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Power Quality Enhancement Using Static Synchronous Compensator in Induction Motor Drive System

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Abstract - The application of a Static Synchronous Compensator (STATCOM) can help to alleviate some of the power quality issues encountered within a refinery consisting of large induction machine loads. The intent of this paper is to demonstrate the improvements obtained with STATCOM for this purpose and also to evaluate economical benefits obtained with it. [1] This work deals with Power quality improvement, Power electronic device used in power systems to regulate voltage and improve Drive System or grid stability by dynamically controlling reactive power flow. A Static Synchronous Compensator (STATCOM) can be used to enhance power quality in induction motor drive systems by mitigating issues like voltage fluctuations, harmonics, and reactive power imbalances. STATCOMs, essentially voltage source converters, inject reactive power into the grid to regulate voltage and improve power factor, leading to better overall power quality. Static Synchronous Compensator (STATCOMs) are shunt-connected devices, meaning they are connected in parallel with the power line.

Key Words: STATCOM, Drive System, THD, Induction Motor, Power Quality, Voltage source converter(VSC), Current source converter(CSC).

INTRODUCTION

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.

The electric power drive system has grown in size and complexity with a huge number of interconnections to meet the increase in the electric power demand. Moreover, the role of long distance and large power transmission lines become more important. Now a day the requirement for power quality becomes more and more important to keep safety of the electrical devices and consumer satisfaction. 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. [2] One is active power and other one is the reactive power as the convention dictates. 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,[15] 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[3].

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,

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$$P = VmaxImaxCos\omega t\ Cos(\omega t - \theta)$$

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 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.

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

1. Starting a high power motor draws a considerable amount of the current form the system and hence causing the voltage sag problem
2. Whenever there is a line to ground fault occurs there is huge current in the system flows hence contributes for the voltage sag
3. A quick change in the amount of load or adding increasing the load contributes for the voltage sag.
4. Sometime if transformer energization is not done in a proper way that too contributes for the voltage sag in the system
5. Voltage sag can occur from the utility home appliances like refrigerator, motor ump etc. we are using at home for the purpose[4].

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 - Voltage sag and Voltage swell

POWER QUALITY PROBLEMS IN INDUCTION MOTOR DRIVES

Voltage Fluctuations: Starting and stopping of induction motors can cause voltage sags or swells, impacting other connected loads.

Harmonics: Induction motors, especially when supplied by non-linear loads or inverters, can generate harmonics that distort the voltage and current waveforms.

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

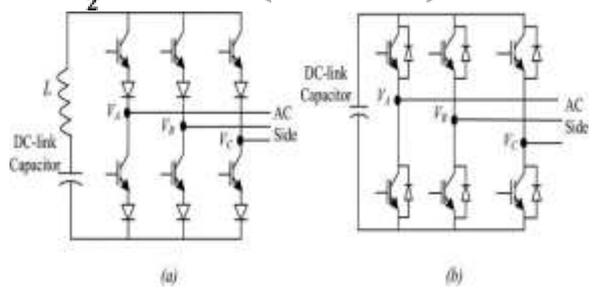

Fig. 1.2 - (a) Current source inverter and (b) Voltage source inverter.

Reactive Power Imbalance: Induction motors require reactive power for magnetization, and depending on the operating conditions, this can lead to a poor power factor and inefficient power delivery.

TYPES OF LOADS

Linear Loads - A linear load is characterized as a load that offers unvarying impedance to the supply voltage leaving the current wave shape to change directly in proportion to the supply voltage. In the event that the supply voltage waveform is sinusoidal steady impedance follows a sinusoidal current waveform. Some representation of linear loads is resistance warming, radiant lighting, motors and so forth.

Nonlinear Loads – [6] A nonlinear load offers changing impedance to the associated voltage with the objective that the present waveform doesn't differ as per the voltage waveform. This prompts a non-sinusoidal current waveform. Nonlinear burdens give substantial impedance at some piece of voltage waveform.

