper application of excitation in the event that the motor synchronizes on reluctance torque.

The Excitation system provides the functions necessary to protect the motor during startup and in the event of asynchronous operation. During startup and restarting, the system prevents overheating of the cage winding. To protect against asynchronous operation, the motor power factor is monitored. Two modes of pull-out protection can trip the motor if resynchronization does not occur after a programmed time delay.

1.3 BASIC BLOCK DIAGRAM:

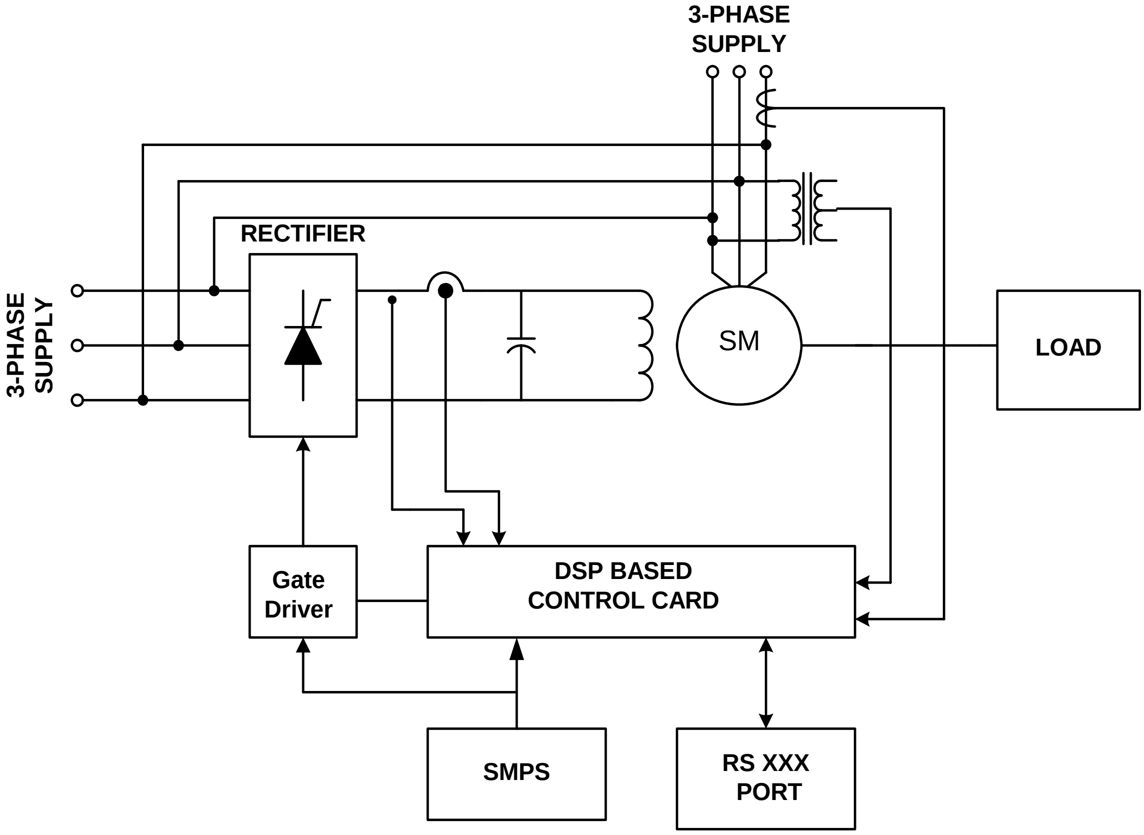


Fig.1.1: Block Diagram of Proposed Excitation System

As shown in block diagram, 3-phase controlled rectifier is used to get the D.C. current, which is given to the field by changing the firing angle of SCR, the excitation current can change. Power Factor is sensed by sensing voltage between motor's two phases and current from third phase. Then that feedback is given to the DSP control card. In this card set points of power factor as per requirement is programmed. So that as the load changes the excitation requirement will also change automatically and power factor is maintain between entered set values.

1.4 LITERAUTRE SURVEY

RICHARD C. SCHAEFER [1]

In This paper titled, *"Excitation control of the synchronous motor"* provides a detailed discussion of the basic theory of operation and control of the synchronous motor. It describes typical synchronous motor starting and provides Information regarding control and optimization of the motor through the use of power factor control or VAR operation that can be helpful in reducing VAR penalties and improving voltage stability of the plant. Typical protection is also discussed involving motor pullout and under- and over excitation concerns.

S. P. BORDEAU [2]

In this paper titled, *"C. Truman Hibbard and the Invention of Automatic Control for Synchronous Motors"* author has discussed about automatic control of synchronous motor. The synchronous motor was created in 1869, nearly twenty years before the invention of the induction motor. Yet, by the beginning of the 20th Century the induction motor had achieved maturity, such that it was being widely applied in industry. The synchronous motor, despite unique features, did not reach a similar degree of acceptance until the eady 1920's. A half-century was required to evolve suitable starting ability by symbiosis with the induction motor, and further to exploit synchronous motor advantages for power factor correction, and finally to remove the limitations of manual starting by development of automatic control for synchronous motors. This article gives some historical background, and recounts the part taken by C. Truman Hibbard in the progress of the motor after 1912. As Chief Engineer of the Electric Machinery Manufacturing

Company, he contributed to the development and promotion of synchronous motors and was the inventor of automatic control for the motor.

Al-Hamrani, M.M. [3]

In this paper titled, *"Power factor correction in industrial facilities using adaptive excitation control of synchronous machines"*, author has discussed how the power factor is maintained by varying excitation**.** Synchronous machines provide a practical way to control VA consumption of the plant. One of the main advantages of using synchronous motors in a plant is their ability to generate reactive power for plant loads. In petrochemical plants synchronous motors are often operated with a constant set point of power factor (PF) without considering overall performance and the dynamic changes of the distribution system in the plant. This often results in less than optimum operating conditions. This paper addresses a new application to automate VAR generation and voltage control in a petrochemical facility using advantages and capabilities of advanced power monitoring devices to optimize VAR and voltage conditions.

Kilowatt classroom, LLC. [4]

*"Synchronous Motor characteristics***",** in this article characteristic of Synchronous motor, constructions, advantages, and excitations methods, field application systems are discussed, which is very useful in designing of the starter.

Gennady F. Verzakov. [5]

"Automatic Digital Controller of Synchronous Motor Excitation", in this article an automated digital controller of synchronous motor excitation (ADCSME) is designed for regulating synchronous motor excitation with a power up to 12.5 MW.A numbers of controllers for operation with synchronous turbo motors (STM) is developed. Purely analog methods are replaced by direct digital control.

The controllers have two modifications:

- For excitation systems with brushes;
- For excitation systems without brushes.

1.5 ORGANIZATION OF THESIS

This work has been organized in nine chapters.

Chapter-1 presents an introduction to the thesis work. It present the identification of the design problem and the objective of the project. A basic block diagram of the whole system is also explained briefly in this chapter.

Chapter-2 states the literature surveyed during the course of the thesis work.

Chapter-3 presents the overview of the synchronous motor, which includes the operating principle, construction, excitation types.

Chapter-4 presents the power factor operation, V-curves, power factor control, automatic power factor correction, power factor regulation, effects of voltage dips on the motor power factor, power factor mode versus var mode

Chapter-5 presents the simulation results of the proposed topology. It also includes the simulation results under different conditions.

Chapter-6 presents the software development part. A DSP based control configuration and how card works have been discussed.

Chapter-7 presents the program algorithms for DSP implementation for the various protections.

Chapter-8 presents the hardware implementation of the proposed topology. Finally, experimental results will be included and discussed.

Chapter-9 gives the conclusion and an outlook on the future development of this research. The references and appendix will be attached at the end of this thesis.

CHAPTER - 2:
SYNCHRONOUS MOTOR: AN OVERVIEW

2.1 GENERAL

To design the any control system for the motor it is necessary to study the motor operating principle, construction, starting methods, different types of excitation systems etc. Different types of exciters are use for the synchronous motor, which are explained in this chapter.

2.2 OPERATING PRINCIPLE

Stator and stator winding (armature) of synchronous motors are identical to components of three phase induction motors. Identical to induction motors, the current that goes through the stator winding generates a rotating magnetic flow that circulates around the air gap. Stator rotating field - When the current goes through the coil, a magnetic field is generated which is based on coil axis and is proportional to the current value.

Fig 2.1 shows a waveform of a balanced three phase system consisting of 3 sets of coils placed symmetrically on the area resulting in a 120º angle. Fig 2.2 represents a three phase motor winding. If the winding is powered by a three-phase system, currents I1, I2and I3 will create at the same time their own magnetic fields H1, H2 e H3. These fields are spaced between them by a 120º angle as well. Besides that, as they are proportional to the respective currents, they will be de-phased in time, also between them by a 120º angle.

The resulting H field, at each point, will be equal to the graphic sum of the 3 magnetic fields H1, H2 and H3 on that point. Figure 2.3 shows this graphic sum for 6 successive points.

On point (1), figure 2.3 shows that field H1 is on maximum stage and that field H2 and H3 are negative and with same value which is equal to half of H1. The 3 fields represented on figure 2.3 (upper part) take into consideration that an arrow pointed to the opposite direction in comparison to what would be normal represents the negative field. The resulting field (graphic sum) is shown on the bottom part of figure 2.3, position (1), having the same direction of phase 1 winding. Repeating the construction for points 2, 3, 4, 5 and 6 of figure1, the resulting H field presents “constant” intensity. However, its direction will “rotate” until completing a turn at the end of the cycle.

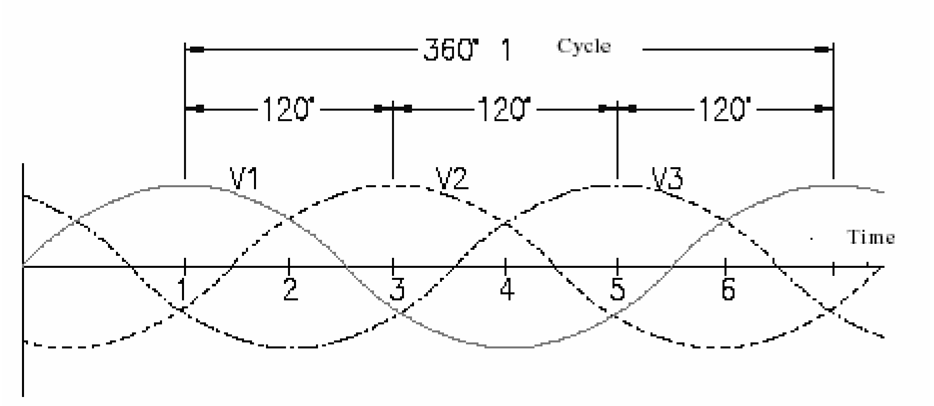


Fig. 2.1: Waveform of a balanced three phase system

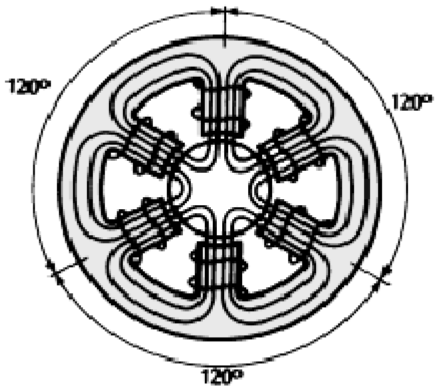


Fig. 2.2: Three phase motor winding

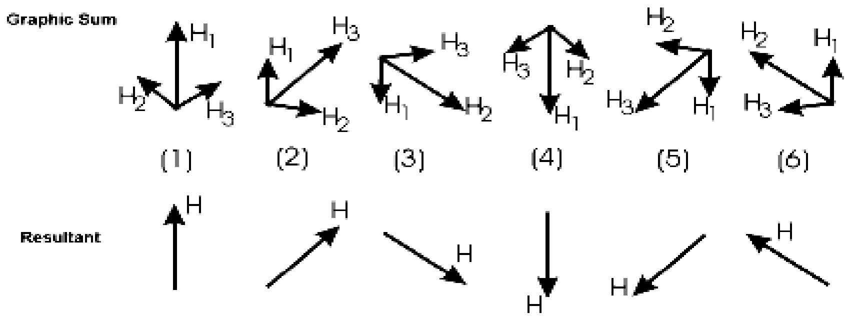


Fig. 2.3: Graphic sum for 6 successive points.

2.3 CONSTRUCTION

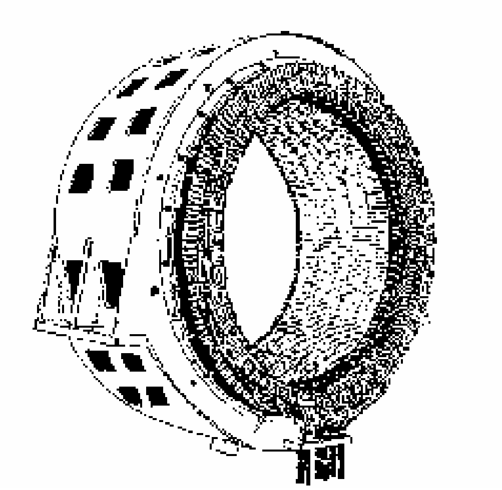


Fig 2.4: A Typical Stationary Stator Winding

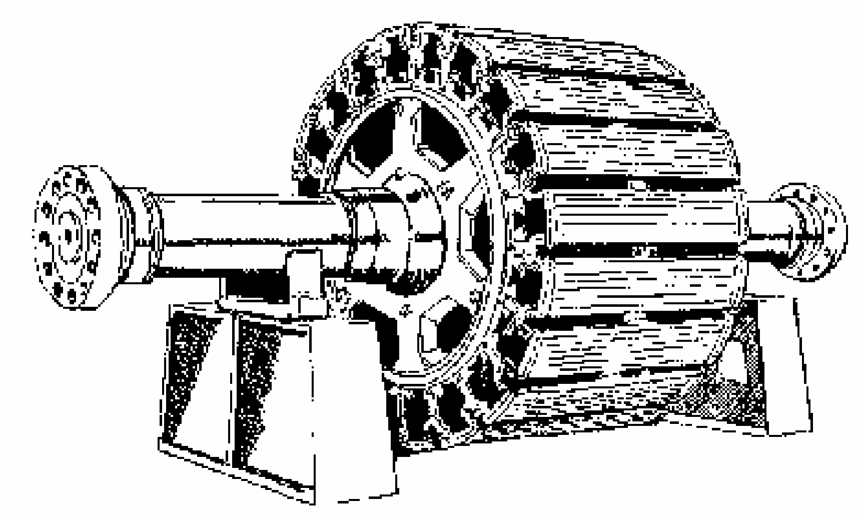


Fig 2.5: A Rotor Field for a Synchronous Motor

Referencing Fig. 2.5, synchronous motors, like synchronous generators, consist of a fixed stator and a field that rotates concentric with the stator. The stator contains armature windings that are electrically connected to the ac supply system while the rotor contains a field winding that is electrically connected to a source of excitation when the motor is at synchronous speed. Since the primary purpose of the field winding is to transform the field into a rotating magnet, the field winding is wound around “poles” attached to the rotor in a configuration that produces magnetically north and south poles that are 180 electrical degrees apart. Because of this arrangement, the field winding is not effectively coupled with the armature windings in the stator, and no net torque is produced in the field when ac power is connected to the stator winding. To produce starting torque, a supplementary winding is provided on the field that effectively couples electromagnetic ally with the armature windings. The rotor is typically constructed with a "squirrel cage" arrangement of bars that are electrically shorted at each end so that the ac power connected to the armature is coupled with the squirrel cage winding at time of startup. This results in a net torque that is applied to the rotor when ac power is applied to the stator, as shown in Fig.2.6.

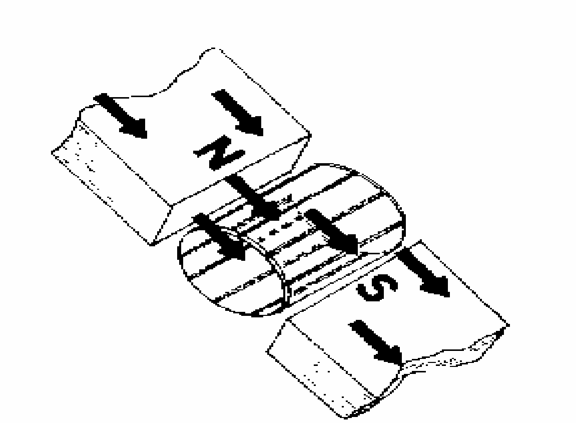


Fig 2.6: Stator Field pole

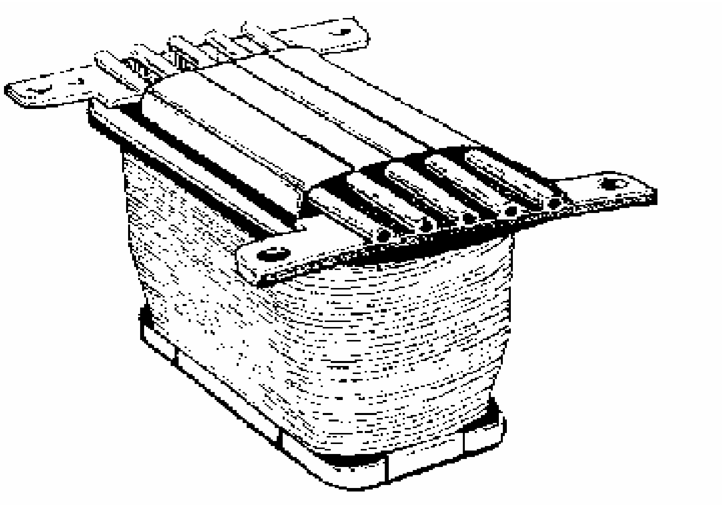


Figure 2.7: A Rotor Field Pole

The synchronous motor then can be started like an induction motor, with the torque on the rotor proportional to the difference between the rotor speed and the frequency of the power being applied to the stator winding. The torque supplied by the squirrel cage is at a maximum when ac power is first supplied to the stator winding, decreases as the rotor accelerates, and approaches zero as the rotor approaches synchronous speed. The absolute value of the accelerating torque is a function of the resistance of the bars in the squirrel cage:

- Higher resistance bars produce higher starting torque (and hotter squirrel cage windings)
- Lower resistance bars produce lower starting torque with less heat generation.

If the starting torque produced by the squirrel cage winding is not adequate to roll the rotor, the rotor is said to be “locked” and ac power must be quickly removed from the stator windings to avoid overheating both the armature and the squirrel cage windings. As shown in Fig. 3.8, the stator winding is connected to the ac supply system at startup, and the bars of the squirrel cage winding on the field produces an accelerating torque on the rotor. The field winding is shorted through a field discharge resistor during startup, and no external excitation is applied to the field.

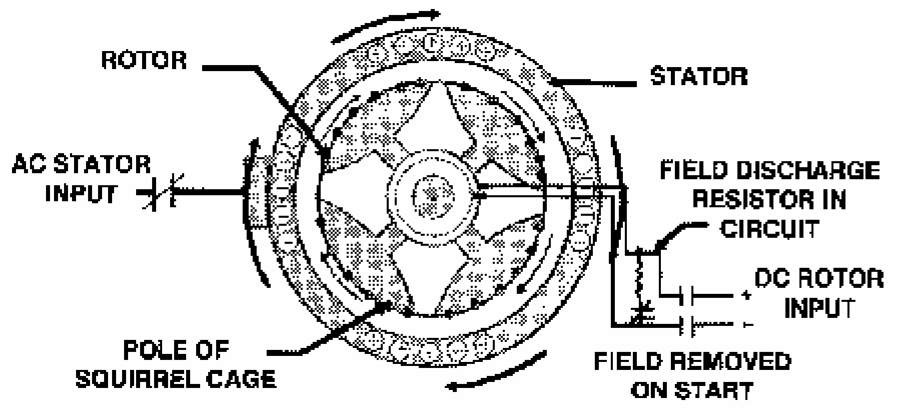


Figure 2.8: Simplistic Drawing Showing the Relation of the Squirrel Cage motor

As the rotor accelerates, the field winding is coupled to the stator field via the armature winding. The ac current is induced into the field at a ‘‘slip” frequency. The slip frequency is the difference between the frequency of the applied ac voltage to the motor minus the frequency associated with the instantaneous speed of the rotor. If the field winding were open circuited during startup, dangerously high voltages could be induced in the field winding; hence a starting resistor is used to limit the voltage seen by the field winding during startup while dissipating the energy induced in the field. The resistance voltage of the starting resistor also affects the synchronizing torque available as the rotor approaches rated speed:

- A low resistance voltage produces higher synchronizing torque.

- Using a high resistance voltage also produces high voltages in the field winding, that can damage the winding or excitations system electronics connected to the field winding.

Sizing the starting resistor is an “art” that relates to the specific motor design, starting torque and allowable field voltages during startup. In some applications, the load is removed from the synchronous motor during startup and gradually applied only after the motor has reached stable operation at synchronous speed, in order to minimize failure to synchronize.

➢ Why synchronous motor is not self started?

Torque is produced that unless the rotor is running at the same speed as the rotating field, no steady torque can be produce. If the rotor is running at a different speed, the two fields will be sliding past each other, giving rise to a pulsating torque with an average value of zero. Hence a basic synchronous machine is not self-starting and some alternative methods of producing a run-up torque are required. The direct current required for field excitation is furnished by the excitation system. The source of power can be a shaft-mounted exciter, a motor-generator set, or a static rectifier.

2.4 EXCITATION TYPES

(1) DC exciter. This is the traditional method. A DC generator mounted on the main shaft may be of either the shunt-wound or the separately-excited type. The output current is fed to the rotor of the synchronous machine through slip-rings.

(2) Static excitation. Here, DC excitation can be obtained by means of a rectifier and a suitable AC supply. This method eliminates the commutation limits inherent in DC exciters. The rectifier unit has no moving parts, requires very little maintenance, and is immune to hazardous or dusty atmospheres. It has two types.

➢ (a). static exciter (with brushes)

Synchronous motors supplied with static exciter are fitted with slip rings and brushes that Allow current powering of the rotor poles through slip contacts. The DC power supply for the poles must come from an AC/DC converter and static controller. The static exciter is much used on VFD applications.

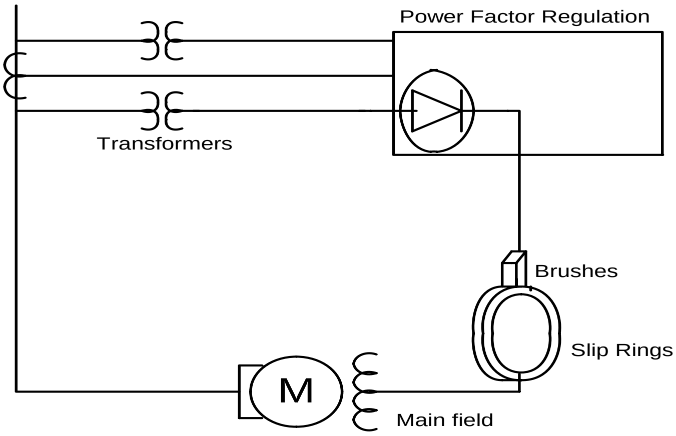


Fig.2.9 Static Exciter

- (b). Brush less exciter

Synchronous motors with brush less excitation system are fitted with a rotating exciter, normally installed on the backside of the motor. The exciter operates as an AC generator with the rotor attached to the motor shaft. It is fitted with a three-phase winding and the stator consists of alternating poles (north and south) and powered by an independent DC source. This three-phase winding is connected to bridge rectifiers. The voltage generated on the rotor is rectified and intended to power the motor field winding. The amplitude of such field current can be controlled through the rectifiers that power the exciter stator field. Synchronous motors with brush less excitation require low maintenance cost once they are not fitted with bushes. Since they are not built with slip electric contacts, avoiding sparking, synchronous brush less excitation motors are recommended for explosive atmosphere applications.

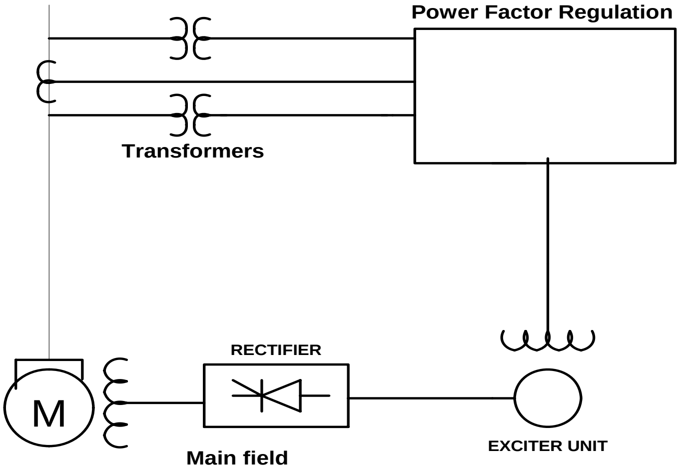


Fig.2.10 Brushless Exciter.

(3) AC exciter. The AC exciter is mounted on the main shaft. Its field is fed from a pilot exciter, whose field in turn is obtained from a permanent-magnet generator. The AC exciter output voltage is rectified and fed to the field of the synchronous machine via slip-rings.

Synchronous motors require a DC power supply to power the field winding (rotor winding), which is usually done through slip rings and brushes (static exciter) or through a brush less rotating exciter.

