A THESIS

ON

"A MATLAB Simulation Model to Improve Voltage Sag Due to Starting of Induction Motor using STATCOM"

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

In

Electrical Engineering

By

Siddharth Mahanand (111EE0215)

Tushar Kanti Jena (111EE0213)

Department of Electrical engineering

National institute of technology

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Under the supervision of

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DECLARATION

This is to certify that Thesis report entitled **"A MATLAB Simulation Model to Improve Voltage Sag Due to Starting of Induction Motor using STATCOM."** which is submitted by us in partial fulfillment of the requirement for the award of degree B.Tech in Electrical Engineering to National Institute of Technology, Rourkela which comprises of only our original work to the best of our knowledge and belief, due acknowledgement has been made in the text to all other material and resources used throughout the length of project .

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CERTIFICATE

This is to certify that the Project entitled **"A MATLAB Simulation Model to Improve Voltage Sag Due to Starting of Induction Motor using STATCOM"** submitted by Siddharth Mahanand (111EE0215) and Tushar Kanti Jena (111EE0213) in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at National Institute of Technology, Rourkela (Deemed University), is an authentic work carried out by them under my supervision and guidance.

Date: Prof. (Mrs.) K. R. Subhashini

Place: Rourkela Department of Electrical Engineering

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ABSTARCT

In industrial sector or process continuity plant the continuity of the industrial processes becomes a more important factor for the organisation profit and economical balance. But sometime its get interrupted due to electrical faults, low voltage supply, voltage sag some mechanical faults or man made mistakes. Out of it voltage sag is one of the most persisting factors to be taken in to account, starting high power loads like induction motors or heavy loads draws a very large amount of current then the system rated specified voltages. So these sags gets detected by the under voltage relays or over current relays and consequently act in opening up of the breaker and hence brings distortion in the process continuity of the plants working processes. And further the cost of restarting the process again and delay in the order supply acts more to the damage done. So, it's really necessary to compensate for the reactive power or the voltage sag occurred during this time. So one of the available alternative is the modern generation FACT controller like STATCOM which is a shunt operated reactive power compensating device or reactive power exchanging device for improving the voltage system profile of the system, so here in this thesis report we will try to investigate the operation of the STATCOM. Its device characteristics, its constructional details and take a special model in the MATLAB simulation to show the compensating ability of the STATCOM and its benefits and con will be figured out. Here we will also find out some of the other ways to improve the voltage sag improvement and theirs features. Little focus will be also on the reactive power analysis, how it affects the system and its necessity will be discussed in brief. Little light will also be given to the FACTS class of the device its modern trends and its benefits to the electrical engineering sector. Here in the STATCOM circuit which comes across the FACT device class will be using a voltage source PWM operated inverter circuits for its operation. The facts technology is mainly based upon implementing power electronics technology in the field of power system dynamics for its stability and improvement of the various important contributing part of the power system like reactive power compensation, improvement of the stability of the system.

INTRODUCTION

In the early days various industrial equipment's we are using were mainly were mechanical in nature which were used to control the industrial processes and were rather tolerant to the voltage sag or voltage disturbances. But in the modern era industrial sector uses a very considerable amount of the electronics equipment's and switches. For example the logic gate controller s like the programmable logic controller (PLC) the sensitive to voltage drives of machines , speed control or process control power electronics drives etc., so one thing is evident that these things are very sensible to the power quality like the magnitude, supply frequency, phase angle, harmonics quantity etc. So it has to be ensured that care must be taken to make them intact with the type of power supply they demands. In industries too there are many appliances and machinery they demands the exactness in the supply unless the systems supply disruption happens and sometimes the various devices that's get connected might get damaged in that processes.so one of the pressing problem out of the power quality problems is the voltage sag problem. This very frequent in nature and causes damage to the system equipment and the process can be interrupted. The voltage sag can be defined as the lowering in the rms voltage of the power supply line between 0.1 to 0.9 p.u. in the fundamental voltage wave with duration from 0.5 cycles to few seconds. Here we have taken the fact that sag can be defined in term of the magnitude and time as its frame. Here the duration is generally taken by the protection system to eliminate the faults out of the system. They are really disturbing and problematic as they are the random events lasts for few seconds due to some random events whose cause cannot be preventable. However they are the one of the famous power quality problem in the industrial sector customers or the shareholder facing today. The concern of treating the voltage sag problem is important as in the modern days the industries are mainly equipped with the power electronics machines and electronics circuits. Here in this project we have tried to simulate a voltage sag model by using MATLAB software and using the Simulink blocks arrangement. A high power induction machine has been taken for the creation of the sag and we used a primitively arranged STATCOM circuit for the compensation of the reactive power during starting of the induction machine and hence evidently the voltage sag improvement. Here we have used a PWM based Voltage source inverter in the STATCOM circuit for its construction. And recorded various parameters like reactive power, active power, and fundamental voltage characteristics during sag and after compensation problems. And compared the waveforms as how it is improving to help maintain the good voltage profile during a sag induced condition.

CHAPTER 1

1.1 Reactive Power

In electrical system the power is expressed as the product of the voltage and current in a circuit and the phase angle difference between them, but further it is of two types active power and the reactive power, active power is the visible power that has been delivered to the load and the reactive power is one of the most important factor that must be maintained in the system for the function of various important electrical machineries like induction motor, transformer, various electrical appliances like refrigerator, microwave oven etc., to be taking these things in a broader sense if we take the utility of the reactive power in the power system then it’s increasingly essential, as the reactive power must be maintained in the system for transfer the electrical power. Reactive power is necessary but managing it in the right way is an essential task.

So, first let’s begin with a simple understanding. That is electrical power consist of mainly two of its component. One is active power and other one is the reactive power as the convention dictates. The active power is easily perceptible to eyes as if like the glowing of bulbs. Power dissipated in the load as heat, or power that has been converted to the mechanical movement.

But In ac circuits the component s like the capacitors and inductors stores a part of the electrical power within them which in a period gradually oscillates between the source and the loads like inductive load or capacitive loads. This periodic reversal of the direction of the flow of the energy is mainly termed as the reactive power in the system. Here the portion of the power is temporarily being stored which is periodically flows back and forth into the system from the capacitors electrostatic fields to the inductive load is mainly to be termed as the reactive power, the electromagnetic devices like induction machine, transformer or a reactive load demands lagging inductive current while electrostatic device demands leading reactive current on general. The reactive power if the system is the unused part of the system, which there present in the system for the transfer of the power from the one circuit to the other circuit. The inductors is a reactive power absorbing source, this can be found out from the fact that whenever we applies a voltage to the inductive device it first build up a magnetic field and then the current follows the voltage with some lagging phase angle. The lagging current reaches its peak current after a certain interval of the time.

Similar is the story of the capacitors ,they are storing the electrical energy in the form of electrostatic field in their circuit, here as if we apply a voltage into the circuit the voltage build up happens and the charge is being stored in the capacitors and the voltage is being then developed across the plates of the capacitors.so evidently the capacitor absorbs the leading current from the system and hence or we can say if the current passes through the inductor then its provide the inductive reactive power that is lagging in nature and if the current passes through the capacitor it provides the capacitive reactive power that is leading in nature.

To write down the equation for the power expression in an inductive circuit we have the following expression for the power delivered to the load.

Let the supply voltage to be = V

And the supply current to be = I

And the electrical power =P (instantaneous power)

The phase angle difference = θ

And supply angular frequency to be = ω

Then the power equation to the inductive load can be written down as,

$$P = V_{max} I_{max} Cos\omega t \; Cos(\omega t - \theta)$$

So mathematically this equation can be decimated in to two parts. That is the active component which is

$$\frac{V_{max} I_{max} Cos\omega t}{2} \; Cos\,\theta(1 + Cos2\omega t)$$

And the reactive component is

$$\frac{V_{max} I_{max} Cos\omega t}{2} \; Sin\,\theta(1 + Sin2\omega t)$$

So, evidently the reactive component and the active components are in quadrature to each other and the angle between them is the power factor angle. The less is the power factor angle the more will be the transfer on the active energy will take place.

Voltage sag is one of the frequent and pressing problem in the industrial sector. IEEE defines define voltage sags as the decrease in the fundamental root mean square voltage of the fundamental voltage wave between the range of 1 pu to the 0.9pu-1pu for a half cycle to few cycles. Longer is the time of the voltage sag then it is called the sustained sag. Here one have to be understanding the difference between the brown out and the voltage sag. Brown out is the lower voltage for minutes or hour but sag is a small phenomenon,

Below given the main causes of the voltage sag is as given here.

- ✓ Starting a high power motor draws a considerable amount of the current form the system and hence causing the voltage sag problem
- ✓ Whenever there is a line to ground fault occurs there is huge current in the system flows hence contributes for the voltage sag
- ✓ A quick change in the amount of load or adding increasing the load contributes for the voltage sag.
- ✓ Sometime if transformer energisation is not done in a proper way that too contributes for the voltage sag in the system
- ✓ Voltage sag can occur from the utility home appliances like refrigerator, motor pump etc. we are using at home for the purpose.

As shown below the voltage sag can be reduced to some extent as per the requirement of system need to have better system performances and increase system stability.

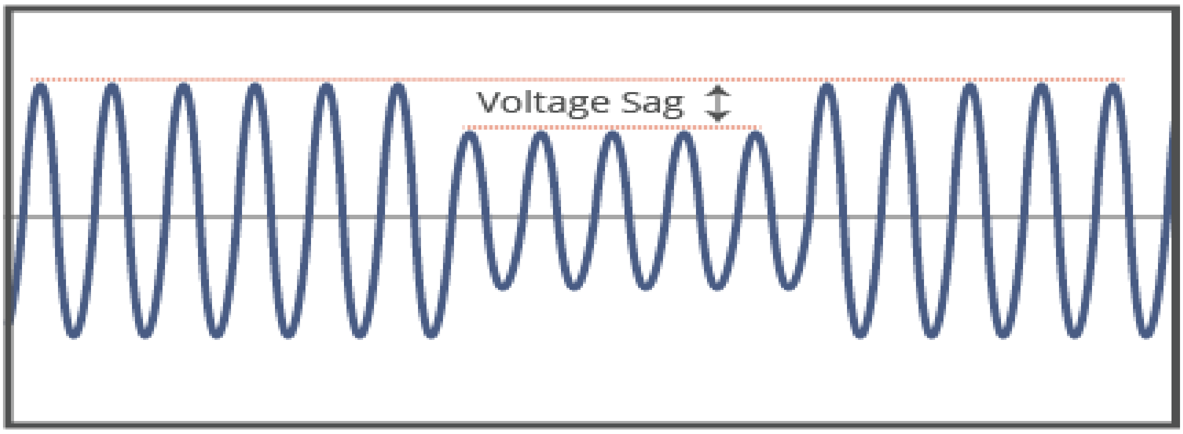

Fig. 1.1

So whenever a voltage sag take place in case of the induction motor starting the system draws a large amount of the inductive current from the system and consequently we have to aim for the compensation of the absence of the lagging reactive current with a capacitive or with a leading voltage current source.