CURRENT SOURCE INVERTER (CSI)

The structure of the current source inverter is shown in Fig.1.2 (a). It is built with six-controllable unidirectional switches. It has to carry the entire current as demanded by the load.

The current source active power line conditioner is connected with PCC through the series transformers, which filters the carrier frequency components from the inverter currents. The dc-current supply is implemented using large dc- inductor in series.

VOLTAGE SOURCE INVERTER (VSI)

The PWM-voltage source inverter is more convenient for shunt active power line conditioner applications, in

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view of light-weight, less expensive, and expandable to multilevel topologies to enhance its execution for higher

power rating compensation with bring down exchanging frequencies. The structure of the voltage source inverter is shown in Fig.1.2. [5] It is built by using six-controllable power transistors with anti-parallel diodes. The voltage source inverter works as present controlled voltage source.

STATCOM

A STATCOM is 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.

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.

Application of STATCOM:

Voltage stability is one of the biggest problems in power systems. Engineers and researchers are trying to consolidate a definition regarding to voltage stability,

besides proposing techniques and methodologies for their analysis. Most of these techniques are based on the search of the point in which the system's Jacobian becomes singular, this point is referred as the point of voltage collapse or maximum load ability point.

Constructional Model of the STATCOM

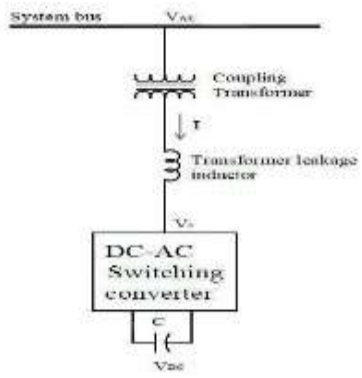

Fig. 1.3 - Block diagram of STATCOM

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.

Working Principle of STATCOM:

To understand the working principle of STATCOM, we will first have a look at the reactive power transfer equation. Let us consider two sources V1 and V2 are connected through an impedance Z = Ra + jX as shown in figure below.

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[7].

Figure 1.4 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.

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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 sets of the 3 phase sets we have taken care the appropriate dc source voltage and pulse widths that are being given to the system[8].

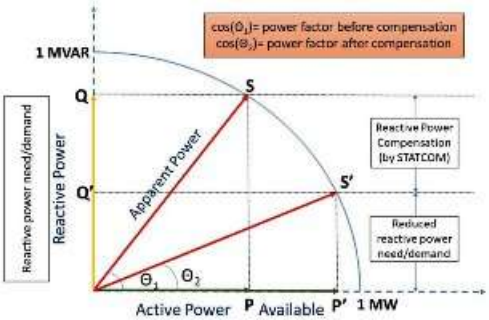

Fig. 1.4 - Reactive Power Compensations

The Operation Principle-

STATCOM has to provide the given amount of the reactive power when needed and absorb the active power or reactive power when needed accordingly. [9]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.

VI-Characteristic of STATCOM

The STATCOM can provide both reactive power in capacitive form and reactive power in the inductive form. And they occur 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.

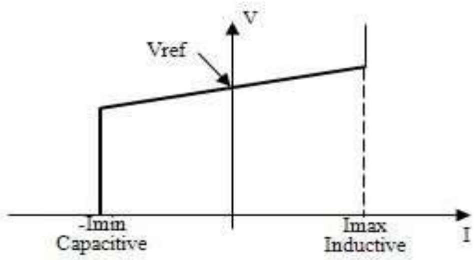

Fig. 1.5 - VI Characteristics

INDUCTION MOTORS

Induction Motor: An induction motor, also known as an asynchronous motor, is a type of AC electric motor that operates based on the principle of electromagnetic induction. Unlike some other motors, it doesn't require a direct electrical connection to the rotor (the rotating part) to induce current in its windings. Instead, the rotating magnetic field created in the stationary part (stator) induces an electric current in the rotor, which then generates the torque necessary for rotation.