2.5 CONCLUSION

For the synchronous motor among the different exciters static excitation is widely used because it has no moving parts, requires very little maintenance, and is immune to hazardous or dusty atmospheres. Brushless excitation system is chosen because they are not built with slip electric contacts, avoiding sparking.

CHAPTER - 3:
POWER FACTOR OPERATION

3.1 GENERAL

Digital excitation control system is mainly used for the power factor operation. It means excitation system control the power factor for the set point even if the load changes. This power factor operation phenomenon is explained for the different modes like VAR (Reactive power mode) mode and power factor mode. Motor V-curves are very important for designing the any digital excitation control system, which is explained in this section.

3.2 MOTOR V-CURVES

It is generally assumed that the line voltage will be substantially constant, and it is apparent from the preceding discussion that load, excitation, line amperes, and power factor are closely related. A family of characteristic curves known from their shape as V curves readily expresses this relationship.

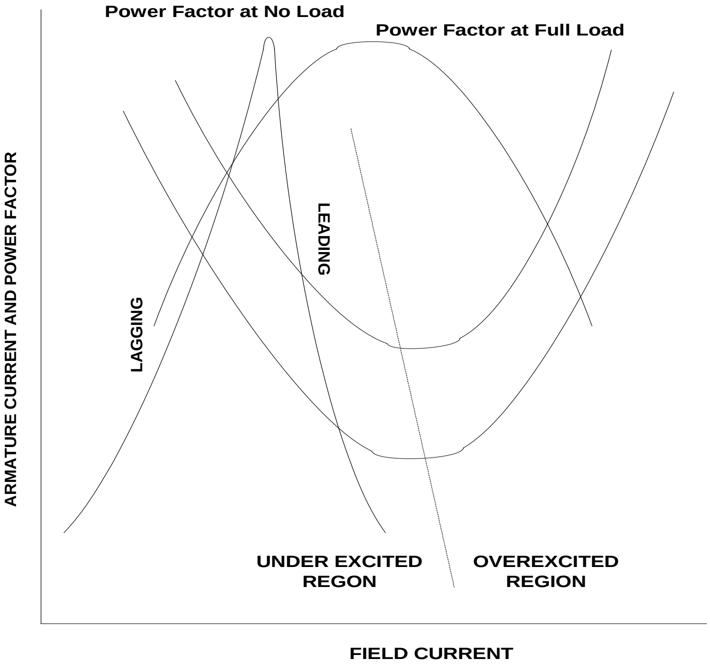


Fig. 3.1 Motor V-curves

These are represented in Fig. 3.1 that for each curve the power is constant and the excitation is varied to give different magnetizing currents. The minimum value of line amperes for each load condition is at 1.0 or unity power factor. As excitation is decreased, the line current will increase and the motor will operate at lagging power factor. Variation in excitation or in field current causes the variation in armature current and curves drawn between armature current and field current for different constant loads are known as "V-curves"

The V- Curves of a synchronous motor give relation between armature current and field current for different power inputs. Similarly the variation of power factor with a variation in field current (or dc excitation) for a constant load gives Inverted V curve.

From V curves for different power inputs it is observed that with low value of field current, the armature current is large and lagging. As the field current is increased the power factor increases and armature current decreases until it reaches its minimum value. When the armature current is minimum, the power factor is unity and the corresponding field current is known as *normal field current or excitation* of the motor for that particular load. The point at which unity power factor occurs is shown by dotted curve. The region in which the field current is less than its normal value is known as *region of under excitation*. If the field current is further increased, the power factor becomes leading and begins to decrease, so armature current begins to increase. This region in which field current is more than normal value of field current or armature current is known as *region of over excitation*.

3.3 POWER FACTOR CONTROL

Power factor is the factor by which apparent power, or kVA, is multiplied to obtain actual power, or kW, in an ac system. It is the ratio of the in-phase component of current to total current. It also is the cosine of the angle by which the current lags (or leads) the voltage. The conversion of electrical energy to mechanical energy in a motor is accomplished by magnetic fields. The poles rotate around the stator. When voltage is applied to a motor, an armature current flows to provide the necessary magnetic push (mmf or ampere turns) to produce a flux that in turn, produces a voltage (back emf) that opposes the applied voltage. This mmf is a magnetizing current. It is loss-less, except for the I^2R losses in the winding and any core loss due to the changing flux in the iron. The magnetic energy is transferred from the line to the motor and back again each half cycle. The net power is zero, and the power factor is zero. The power factor of a synchronous motor is controllable within its design and load limits. It may operate at unity, leading, or in rare cases, lagging power factor.

Once the synchronous motor is synchronized, the field poles on the rotor are in line with the rotating magnetic poles of the stator. If dc is applied to the rotor pole windings, the rotor can supply the necessary ampere-turns to generate the flux that produces the internal motor voltage. Thus, the field current can replace part or all of the magnetizing current. In fact, if more dc field current is supplied, the increased flux will try to increase the line voltage. To increase the line voltage, the motor will supply ac-magnetizing current to all magnets on the system to increase their magnetic flux. This is leading power factor. Fig. 3.2 illustrates how the change in the excitation causes the ac line current to lead the ac source voltage, be in phase with the source voltage, or lag the source voltage depending upon if the synchronous motor is over or under excited.

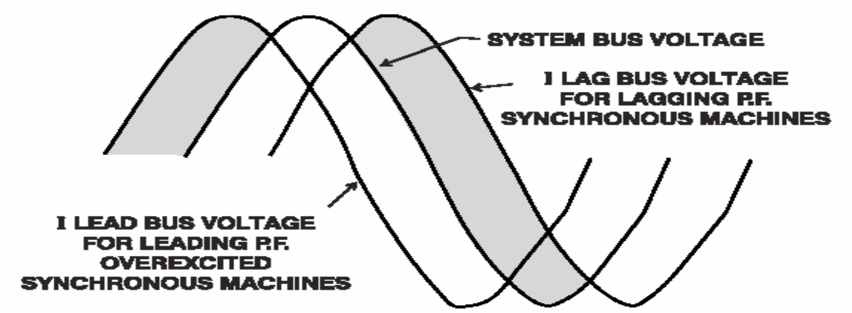


Fig. 3.2 Leading and Lagging Current as affected by Field Excitation

3.4 SYSTEM POWER FACTOR CORRECTION

By operating synchronous motors with a leading power factor, the overall system power factor can be shifted toward unity. Varying the amount of excitation current delivered to the motor field during operation can control the power factor of a synchronous motor. As the dc field excitation is increased, the power factor of the motor load, as measured at the motor terminal, becomes more leading as the overexcited synchronous motor produces vars. If excitation is decreased, the power factor of the motor shifts toward lagging, and the motor will import VARs from the system.

3.5 EXCITATION SYSTEM CONTROLS THE POWER FACTOR

To take full advantage of the synchronous motor, it is necessary to have an excitation system that will maintain constant power factor regardless of load and ac supply variations to the excitation controller. Today’s excitation systems are designed with features to help improve the quality of machine control. For this system, a digital controller was specified by the engineering consultant with the following feature:

[1] Power Factor Control
[2] Under Excitation Limiting
[3] Over Excitation Limiting
[4] Manual Control

➢ AUTOMATIC POWER FACTOR CONTROL

The digital controller is designed to maintain a specific cosine angle by measuring the real power into the motor and adjusting the excitation into the field to provide the correct amount of kvars to maintain the cosine angle. Any voltage variation to the system or load change that would affect the power factor is immediately modified via the excitation system to restore the cosine angle and power factor of the machine.

The automatic control eliminates the concern with an ac supply variation to the excitation system that could otherwise result in pole slip due to too little excitation for the motor field. Additionally, digital systems are equipped with safeguards to prevent pole slip from occurring. These include:

- Field Forcing Margins
- Under Excitation Limiting
- Over Excitation Limiting

• FIELD FORCING

Field forcing provides a means to maintain constant voltage into the field even when the ac supply voltage drops as much 30-40%. Hence if the field voltage required by the motor were 100 Vdc at .9 power factor lead and the digital controller were selected to provide 150 Vdc maximum ceiling voltage, The digital controller would be able to provide 100 Vdc to the field even if the supply voltage into the controller were to drop 50%. The additional margin could mean the difference between continue process control or a machine trip and plant outage.

• UNDER EXCITATION LIMITING

Digital controllers also are equipped with under excitation limiters. These devices have always been popular for generators, but also very practical for synchronous motors using digital controllers. The under excitation limiter monitors the kW into the synchronous machine as compared to the kvars being supplied. Should the kvars drop below acceptable levels needed to maintain synchronism, the under excitation limiter will cause an increase in excitation to prevent a machine trip.

- **OVER EXCITATION LIMITING**

To ensure that too much excitation is not applied into the rotor for extended periods of time, the excitation system is equipped with an over excitation limiter. The over excitation limiter monitors the field current and if it should remain too high for extended periods, the excitation limiter will react by restricting any further increased field current and restore the level within a safe operating region for the machine.

3.6 POWER FACTOR REGULATION

Power factor regulation is useful in those applications where motors are subjected to high-level transient impact loads (such as chipper drives). The PF regulator senses the power factor dip that occurs when the motor is loaded and causes the SCR Exciter to respond with a boosted output. As a result, the pullout torque of the synchronous motor is increased for the duration of the transient load.

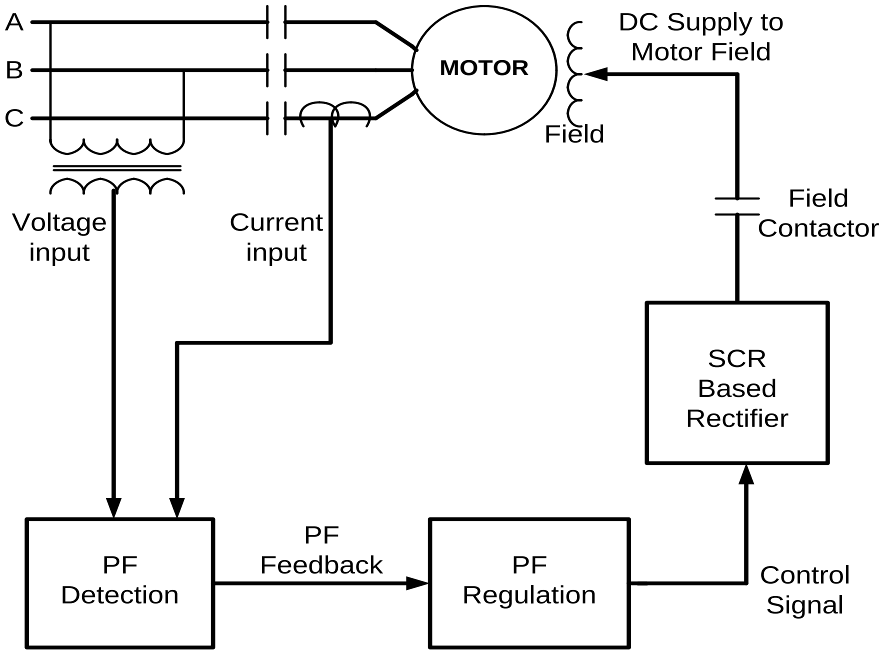


Fig. 3.3 PF Regulation

After the load subsides, the regulator senses an excessive leading power factor and causes the SCR to reduce its output. This automatic boosting of field current to avoid pullout is called field forcing. The Power Factor regulator thus provides automatic boosting when field forcing is required and economical low field operation when the motor is idling. Another application of the power factor regulator is to control power factor swings that result from various levels of loading so as not to cause fluctuations in the plant system voltage. The Excitation system provides the control signal to the variable SCR exciter when PF regulation is required. See the fig. 3.3 for a functional operation overview of this feature.

3.7 POWER FACTOR OPERATION

Motor pull-out protection is provided by a circuit, which monitors power factor and has a built-in time delay to prevent inadvertent tripping on transients. The excitation system senses power factor by monitoring the voltage across motor Phases One and Two and the current in Phase Three.

FSL: Loading Relay. This relay picks up when the motor is fully synchronized and ready to be loaded. It is controlled by the "FSL Delay" programmable set point.

The excitation system automatically suppresses power factor protection until the programmed set point "FSL" times out. The excitation system can be programmed to suppress power factor trip action if the line current is less than 6 percent or 50 percent of the rated full load current via the PF Suppression set point. Selecting the "Ridethru" mode for the PF Mode set point places the excitation system into ride-through mode. Selecting the "Re-sync" mode for the PF Mode set point places the excitation system into resync mode.

3.8 EFECTS OF VOLTAGE DIPS ON MOTOR POWER FACTOR

Solid-state excitation systems have an effect on the way motor power factor responds to line voltage dips. The effect may be to cause a power-factor relay to operate inadvertently. This causes the motor to trip on lagging power factor caused by a transient condition, which is not an actual pull-out condition.

A solid-state exciter differs from a rotating exciter in the way it responds to voltage dips. The rotating inertia of a Motor-Generator set may maintain excitation voltage relatively constant for several seconds, but a solid-state exciter has practically no built-in delay in the way it responds to line voltage. Therefore, any delay in change of motor-rotor flux following an excitation voltage change is determined by the time constant of the rotor field poles themselves.

Assuming the condition of a line voltage decrease of 15% with the motor initially at unity power factor, the power factor will swing leading momentarily because the generated EMF does not change until the rotor flux decreases (determined by field time constant). The motor will tend to maintain constant horsepower by slightly increasing line current. As the field flux decreases, generated EMF also decreases, and the power factor will move back towards unity, and there will be a load angle increase to permit motor torque to be restored to that required to drive the load. During both of these sequences the motor power factor has not become significantly lagging, so the power-factor relay does not operate.

Finally, when line voltage comes back to normal, the power factor will momentarily swing over to lagging and the power factor protection relay will trip because the rotor flux does not respond as rapidly to change as the stator. The generated EMF is low relative to line volts for a time period long enough to operate the relay.

3.9 VAR OPERATION MODE VERSUS POWER FACTOR MODE

The use of VAR mode versus power factor operation is application dependent. For relatively constant loads, power factor operation is the preferred operating mode of the synchronous motor. Conversely, for applications such as ball mill grinders and chipper motors, VAR control may be favored. These motor loads tend to be cyclic which produces momentary power surges in the system. If the system operates in power factor mode, the power surges will be sensed and cause the excitation system to produce cyclic surges of field power in response to the load. This will result in the power factor meter appearing unstable in response to the pulsing load. For these applications, VAR control provides the best solution. In VAR mode, the pulsating power component is not sensed by the controller, so the system provides smooth, stable operation for the motor and the plant. When plant bus voltage sags due to heavy internal plant loads, boosting VAR output from the synchronous motor to raise terminal voltage is best accomplished in the VAR mode. Here, the excitation system over excites the motor field, resulting in an increased plant voltage.[1]

3.10 CONCLUSION

From the V-curve normal excitation current at unity power factor is decided. So based on that under excitation limiter and over excitation limiter will be set. Also power factor regulation is carried out by means of the excitation (Rectifier output current). If voltage dip comes into the line and this condition will remain for extended period of time then power factor protection relay will trip. Based on the nature of load we can operate the excitation system in different modes i.e. PF mode, VAR mode.

CHAPTER - 4: SIMULATION OF PROPOSED TOPOLOGY

4.1 GENERAL

Simulation is carried out in the PSIM software. The value of the different parameters, which considered for simulation, is given below.

Input Power = 3-phase, 415 V, 50 Hz.
Output power = 80 kW
Rs (Stator) = 0.1 ohm
Ls (Stator) = 0.79 mH
Ldm (d-axis mag. Ind.) = 4.1 mH
Lqm (q-axis mag. Ind.) = 2 mH
Rf (field) = 0.7 ohm
Lf (field leakage indu.) = 0.37 mH
Rdrl (damping cage) = 0.17 ohm
Ldrl (damping cage) = 0.28 mH
Rqr (damping cage) = 0.17 ohm
Lqrl (damping cage) = 0.28 mH
Ns/Nf = 1
No. Of poles = 4
Output Filter Capacitor = 9400 uF.
Tc = 150 N-m.
Simulation Time = 6 sec.

4.2 OPEN LOOP SIMULATION WITH DLL BLOCK

Fig. 4.1 shows the open loop simulation diagram of proposed topology. Three phase bridge rectifier is used to generate DC supply for field of synchronous motor. Input voltage and current are sense and it given to the DLL lock. According to DLL algorithm program power factor is calculated and it is compare with actual power factor.

Fig. 4.2 shows the algorithm for DLL block to calculate power factor from method 1. As shown in Fig. 4.2 power factor is measured by taking the waveforms of voltage and current. As per this algorithm counters will start when the voltage and current are positive. By taking the difference between the voltage and current power factor will be calculated. But here one problem is occurred, when transient take place. Due to this transient zero crossing of voltage and current fails to give actual power factor.

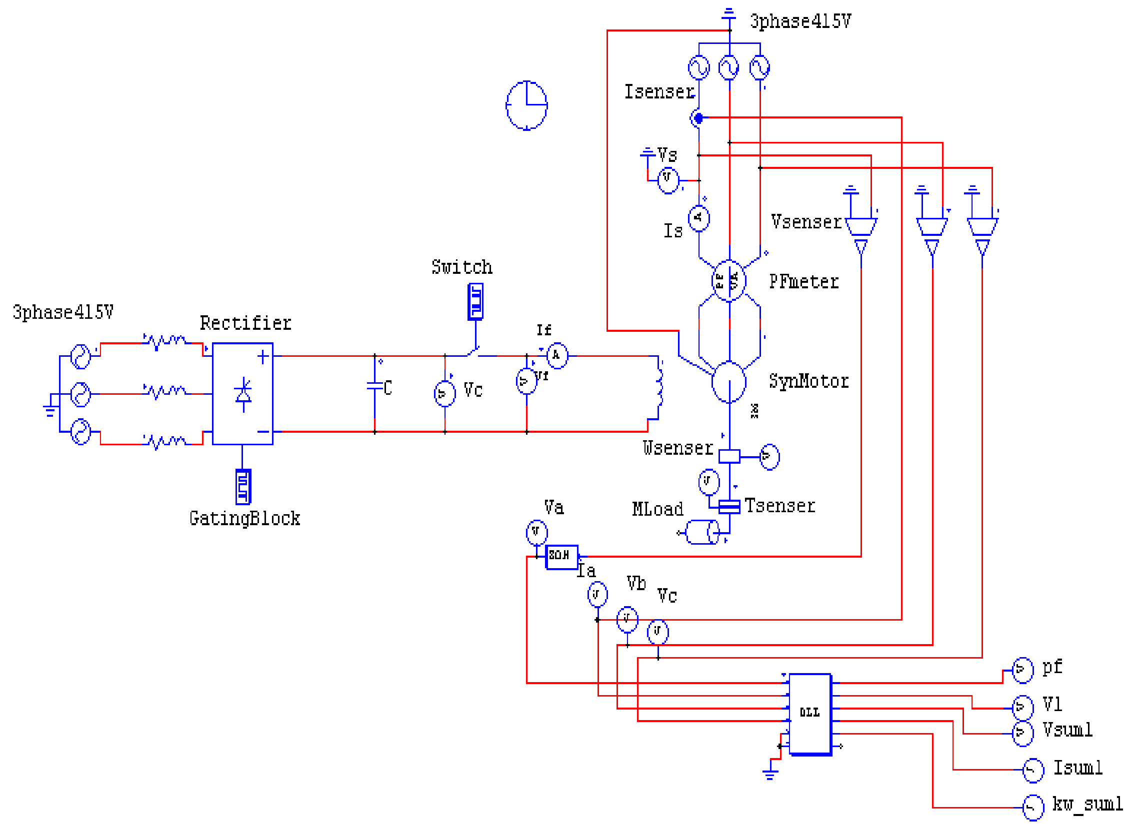


Fig. 4.1 Open Loop simulation with DLL block

4.2.1 Flow-chart for the power factor program (method 1)

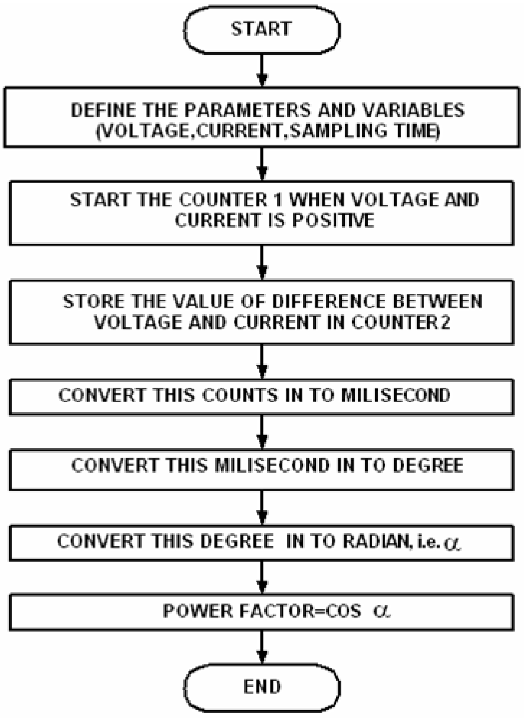


Fig. 4.2 Algorithm of the DLL Program- Method-1.

4.2.2 Flow-chart for the power factor program (method 2)

Fig. 4.3 shows the algorithm for DLL block to calculate power factor from method 2. In this method power factor is calculated using active and apparent power in one cycle. By taking sample 1 cycle is equal to 256 count.

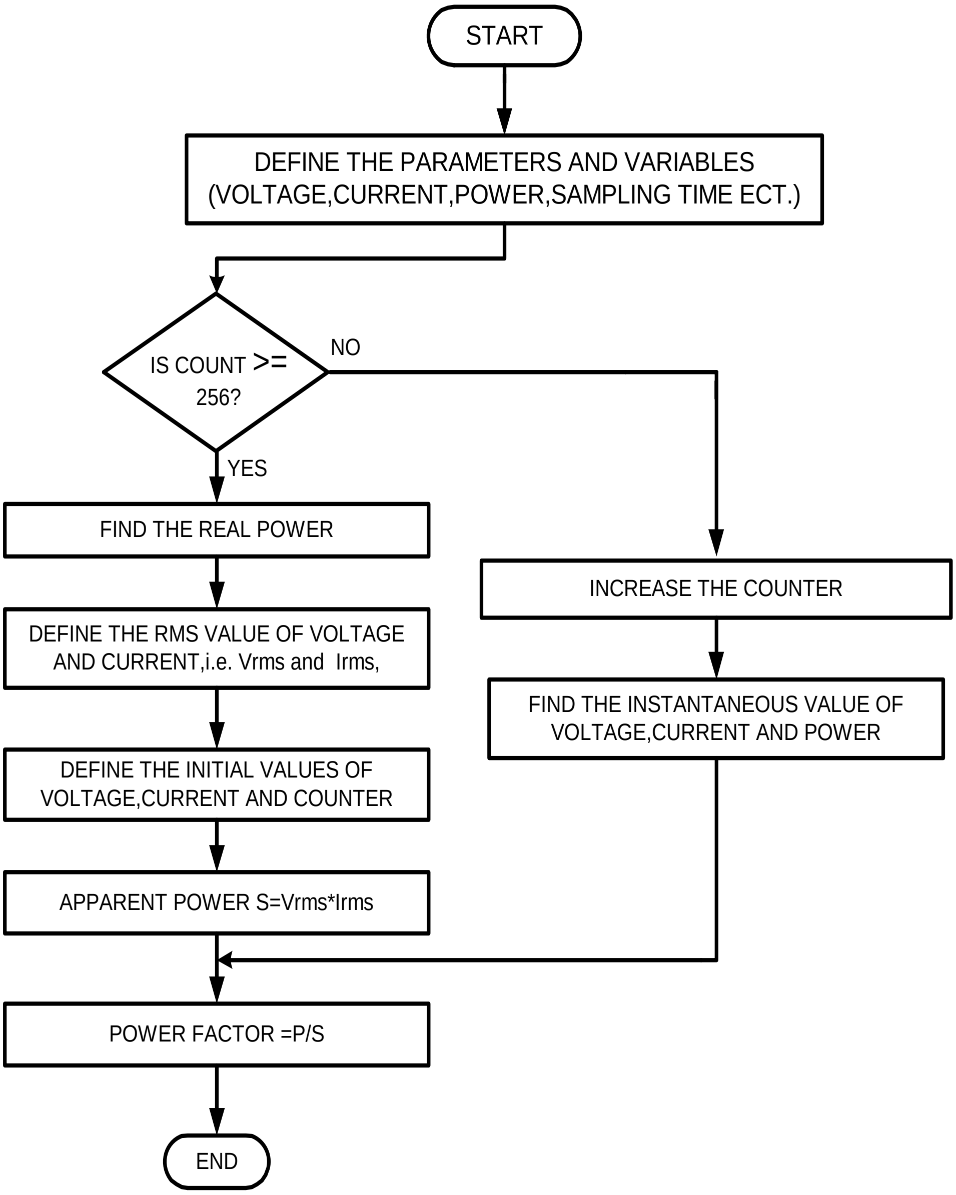


Fig. 4.3 Algorithm of the DLL Program (Method-2).

Fig. 4.4 shows the field current, field voltage and speed at firing angle of α=119°. Fig. 4.5 shows the calculated and actual power factor of the system. As shown in the fig. 4.5 DLL output power factor and System power factor is similar. So the program is successfully implemented in the DLL block. Fig. 4.6 shows the system input voltage and current to check the status of power factor.