1.2 Essence of Reactive Power Compensation

The need of the reactive power compensation arises due to the fact of transferring the electrical power from one end to other has to include the both active power and the reactive power. As we know the vector sum of the two vectors that is the active power and reactive power is the gives the total power in the circuit. But the thing is that we need not have to include reactive power as it can be availed by the others source as it is being in occurring as the unused power in the system which is being oscillating through the system in the line and the source. The generator need not have to supply the reactive power itself. And the angle of the cosine between the reactive power and the active power gives the power factor angle. The lesser the angle the more efficiently will be the power will be transferred. So the reactive power compensations main objective is to maintain the power factor angles in the less acceptable unit limit. But the reactive power is an essential part of the system. Without it, the power can't be transferred from one circuit to another. So in between instead of being supplied by the generator we need to give into the reactive VAR in to the system without drawing from the generator. So this will reduce the power generating capacity of the generating station and hence saves the precious fuel and energy resources.

Hence to summarize the above mentioned point the reactive power compensation is being done is due to the following points.

- Compensation of the reactive power provides better voltage regulation capability.
- The stability of the system increases considerably
- The utilization factor of the machine connected to the ac system increases.
- The line losses whether through the inductance or the resistors decreases considerably
- To prevent voltage disturbance as well as the voltage sag.

The impedance of the line and the need of the generating VARs results in the considerable drop in the system hence it's not a desirable thing that the VARs are to be supplied by the generators its self, previously we saw various means by which we can compensate the reactive power in the system. One of the famous compensator in the modern age is STATCOM which we shall discuss in the next page. And so far the main concern is that with us is that we are analysing the voltage sag tendency in a circuit and how reactive power is associated with them and how these things can be treated accordingly with that, further we will try to investigate what are the pressing causes that are causing the voltage SAG and what are its region and its relation with the reactive power of the system.

1.3 Briefing on Facts

The FACTs or the flexible ac transmission devices are the power electronics based compensating devices which are modelled to compensate the reactive power or exchange of the real power between the device and the system hence helping contributing for the stability and transient stability of the device. The heart of the FACT devices are the power electronics switches based devices. They carries out all the necessary task for the evaluation process. The FACT devices are famous and came to lime light as due to their excellent task performing ability and the fast switching response and the actions.

Below one can see the various kind of the FACTS VAR generators has been listed. Here we will look upon the various possible ways for the compensation of the reactive VAR and the available alternatives for the compensation work to be look upon.

Flexible AC transmission system or FACTS devices used nowadays are:

1. Various VAR generators

   i. Synchronous condenser
   ii. Capacitor banks
   iii. Thyristor operated VAR generators
      - ✓ Thyristror switched capacitors(TSCS)
      - ✓ Thyristor controlled reactor(TCRS)
      - ✓ Combination of the TSCS and TCRS
      - ✓ Thyristor controlled series capacitor

2. The self-commutated VAR generators are including some of the fact devices

   i. Static synchronous compensators (STATCOMs).
   ii. Static synchronous series compensators (SSSCs).
   iii. Unified power flow controllers (UPFCs).
   iv. Dynamic voltage restorers (DVRs)

1.4 Recent Developments

This presents investigation of time-proportion controlled autotransformer as a relieving gadget for voltage Sag [11] aggravation. Control circuit taking into account load RMS and voltage list detecting circuit in view of top recognition are utilized. Usually dynamic voltage restorer and STATCOM are utilized for moderation of voltage sag. The control circuit of the moderating gadget is utilized to create PWM signal pulses taking into account time-ratio control to differ the essential voltage of the auto transformer in order to keep up sought load voltage. Quick identification of voltage sag is accomplished by utilizing peak recognition circuit which persistently appraises the top conceal of the supply voltage. The alleviation gadget is straightforward in development and comprises of a solitary PWM insulated gate bipolar transistor (IGBT) switch in a scaffold design, a thyristor detour switch, an autotransformer and a voltage controller every stage. Thus it has less exchanging components when contrasted with ordinarily utilized DVR and STATCOM.

Extreme arrangement of power quality change is to outline a moderation gadget which is financial, conservative and dependable. The compensator considered in this methodology/trial has a solitary exchanging gadget every stage and consequently lessened gate drive circuit size, however has the Capability to supply the obliged undistorted load voltage and currents. No energy storage device is required thus is less expensive than generally accessible mitigation devices. Simulation analysis is performed for three stage distribution system with two instigation engines and a delicate burden. This paper considers the voltage moderation plot that utilization one and only shunt sort PWM switch, an air conditioner converter topology for yield voltage control and an autotransformer .is utilized to support the data voltage rather than a two winding transformer. IGBT switch is associated with essential side of the autotransformer. Voltage and current distribution in the autotransformer. The compensator considered is of shunt sort as the control voltage created is injected in shunt. A transformer with turns proportion N1: N2 =1:1 proportion is utilized as an autotransformer to help the voltage on the load side when sag is distinguished. At the point when list is recognized by the voltage controller, IGBT switched ON and is controlled when proportion controlled PWM pulse generator such that the load voltage on the optional of autotransformer is the craved rms voltage.

Voltage sag [13] brought about by induction motor beginning is one of the fundamental driver bringing about touchy gear dropout .A Simulation model of Dynamic voltage restorer (DVR) has been proposed to mitigate voltage sag created by high-power induction motor starting. Taking into account these examinations, a control method, power grid voltage and load current. Dynamic Voltage Restorer (DVR) is an arrangement associated custom power device. The essential capacity of DVR is to distinguish any voltage sags happened in the power distribution network and infuse particular power to secure sensitive load. The DVR taking into account H bridge inverter in the distribution network. The principle components of the each stage are the Energy Storage System, the Voltage Source Converter, the LC filter and the Coupling

Transformers. The DVR can make up for single-stage sag, furthermore can adjust for three-stage sags thoroughly. DC energy storage device gives the genuine power Requirement of the DVR amid compensation. The center component of DVR is the Voltage Source Inverter (VSI) which is essentially used to change over the DC voltage supplied by the energy storage device to an AC voltage. It repays sag voltage in arrangement AC voltage and is coupled through infusion transformer to the main system.

The direct on line (DOL) starting of a high power induction motor causes an intense voltage sag [12] in the power supply system. Line to line and line to ground issues are a percentage of the reasons for voltage sags and voltage unbalance in the power supply system for businesses and business structures. This methodology/test examines mixture simulation methods to tackle power quality issues emerging from the DOL starting of a high power induction motor. The proposed arrangement uses the Static Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). In addition, the voltage sag amid the DOL starting of a high power induction motor could be further delayed because of an expanded starting time. Protracted starting times are brought about from a considerable diminishment in the starting torque under a decreased voltage accessible at the engine terminals. Likewise, a line to ground issue causes voltage unbalance. Thusly, voltage unbalance and lists bring about a generously delayed starting time for a high power induction motor bringing about a poor power quality for whatever is left of loads joined at the purpose of common coupling (PCC).

CHAPTER 2

2.1 Introduction to STATCOM

A STATCOM is one of the famous and important member of the FACT family. It has a very special ability to absorb reactive power and provide reactive power, and again absorbing real power in and providing real power out of the system. The STACOM is a shun compensated device .the STATCOM can provide 3-phase controlled waves of Various parameters like the phase angle ,frequency, voltage magnitude etc. it is actually a kind of a solid state switching device which have the capability to generate and accept real power and reactive power independently . Here the STATCOM has the heart of the device is the VSI that is the voltage source inverter. A static capacitor is used to provide the constant dc voltage supply to the STATCOMs voltage source inverter. The STATCOMs outer terminal is connected through a leakage reactance to the system or the main voltage bus that is to be connected. And here we have the constant power of the dc voltage is being supplied by the chosen well designed capacitor which can give a constant dc voltage to the VSI terminal of the STATCOM. The unique ability of the STATCOM to absorb the reactive power and the real power when needed with the fast response makes it a special device.

Here we can look for the STATCOM for the following purposes as listed below,

i. To control of the dynamic voltage in a power system and in distribution system
ii. Used to treat during the power oscillation damping condition
iii. The device can be also be utilized to treat the transient stability of the power system
iv. Sometime the voltage flickering control can be easily be done through IT
v. The uniqueness in the STATCOM is that it can exchange both active power and reactive power with the system with a connected line exchange with the dc energy system
vi. The STATCOM can be considered a very similar device just as it is a synchronous machine. Both have the same tendency to generate 3-phase electrical power with the given controlled frequency, phase angle and the magnitude of the fundamental voltage. They both can generate the reactive power and active power for the system. But one of main difference between them the STATCOM can provide the electrical power exchange for the small period of time but the synchronous machine can generate continuously for the given system .So, the above point shown the utility of the STATCOM circuit.

2.1.1 Constructional Model of the STATCOM

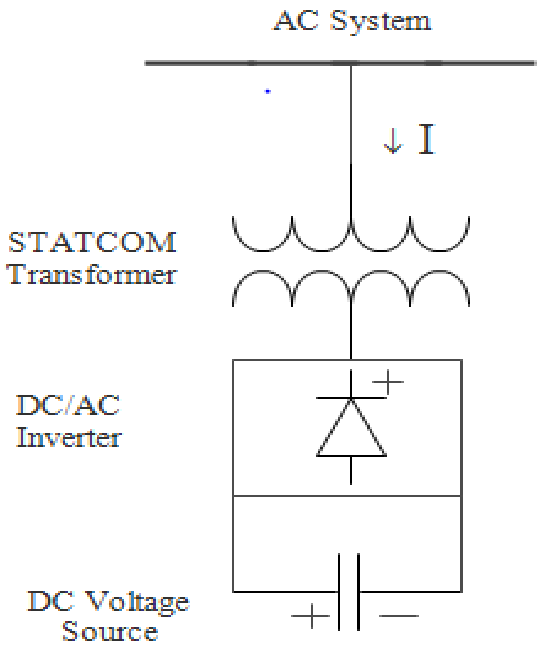

Fig 2.1

The basic block of the STATCOM has been shown above here, as we can depict from the figure about its construction in the MATLAB, here we have a transformer coupled to the ac system, a VSC circuit and which is connected to a dc source here in this case we have taken the dc capacitor as our constant dc voltage source. Here in its simplest for of the construction the figure depicts the STATCOM being made up of the a coupling transformer whose especially leakage impedance is being acts as the inductance that's connects the STATCOM circuit and the ac bus system.