- An induction motor (also known as an asynchronous motor) is a commonly used AC electric motor.
- In an induction motor, the electric current in the
- rotor needed to produce torque is obtained via electromagnetic induction from the rotating magnetic field of the stator winding.
- The rotor of an induction motor can be a squirrel cage rotor or wound type rotor.
- Induction motors are referred to as ‘asynchronous motors’ because they operate at a speed less than their synchronous speed.

Construction of Induction Motor -
A Induction motor mainly consists of two parts called as the Stator and the Rotor. The stator is the stationary part of the induction motor, and the rotor is the rotating part. The construction of the stator is similar to the three-phase synchronous motor, and the construction of rotor is different for the different machine.

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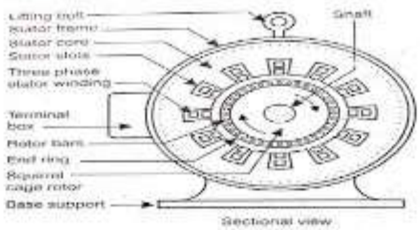

Fig. 1.6 - construction of Induction Motor

Construction of Stator

The stator is built up of high-grade alloy steel laminations to reduce eddy current losses. It has three main parts, namely outer frame, the stator core and a stator winding.

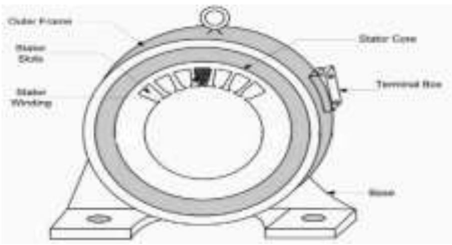

Fig. 1.7 - Construction of Induction Motor Stator

Outer frame

It is the outer body of the motor. Its main function is to support the stator core and to protect the inner parts of the machine. For small machines, the outer frame is casted, but for the large machine, it is fabricated.[10] The figure below shows the stator construction.

Stator Core

The stator core is built of high-grade silicon steel stampings. Its main function is to carry the alternating magnetic field which produces hysteresis and eddy current losses.

Stator windings

The core of the stator carries three phase windings which are usually supplied from a three-phase supply system. The six terminals of the windings (two of each phase) are connected in the terminal box of the machine. The stator of the motor is wound for a definite number of poles,

Construction of Rotor

The rotor is also built of thin laminations of the same material as the stator. The laminated cylindrical core is mounted directly on the shaft. These laminations are slotted on the outer side to receive the conductors.

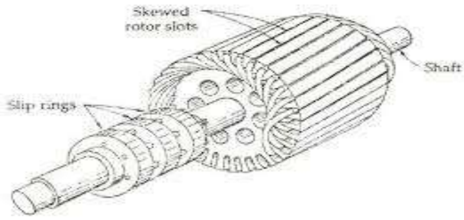

Fig. 1.8 - Construction of Rotor

There are two types of rotor.

(i) Squirrel Cage Rotor (ii) Phase Wound Rotor

Squirrel Cage Rotor

A squirrel cage rotor consists of a laminated cylindrical core. The circular slots at the outer periphery are semi-closed. Each slot contains uninsulated bar conductor of aluminium or copper. At the end of the rotor the conductors the short-circuited by a heavy ring of copper or aluminum. The rotor slots are usually not parallel to the shaft but are skewed.

Working Principle of Induction Motor - The motor which works on the principle of electromagnetic induction is known as the induction motor.

Torque Speed Characteristic of an Induction Motor

Torque Speed Characteristic is the curve plotted between the torque and the speed of the induction motor. At the maximum torque, the speed of the rotor is expressed by the equation shown below.

The curve below shows the Torque Speed Characteristic.