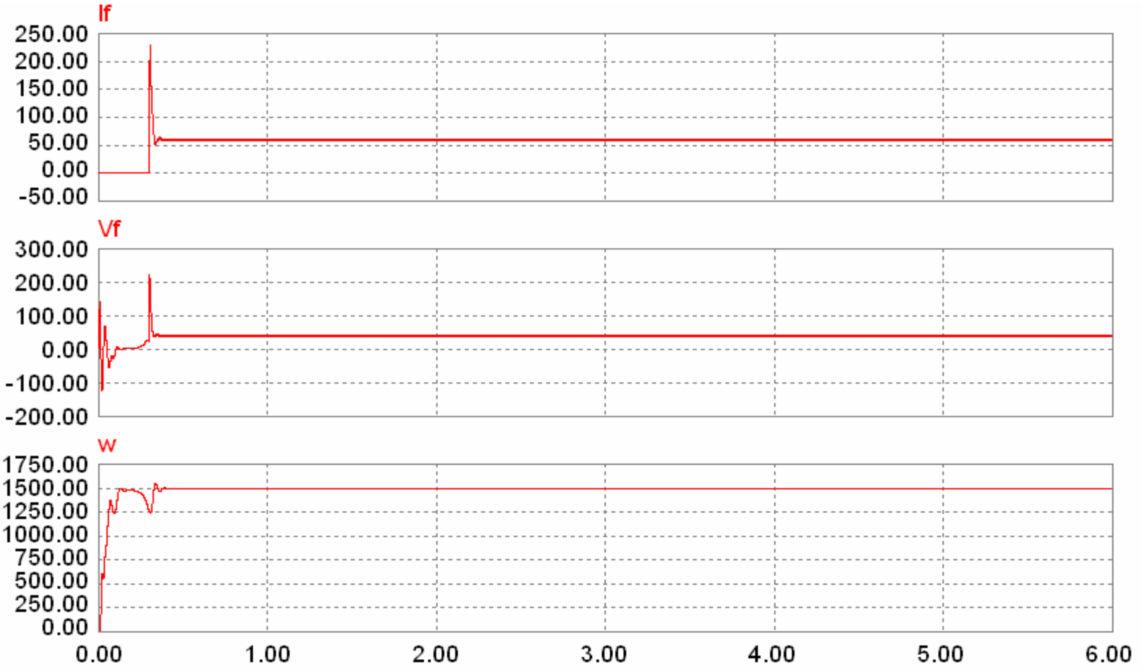


Fig. 4.4 Field current, field voltage, and speed for firing angle (α=119°)

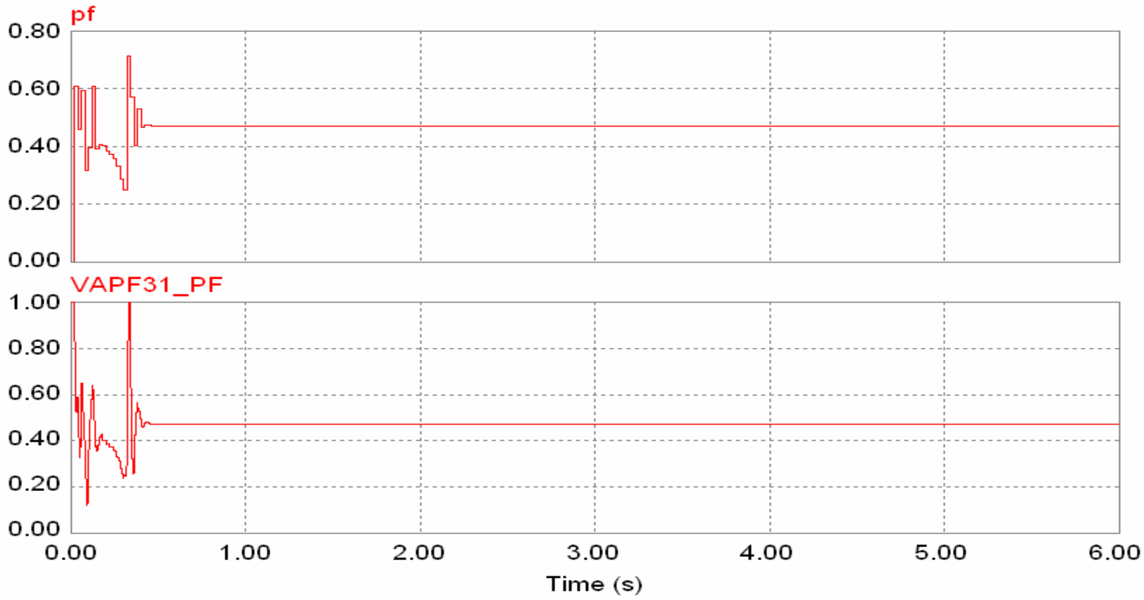


Fig. 4.5 Calculated and actual power factor for firing angle (α=119°)

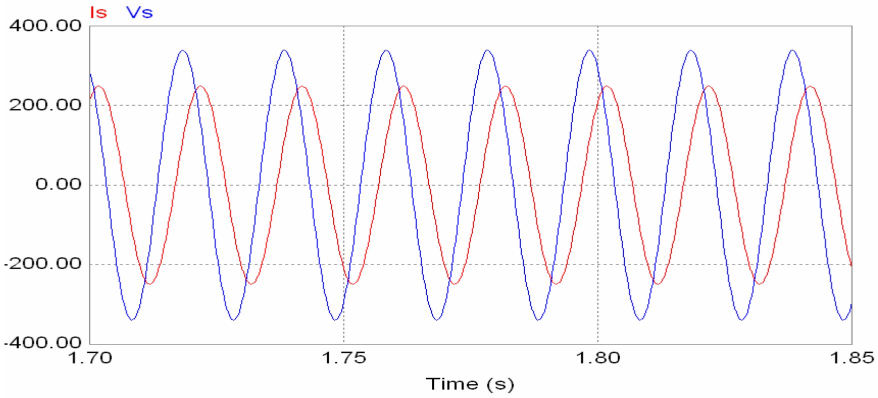


Fig. 4.6 Input Voltage and Current Waveforms (α=119°)

In below section at different firing angle α, waveforms of field current, field voltage, speed, calculated and actual power factor are shown.

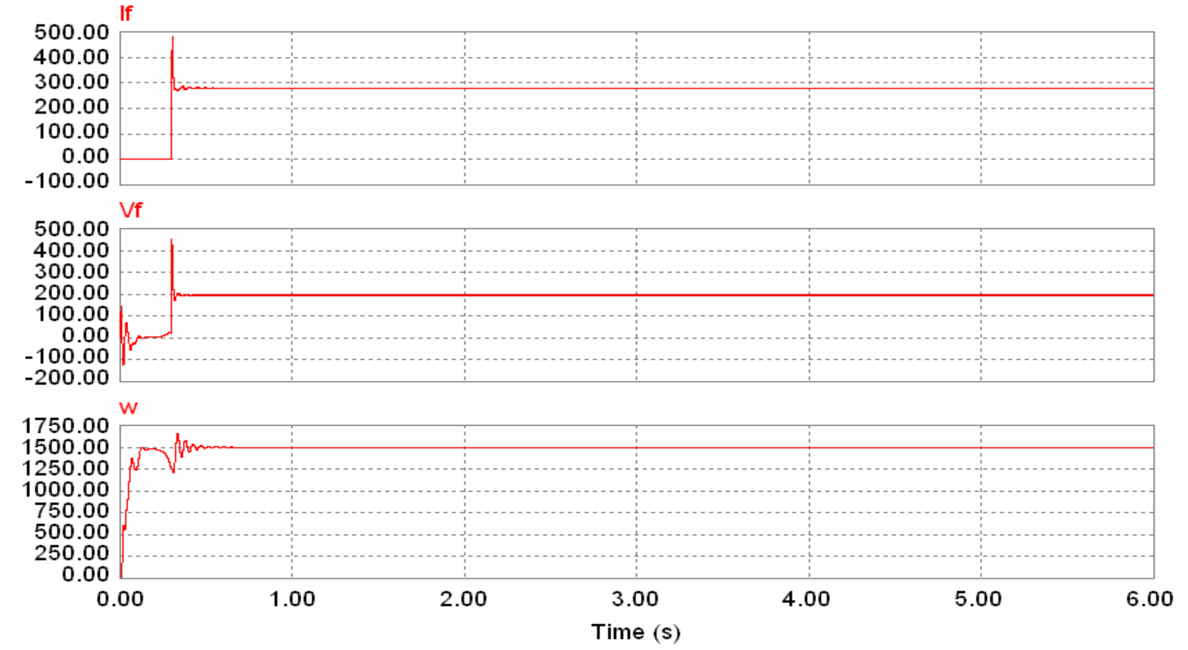


Fig. 4.7 Field current, field voltage, and speed for firing angle (α=91°)

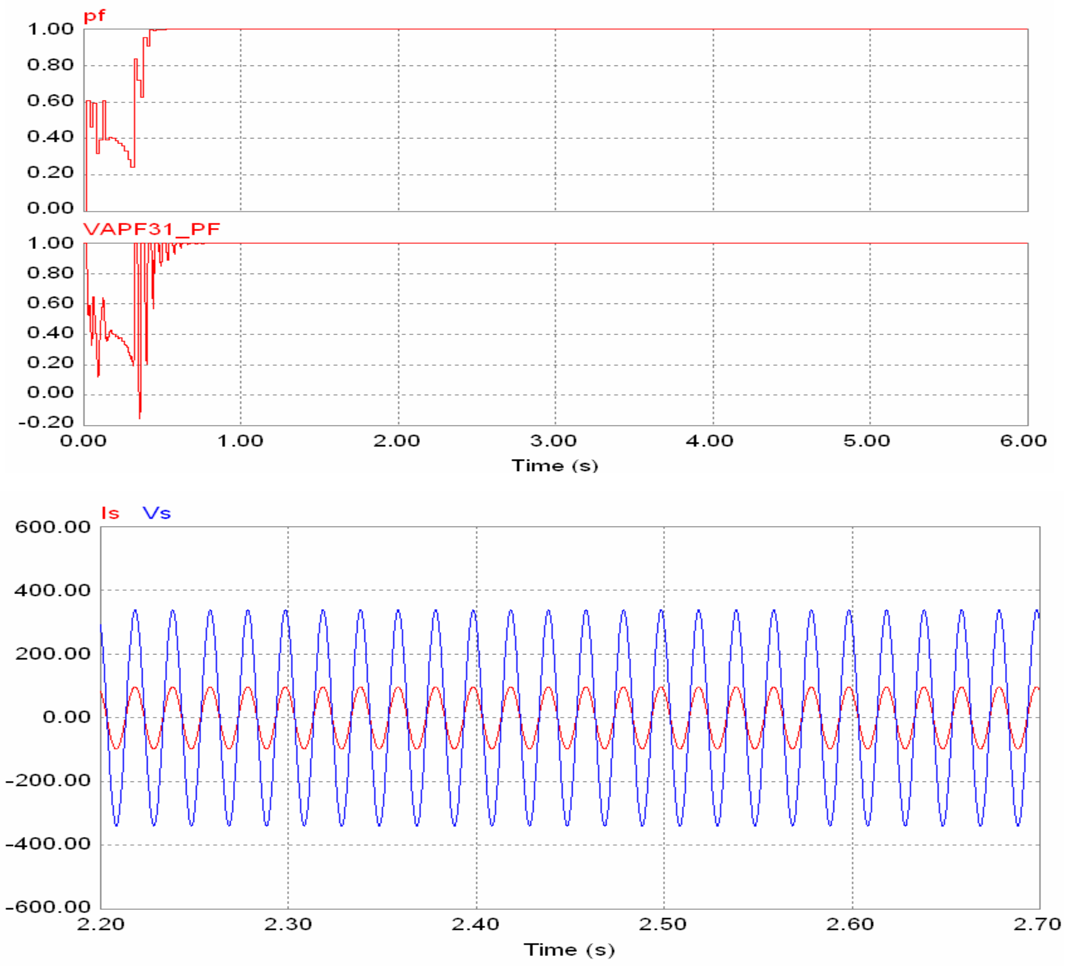


Fig. 4.8 Calculated and actual power factor, input current and voltage for firing angle (α=91°)

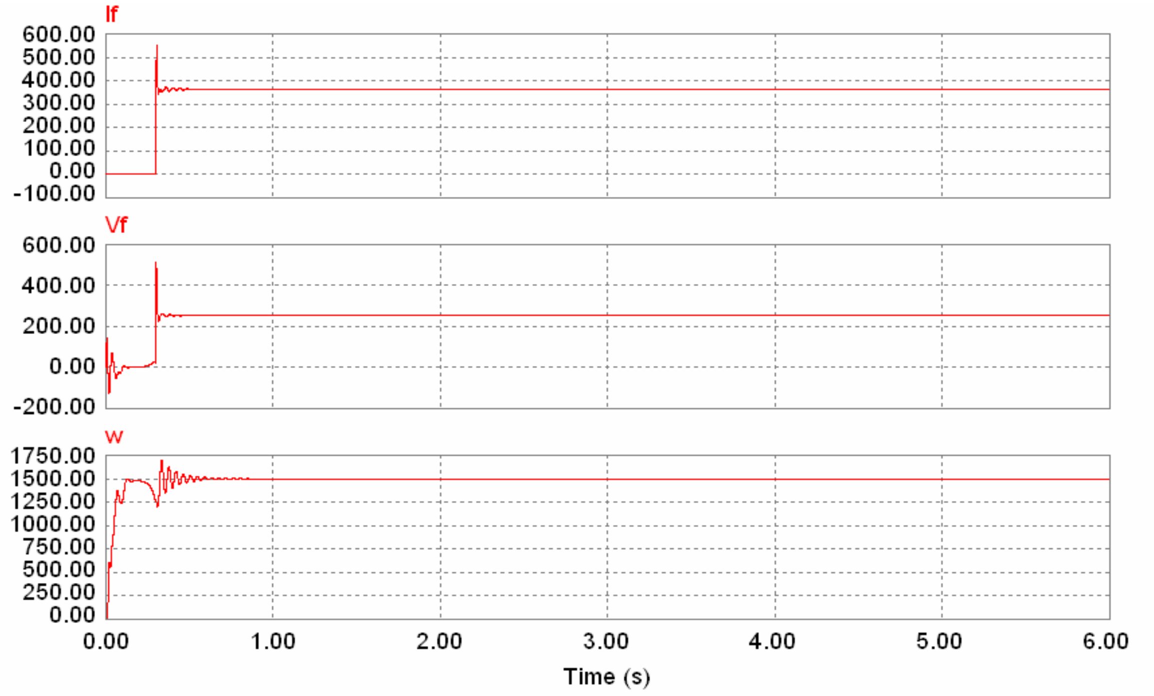


Fig. 4.9 Field current, field voltage, and speed for firing angle (α=53°)

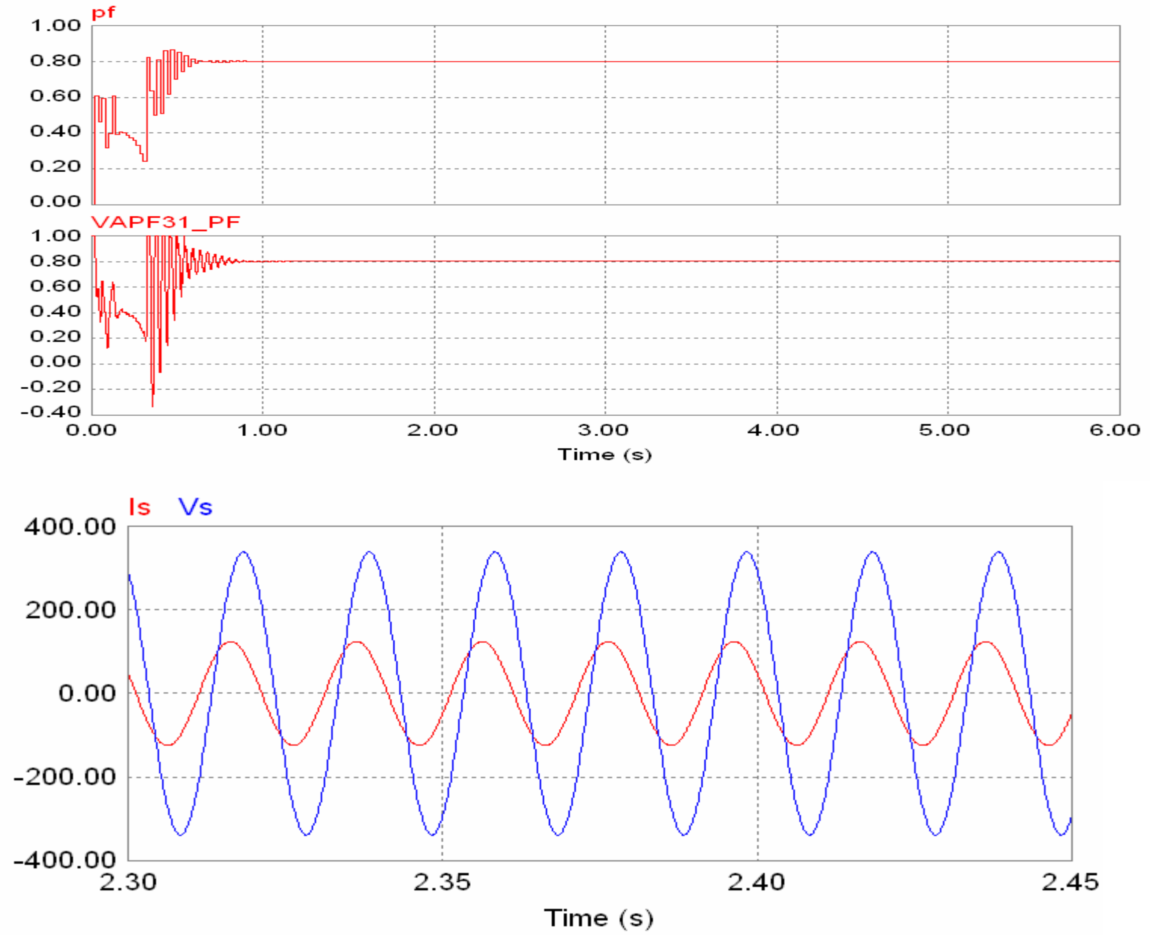


Fig. 4.10 Calculated and actual power factor, input current and voltage for firing angle (α=53°)

RESULT TABLE 1 :(For Open Loop Simulation)

Sr. No.	Firing Angle ($\alpha°$)	I_f (Field Current) A	V_f (Field Voltage) V	DLL output P.F.	System P.F.	Status
1.	119	56	39	0.46	0.47	Lagging
2.	100	189	133	0.8	0.8	Lagging
3.	91	238	167	1	1	Unity
4.	85	277	195	0.91	0.91	Leading
5.	80	364	254	0.8	0.8	Leading
5.	60	463	324	0.52	0.52	Leading
6.	53	494	346	0.46	0.47	Leading

So here from the result table 1 and from the waveforms at the different firing angle PF variation range is decided. Beyond tabulate range of power factor the waveforms of the field current (I_f), Field voltage (V_f) and speed (ω) are distorted. So that is not adequate for the stable and smooth operation of the motor. At the unity power factor the value of the field current is known as *normal excitation current*.

4.3 CLOSE LOOP SIMULATION WITH DLL BLOCK:

As shown in the Fig. 4.10 actual power factor is taken as a feedback. By giving the reference power factor to the error detector difference is generated. Based on that firing angle will be set and according to that field current will also set and maintain the constant Power factor. Once the desired power factor will enter then even if the load is change then also set power factor will maintain at synchronous speed. In Fig. 4.11 waveforms of the field voltage (V_f), field current (I_f), power factor are shown. Here different Reference power factor (or Set PF) is taken.

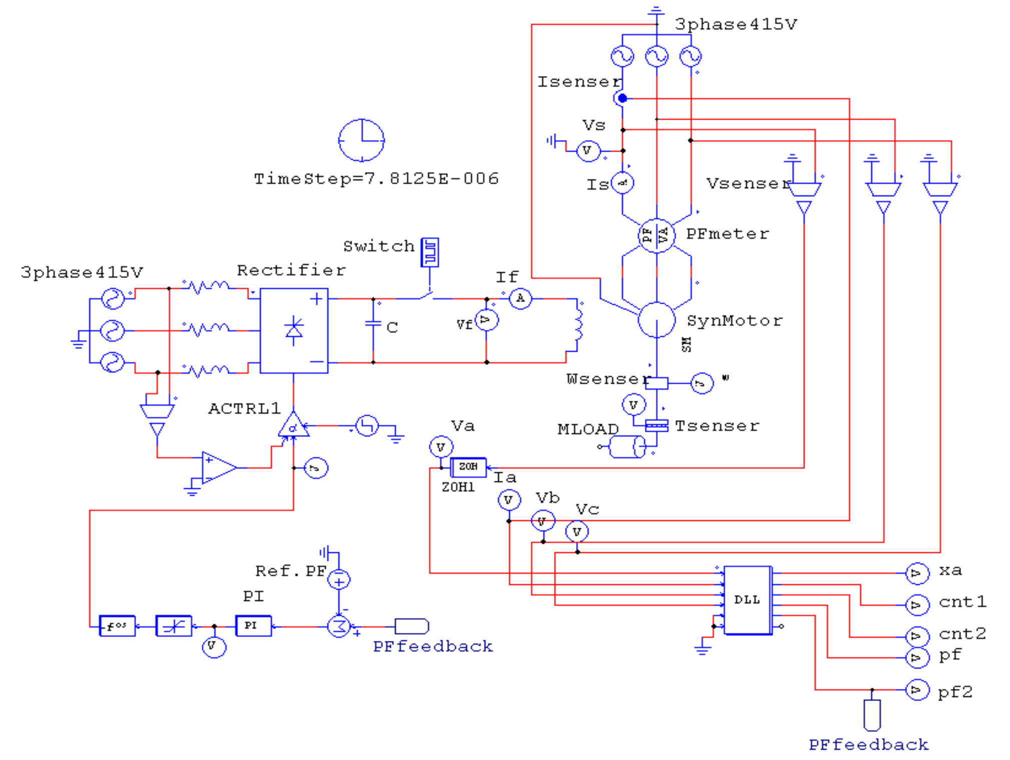


Fig. 4.11 Close Loop Simulation with DLL Block

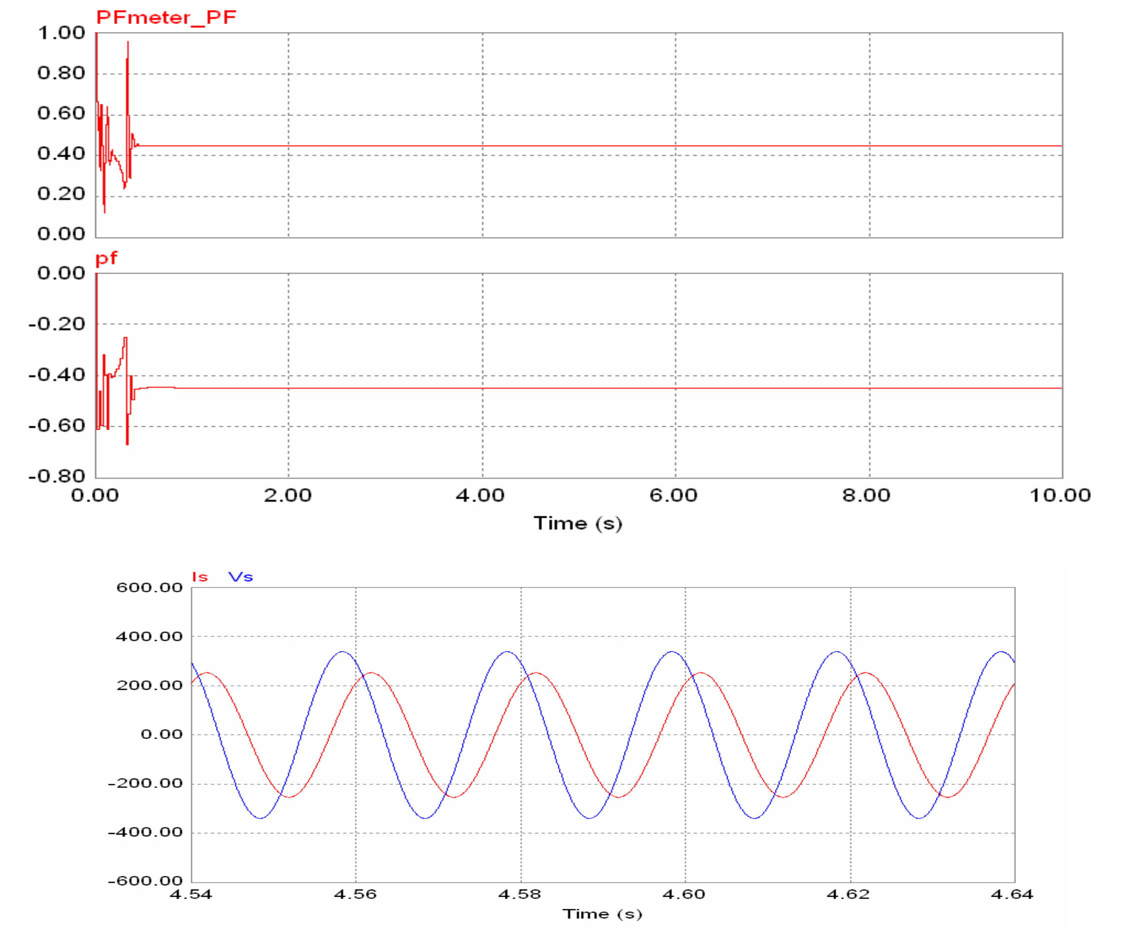


Fig. 4.12 Calculated and actual power factor, input current and voltage for firing angle (ref= 0.45 p.f. lag)

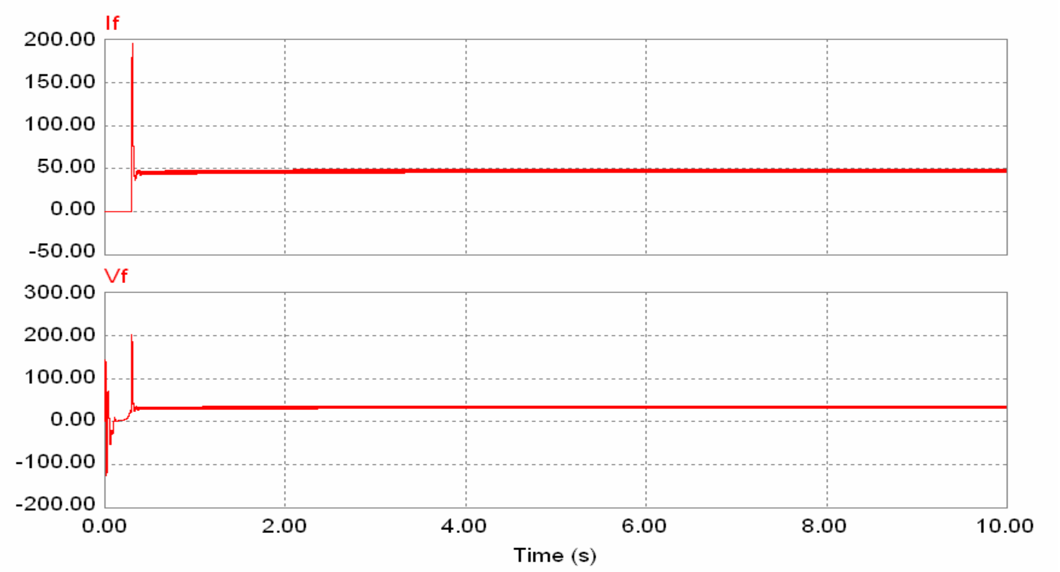


Fig. 4.13 Waveforms of field current (I_f), field voltage (V_f), $I_f = 46$ A, $V_f = 32$ V. (ref= 0.45 p.f. lag)

By taking the values of the different power factor (Reference) simulation is carried out. For particular reference power factor corresponding waveforms of actual power factor (PFmeter), DLL output power factor (PF), Stator current and voltage, field current (I_f), field voltage (V_f), waveforms are shown in below section.