Figure clearly shows that whenever the STATCOM voltage is increased above the system ac voltage the current goes out of the STATCOM circuit and compensates the reactive power to the ac system voltage it has been connected to the bus system. And converse is also true in this case as per the given case, if the STATCOM voltage decreases below the system voltage then the current form the system is flows down to the STATCOM and the reactive power is absorbed.

2.1.2 Functioning of the STATCOM

Here the STATCOM that has been prepared in the MATLAB, It operates similar to the theoretical operation of the STATCOM we have seen in the circuit as per given value. Here the statcom is made up of a VSC and have consist of the 6 pairs of the switches which are arranged to form the inverter circuits and ,the inverter circuits is being controlled by the PWM pulse according to the demand of the system voltage . Here to generate the value fundamental magnitude of the voltage set s of the 3 phase sets we have taken care the appropriate dc source voltage and pulse widths that are being given to the system.

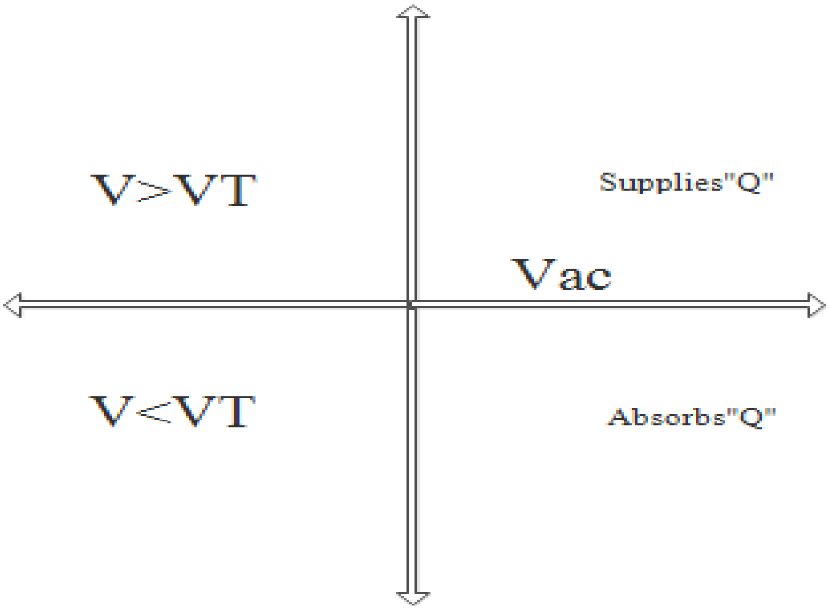

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Fig. 2.2

The reactive power supplied by the STATCOM is given by

$$Q = \frac{Vstatcom - Vs}{X} \times Vs$$

Where,

Q is the reactive power.

$V_{STATCOM}$ is the magnitude of STATCOM output voltage.

V_S is the magnitude of system voltage.

X is the equivalent impedance between STATCOM and the system. When Q is positive the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system.

The current derived from the compensator is 90^{o} shifted with respect to the ac bus voltage, and it can be leading in nature (generates reactive power) or lagging in nature (absorbs reactive power).and at last a coupling capacitor is being used to maintain dc voltage to the inverter. An uncontrolled diode bridge is being coupled with the capacitor to make it charge all the time. The diode bridge derive the power from the main supply voltage of the bus.

2.2 The Operation Principle

The operation principle of the STATCOM is very simple. It has to provide the given amount of the reactive power when needed and absorb the active power or reactive power when needed accordingly. The exchange of the power between the STATCOM and the device ac system is purely an electronic exchange system. The heart of the STATCOM lies in a VSC (voltage source converter). It is where the reactive power for the system is being generated. Not inside the capacitor where the reactive power is generated. STATCOM is purely a compact device and very effective in nature. Its power electronics equipment inter connects between each other and they generates the required reactive energy for the exchange with the reactive system. Its unique ability to provide leading VAR and accepting the lagging VAR from the system makes it stand aside. This obviates the requirement of the reactor or capacitance heavy banks with a simple compact power electronics module, can be neglected. The main exchange of the energy between the system and the STATCOM can be carried out by the changing the voltage magnitude and the phase angle of the output of the STATCOM of the system. When the voltage of the STATCOM is increased above the bus system voltage the STATCOM provides the reactive power and when the system bus voltages is deeps down from the given bus voltage the STACOM draws the reactive VAR from the system. And if the output is equals the bus voltage of the ac system the no exchange of the electrical power happens.

So making the changes in the value of the phase angle of the STATCOM can effects the reactive power exchange with the system and the value of the phase angle of the STATCOM is increased above that of the ac bust system then then STACOM provides the real power in to the system and the when the ac voltage phase angle is greater than the STATCOM phase angle then real power flows into the system. The STATCOM is connected to the AC bus system through an inductor. so when the STATCOM provides the output power , the power flows through the inductor hence the outgoing power is the capacitive inductive power in nature, and when the energy is coming it from the energy source , the electrical currents comes from the inductive load and the STATCOM circuit absorbs the inductive reactive power, and here while absorbing the electrical power the VSC acts as an 3 phase rectifier bridge, the pulse width modulation process helps in this process and makes the reactive power absorption process a simpler one in the direction. The designing of the STATCOM VSC and the reactor determines a measure role in the deciding the functioning output of the STATCOM and plays a major role in playing the STATCOMS output voltage source.

The STATCOM provides the desired output electrical power with the frequency and the phase angle accordingly. Inside the STATCOM the various power electronics switches reconnects themselves in the orderly fashion to create the reactive power generation in to the system, so it can be taken an inference that the capacitor plays no role in the generation of the reactive power inside a SATCOM circuit, the only function it serves is that exchange of the real power to the VSC circuit and this exchange is provided by the constant dc voltage supply to the inverter circuit. Terminal inside the STATCOM are interconnected in various ways to connect each other exchanging of the reactive power in various possible manner. So while designing the STATCOM circuit care has to be taken to choose the accurate dc capacitor terminal voltage circuit.

So to design the DC capacitors voltage design, the capacitance value has to be carefully chosen which further depends upon the various factors, so for a STATCOM to generate the required VAR a dc constant link voltage must be connected across its link, here in this case the purpose is being served by a capacitor of the chosen value. To decide the amount of the magnitude of the capacitor it has to such that the dc voltage across its terminal will always be maintained constant and its should be withstanding the fluctuation of the ripple voltage and the switching transient of the VSC. The one of the primary need for the capacitor is to provide the circulating current direction for the dc capacitor in the VSC circuit.

We know that the VSC produces the staircase wave in the system in as the 6 pulse generation. During the pulse generation of the fundamental voltage, the dc capacitor should be able to with stand the electrical switching surges during the various times. And hence not to violate the power equation capability of the input power given by the electrical system and the voltage outgoing through the VSC. So one of the factor that is taken into decide the designing the factor for the switching transient that happens during the turn on and off process of the VSC circuit.

The VSC circuit have that similar level of rating during the operation with the inductive current or the during the operation with the capacitive kind of the operation, the another point about the STATCOM is that it has the twice the range of the MVAR capacity as it can take in leading reactive power and gives out reactive power. And here as mentioned above a dc capacitor bank is required for the operation of the VSC. The reactive power of the STATCOM is being produced by the power electronic way of the converter action. During the transient condition here we choose the pulse width modulation of the circuit carefully such that it can withstand the transient current.

2.3 VI-Characteristic of STATCOM

The STATCOM can provide both reactive power in capacitive form and reactive power in the inductive form. And they occurs independently, another point can see from that is the device can provide the rated capacitive current even in the voltage of 0.15pu voltage also. This implies that the STACOM is being capable of providing the full capacitive power and is independent of the system voltage irrespective, another function of the STATCOM is to handle the power circuit during the faulty conditions too, so during the fault condition the STATCOM has to generate a very large amount of the capacitive power too. So the transient limit of the STATCOM circuit is extended from the rated value of the capacitor, which can even conveniently provide the reactive power during the faulty condition. The maximum amount of the transient current that is allowable is decided by the factor of the current switch off capability of the power electronic switch of the voltage source inverter. And similarly one can notice the extended capability of the inductive power transient region of the STATCOM circuit as given here. And in the inductive zone of the operation of the STATCOM the deciding factor for the dc capacitance value is the, in this region they are naturally commutated and their operation is being decided by the factor of the maximum short circuit current in the circuit. Or the temperature rise in the switches due to the short circuit current.

But in the real world situation the semiconductor operated devices are having some losses which are inherent to them. So hence here it is observed that the dc capacitance voltage diminishes however when the STATCOM is being used for the VAR compensation the converter can help maintaining the constant dc voltage into the system. This phenomenon is being achieved by the fact that making the phase angle difference a slightly lesser than the ac system voltage and hence the as the phase angle difference the real power in the system rushes down into the STATCOM that real power being received by the capacitor and the voltage across the capacitor is maintained constant as a result. The phase angle lagging that has been provided is generally of 1° to 0.2°.

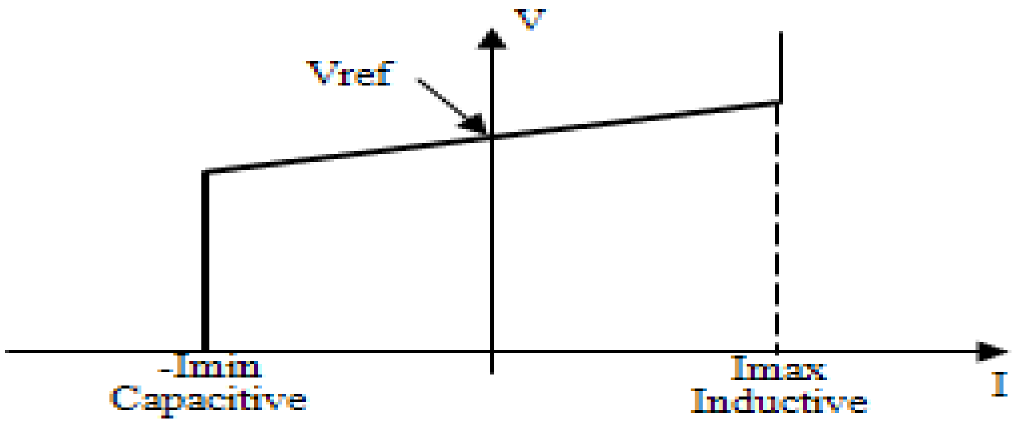

Fig.2.3

Here in the figure we can see the VI characteristic of the STATCOM. As form the figure one can conclude that the reactive power control between the STATCOM circuit and ac system voltage can be controlled by the voltage difference between the ac system bus voltage and the STATCOM voltage. So evidently any combination of the generation of the ac system voltage and phase can carried out by the STATCOM circuit. And extremely effective strategies for the control of the real power and ac active power can be devised using a STATCOM circuit, and this can be utilized to improve the transient and dynamic capability of the STATCOM circuit.