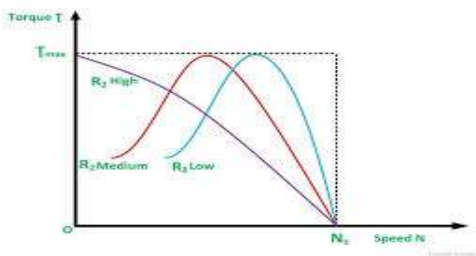

Fig. 1.9 - Torque Speed Characteristic of an Induction Motor

Applications

- Induction motors are used widely in:
- Industrial machinery: Conveyors, pumps, and cranes.
- HVAC systems: Fans and blowers.
- Household appliances: Washing machines and refrigerators.
- Electric vehicles: Due to efficiency and reliability.

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 analyses 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, [11] 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.

Simulation and 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-DRAW max and indicative symbol has been cited with suitable.

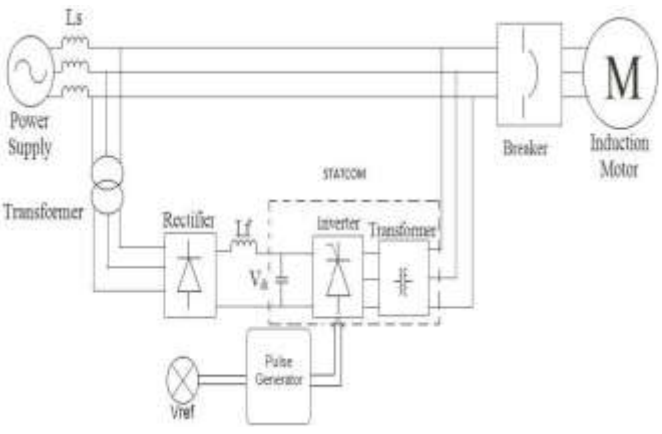

Fig. 1.10 - STATCOM Circuitry Along the Main Line

Case-1 –Without Use of STATCOM

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[13] .
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.
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

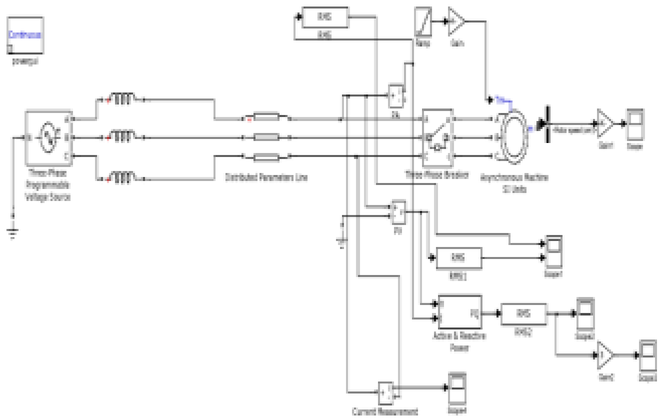

Fig. 1.11 - Simulation model Without Use of STATCOM

The scope back grounds were changed from black to white and line spacing colours were black. Waveform plotting colour is changed yellow to blue.

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. Three phase breaker was taken from the simpower system. [12] Voltage and current measurement blocks were taken and connected to corresponding scope and the current and voltages from 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.

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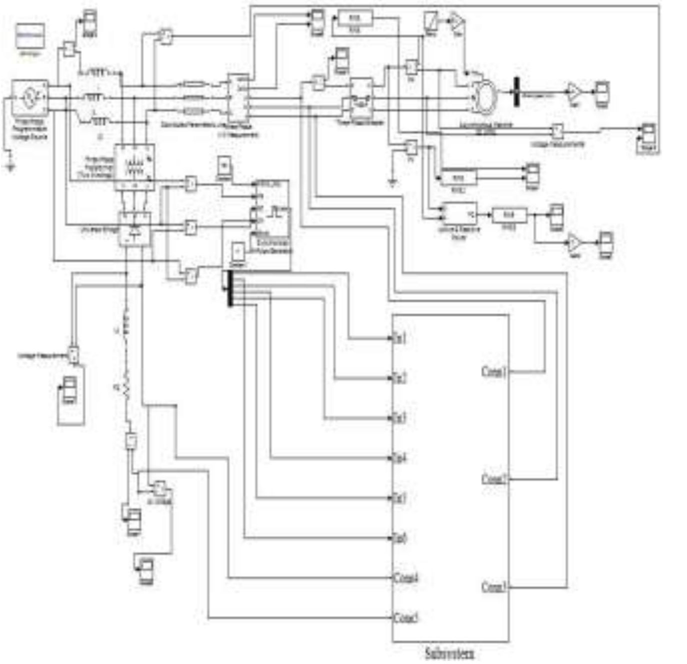