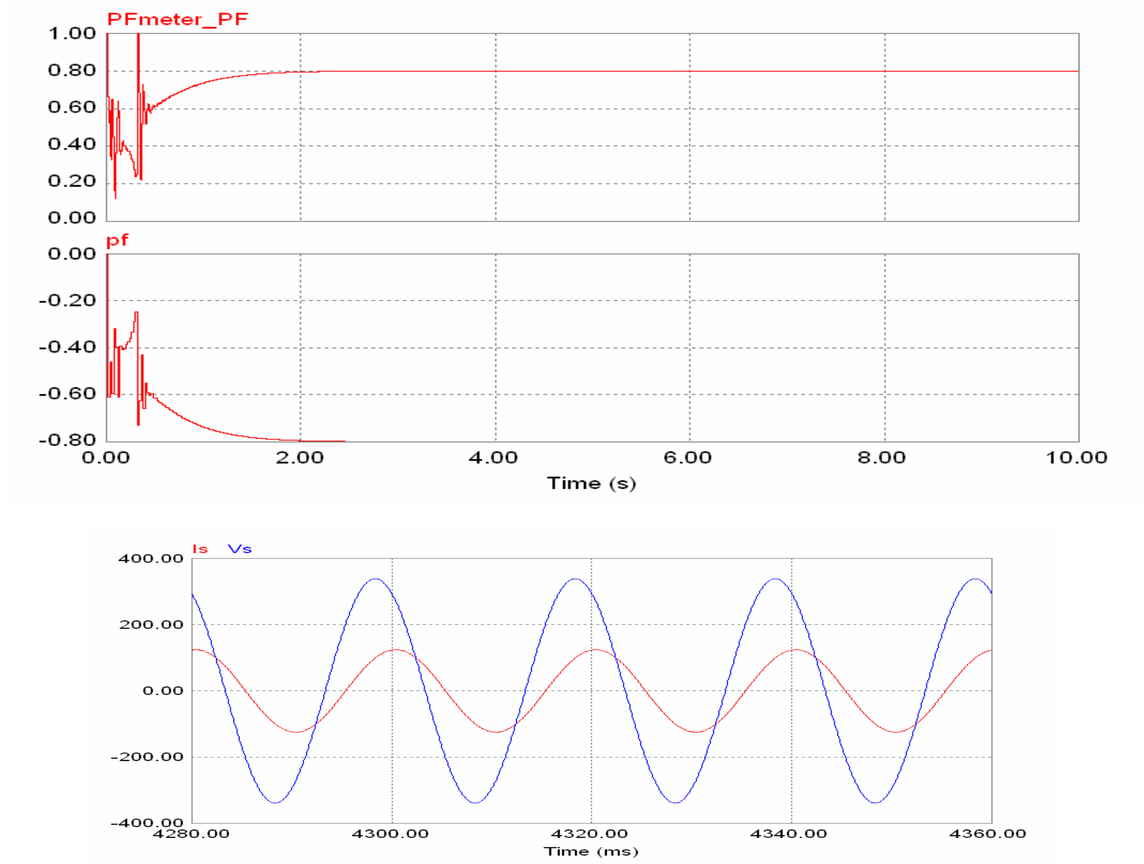


Fig. 4.14 Calculated and actual power factor, input current and voltage for firing angle (ref= 0.8 p.f. lag)

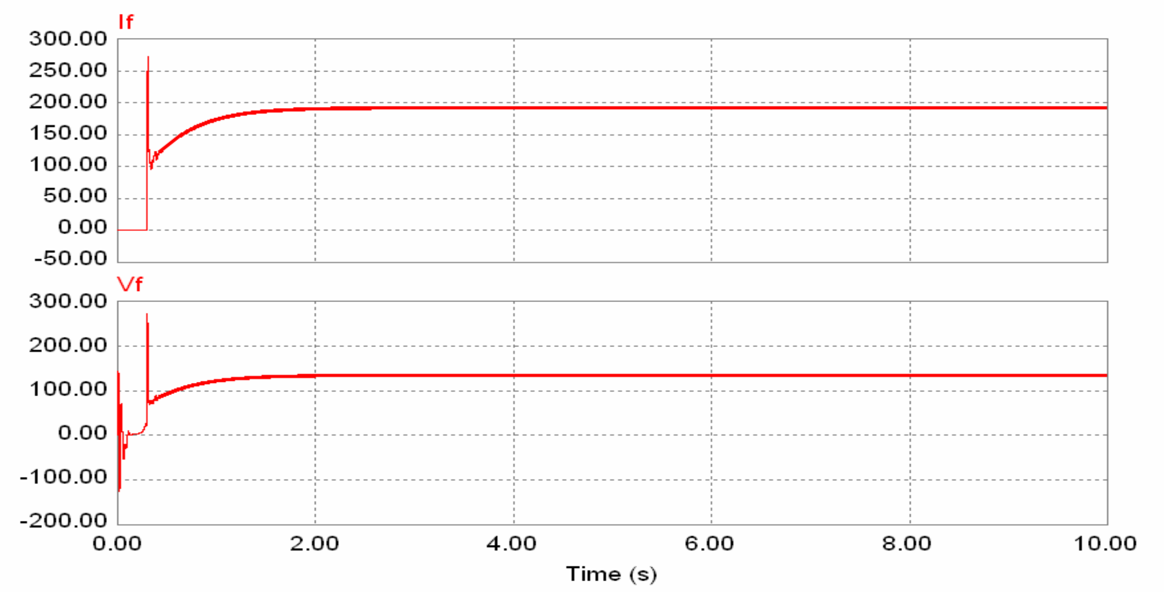


Fig. 4.15 Field current (I_f), field voltage (V_f), $I_f = 191$ A, $V_f = 135$ V (ref= 0.8 p.f. lag)

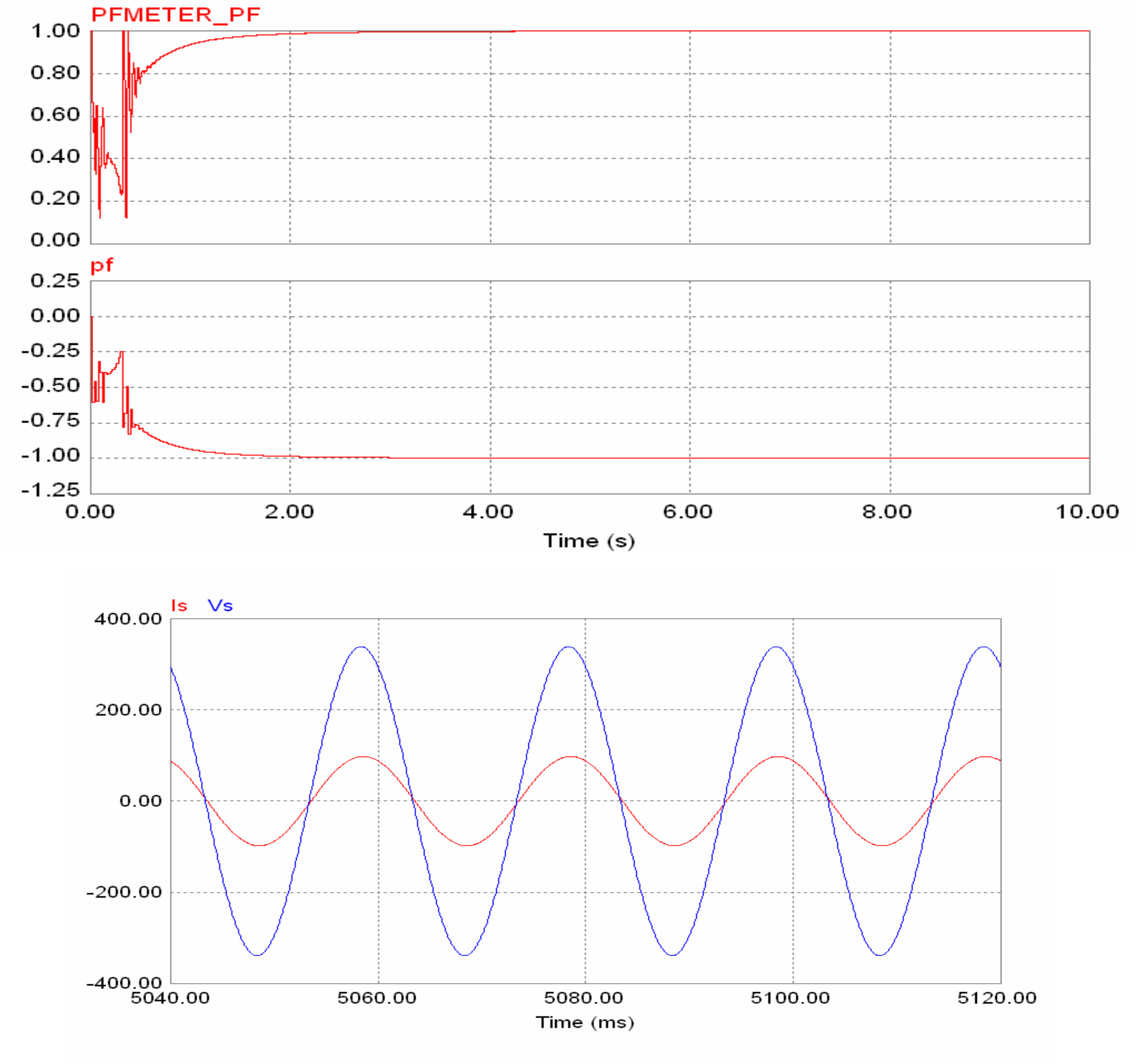


Fig. 4.16 Calculated and actual power factor, input current and voltage for firing angle (ref= unity p.f.)

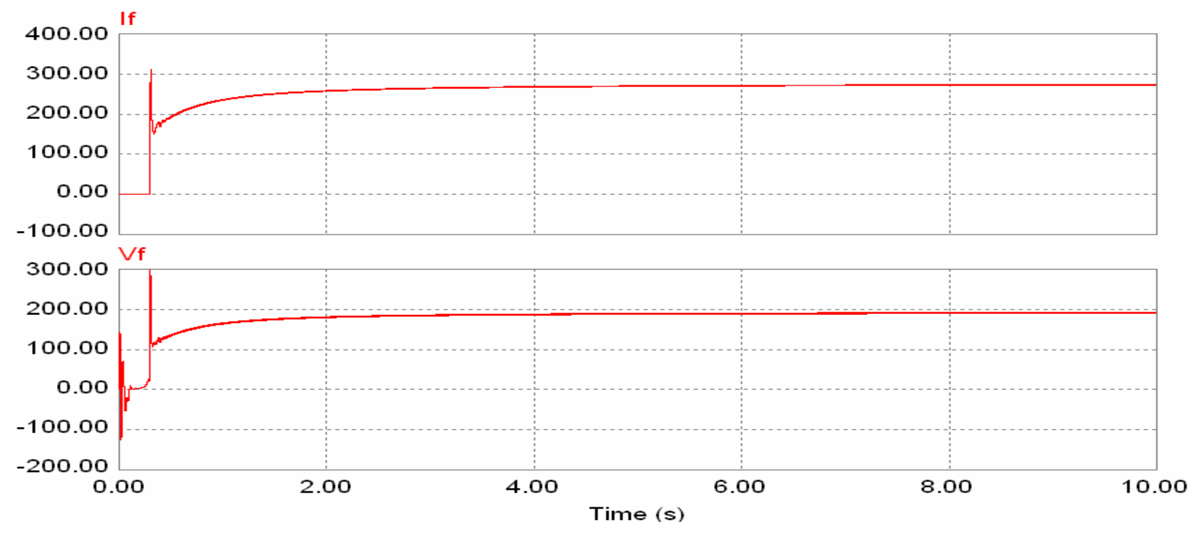


Fig. 4.17 Field current (I_f), field voltage (V_f), I_f = 270 A, V_f = 190 V (ref= unity p.f.)

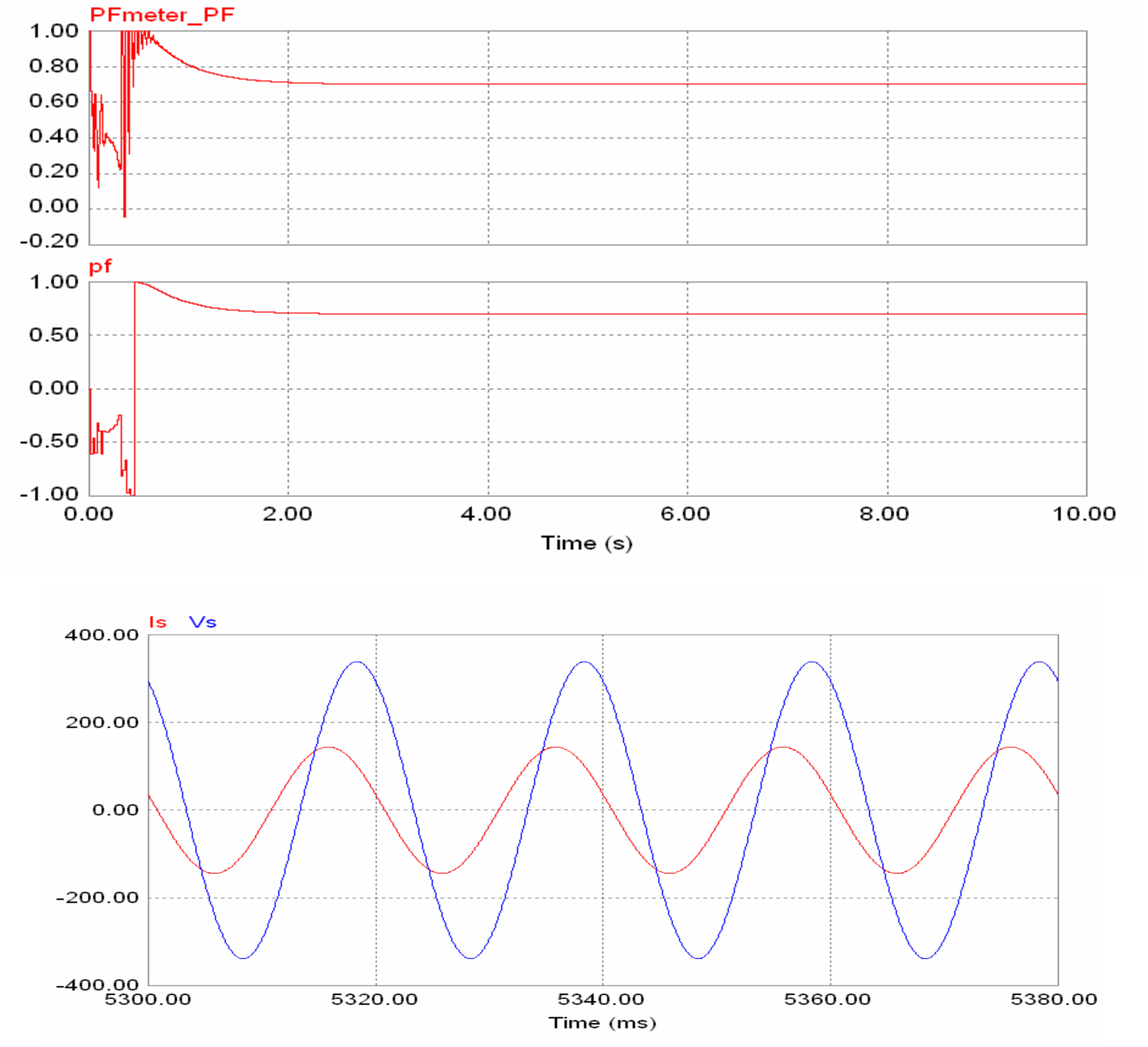


Fig. 4.18 Calculated and actual power factor, input current and voltage for firing angle (ref= 0.7 p.f. lead)

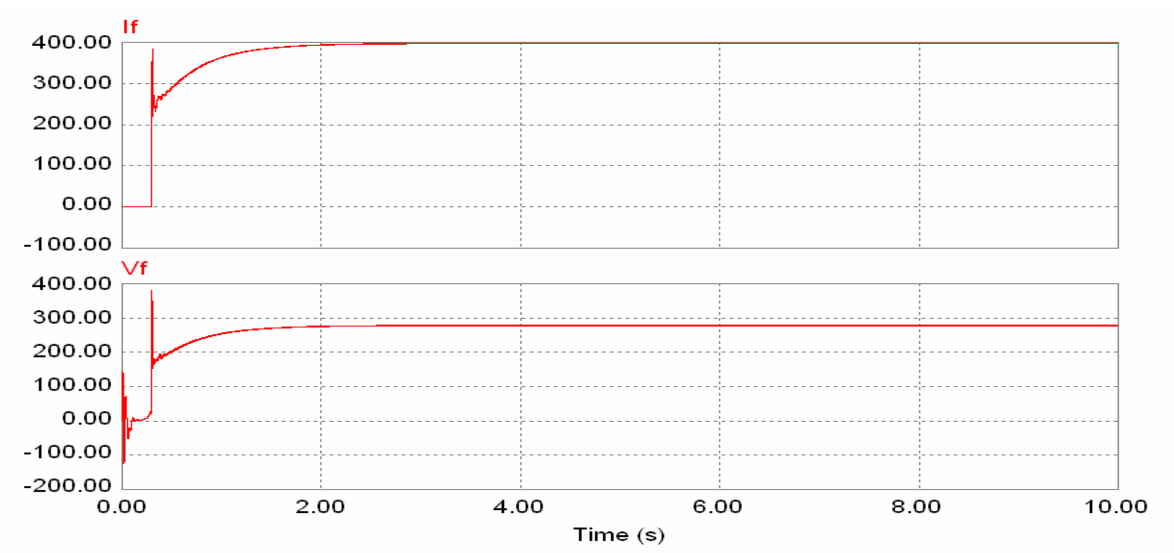
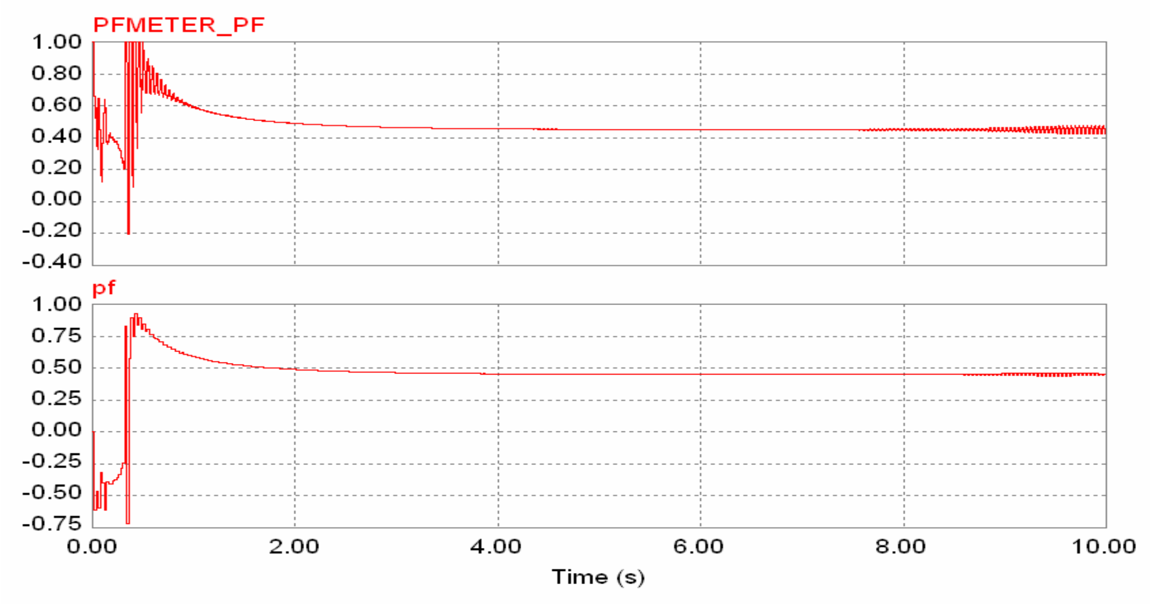


Fig. 4.19 Field current (I_f), field voltage (V_f), $I_f = 397$ A, $V_f = 278$ V (ref= 0.7 p.f. lead)



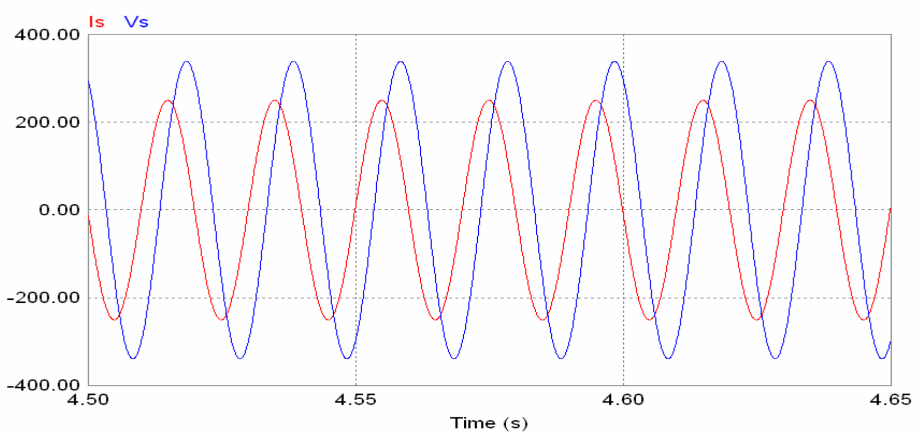


Fig. 4.20 Calculated and actual power factor, input current and voltage for firing angle (ref= 0.45 p.f. lead)

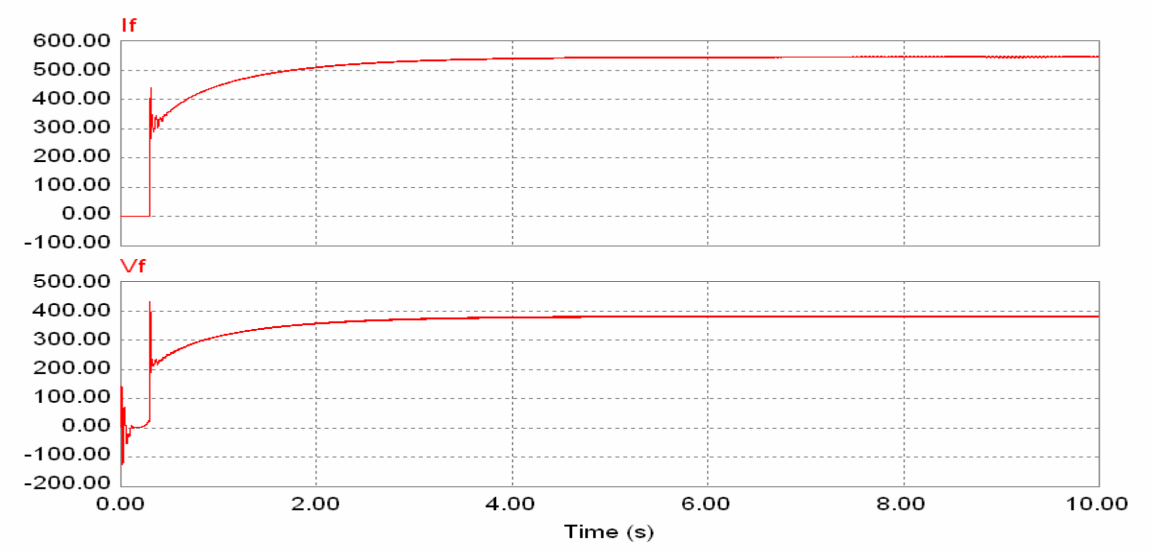


Fig. 4.21 Field current (I_f), field voltage (V_f), $I_f = 542$ A, $V_f = 382$ V (ref= 0.45 p.f. lead)

RESULT TABLE 2: (FOR CLOSE LOOP SIMULATION)

Sr. No.	Ref. PF (Set PF)	I_f (Field current)	V_f (Field Voltage)	DLL output PF (Calculated PF)	Actual PF
1.	0.45 (Lagging)	46	32	0.45	0.45
2.	0.5 (Lagging)	75	55	0.5	0.5
3.	0.6 (Lagging)	125	87	0.6	0.6
4.	0.7 (Lagging)	162	115	0.7	0.7
5.	0.8 (Lagging)	191	135	0.8	0.8
6.	0.9 (Lagging)	223	155	0.9	0.9
7.	**1.0 (Unity)**	**270**	**189**	**1.0**	**1.0**
8.	0.9 (Leading)	332	233	0.9	0.9
9.	0.8 (Leading)	363	253	0.8	0.8
10.	0.7 (Leading)	397	278	0.7	0.7
11.	0.6 (Leading)	440	307	0.6	0.6
12.	0.5 (Leading)	500	351	0.5	0.5
13.	0.45 (Leading)	542	382	0.45	0.45

So here from the different simulation results for the different reference power factor waveforms of power factor (Actual and DLL output), stator current and voltage, field current (I_f), Field voltage (V_f), are taken. Here minimum set range of the power factor is 0.45. Power factor will be change from 0.45 to unity and also up to 0.45 leading. In the Fig. 4.11 to Fig. 4.20 the waveforms for the different set power factor i.e. 0.45(Lagging), 0.8(Lagging), 1(Unity), 0.7(Leading), 0.45(Leading) and related that power factor waveforms of the power factor (Actual and DLL output), stator current and voltage, field current (I_f), Field voltage (V_f), are shown.