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CHAPTER 3

3.1 Problem Statement

Voltage sag is one of the most persisting cause in an electrical energy operated plants or industries, IEEE defines the voltage sag as the decrease in the magnitude of the fundamental voltage wave from the unit value of 1pu to between the value 0.1pu -0.9pu in the terms of the rms voltage .this can be last for any duration between 0.5 cycles to some few cycles. And there are many reasons which are responsible which we shall analyse in the upcoming times, but here we want simulate a model in MATLAB environment using SIMULINK block diagram to show a condition of sag while starting a high power induction machine and how the sag happens during the entire cycles its nature, and then here we have the tried to design a STATCOM circuit which is using a 6 pulse VSC circuit which is PWM operated. And incorporated the STATCOM circuit in to the main ac bus system for using it as a source to supply the reactive power to the bus during the faulty condition or the voltage sag condition. As we knows that starting a high power induction machine draws a very large amount of current that is 6-10 times the normal rated current and is sufficient cause a fault In the system, and as we knows that the power factor of the induction machine as a load is very low and so the reactive power of an induction machine during the process of starting is considerably high in amount and it the amount of the inductive power diminishes as the speed of the motor increase.

So, a simulation based model has been under taken in this project consists of a high power induction machine and a supply system. The reactive power supplied during starting to prevent the voltage sag is done by applying a STATCOM circuitry along the main line power supply which provides the reactive power during the starting of the induction motor. All the simulation is done in the MATLAB environment and the waveforms associated with the starting with normal power line supply and that of supplied with the STATCOM passage has been recorded and compared to see the difference and enhancement it is bringing in to mitigate the voltage sag problem during starting large induction motor. Special care has to be taken during the selection of the dc capacitance value as if the frequency of the resulting harmonic component coincides with the resonance frequency of the dc capacitor and the coupling reactance. And further after finishing the circuital analysis with the thyristor based VSC circuit we have taken IGBT based electrical voltage source circuit as per the given behaviour. And various papers related to the sag has been studied in this paper and their mitigation process also has been also been learnt. But at end we will try to take the theoretical conclusion of the advantage of the STATCOM and its various good capabilities.

3.2 Matlab Modelling

Below the image depicts the flow diagram of the simulation in which a power supply, breaker and high power induction machine has been modelled in the MATLAB environment. Then the reactive power supply system has been modelled with the help of the STATCOM system implementation in it. The construction details of the STATCOM are given in the subsequent pages. Figure -2 represents the block diagram model of the project different diagram has been cited with the help of the software E-DRAWmax and indicative symbol has been cited with suitable.

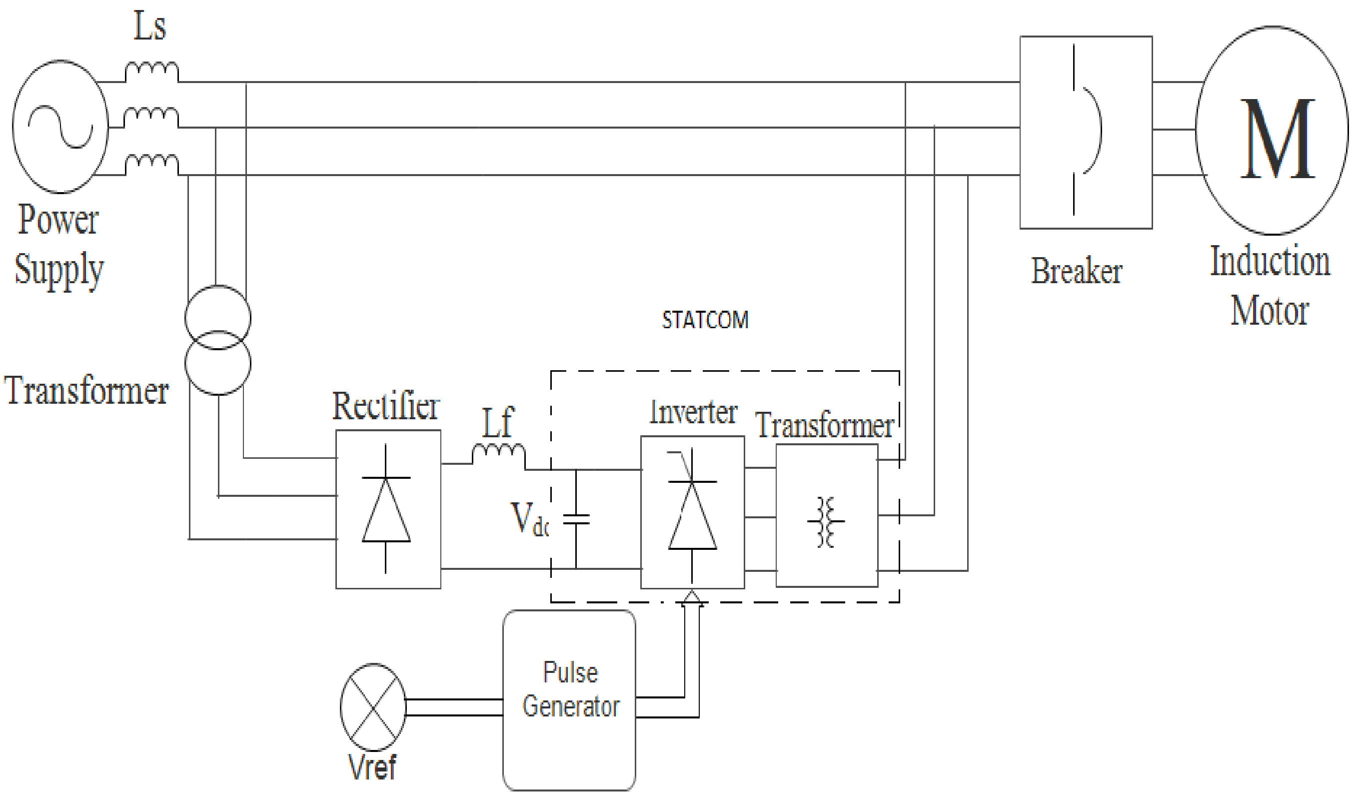

Fig.3.1

so according to this block diagram we are arrangeing the different blocks accordingly . here as simple over veiw a 3 phase system is being connected to the induction machine whose rateing is choosen as high as high as possible to create the sag in the block, here we can also observe the block diagrame of the statcom system in which the pulse generator is being fixed appropriately, and the dc link capacitor is being charged by the diode rectifier bridge,The comparision signals or the referenec signals for the pulse is generator is being taken form the line voltage . and accordingly the vsc is operatied, further purpose of the link inductor here we have taken the transformer whose link is being taken as the leakeage inductor for the statcom circuit operation as wre have seen previously.

3.2.1 Work done: STATCOM Based on Thyristor Switches

Initially various papers were followed from various journals and papers on the topic of voltage sag problem during starting of high power induction machine. A simulation based on the above mentioned model has been attempted with Taking STATCOM as its heart in MATLAB environment. Basically we have proceeded with two conditions of STATCOM operation. Firstly without using the STATCOM and secondly using a STATCOM to run a high power induction machine.

3.2.1.1 Case-1 –Without Use of Statcom

To simulate this we first taken blank document page in MATLAB software, then using Simulink library browser we got Sims cape option, then after entering in to that using the SIMPOWER system we selected the desired electrical source i.e. 3 phase programmable voltage source and a ground. The appropriate values were given. Then we went for 3 inductors which represents the transmission line approx. Reactance’s values. As we know transmission line needs distributed parameters line for good MATLAB simulation we got it from Simulink library browser. Then we went for asynchronous machine which was also available in the SIMPOWER system. We connected all those blocks with the help of conducting wires and for the measurement we took one voltage measurement block and Two current measurement blocks .As we know we have to calculate the rms value of current and voltage. We connect according to the principle i.e. current measurement block in between distributed parameters line and synchronous machine. And voltage source measurement block connected with positive end with line and negative terminal was grounded. We took active and reactive power block from the library and we connected them to a scope through an rms block and the inputs were corresponding voltage and corresponding current which are measured from their corresponding block.

To verify the asynchronous machine rotor speed characteristic we chosen line DEMUX that is connected to the gain block which is subsequently connected to a scope which is the output terminal of the synchronous machine. Asynchronous machine mechanical input was feed from a ramp signal through a gain block to have a smoothen input and to run the system which connected as said by above continuous.

Powergui block for the proper simulation. Simulation time taken as 0.5minutes.Then we went for the simulation and the corresponding rotor speed characteristic, voltage current waveforms and active power-reactive power waveforms were observed and recorded in the scope. The scope back grounds were changed from black to white and line spacing colours were black. Waveform plotting colour is changed yellow to blue.