Fig. 1.12 - Simulation model Without Use of STATCOM

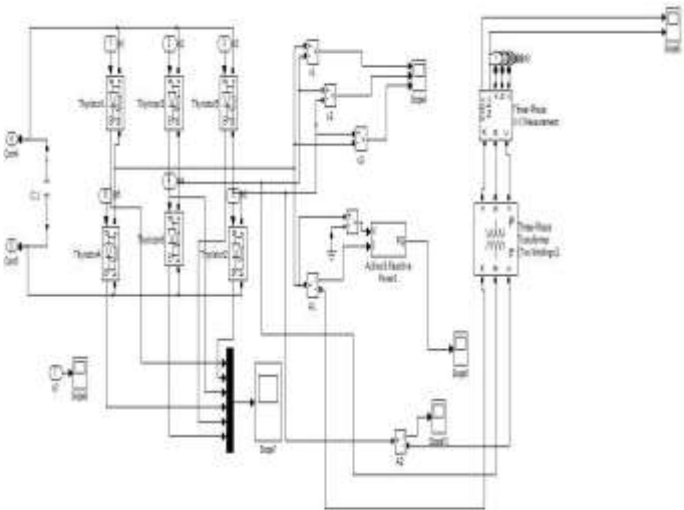

Fig. 1.13 - Simulink Model for Voltage Source Inverter

Results Using Thyristor Based STATCOM

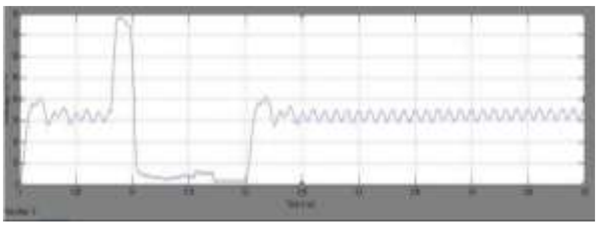

Fig. 1.14 - Voltage Sag during the normal starting of the induction motor.