4.4 POWER FACTOR VARIATION IN THE CLOSE LOOP

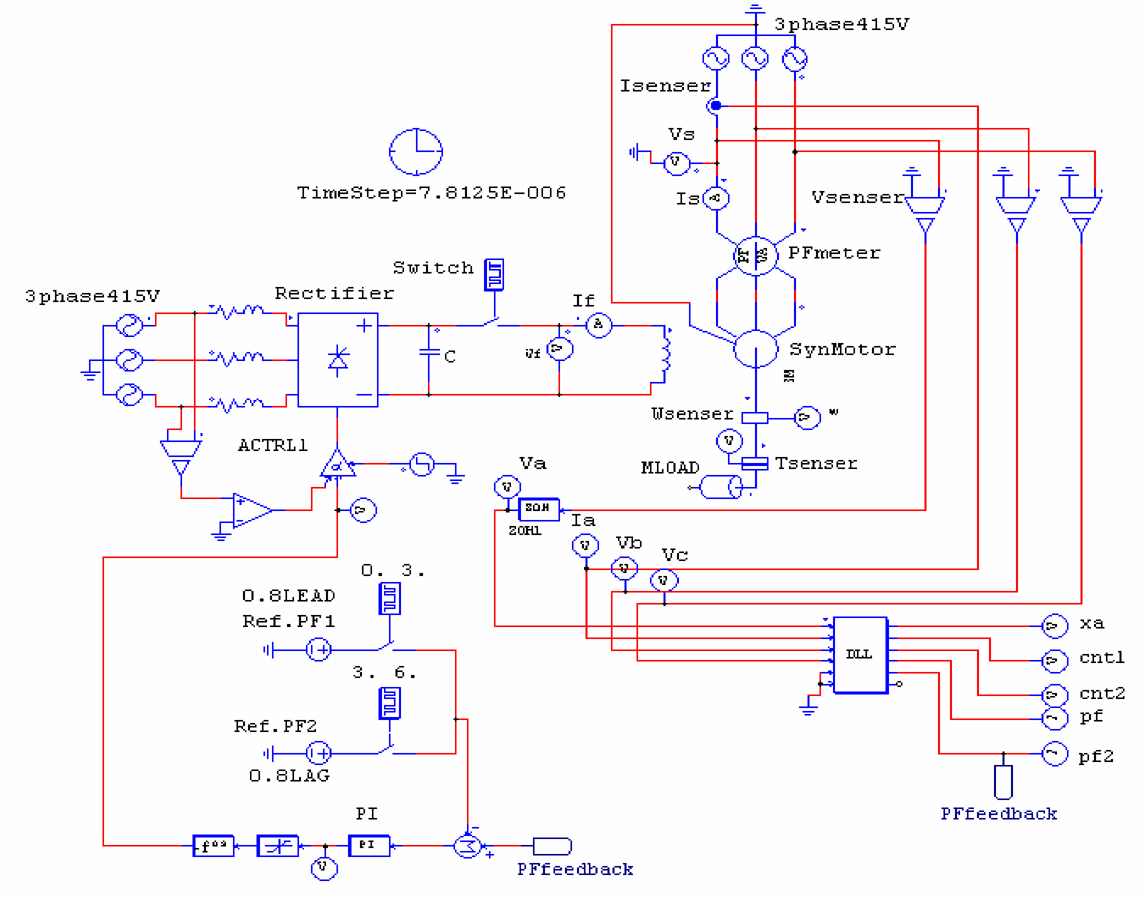


Fig. 4.22 PF variation in close loop System

In this digital excitation control system power factor is also change from one set value to another set value. As shown in Simulation diagram Fig. 4.22 the power factor is given 0.8 lead for 0 to 3 sec and 0.8 lagging for the 3 to 6 sec. From the waveform it’s clearly seen that the field current and voltage is changed for the leading and lagging power factor. For leading power factor filed current is high and for lagging power factor field current is low, which is evident from the waveform.

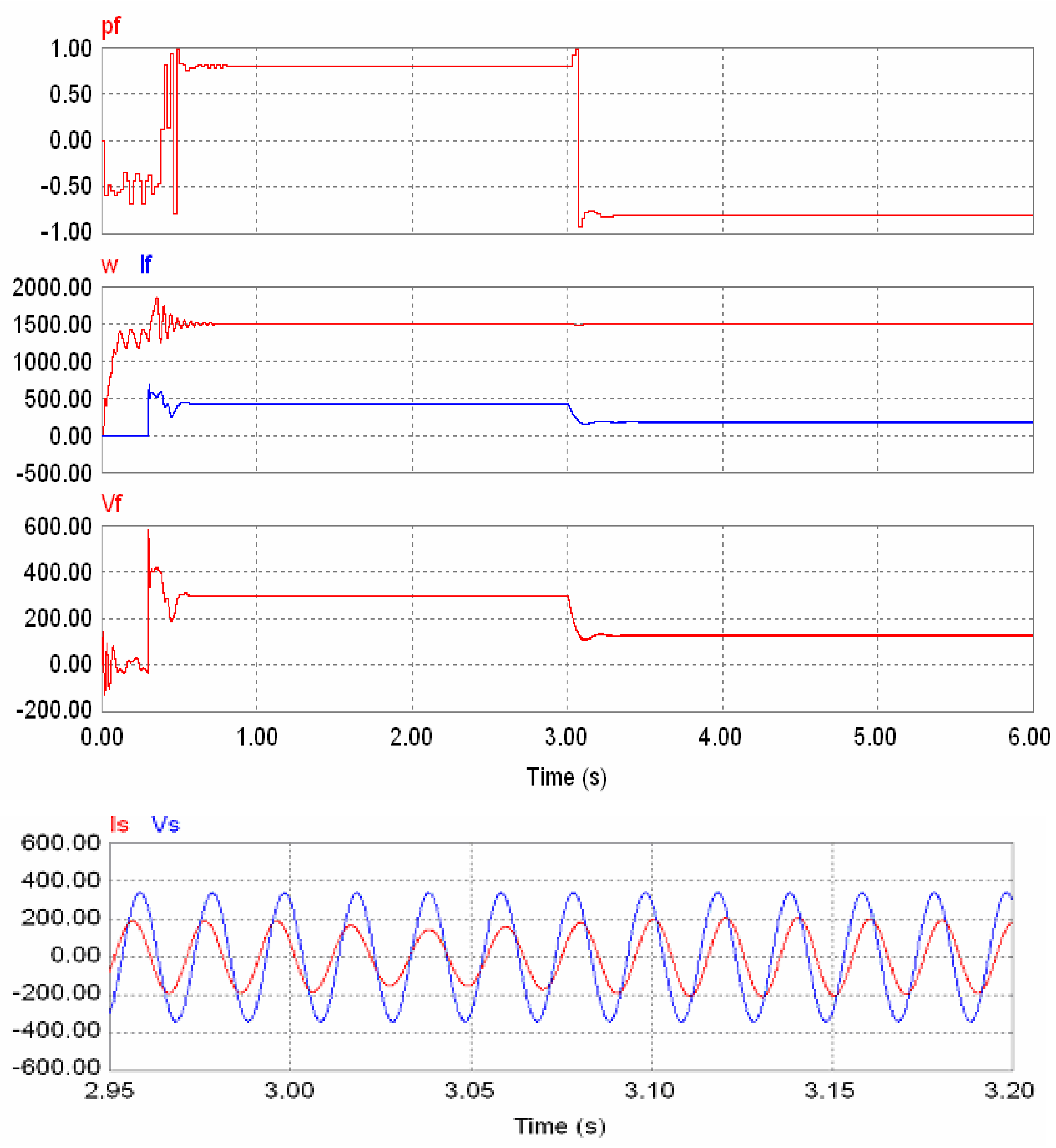


Fig. 4.23 Leading and Lagging power factor, speed, field current and voltage,
Stator current and voltage waveforms

As shown in Fig. 4.23 here the power factor is 0.8 lead for 0 to 3 sec and 0.8 lagging for the 3 to 6 sec. From the waveform it's clearly seen that the speed is constant when power factor is change over from leading to lagging. From the stator current and voltage waveform it's clearly seen that how the power factor is change from leading to lagging.

4.5 LOAD VARIATION IN THE CLOSE LOOP

As shown in Fig. 4.24 load variation is carried out. First of all simulation is carried out for no load condition and then other simulation is carried out for loading condition (300 N-m). It’s clearly observed from the simulation result in Fig. 4.25 and 4.26 the field current is changed for no load and full load condition to maintain the set power factor 0.9 Lead. For loading condition field current is increases to maintain the reference power factor 0.9 lead. Waveforms of power factor, speed, field current and voltage for no load condition and loading condition are shown in Fig. 4.25 and Fig.4.26.

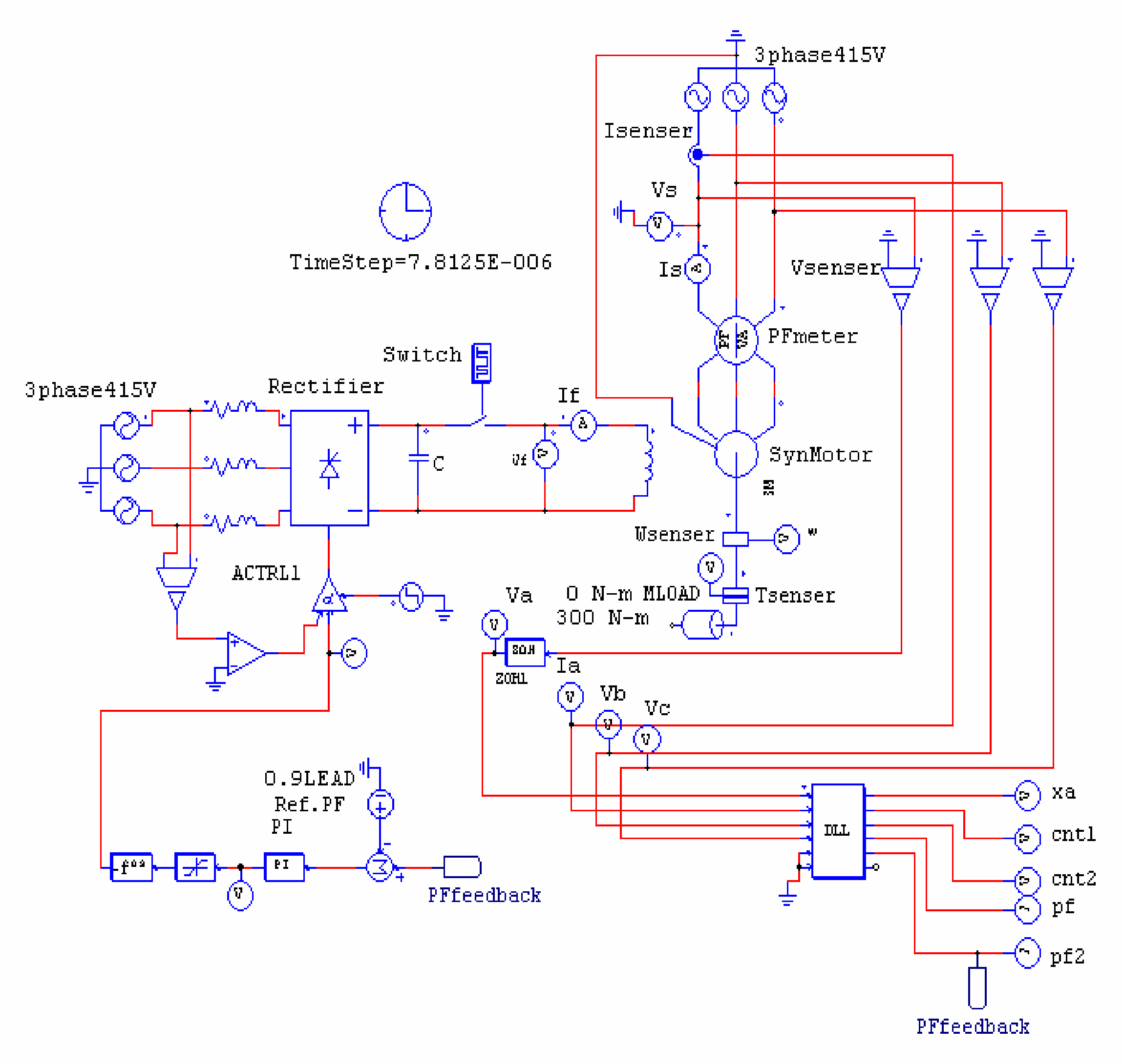


Fig. 4.24 Load variation in close loop System

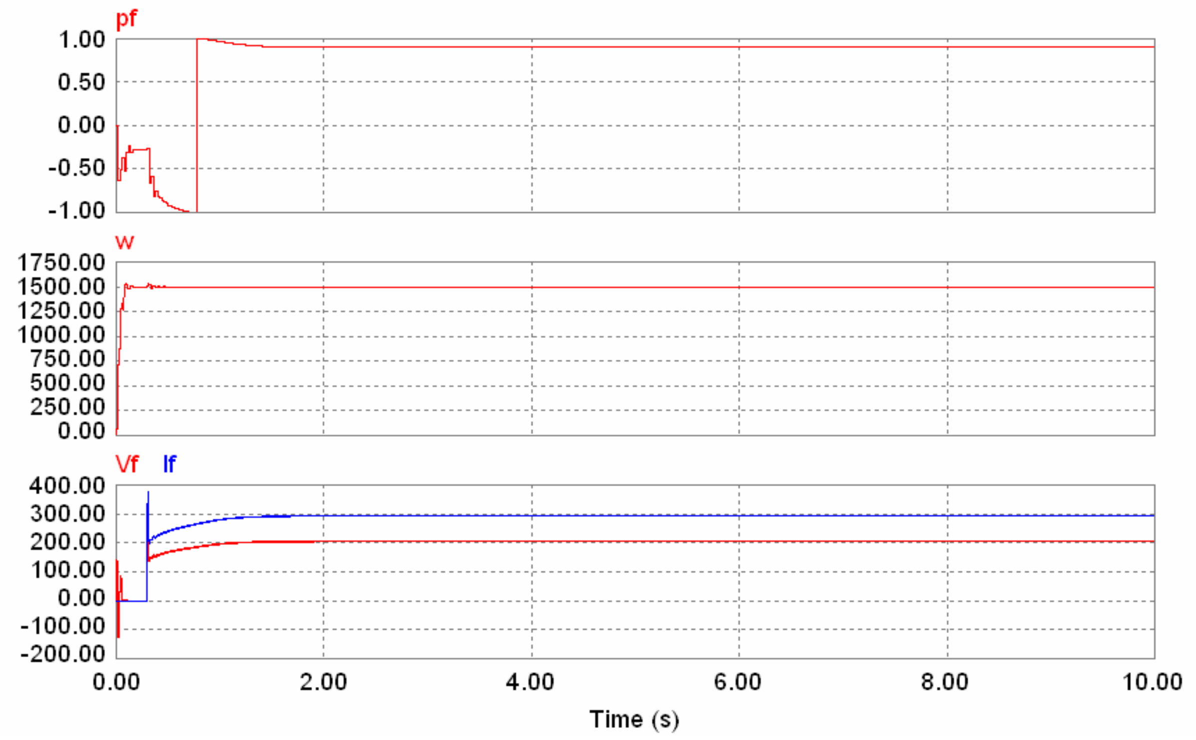


Fig. 4.25 Power factor, speed, field current, and voltage for no load condition ref pf =0.9 (Lead), I_f = 300 A, V_f = 200 V (NO LOAD)

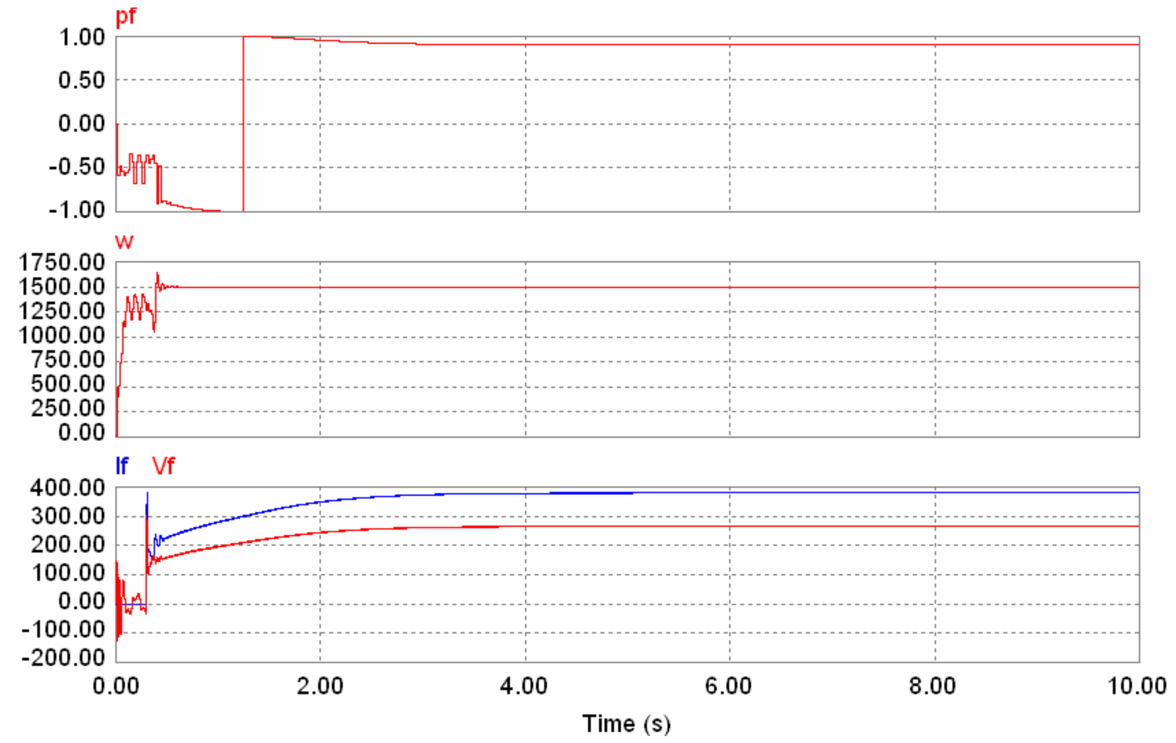


Fig. 4.26 Power factor, speed, field current, and voltage for loading condition ref Pf =0.9 (Lead), I_f = 380 A, V_f = 265 V (FULL LOAD=300 N-M)

4.6 CONCLUSION

From simulation results by changing the firing angle of the rectifier the excitation current, voltage and power factor would be change In open loop and close loop system Calculated (DLL output PF) power factor and actual (System) power factor is compared and both are same. From close loop simulation it’s observed that if load is change then firing angle is changed automatically. By giving the desired power factor as a reference the firing angle will change automatically and set the necessary field current and maintain the constant power factor. Selecting the appropriate excitation system depends on the field current required for the motor field. Finally from the simulation results the power factor of the motor can be change within certain range and motor is operated at unity or leading power factor as per requirement.

CHAPTER - 5: DSP CONTROL CARD AND PROGRAMING

For this Digital Excitation system DSP control card TMS320F2811 is used. Firing pulses for the thyristor based controlled rectifier are generated by using this card. Also power factor regulation program and other protection programs have been implemented in this card. So overview and other features of this card are as follow.

5.1 INTRODUCTION

The control board PCA-2005/B is a multipurpose board and specifically designed to meet the high-end performance of the power electronics products like Soft Starter, AC Power Controller & Control Rectifier.

It uses 32-bit High-Performance Digital Signal Processor TMS320F2811. The control board generates the control signals for phase controlled rectifier. It accepts various inputs from different control circuits and digital operation panel (LCD keypad) to generate the necessary control and gate signals.

The TMS320F2811 (U1) is the heart of this card. It handles the user interfaces and core algorithm and generates Thyristor gate signals. The PCA-2005B is connected to PCA-2012 Display Card with RS-485 link. PCA-2012 displays the parameters of the Excitation system.

This card has different blocks for the voltage and current measurements. It measures the following:

- Input voltage V_{RY} & V_{YB}
- Feedback voltage
- Output Voltage
- Input current of R, Y and B phase
- Heat sink temperature
- Analog input references 0~10V
- Analog input references 4~20mA

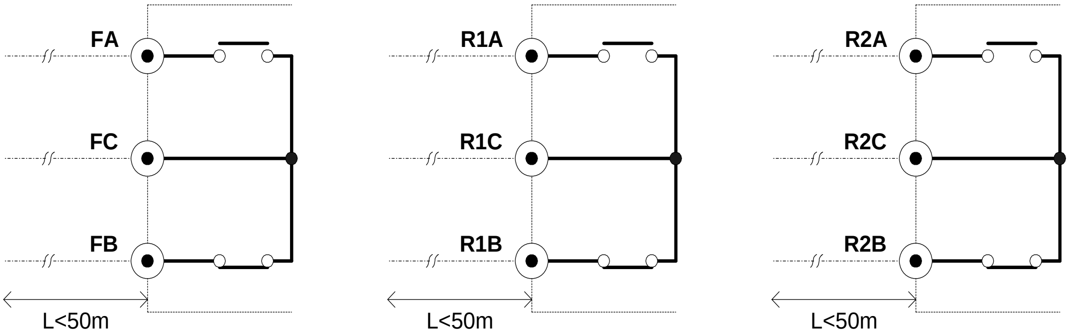
➢ POWER SUPPLY

PCA-2005B uses different power supply for its peripherals. They are +1.9V, +3.3V, +5V, -15V, +15V and +24V. External Power Supply Board (SMPS) is used to get

+5V, +15V, +24V and –15V. They are available at J6 of PCA-2005B. +1.9V and +3.3V are derived internally from +5V.

➢ PROGRAMMABLE RELAYS (K2 & K3) AND FAULT RELAY (K1)

Two programmable relays and one fault relay is available for the user. The programmable relays will function as per programmed option and the fault relay operates in case of fault occurrence.



FAULT RELAY PROGRAMMABLE RELAY1 PROGRAMMABLE RELAY2

Fig.5.1 the programmable relays

➢ SERIAL COMMUNICATION TERMINALS

This board provides two wire RS-485 serial communication using MODBUS-RTU protocol. Two terminals RX and TX are provided for this purpose. The terminal resistance (120Ω) between RX and TX can be introduced by placing Jumper JP3 to “LD” position.

➢ ENCODER FEEDBACK TERMINALS

These terminals are used to provide motor speed feedback, which is required in case of close loop operation. The line driver type +5V operated encoder is required for this purpose. Two channels A and B will be connected at PA, PAN and PB, PBN terminals respectively. This board also provides +5V power supply required by the encoder. Refer additional information for the wiring and usage of encoder. These terminals are reserved for the future use.

➢ CAN BUS COMMUNICATION TERMINAL

Two terminals (CANH & CANL) are reserved for the CAN Bus communication for the future use.