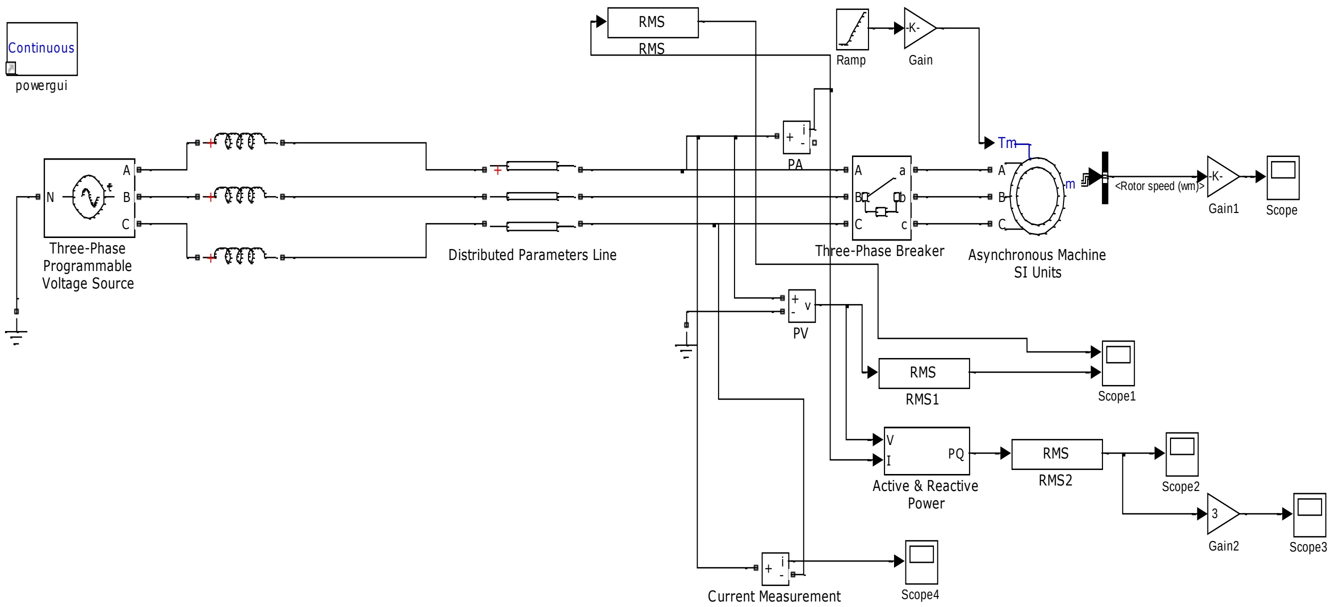

Fig. 3.2

3.2.1.2 Case 2- Simulation with STATCOM Circuit

We took 3 phase programmable voltage source block with grounded neutral, and connected it with 3 inductances, 3 distributed parameter lines and a 3 phase voltage- current measurement blocks as we did it in the previous case. Then 3 phase breaker block is added just before the asynchronous machine.3 phase breaker was taken from the simpower system. Voltage and current measurement blocks were taken and connected to corresponding scope and the current and voltages from the these blocks were connected to active and reactive power measuring block which was then connected to scope through rms block. And for the asynchronous machines mechanical input was given by a ramp signal and its output is observed in a scope through a demux.

From the main transmission line we took a connection and stepped down its voltage through a transformer. We then feed it to an uncontrolled rectifier bridge. Then the output of this rectifier was connected to a smoothening inductor for getting better dc put and to lessen the ripples. The out from the uncontrolled diode rectifier bridge now being used to charge the coupling capacitor of the STATCOM circuit .now to design the VSI required in the circuit we implemented PWM technique. For this, we took a reference voltage signals from the transmission line and connected it to a controller named as synchronised six pulse generator. This is to be compared with the STATCOM voltage source. Firing angle controller was used to control the firing angle of the thyristor based VSI to control its out voltage. The output was connected as an input through a step up transformer which was connected back to main transmission line. We have to take care that phase angle and frequency should be the STATCOM voltage to the main power line.

The idea behind connecting a STATCOM circuit is that to compensate the reactive power deficiency happening during starting of high power induction motors ,as when we starts an induction motor the secondary terminal is short circuited which demands very high magnetic current or inductive current to produce the initial starting torque. Which must have to be given by the supply system.so a large current demand during starting the induction motor creates a voltage sag in the system.so the STATCOM current must compensate this amount of current to avoid the voltage sag during the starting. But current which is provided by the STATCOM circuit is leading VARs in nature to get it in to the line voltage phase we must design the transformer inductance suitably such that if it drops across the inductor then the output current has to be in phase with the supply system voltage of the 3-phase system.

If the frequency of the resulting harmonic component coincides with the resonance frequency of the dc capacitor and the coupling reactance then the resulting harmonic distortion at the ac side can be very high. The dc capacitor resonance may lead to excessive magnifications of some Harmonic components and increasing harmonic distortion of the STATCOM current. In the simulation, the coupling reactance is not considered so the possibility of harmonic resonance to occur will be reduced. But consideration of harmonic resonance is given because loads are inductive and this may have some effect on the dc capacitance. Now for the measurement purpose we took capacitor voltage measurement separately in one scope and the three phase out put voltage waveform of inverter is taken in another scope.

The reactive power and active power of the inverter feed to the system are observed in another scope through active–reactive power block. For the confirmation we measure the three phase voltage and current measurements of the desired output waveforms. At last we added powergui continuous block to the simulation for the simulation to be completed. Here the simulation time was given as 0.5sec.Then all the respective waveforms and characteristics were made into the observation.

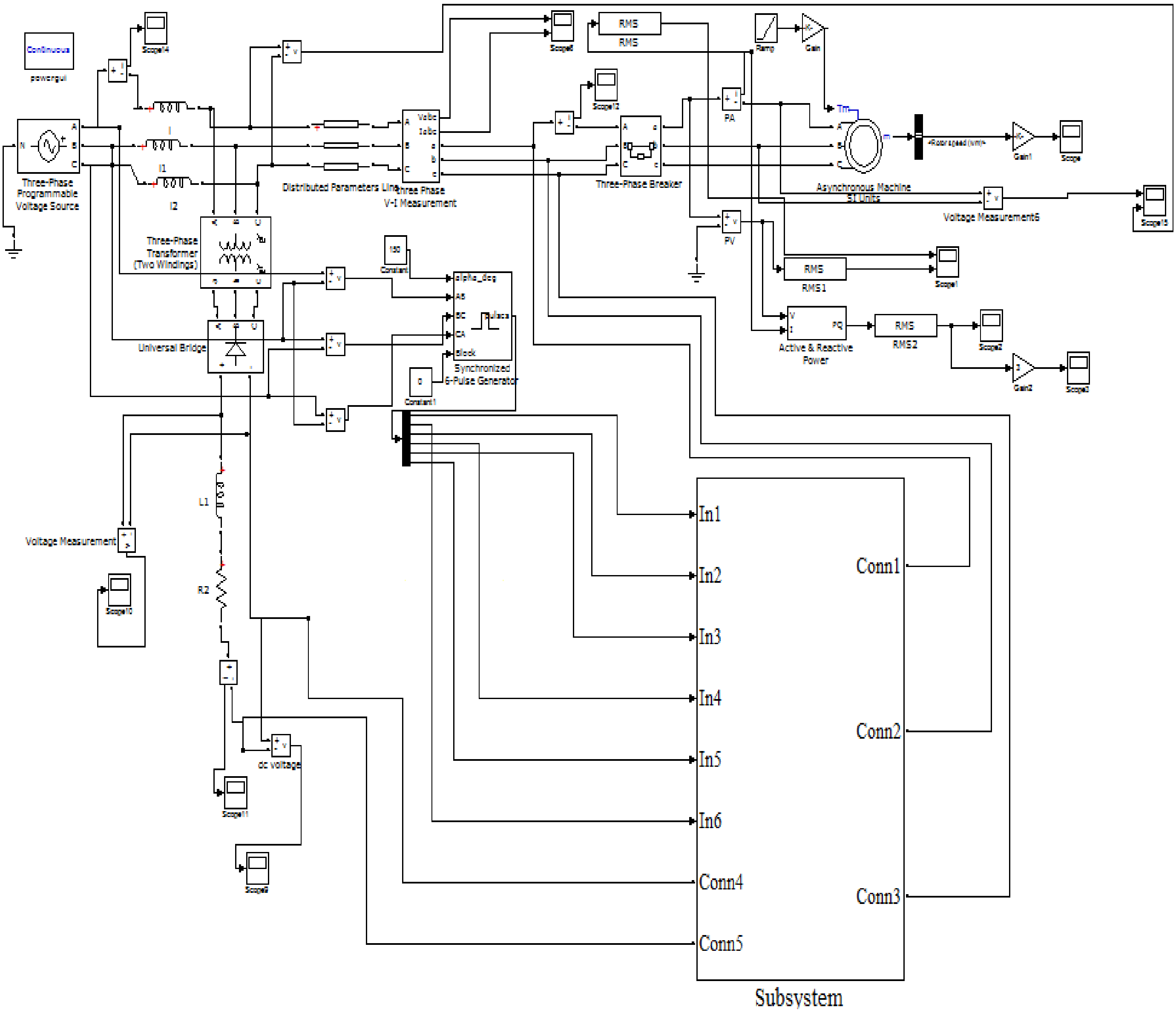

Fig. 3.3

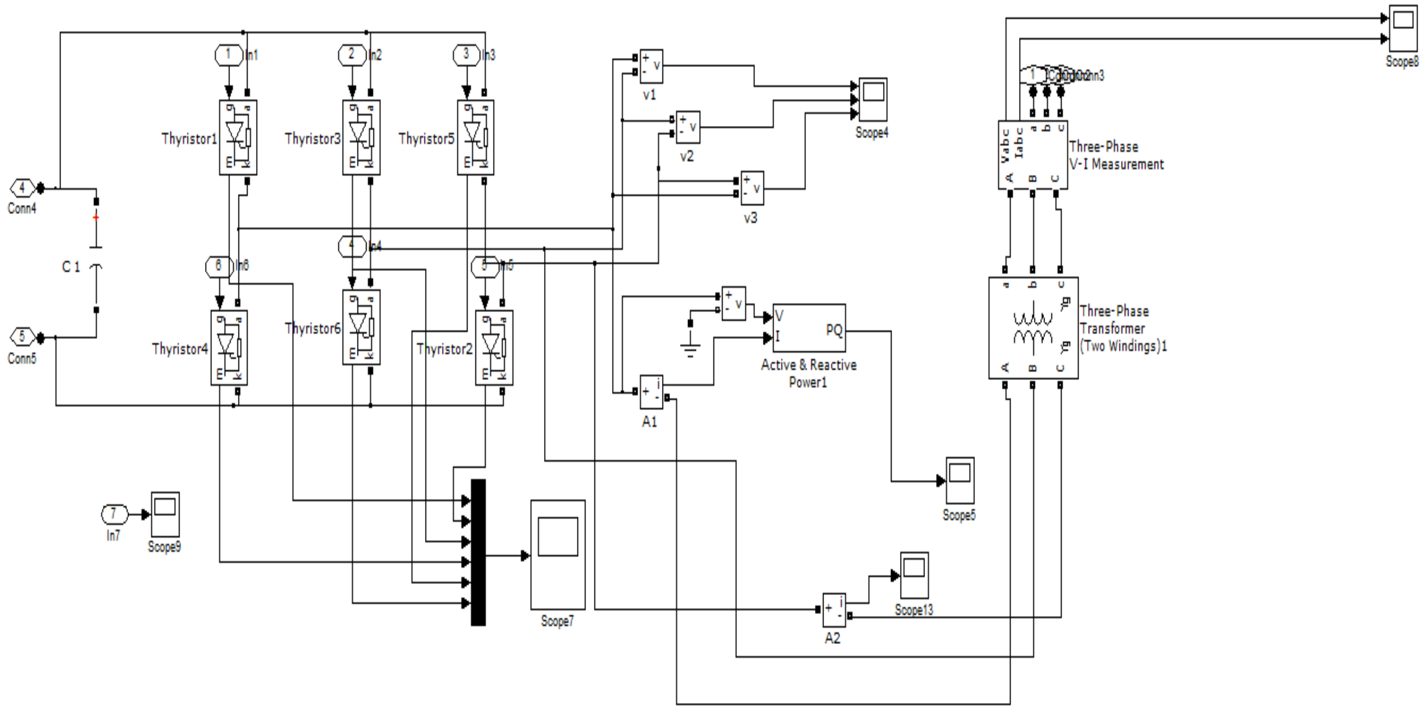
Conn4
Conn5
C 1
In1
In2
In3
In4
In5
In6
In7
Thyristor1
Thyristor3
Thyristor5
Thyristor4
Thyristor6
Thyristor2
v1
v2
v3
Scope4
A1
A2
Active & Reactive Power1
Scope5
Scope7
Scope9
Scope13
Scope8
Three-Phase V-I Measurement
Three-Phase Transformer (Two Windings)1