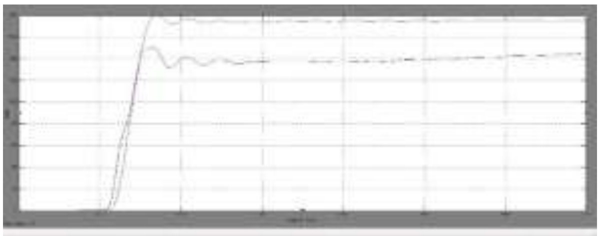

Fig. 1.15 - Rotors Oscillation During Starting of the Induction Motor

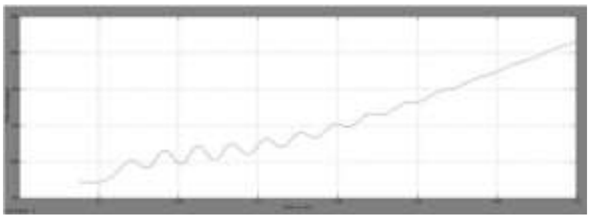

Fig. 1.16 - During Starting of the Induction Motors

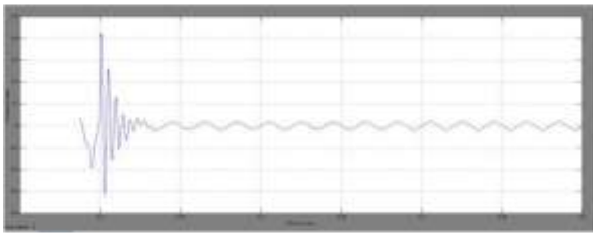

Fig. 1.17 - Current During Starting of Induction Motor

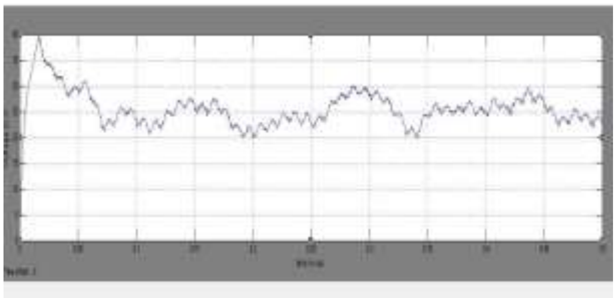

Fig. 1.18 - Voltage Profile of Starting Performance With STATCOM

Results Using IGBT Based STATCOM

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[14].

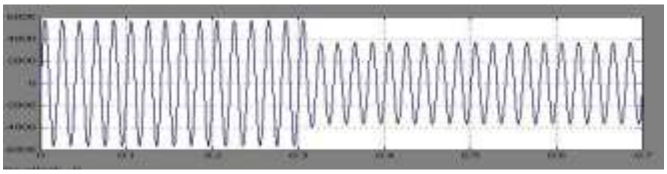

Fig. 1.19 - Sag Occurrence in volatge

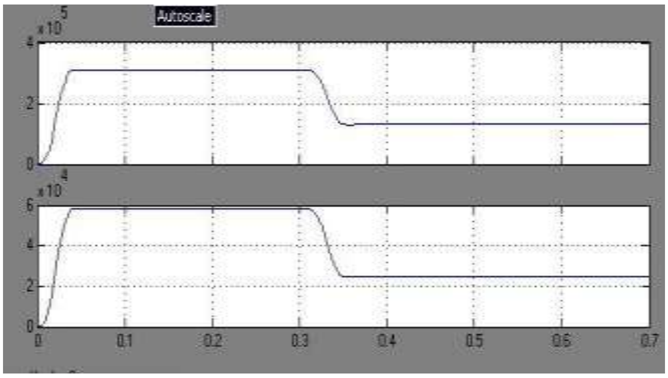

Fig. 1.20 - Active and Reactive Power

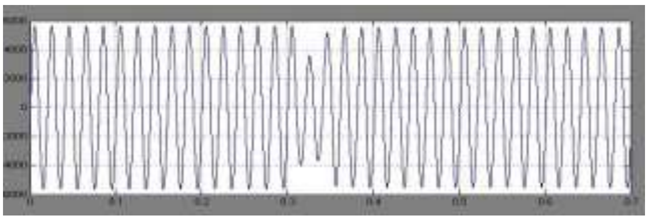

Fig. 1.21 - Voltage Profile During Sag

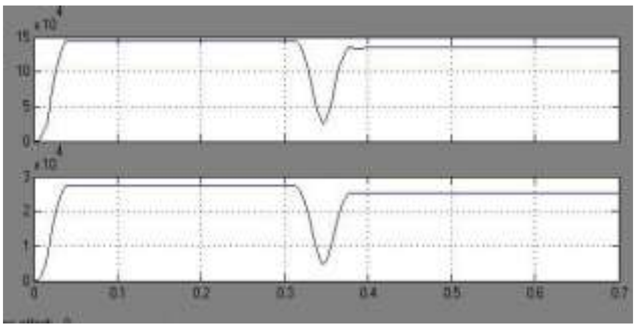

Fig. 1.21 - Voltage Dip Condition

Conclusion

The simulation results of a power system using a Static Synchronous Compensator (STATCOM) confirm that the proposed control concept is satisfied. The results shown in this chapter also confirm that STATCOMs can be used to compensate the reactive power dynamically in the ac power system. In this study, 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.

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