➢ INPUT VOLTAGE FEEDBACK CIRCUIT

Three-phase input is connected to J3, J4 & J5. The signal is then isolated and attenuated through differential amplifier circuit using U10. The attenuated analog signal of V_{RY} phase and V_{YB} phase are given to ADC of digital signal processor. *The analog signal at this point will be approximately 1.8 volt rms @ 415Vac***.** The zero crossing detector of V_{RY} is also provided to the DSP.

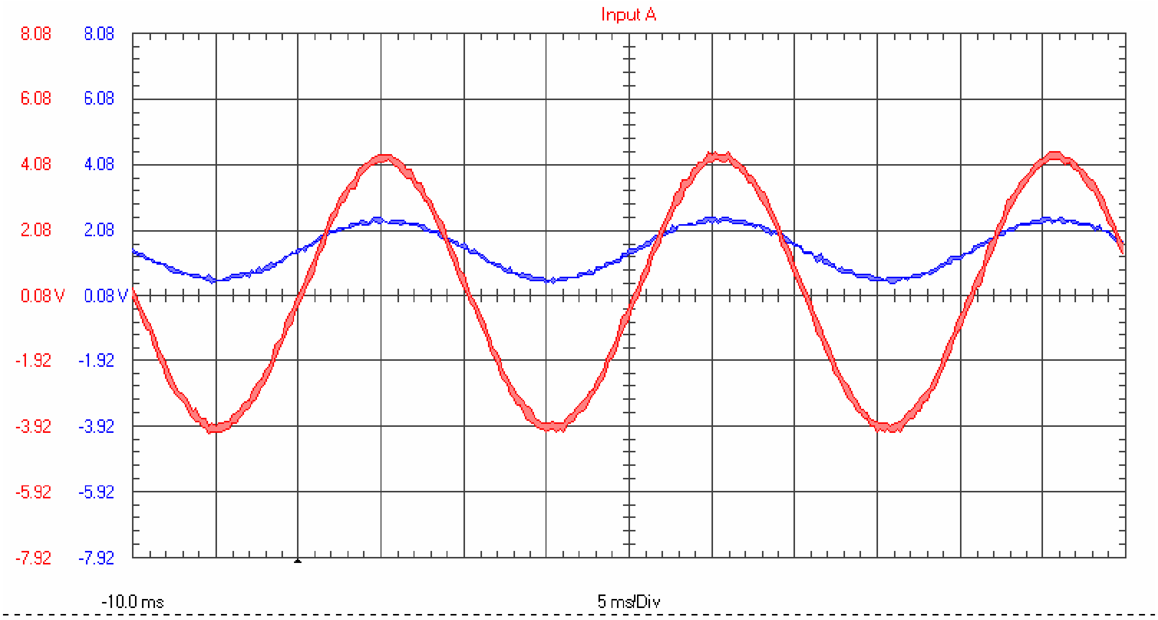


Fig. 5.2: Waveform at VIRY on CH-A and D13 on CH-B.

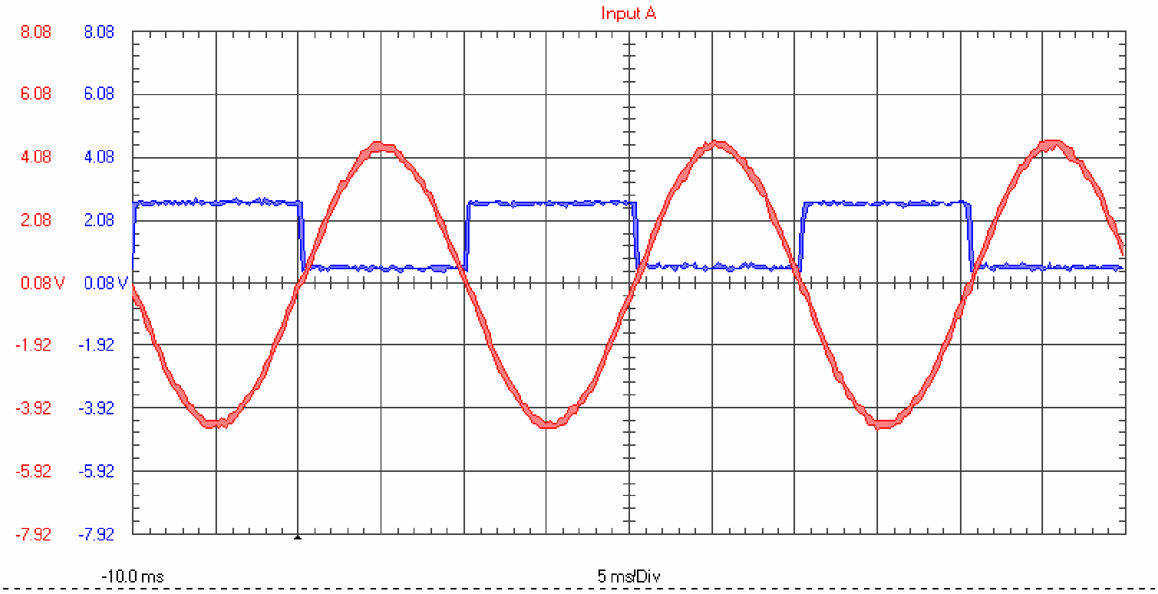


Fig. 5.3: Waveform R88 on CH-A and R149 on CH-B.

➢ HEATSINK TEMPERATURE FEEDBACK

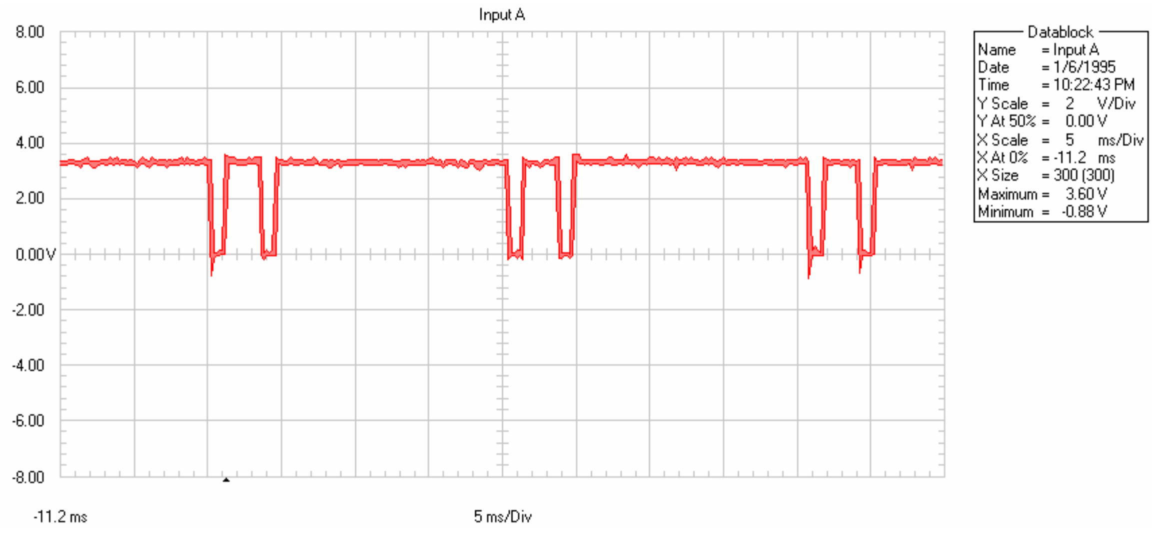
Thermister is used to get the heatsink temperature feedback and is connected to this board at J10. The thermister resistance will vary according to the heatsink temperature. The resistance will be 20k @25 °C. The analog signal proportional to the heatsink temperature is given to DSP. This is used to display the heatsink temperature and to protect the unit against over temperature condition.

➢ CURRENT FEEDBACK

This board is provided the provision for measurement of all the three phase current. The output of the current transformer of R, B and Y phase is connected at J9. Refer pin configuration of J9 for detail. The jumper J8 is used if current sensor is used to measure the current.

5.2 Thyristor Gate Pulse Generator Using DSP Card

In this Board, GPIOA0- A5 is used to generate the Thyristor gate pulses.



Name = Input A
Date = 1/6/1995
Time = 10:22:43 PM
Y Scale = 2 V/Div
Y At 50% = 0.00 V
X Scale = 5 ms/Div
X At 0% = -11.2 ms
X Size = 300 (300)
Maximum = 3.60 V
Minimum = -0.88 V

Fig. 5.4 Thyristor gate pulses.

CHAPTER - 6: SYNCHRONOUS MOTOR PROTECTION: DSP IMPLEMENTATION

6.1 GENERAL

In this system different protections are provided which are as follow. How those protections are provided and different strategies for the particular protection has been discussed. Following protections have been provided in the programming of DSP.

6.2 DIFFERENT PROTECTION

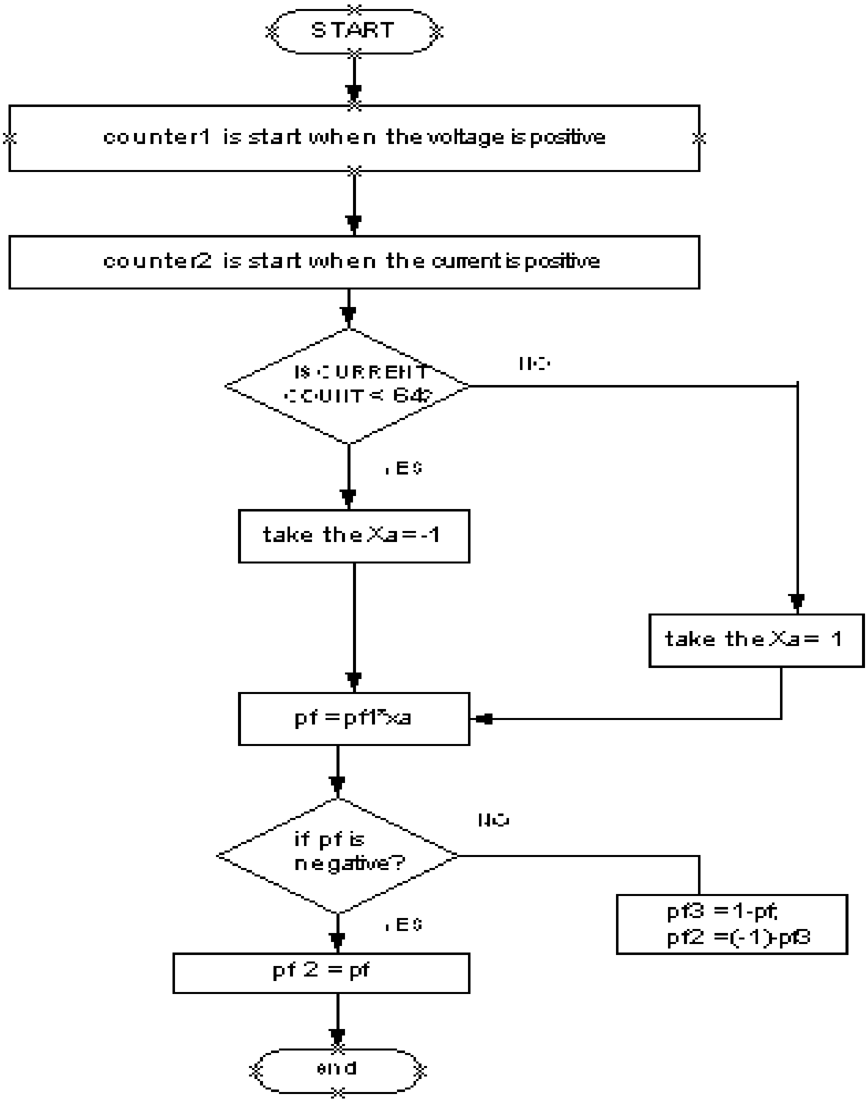
(1) Power Factor (Pull-Out) Protection

The system provides pull-out protection for synchronous motors operating in either generating or motoring modes. The system provides power factor settings and displays the measured leading/lagging power factor. The power factor regulation option enables field forcing in advance of a pull-out condition. Motor pull-out protection is provided by a circuit which monitors the power factor and has a built in time delay to prevent inadvertent tripping on transients.

So for this protection first power factor is found. For that program is implemented into the DSP control card. For this flowchart is shown in Fig. 4.3.(Chapter-4)

After finding the power factor leading-lagging logic has been implemented into the DSP control card. (Algorithm is shown in Fig. 6.1) Because power factor protection provided above and below the leading and lagging power factor ranges. i.e. if power factor will go above the 0.45 lead or below the 0.45 lag the power factor relay will trip. Because beyond these ranges motor speed is not maintain the constant. If the set power factor is also not maintain then this protection is provided by a circuit which monitors the power factor and has a built in time delay to prevent inadvertent tripping on transients.

➢ **Algorithm Of The Leading-Lagging Logic**



6.1 Algorithm of the Leading-Lagging logic program for DSP

(2) Squirrel Cage Winding Protection

An important motor protection function is preventing squirrel cage winding overheating during motor starting. For brushless motors squirrel cage protection is derived from stator current inputs. Protection characteristics are shown in the following graph and the thermal limit is defined by the Stall Time and Locked Rotor Amps relay set points.

For collector ring motors the squirrel cage protection algorithm is based on motor rotation speed during acceleration. Speed is determined from the frequency of the induced rotor voltage across the rotor discharge resistor. At less than synchronous speed the following typical cage heating protection characteristics are used:

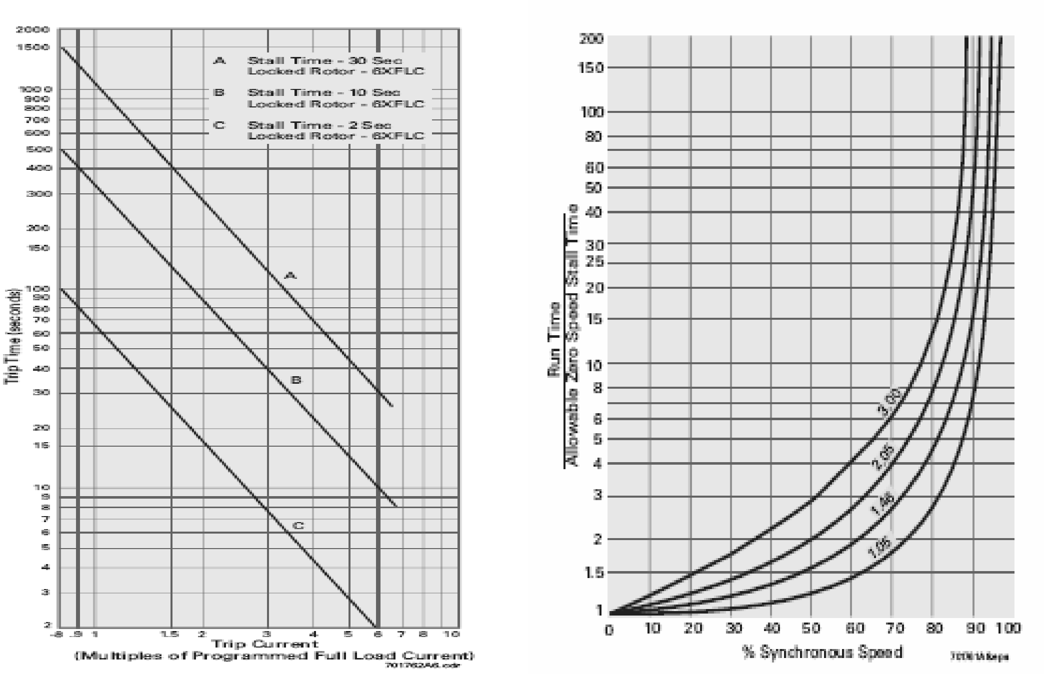
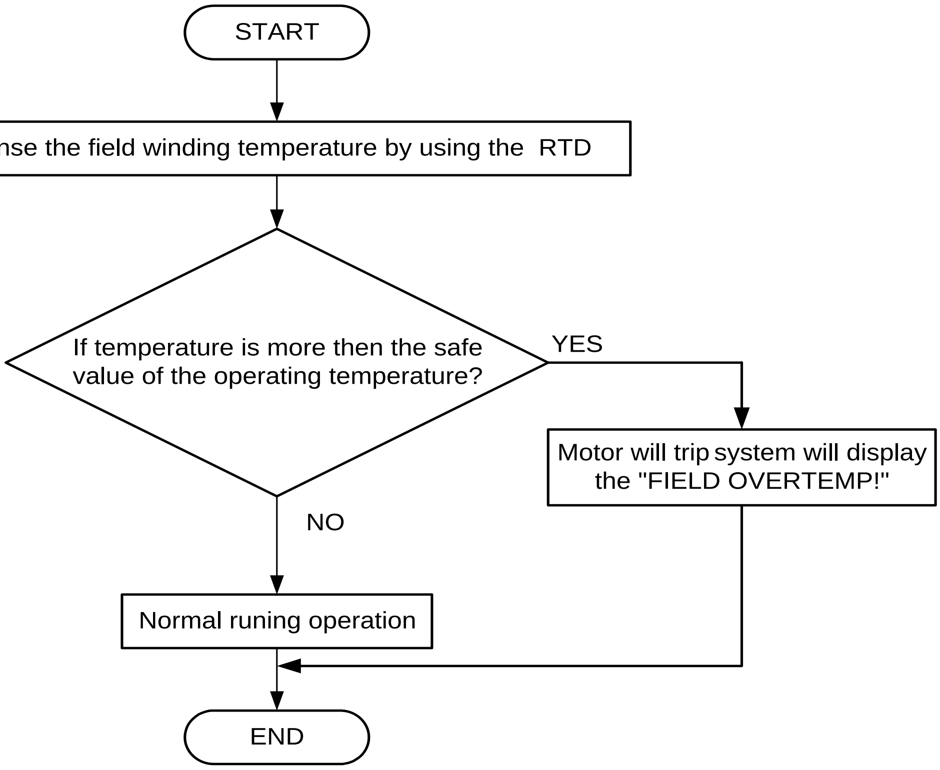


Fig. 6.2 Typical cage heating protection characteristics for Brushless and collector ring motors.

(3) Field Winding Over temperature

This function emulates a resistance temperature device (RTD) on the field windings.

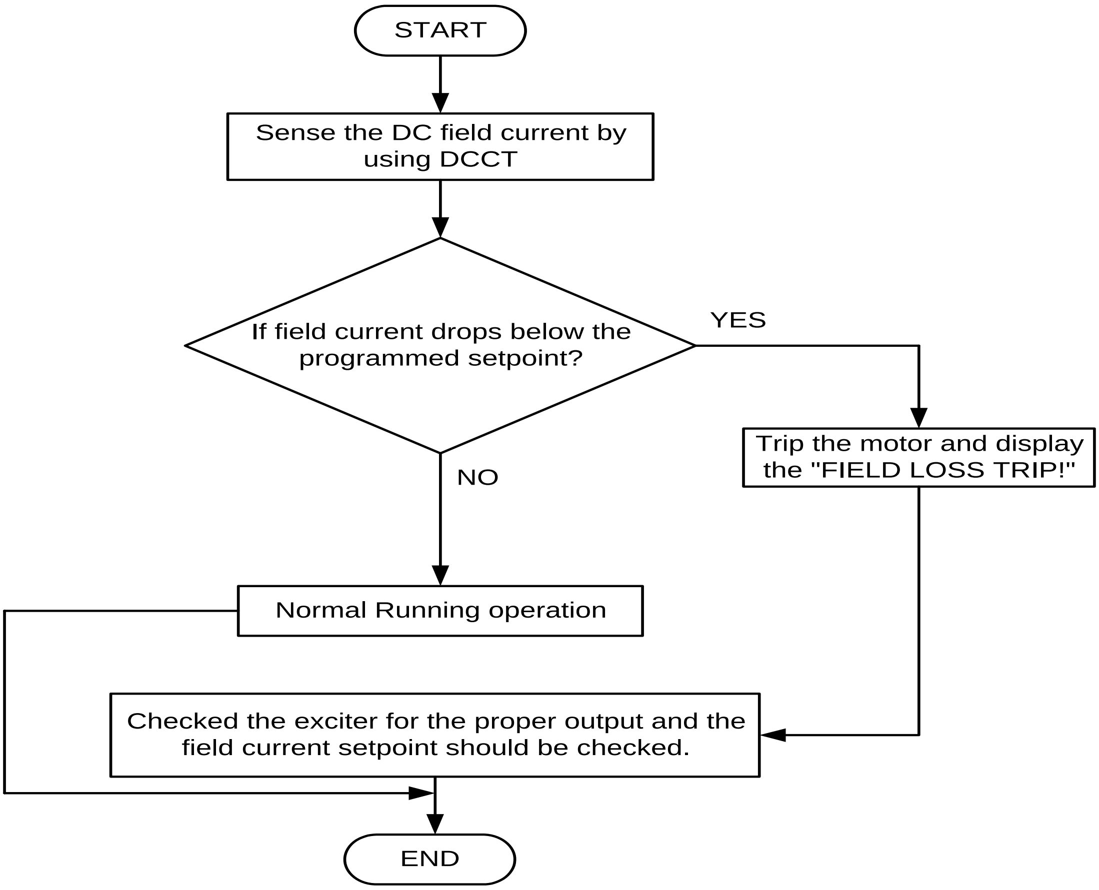


6.3 Flowchart for the Field Winding over temperature.

As the ratio of field voltage to field current increases, the field resistance increases, indicating an increase in temperature of the field winding. Field Winding Over temperature is only available with the DCCT and Field Current Calibration Module. Calibration Module provides calibration adjustment to obtain correct field amp readings.

(4) Dc Field Current Loss Protection

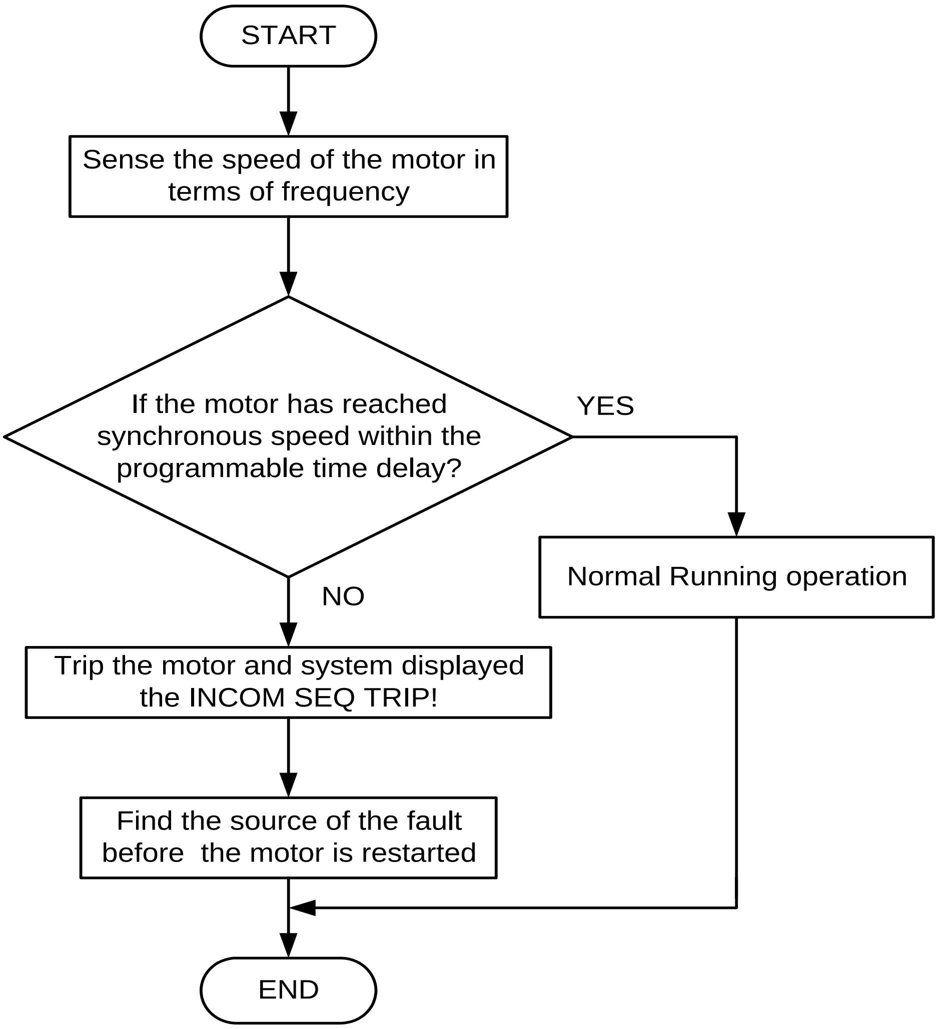
This feature trips the motor when field current drops below the programmed set point after the motor has synchronized. So to implement this protection into the DSP control card one program set value has been entered.