Fig. 3.4

CHAPTER 4

4.1. Results Using Thyristor Based STATCOM

After the simulation was run successfully the performing characteristic were observed though the different blocks deployed for recording the current, voltage ,reactive and active power recordings respectively. Simulation of the project can be seen in the figure number 5 'Where the exact SIMULINK block diagram has been cited. Exact connections and arrangement has been done as described during the work done procedure. The block diagram connection made in SIMULINK MATLAB model is only for direct operation of the induction motor (case-1) in which we directly starts up the high power induction motor so we connect the supply 3-phase voltage source directly to the induction machine though a breaker .

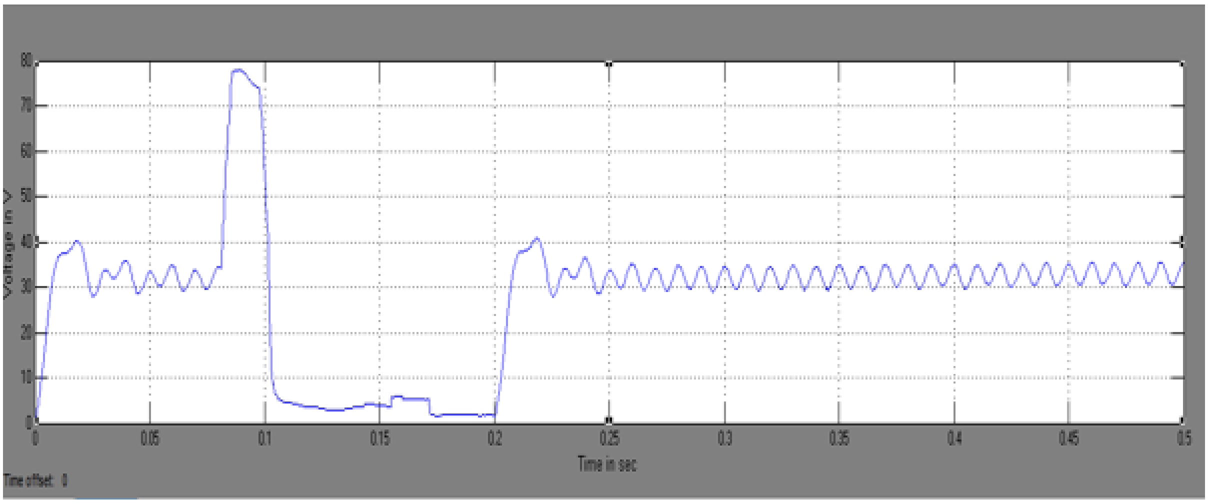

Fig. 4.1

And in case -2 we implemented the STATCOM circuit into the system, the details work of simulation has been cited in the figure 3.3 in which we have chosen thyrister as the self-commutating device for the VSI (voltage source inverter) and transmission line voltage has been taken as the V_{ref} for the PWM based VSI converter, whose output always depends on the transmission line voltage as the comparator circuit exists inside the inverter. The observation we made from the simulations are indicative of the voltage sag we were expecting during the starting of the induction motor. Figure 4.1 indicates voltage sag occurred during the normal starting of the induction motor. The main reason why the voltage sag the wave form shows is

Induction motor can be compared to an electrical transformer with the secondary short circuited. Primary winding of the transformer can be compared to the stator winding of the induction motor and the rotor winding is considered as the short circuited Secondary winding of the transformer induction motor consists of two branch circuits which are in parallel.

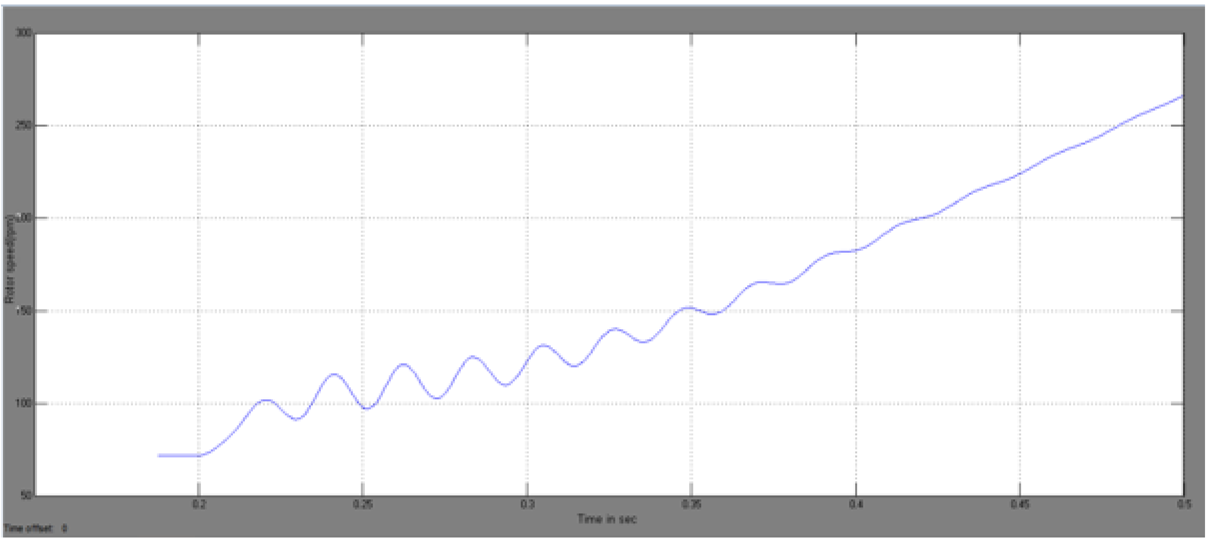

Fig. 4.2

This induced emf produces electrical current in rotor windings. Current generated in the rotor windings produces a field which in turn produces torque to rotate the motor. Once the rotor starts picking up the speed, current drawn by the machine decreases. The time required for staring of the motor depends on the time required for the acceleration which depends on the nature of the connected load. These inrush currents drawn by induction motor during starting can result in large dip in connected bus voltages. This dip in bus voltages can impact the performance of other motors operating on the bus. Voltage dips during starting of large motors can trip some of the motors operating on the same bus. So figure 4.2 in the SIMULINK represents the rotors oscillation during the starting of the induction motor.Intially as the voltage dip or sag encountered by the induction motor forces the motor into uneven torque and rise in speed is not uniform and the rotor oscillates due to repeated voltage sag for the few minutes but as the time passes with the stabilized voltage after the rotate speed increases with a uniform acceleration. So this clearly illustrates the fact that voltage sag is lasts for few power cycles and if it lasts for a longer durations then the system may face severe consequences like trip of the other motors in bust or the damage to the rotor of the motor or its winding in the process.

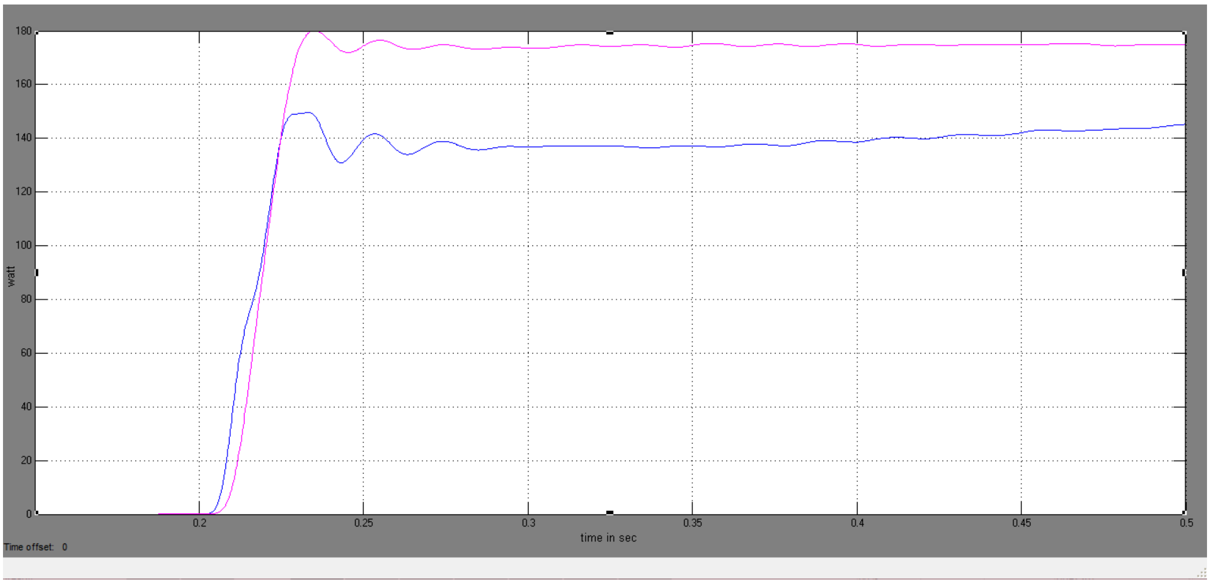

Fig.4.3

Moving on to the next figure we have figure 4.3.the significance of this figure is that during the starting of the induction motors the machine absorbs both the active power and reactive power both.in the figure 4.3 the blue line plotting indicates the reactive power absorbed during the starting and the pink line shows the active power absorbed during the starting. The main idea behind the power flow is that active power flows from leading VAR to lagging VAR so active VAR is flowing in. and also the reactive power also flows from source having high

voltage to lower voltage.

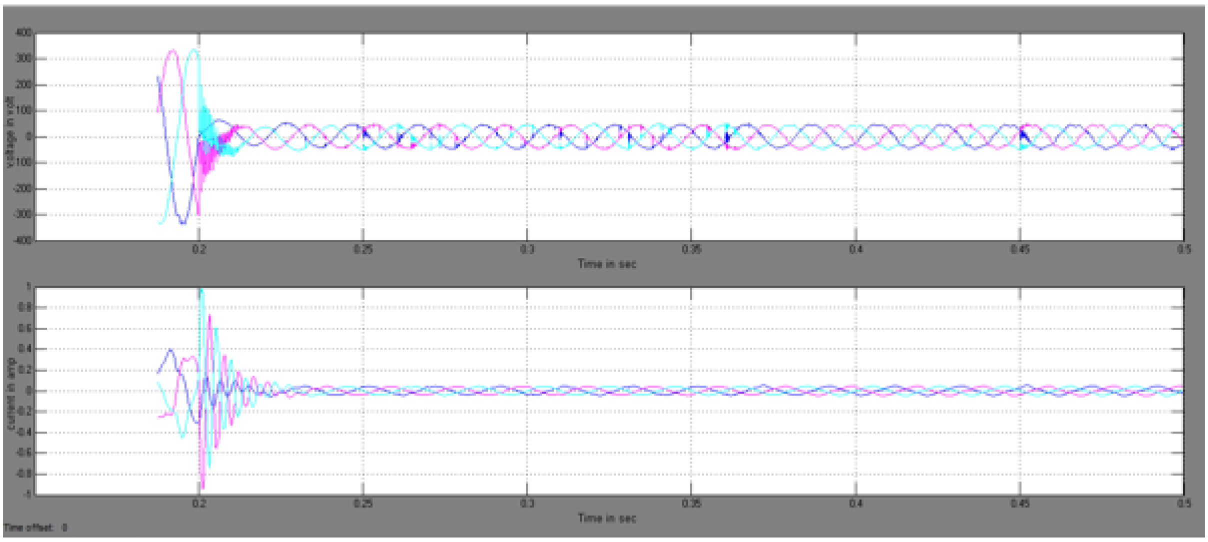

Fig. 4.4

And now the figure 4.4 is the plotting of the PWM controlled VSI which is showing the 3 – phase waveforms each phase displaced by 120 degree and is in the phase with the main line supply respectively with their phases. The output of the VSI implemented can be controlled by the controlling the thyristor angle control. There is two type of the operation of the STATCOM i.e. inductive operation when the system voltage (Vs) is lower than the Vs .then the current flows into the circuit through the transformer inductance which sifts the current into the capacitive domain. And then in capacitive operation the reactive power compensation is done by the capacitive current supplied by the STATCOM to be dropped across the transformer impedance.

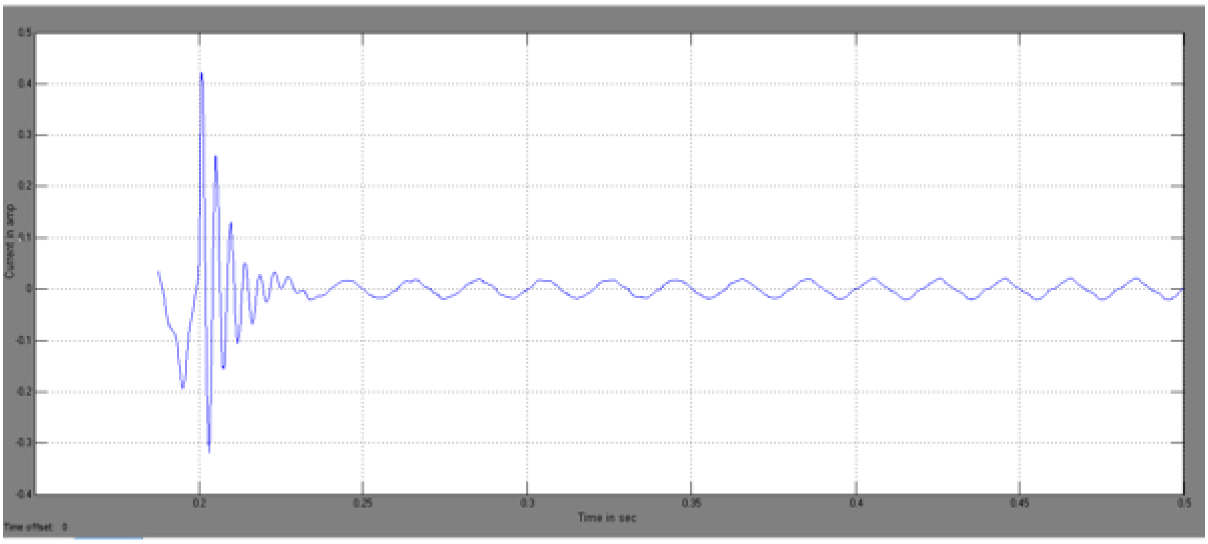

Fig.4.5

Figure 4.5 in this case clearly depicts during operation of the given circuit with the help of a STATCOM circuit, the STATCOM is providing the required amount of the reactive current during starting of the induction machine then after it gets stabilize the voltage or sag is omitted after the few cycles the STATCOM comes into its normal current value.

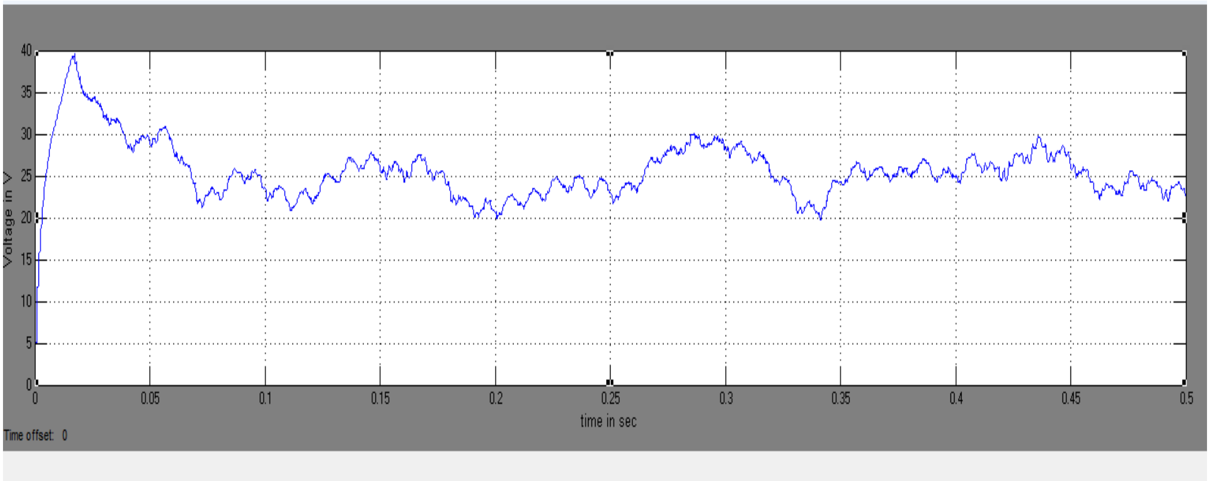

Fig.4.6

And the figure 4.6 shows the voltage profile of starting performance with STATCOM to the induction machine which is an improved voltage profile. And not much sag has been seen as the reactive current has been compensated by the STATCOM.

4.2. Results Using IGBT Based STATCOM

Here in this model of simulation model we are implementing IGBT based VSI in the STATCOM .as the switching characteristic and low losses during switching the IGBT is expected to be performing better in the STATCOM circuit.so hence the model of VSI was built using IGBT as its switches.so accordingly as we have seen in the previous simulation we will proceed in using the same procedure and steps.so for this we first 3-phase supply was connected to a 3 phase induction motor using 3-phase circuit breaker and to represent the line parameter of the transmission line 3 inductance were connected in series and assigned the appropriate inductance values. Here the purpose of the circuit breaker is create an intentionally simulated condition for recording of different parameters associated with the 3-phase supply and in addition to that a protective device for the load. Now we have to model the STATCOM circuit for which a VSI based inverter was assembled as in six pulse inverter. And for supplying of the dc power to the system we chosen here the dc source as a DC capacitor acting as the constant dc voltage source for the inverter, the capacitance value chosen referring to various papers in such a way that the capacitance value can withstand the slightest transient in voltage converter, and the VSI is controlled suitably by applying pulses from the synchronised pulse generator. The output of the VSI is now interfaced to an inductor L. and further using a transformer the voltage was stepped up to the system voltage required here. And the terminals from the STATCOM were connected to the BUS with equalising the phase sequence and the frequency to the STATCOM voltage.

Now for the proceeding of the simulation we first intentionally closed the breaker 0.3 seconds to connect the 3-phase induction motor with the supply. Now as designed with appropriate rating we created voltage sag immediately after closing the breaker circuit, then as the inherent quality of induction machine it will draw more current and there will be a sag appear which can be found in figure

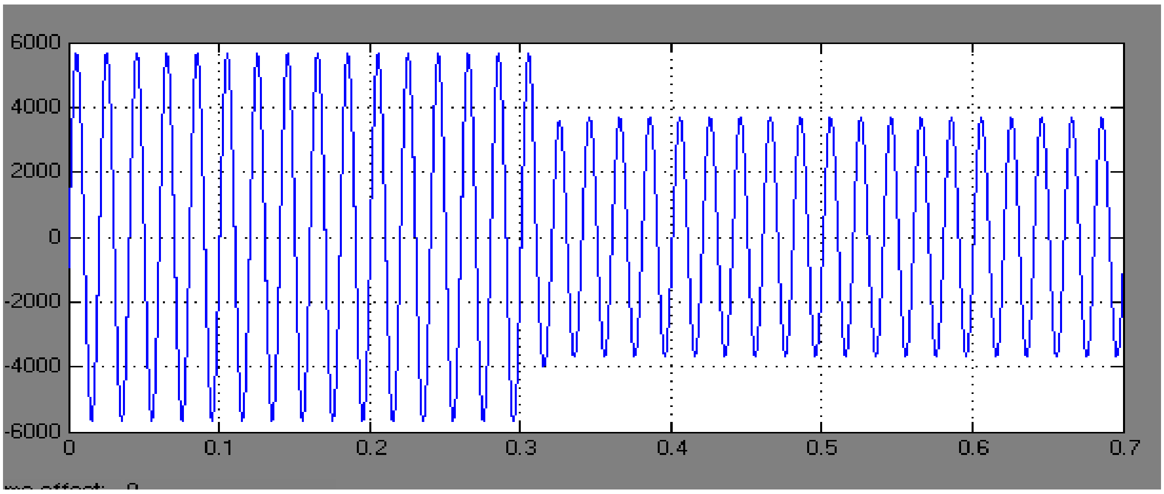

Fig.4.7

After the 3rd second we can depict the sag occurrence in the system.so we recorded the voltage sag using proper block arrangement. And there after we also recorded the active power and reactive power during the sag condition as in the below figure we can see.

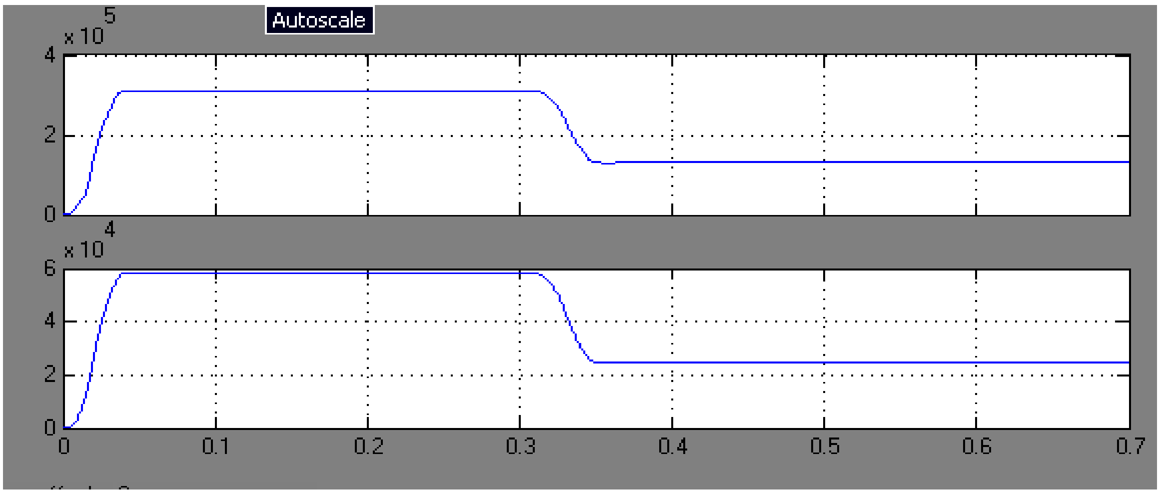

Fig.4.8

Here the active and reactive power supply is can be seen to be dipping down when the the sag happened which consequently brings down the system voltage.

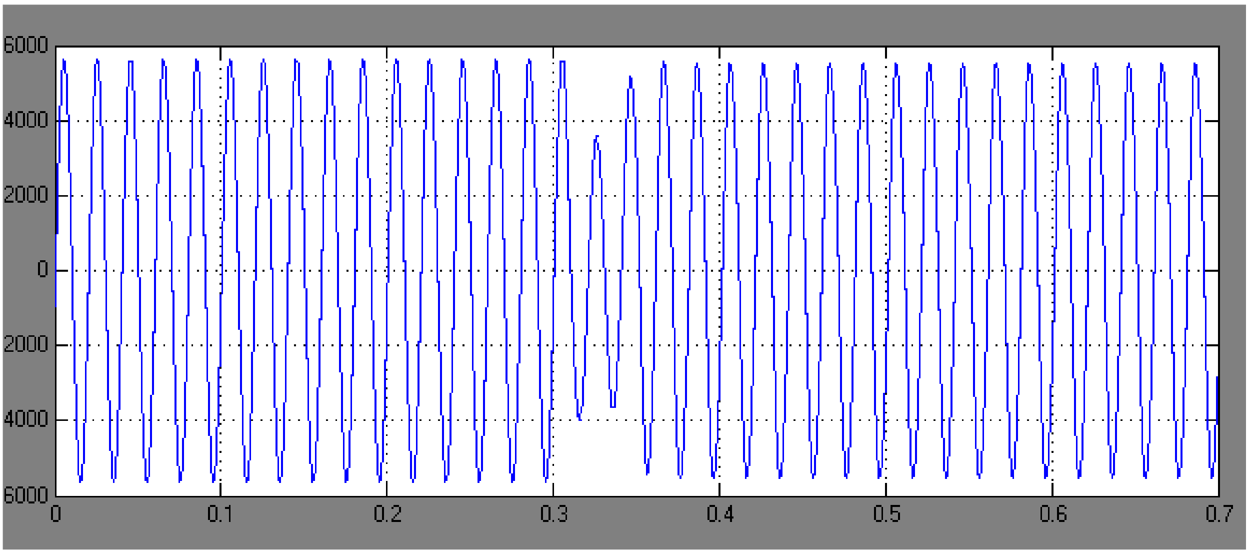

Fig.4.9

Here we saw the voltage profiled improved considerably, and below the compensated reactive power is has been visualised in the SIMULATION where both active power and reactive power associated with the profile improved with in a nominal amount of time. The figure here shows the active reactive power profile with STATCOM profile.

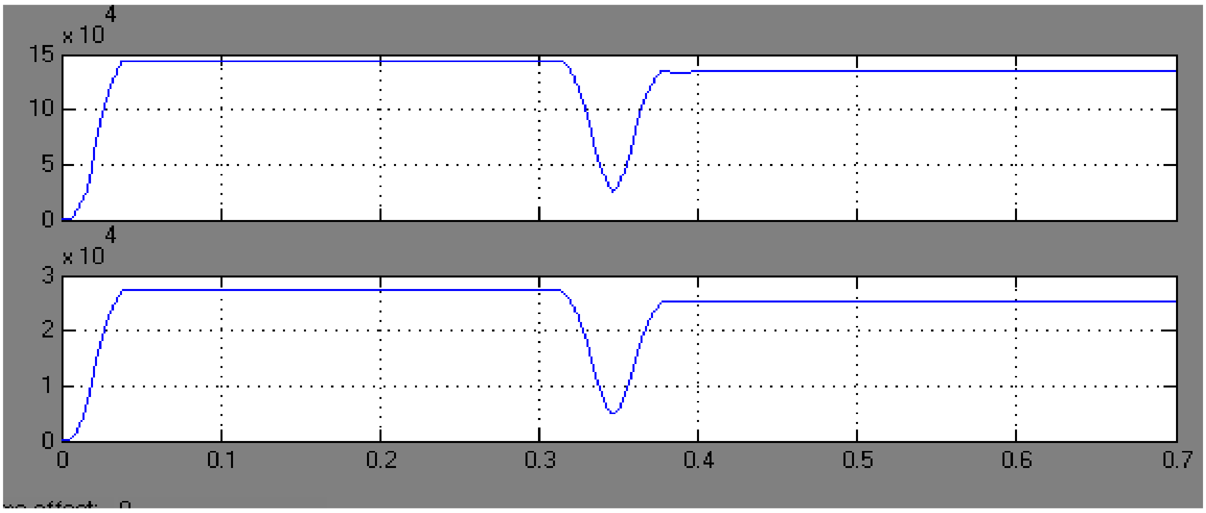

Fig.4.10

Here we can see the STATCOM current variation during the voltage dip condition and here STATCOM is supplying the reactive current to the system as below we can see the STATCOM is acting for the as a reactive power compensator here, supplying the needed reactive power during the sag time and restabilizes the system.

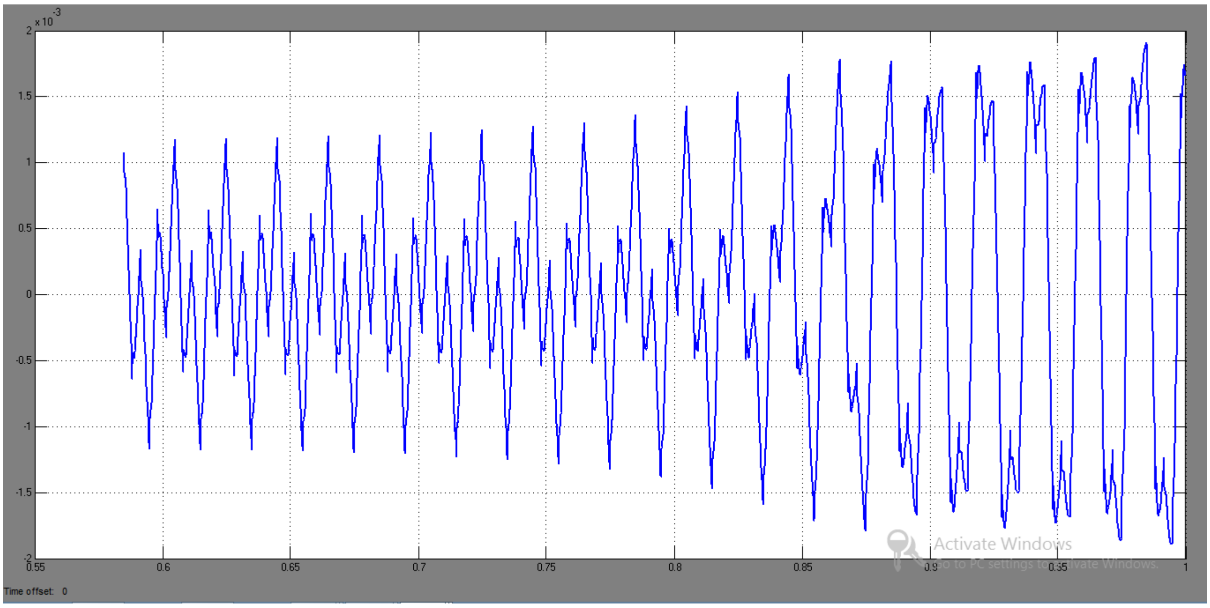

Fig.4.11

CONCLUSION

In this PROJECT, the simulation model of static synchronous compensator STATCOM based thyristor has been constructed on Matlab/Simulink software. Reactive power generation was achieved by charging and discharging the energy storage capacitor. The amount of reactive power is depending upon the thyristor-firing angle. The magnitude of the STATCOM terminal voltage was controlled with respect to the system voltage. STATCOM model Tested on Matlab/Simulink has shown that it can improve the voltage sag vector (magnitude and duration). Furthermore, it has shown the fast response of the STATCOM to voltage sag phenomena. Simulation results shown that the voltage sag improvement offered by a STATCOM may significantly reduce the number of trips in the sensitive equipment.

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