6.4 Flowchart for the DC Field current loss Protection

(5) Incomplete Sequence Protection

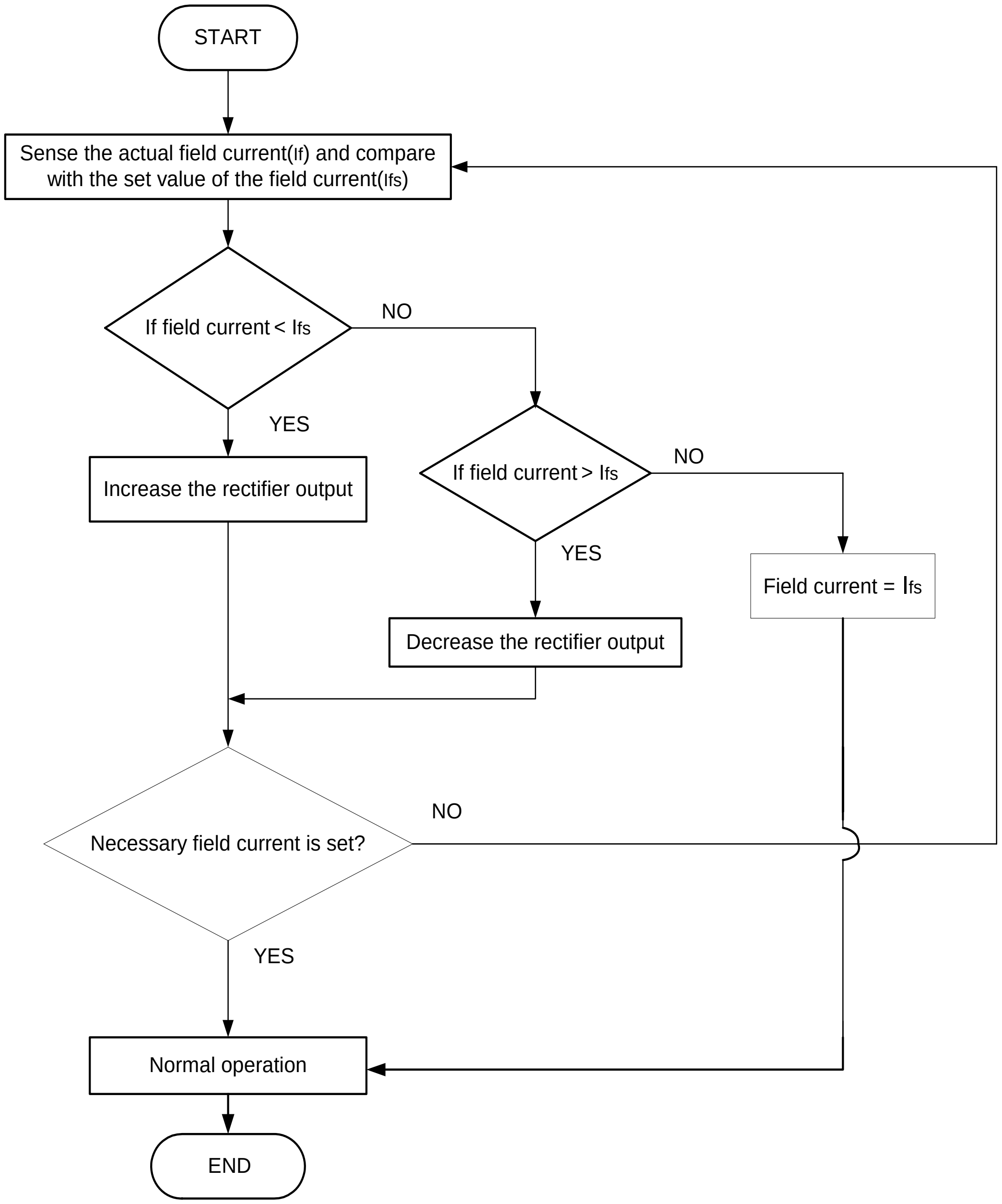
The Incomplete Sequence protection will trip if the system detects that the motor has not reached synchronous speed within the programmable time delay. The source of the fault should be to implement this protection into the DSP control card algorithm is shown in Fig. 6.5.



6.5 Flowchart for the Incomplete Sequence Protection

(6) Field over current Protection

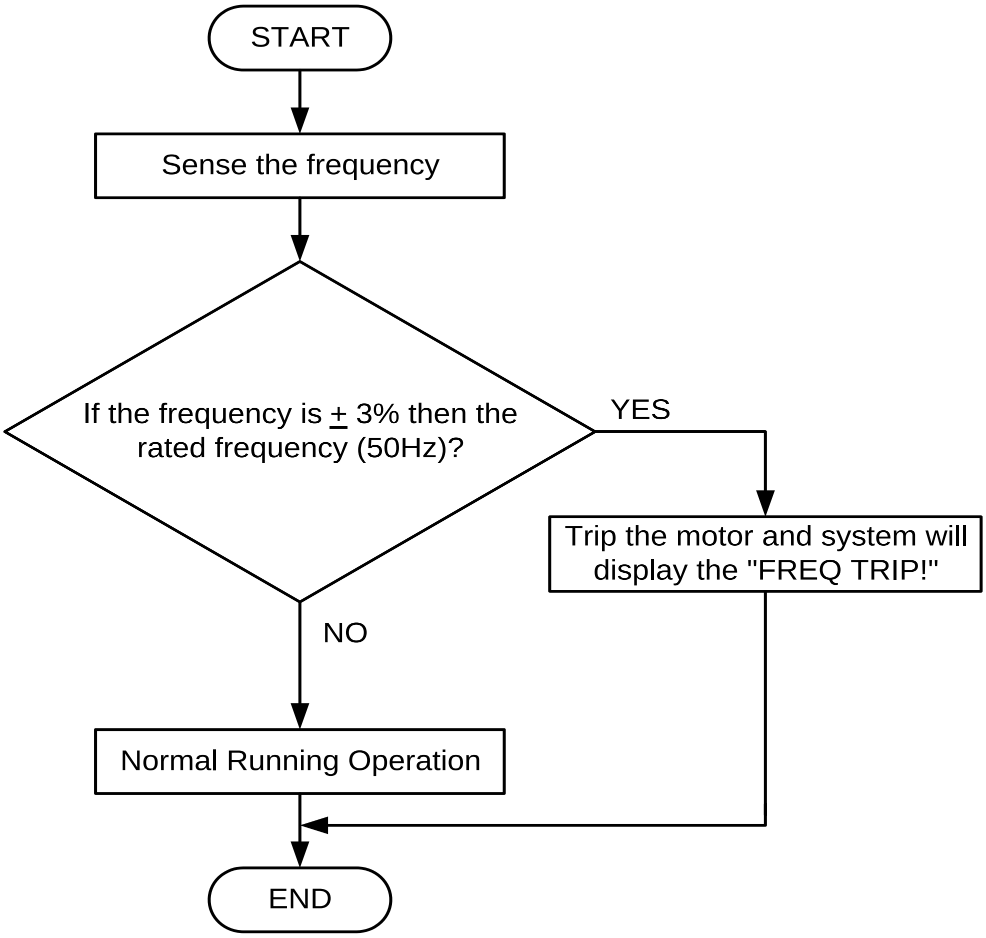
For this protection field current will be monitor by using the DC current transducers. This actual field current is compared with the set field current and if the necessary field current is not provided then this process will be repeated.



6.6 Flowchart for the over current protection

(7) Under/Over Frequency Protection

If the frequency will change the ±3% of the rated frequency then motor will trip. For this program is implemented in the DSP control card. Algorithm is shown in Fig. 6.7.



6.7 Flowchart for the under/over frequency

CHAPTER - 7: EXPERIMENTAL RESULTS

7.1 GENERAL

Various quantities and Waveforms have been observed and recorded for the further analysis. The photographs of the prototype test setup will be shown. 3-phase control rectifier has been tested and the thyrisor gate pulses, (with and without chopping), input current, and output voltage waveforms are shown in Fig.

7.2 HARDWARE SETUP OF THE PROPOSED TOPOLOGY

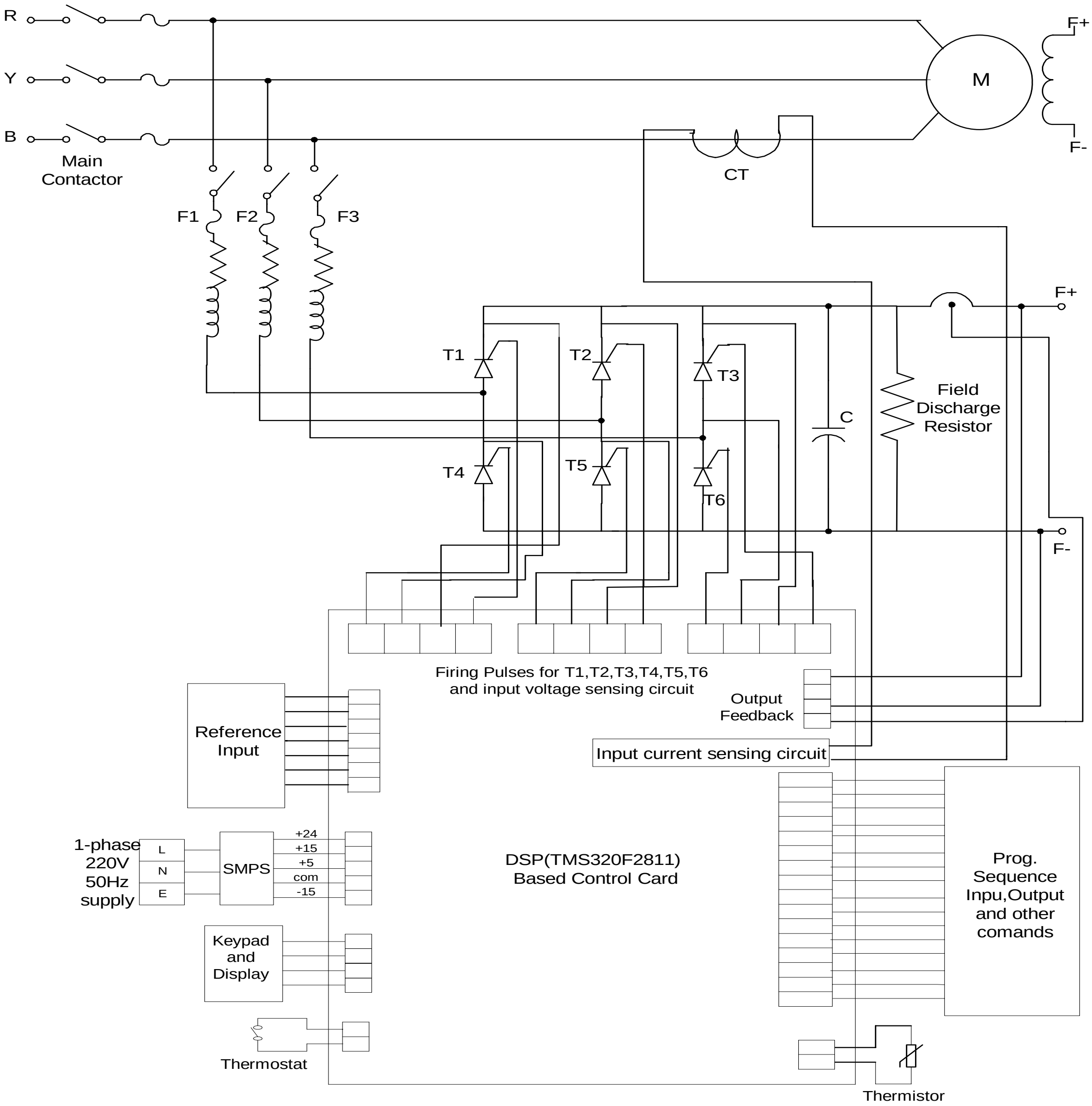


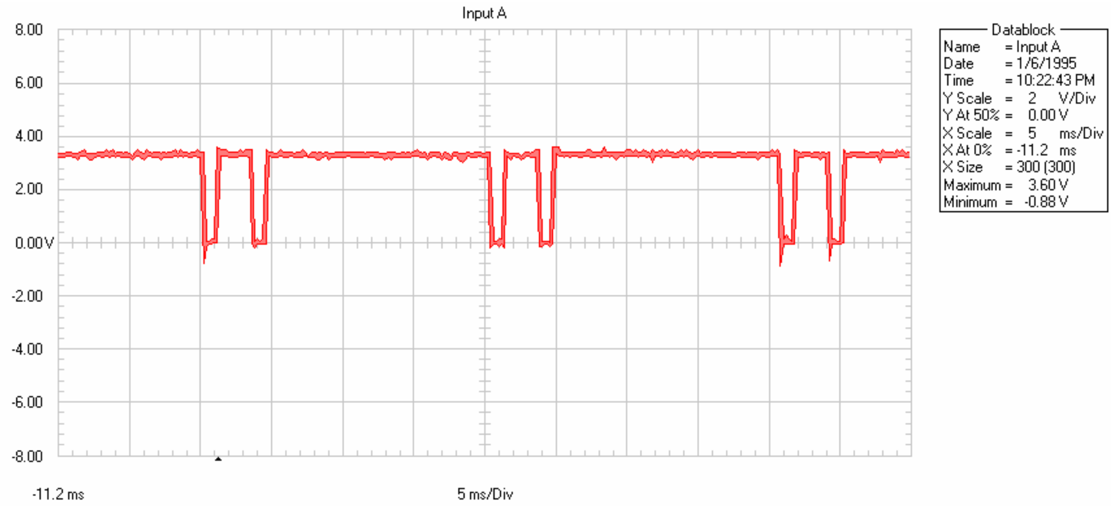
Fig. 7.1 Hardware setup for the digital excitation control system

3-phase controlled rectifier is used to get the D.C. current, which is connected to the R-L load. By changing the firing angle of SCR, the excitation current can change. Hall effect sensor has been used for the current sensing. Input voltage is sensed by using the input voltage feedback sensing circuit, which is discussed in Chapter-6. Then that feedback is given to the DSP control card. Before connecting to the actual system, to verify the control algorithm, the control algorithm was checked using resistive load.

Fig. 7.1 shows the circuit description of hardware setup.

7.3 EXPERIMENTAL RESULT

Thyristor gate pulses are generated from the DSP control card and recorded in the digital scop which is shown in Fig. 7.2. Chopping is carried out to reduce the switching losses of thyristors. Gate pulses with and without chopping are shown in Fig. 7.3 and Fig 7.4. Input current waveform for the 3-Phase Controlled Rectifier is shown in Fig. 7.5. For 3-phase controlled rectifier high rating thyristor SKT-760 (Semikron) is used, which is 700 A, 600 V rating, capsule type thyristor. Here 200 uS duty cycle with 8 kHz switching frequency. Rectifier output voltage waveforms without filter capacitor are shown in Fig. 7.6, 7.7 and 7.8. For 3-phase controlled rectifier output voltage waveforms are taken with two filter capacitor value 400 V, 4700 uF connected in parallel to the output of the rectifier. Rectifier output voltage waveforms with filter capacitor are shown in Fig. 7.9, 7.10 and 7.11.



Name = Input A
Date = 1/6/1995
Time = 10:22:43 PM
Y Scale = 2 V/Div
Y At 50% = 0.00 V
X Scale = 5 ms/Div
X At 0% = -11.2 ms
X Size = 300 (300)
Maximum = 3.60 V
Minimum = -0.88 V

Fig. 7.2 Thyristor gate pulse (Without chopping)

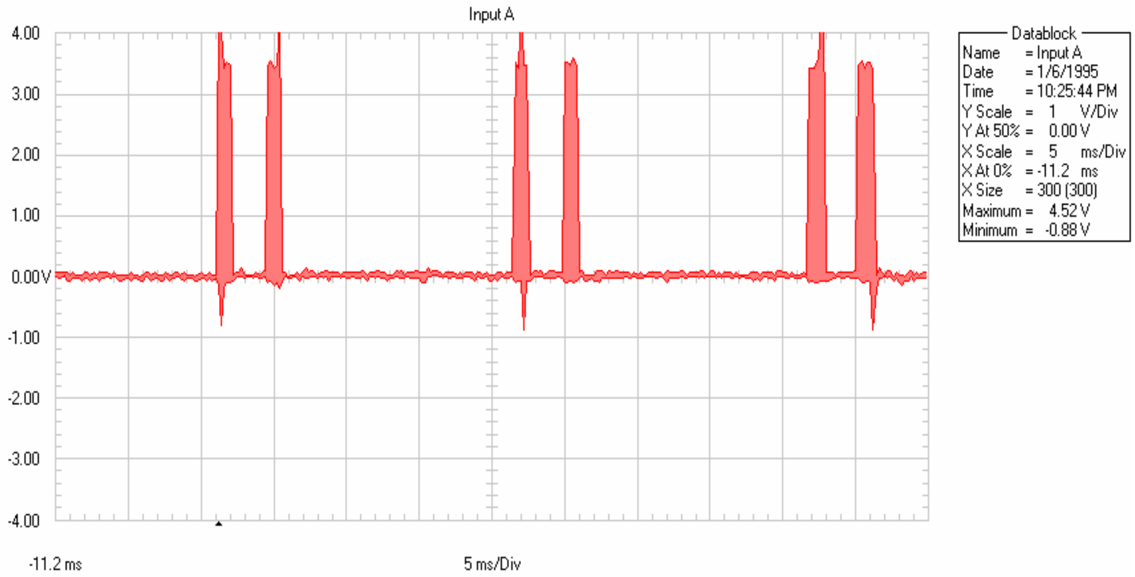


Fig. 7.3 Thyristor gate pulse (With chopping)

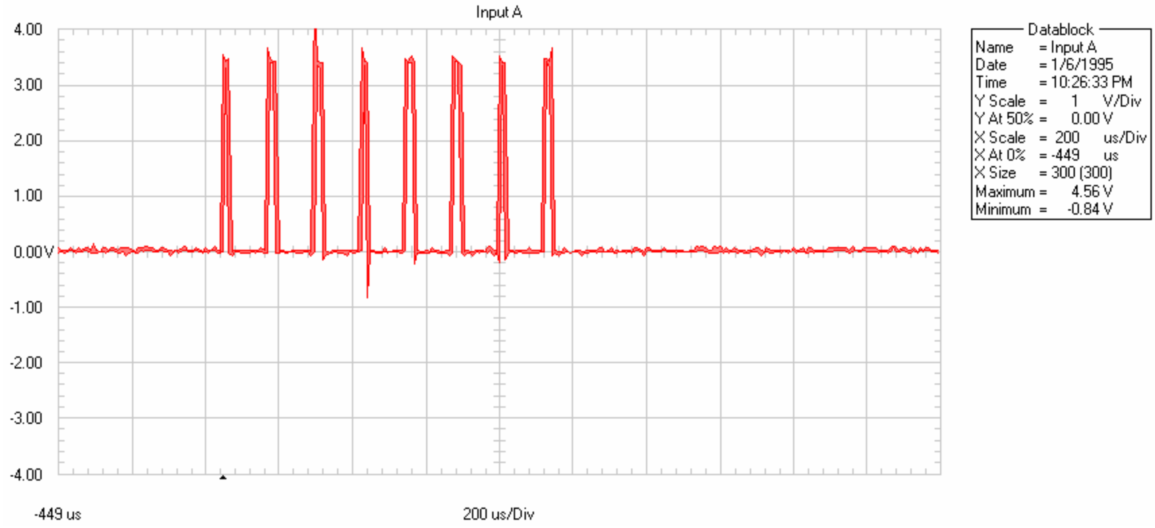


Fig. 7.4 Enlarge portion of Thyristor gate pulse (With chopping)

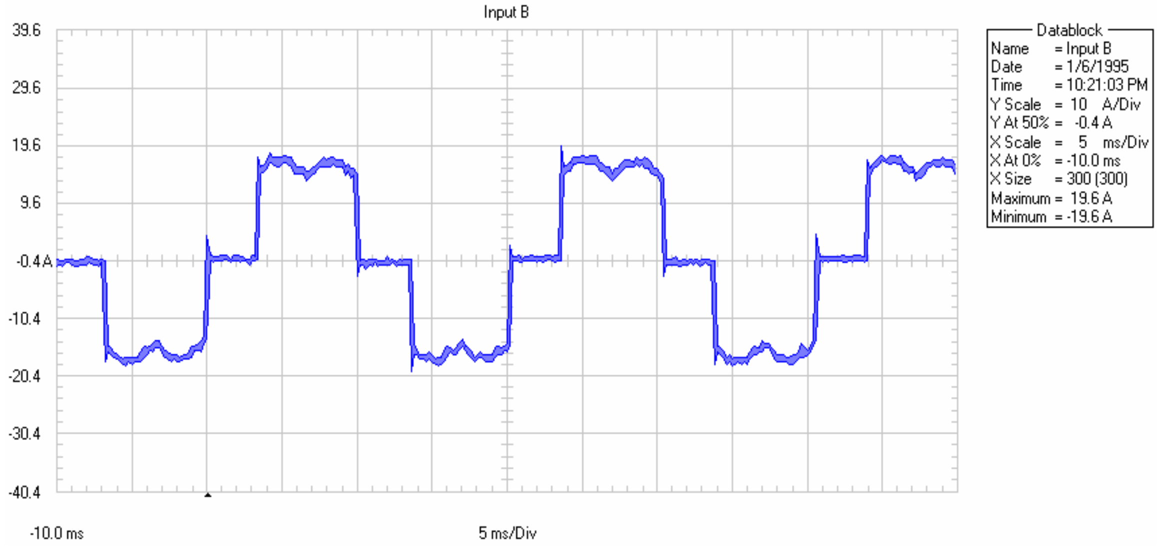


Fig. 7.5 Input current waveform

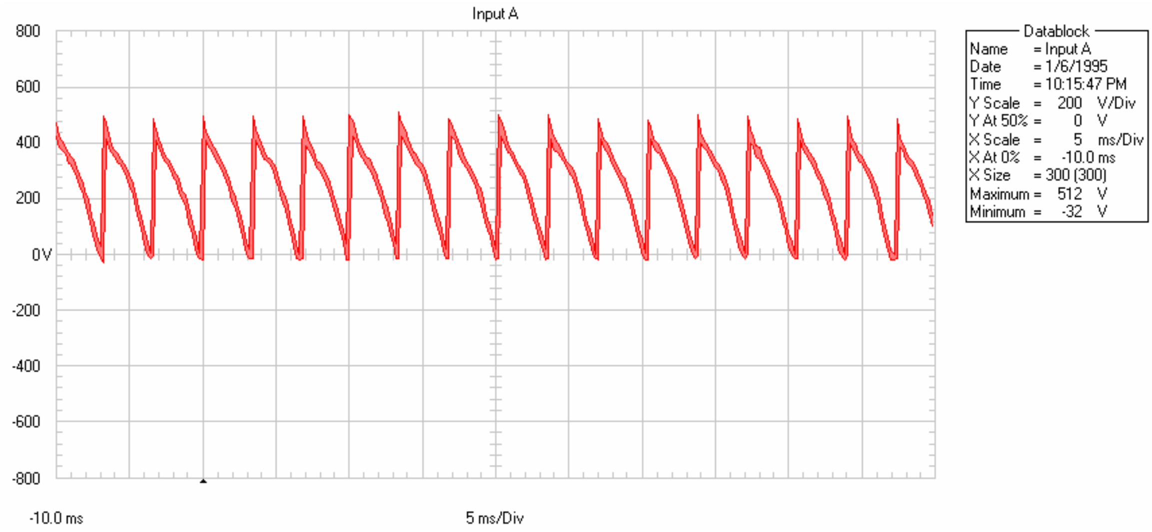


Fig. 7.6 Output voltage Vo (Avg.) = 95 V (Without filter capacitor)

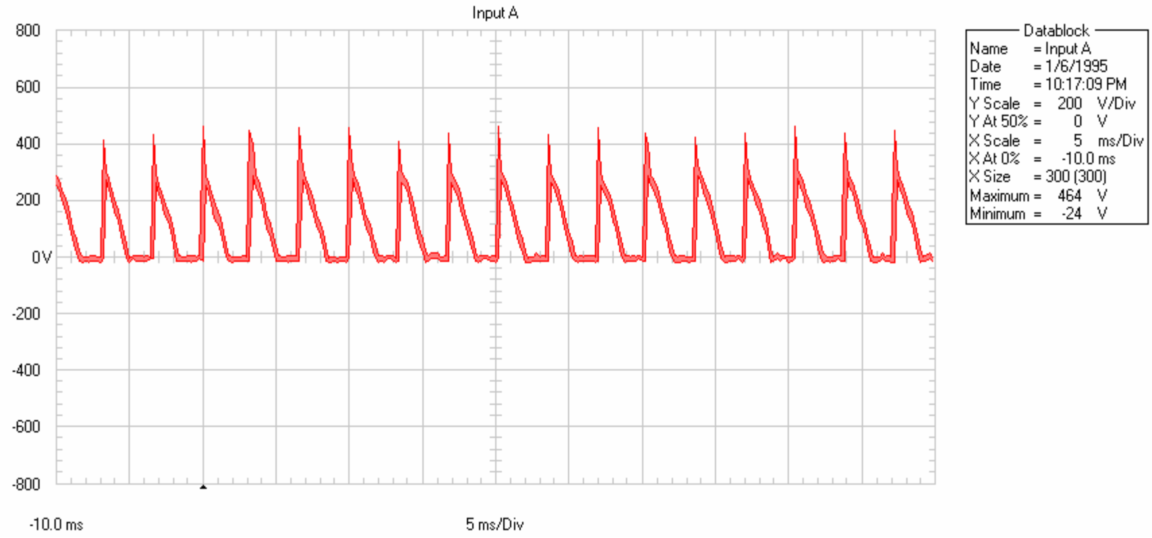


Fig. 7.7 Output voltage Vo (Avg.) = 165 V (Without filter capacitor)

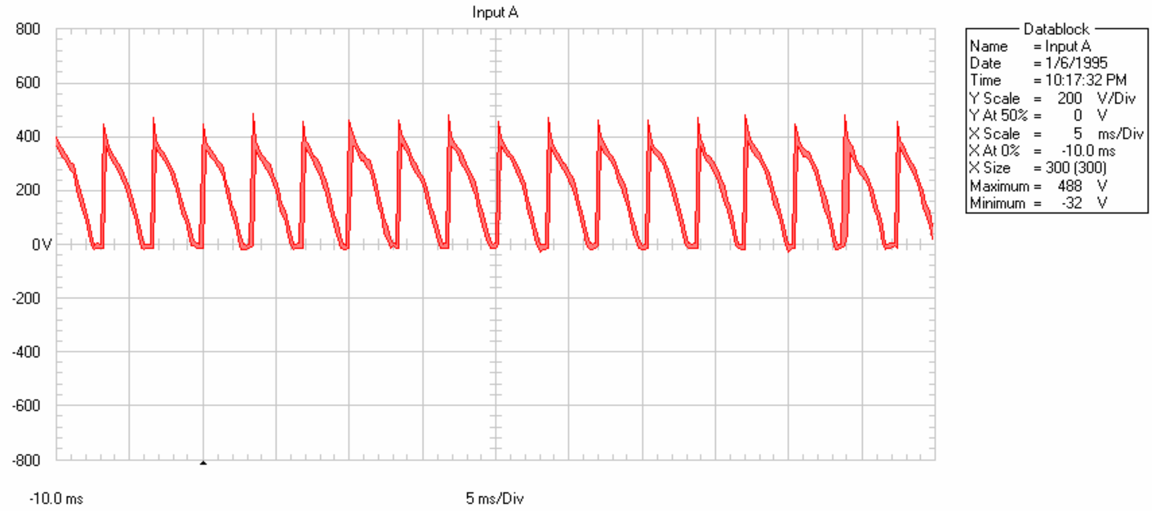


Fig. 7.8 Output voltage Vo (Avg.) = 250 V (Without filter capacitor)

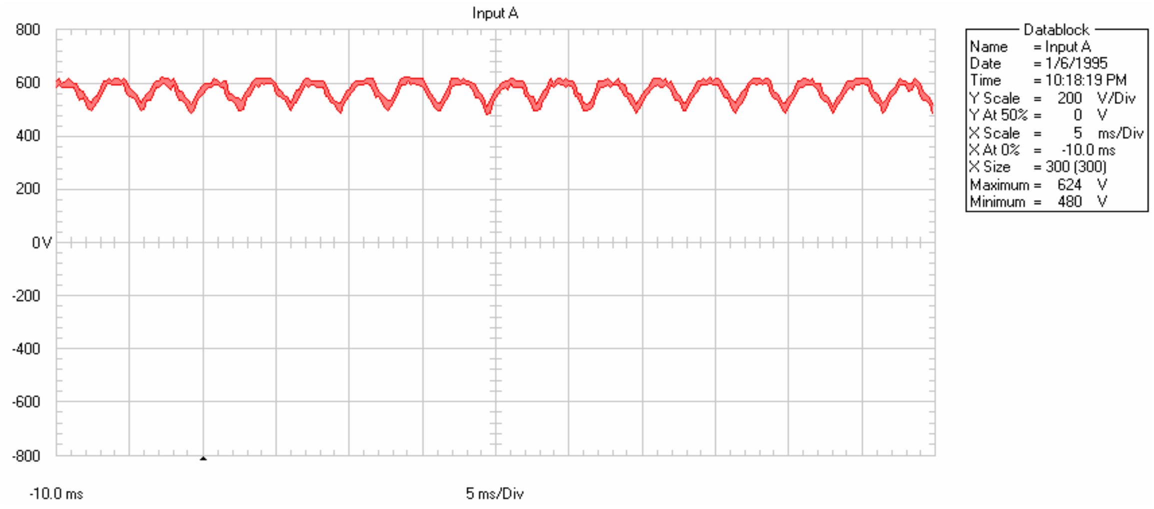


Fig. 7.9 Output voltage Vo (Avg.) = 580 V (Without filter capacitor)

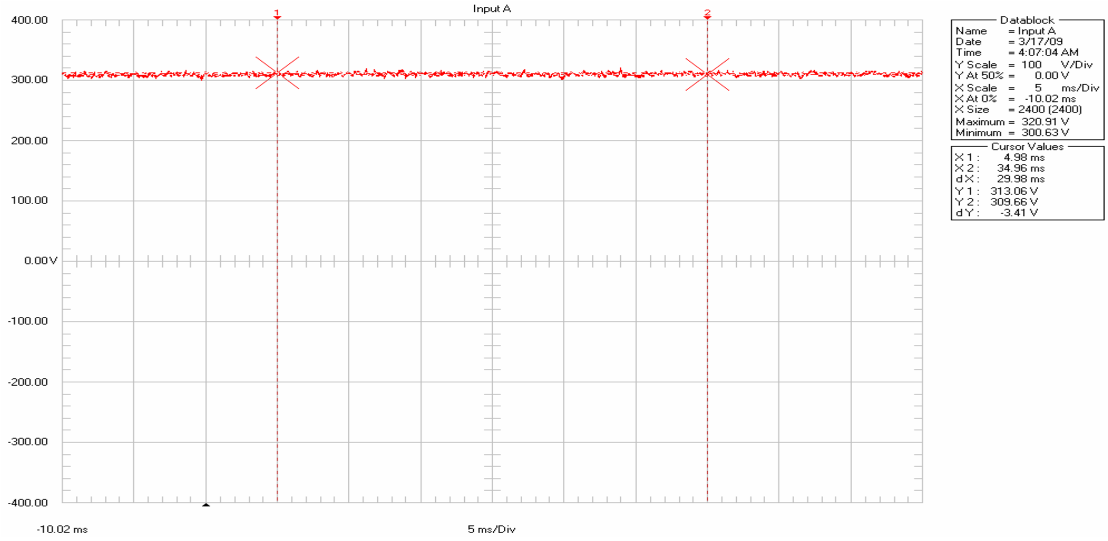


Fig. 7.10 Output voltage Vo = 315 V (With filter capacitor)

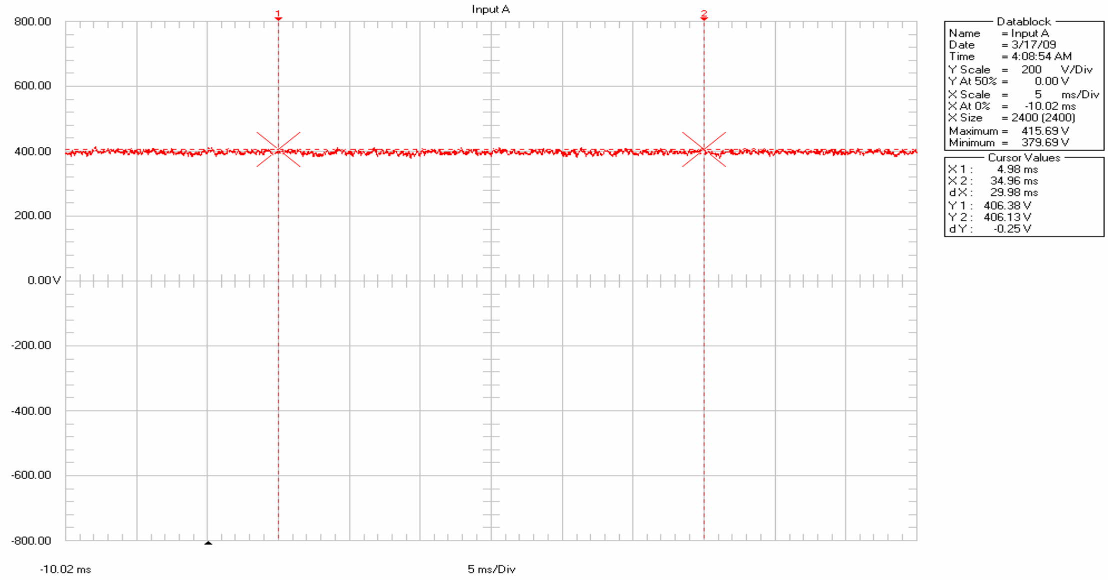
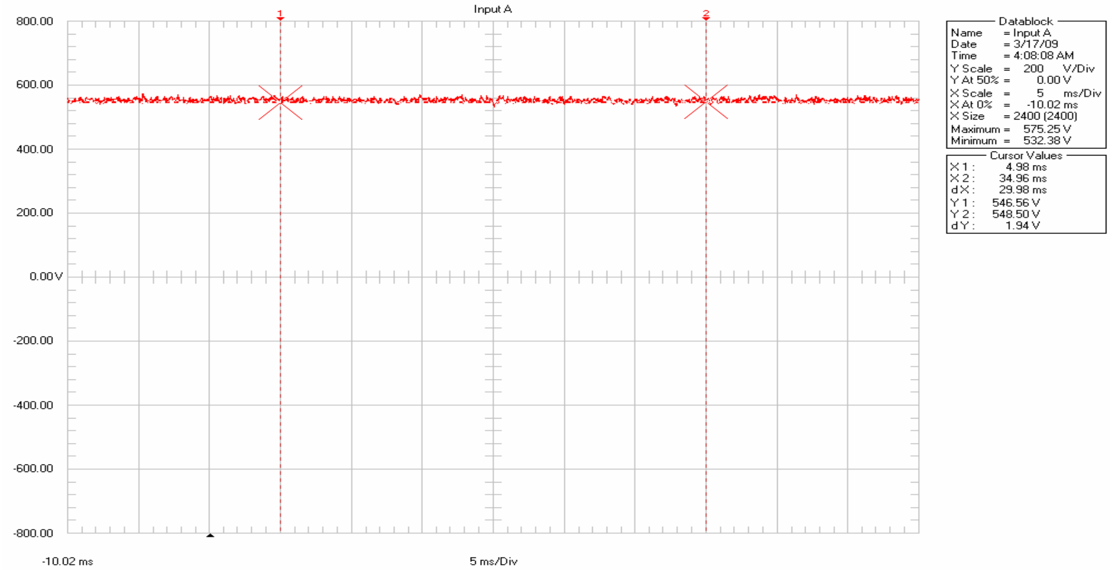


Fig. 7.11 Output voltage Vo = 400 V (With filter capacitor)



Datablock
Name = Input A
Date = 3/17/09
Time = 4:08:08 AM
Y Scale = 200 V/Div
Y At 50% = 0.00 V
X Scale = 5 ms/Div
X At 0% = -10.02 ms
X Size = 2400 (2400)
Maximum = 575.25 V
Minimum = 532.38 V

Cursor Values
X 1 : 4.98 ms
X 2 : 34.96 ms
dX : 29.98 ms
Y 1 : 546.56 V
Y 2 : 548.50 V
dY : 1.94 V

Fig. 7.12 Output voltage Vo = 575 V (With filter capacitor)

7.4 CONCLUSION:

In this chapter experimental results of rectifier are shown**.** Firing pulses for the 3-phase controlled rectifier is also generated as per appropriate sequence. Pulse width and amplitude is also sufficient for firing the thyristors. Rectifier output is tested for the different duty cycles. Output voltage is smooth which is necessary for motor field.

CHAPTER - 8: CONCLUSION AND FUTURE WORK

8.1 CONCLUSION

The module of Digital excitation control system was developed and simulated in the PSIM 6.0 Power electronics simulator. Simulation model is based on the 80kW motor.

The main aim of this dissertation work to develop a digital excitation control system for synchronous motor that offers high performance that is equal or better than the other systems. For the synchronous motor among the different exciters static excitation is widely used because it has no moving parts, requires very little maintenance, and is immune to hazardous or dusty atmospheres. Brushless excitation system is chosen because they are not built with slip electric contacts, avoiding sparking. power factor regulation is carried out by means of the excitation (Rectifier output current).. Based on the nature of load we can operate the excitation system in different modes i.e. PF mode, VAR mode. The theoretical findings can be supported with reference from chapter 3 and chapter 4.

PSIM is good simulating software for simulation of the power electronic circuits, so the simulation of the proposed topology has been done using PSIM software. According to the simulation results, it can be conclude that by changing the firing angle of the rectifier the excitation current, voltage and power factor would be change. In open loop and close loop system Programmed (DLL output PF) power factor and actual (System) power factor is compared and both are same. From close loop simulation it's observed that if load is change then firing angle is changed automatically. By giving the desired power factor as a reference the firing angle will change automatically and set the necessary field current and maintain the constant power factor. Selecting the appropriate excitation system depends on the field current required for the motor field. Finally from the simulation results the power factor of the motor can be change within certain range and motor is operated at unity or leading power factor as per requirement. Also from the simulation results, it can be seen that power factor, voltage, and current waveform remain same in different condition and transient response is also fast.

From the hardware results it has been conclude that firing pulses for the 3-phase controlled rectifier is also generated as per appropriate sequence. Rectifier output is tested for the different duty cycles. .

8.2 SCOPE FOR FUTURE WORK

This project provides the power factor improvement (Regulation) in the different condition for the different set points of PF. Following points propose the future work to be carried out in this project to improve the performance.

(1) This prototype was performed using 3–phase, 415 V; it can be tested with high voltage supply.

(2) This system is tested with the R-L load, so it has to be tested with actual motor.

(3) The range of this digital excitation control system is –0.45 (Lagging) to +0.45(Leading), so it can be increase up to 0(Lagging) to 0(Leading).

(4) In this topology tapped transformer can be used at the input side of the rectifier.

(5) In this system power factor is found by calculating the apparent power to the real power, but this system can be also developed that use *phase locked loops* to determine voltage and current vectors calculating: magnitude, speed and angular relationships of the vectors. From these vectors power, vars, and power factor are calculated for each millisecond.

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LIST OF PAPER PUBLISHED

At National Level

[1] Swapnil N. Jani, J.G. Jamnani and Vinod Patel, “*Simulation and Development of Excitation Controller for Synchronous Motor*.” 3rd National Conference on Current Trends in Technology, NUCONE 2008, pp 256-259, November 2008.

[2] Swapnil N. Jani, J.G. Jamnani and Vinod Patel, “*DSP Based Excitation Controller for Synchronous Motor.”* National Conference on Power Electronics & Power Systems Rajkot, PEPS 2008, November 2008.

At International Level

[1] Swapnil N. Jani, Devendra Tandel, J.G. Jamnani and Vinod Patel, “*Simulation and Development of DSP based Digital Excitation Control System for Synchronous Motor*.” at International conference on electrical energy system & power electronics in emerging economies-2009, SRM University, Chennai.

APPENDIX A: DSP CONTROL CARD DETAILS

➢ Features of TMS320F28xx series of controllers:

Designers have recognized the opportunity to redesign the existing systems to use advanced algorithms that yield better performance and reduce system component count. DSP's enable:

- Design of robust controllers for a new generation of inexpensive motors
- Elimination or reduction of memory looks up tables through real time polynomial calculations, there by reducing system cost.
- Use of advanced algorithms that can reduce the number of sensors required in a system.
- Control of power switching inverters, along with control algorithm processing
- Single processor control of multi motor systems

➢ DSP Control Card PCB 2005B:

It uses **32-bit High-Performance Digital Signal Processor TMS320F2811**. The control board generates the control signals for AC Voltage controller operation. It accepts various inputs from different control circuits and digital operation panel (LCD keypad) to generate the necessary control and gate signals.

The TMS320F2811 is the heart of this card. It handles the user interfaces and core algorithm and generates Thyristor gate signals. The PCA-2005B is connected to PCA-2012 Display Card with RS-485 link. PCA-2012 displays the parameters of the Soft Starter. Fig. II shows pin diagram of DSP TMS320F2811

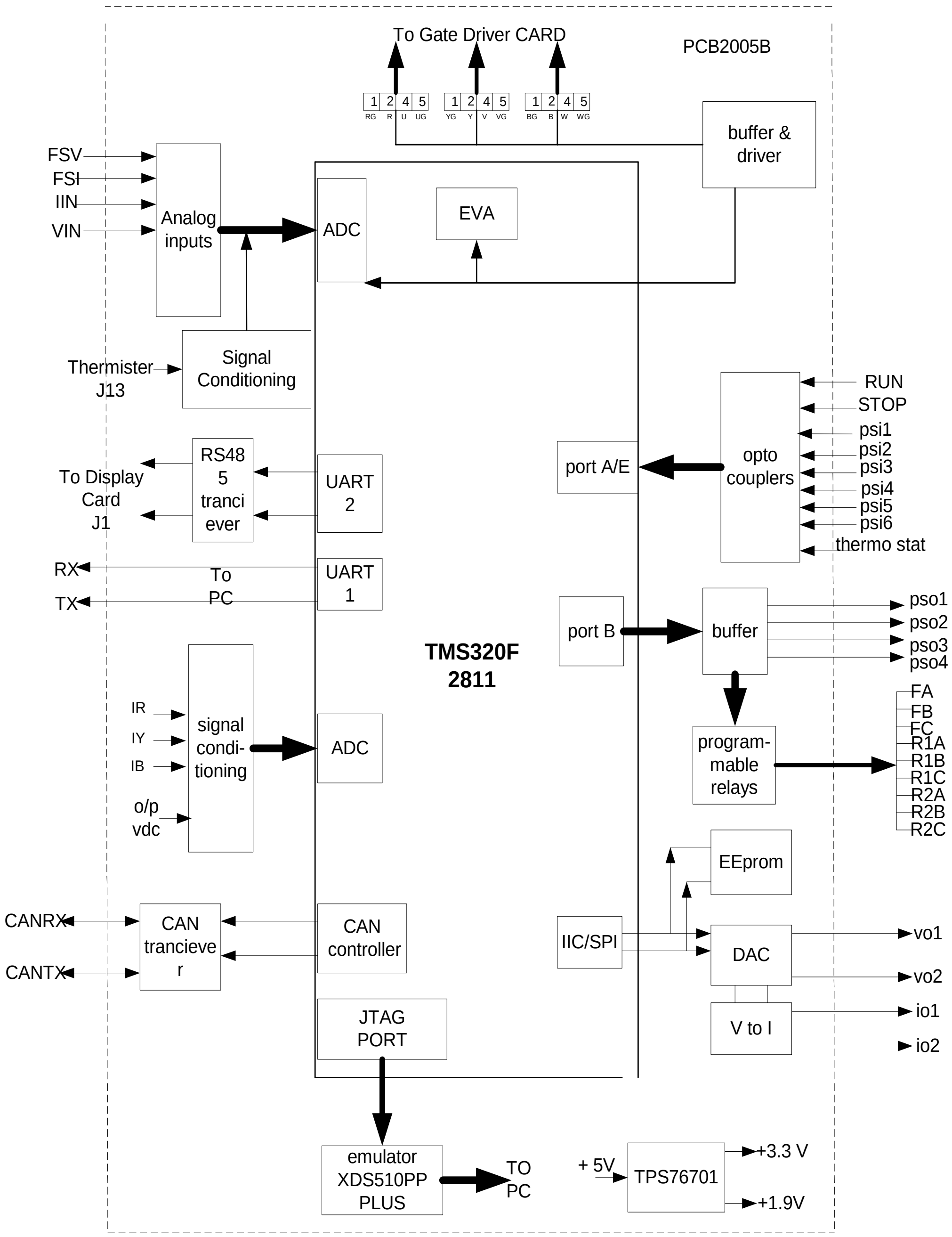


Fig. A Block diagram of DSP control card PCA 2005B

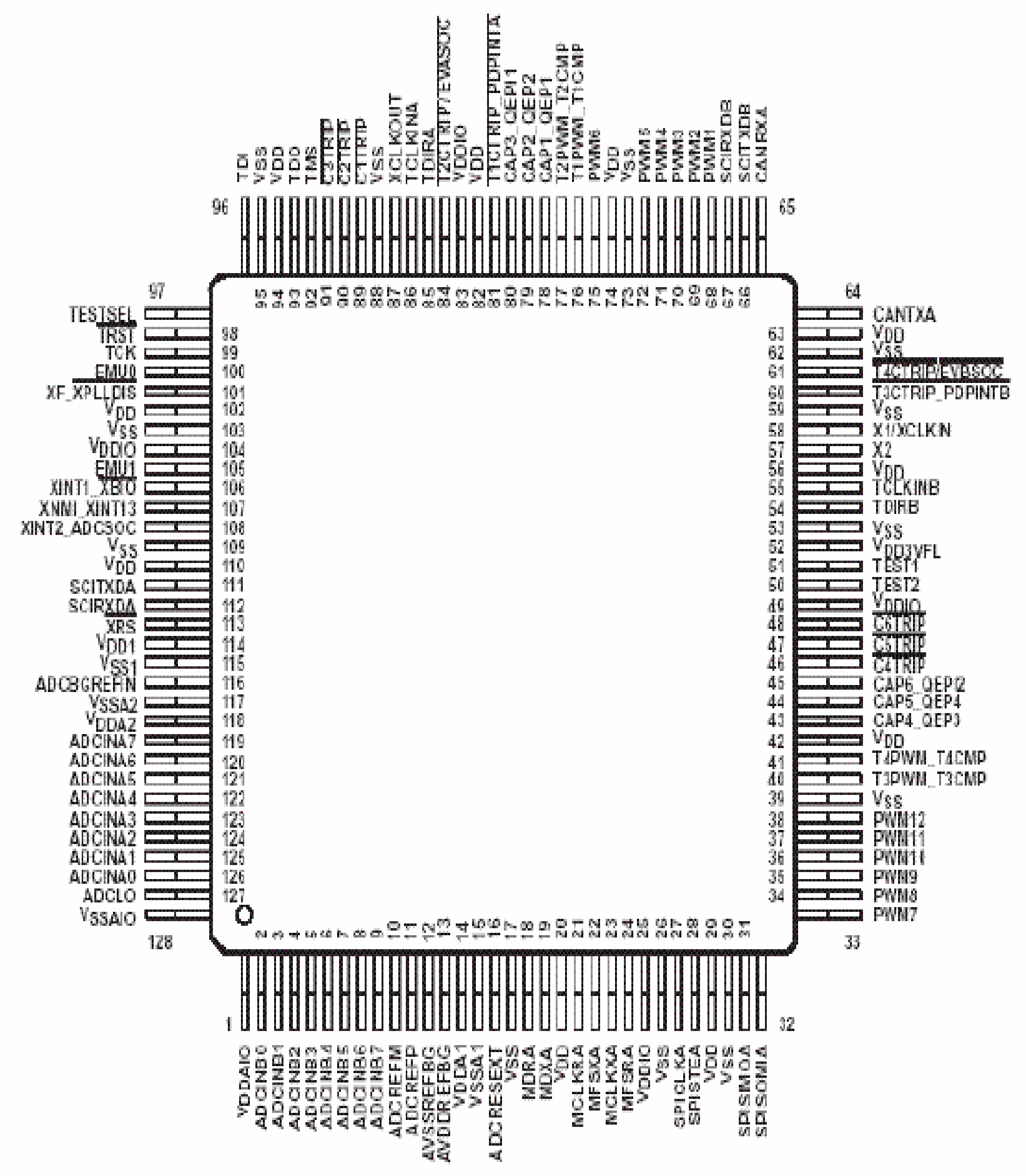
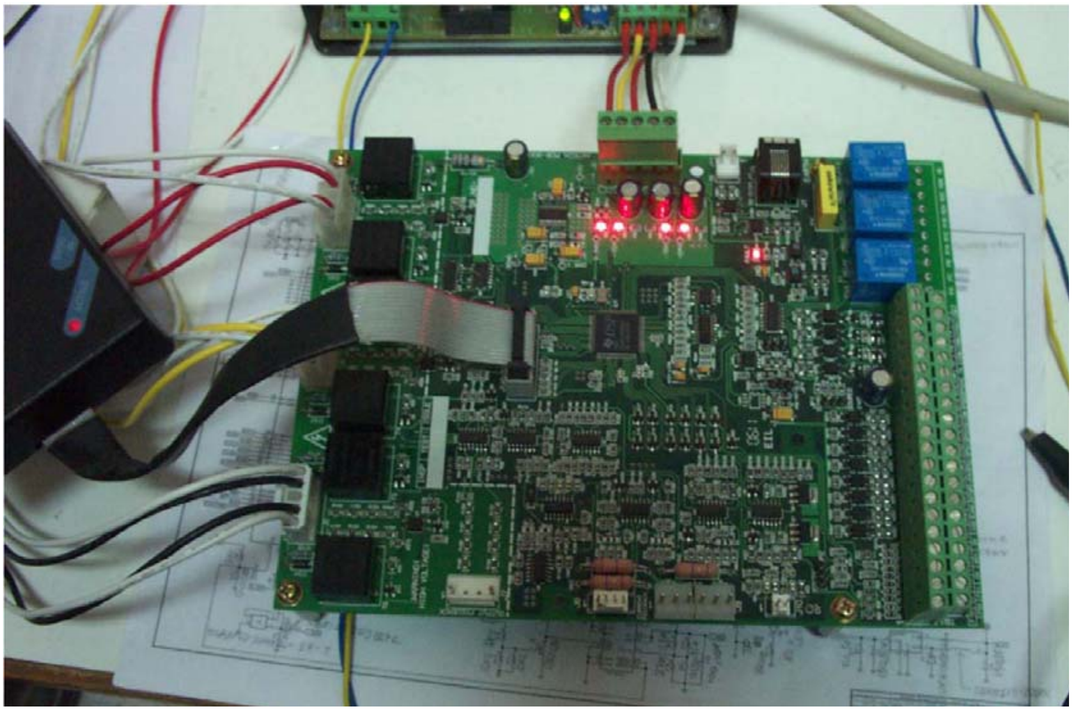


Fig. B Pin diagram of DSP TMS320F2811

APPENDIX B: HARDWARE PHOTOS

DSP CONTROL CARD:



3-PHASE CONTROLLED RECTIFIER: