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MITIGATION OF VOLTAGE SAG BY THYRISTOR CONTROLLED SERIES CAPACITOR AND PWM GENERATOR AND THEIR COMPARISON

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Abstract: **In the recent past, one of the problem that got wide attention is the power system instabilities with the lack of new generation and transmission facilities and increase in the load demand of electrical power is continuously rising at a very high rate, due to rapid industrial development. Power quality is the main problem that the industry is facing today. Power electronics and advanced control technologies have made it possible to reduce the power quality problems. Among power system disturbances, voltage sags, swells and harmonics are some of severe problems to the sensitive loads. The series compensation method is best suited to protect such loads against those disturbances The series compensator device thyristor controlled series capacitor is used for improving power quality of power system. The role of the compensator is to mitigate the effects of voltage sag. The thyristor controlled series capacitor method approach is different from another conventional method and provide effective solution in power system. A control strategy for the Series Compensation is developed to regulate power flow and minimize the losses in the power system. This is achieved through phase adjustment of load terminal voltage. It leads to an increase in the ride through capability of loads to the voltage sags/swells. In this thesis work, results show a comparative study of output voltage across a nonlinear load using Thyristor Controlled Series Capacitor device control through PWM Generator six pulses control and Thyristor Controlled Series Capacitor control through firing angle control for the reduction of voltage sag in transmission line. The simulation results showed that the proposed series compensator was efficient in mitigating voltage sags and improve the power quality of power system. This approach is different from conventional methods and provides effective solution. If this method is enhanced in future could provide much more improved power quality.**

I. Introduction

1.1 Overview

Modern electric power utilities are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. Flexible AC Transmission Systems controllers are used to control various power system problems. Power Quality in electric network is one of today's most concerned areas of electric power system.

Power quality is the combination of voltage quality and current quality. Power quality is the set of limits of electrical properties that allows electrical systems to function in their intended manner without significant loss of performance or life. The electrical power quality is more concerned issue. The main problems are stationary and transient distortions in the line voltage such as harmonics, flicker, voltage swells, voltage sags and voltage asymmetric.

Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads, because the occurrence of voltage sag in the system can cause devices/process down time, effect on product quality, failure/malfunction of equipments etc., the occurrence of voltage sag in the system can cause excessive losses and heavy loading ,nonlinear load. To avoid those undesirable affects the proposed method mitigates the problems caused by voltage sag. System, followed Simulink model and comparative study of output across nonlinear load with PWM Generator and with thyristor controlled series capacitor applied to the transmission system. It is followed by control of voltage sag and finally simulation results are shown. This paper analysis the key issues in the voltage sag problem and power quality using series compensator type of TCSC device. Voltage sag occurs due controlled series capacitor to the connection of the main drive load (non linear load).

All these factors affect the nonlinear load which is connected in parallel to the main drive load. So the proposed system protects the nonlinear load by mitigating the voltage sags using thyristor controlled series capacitor device technique. In an interconnected transmission network, power flow control is a key problem in designing and operating. Requirement of interconnected networks, unforeseen increase of load demands, limitations on installation of power plant in appropriate places and limitations on building new transmission lines are the factors that lead to such problems.

The employment of FACTS devices in transmission lines becomes necessary owing to reasons like over loaded transmission lines in special paths, power flow in unwanted paths, and non-optimal operation of line capacity. The major concern in world-wide transmission systems at present is power quality. For instance consumers like industrial plants mainly deal with automated processes and if the line voltage is not up to the levels of the expected quality due to voltage sags or flicker, they may incur economic losses. Therefore proper quality attached to the line voltage at the point of common coupling is very necessary. This quality cannot be achieved with conventional equipment in majority of the cases.

In the last decade, improvement of power quality has been one of the most vital subjects in the development of transmission system and low voltage systems. Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. The series compensation method is best suited to protect such loads against those disturbances. The use of a series compensator (SC) to improve power quality is an isolated power system is investigated. The role of the compensator is not only to mitigate the effects of voltage sag, but also to reduce the harmonic distortion due to the presence of non linear loads in the network.

1.2 Literature Survey

Power Quality in electric network is one of today most concerned area of electric power system .The power quality has serious economic implication for consumers, utilities and electrical equipment manufactures. This impact of power quality problems is increasingly felt by customers industrial, commercial and even residential. Some of main power quality problems are voltage sag, swell, transients, harmonic and flickers etc. This thesis work present for the voltage sag reduction in the transmission system. By the power electronics device TCSC series compensation device for the improve voltage quality of system. Power electronic device we refer to FACTS device thyristor controlled series capacitor series controller used for the power quality improvement and power quality problems in voltage sag reduction in transmission system. TCSC is series compensation device used for the voltage quality improvement in transmission system. This TCSC device is most efficient and effective device in the modern FACTS power device used in transmission networks.

Several research paper and report addressed the subject of improving power quality in Transmission system by the used of custom power devices. The following present a brief review of the work under taken so far.

Power systems quality **Mark F. / Roger C. Dugan /Mc Granaghan Surya santoso / H. Wagne Beaty** Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power. The term power quality has become one of the most prolific buzzwords in the power industry since the late 1980s. It is an umbrella concept for a multitude of individual types of power system disturbances. The issues that fall under this umbrella are not necessarily new. What is new is that engineers are now attempting to deal with these issues using a system approach rather than handling them as individual problems.

D.Jovcic, G.N.Pillai IEEE Transactions on Power Delivery, Vol. 20, No. 2, April 2005, et al[1] Thyristor-Controlled Series Capacitor (TCSC) is a series FACTS device which allows rapid and continuous changes of the transmission line impedance. It has great application potential in accurately regulating the power flow on a transmission line, damping inter-area power oscillations, mitigating subsynchronous resonance (SSR) and improving transient stability.

Wang. T. X. and Choi S. S et al [5] Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. The series compensation method is best suited to protect such loads against those disturbances. The use of a series compensator (SC) to improve power quality is an isolated power system is investigated. The role of the compensator is not only to mitigate the effects of voltage sag, but also to reduce the harmonic distortion due to the presence of non linear loads in the network.

S.Sadaiappan, Dr.P.Renuga2 et al [3] Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. The series compensation method is best suited to protect such loads against those disturbances. The use of a series compensator (SC) to improve power quality is an isolated power system is investigated. The role of the compensator is not only to mitigate the effects of voltage sag, but also to reduce the harmonic distortion due to the presence of non linear loads in the network. In this paper, a series compensator is proposed and a method of harmonic compensation is described and a method to mitigate voltage sag is investigated.

Vatsal J. Patel1, C.B.Bhatt 2 et al [6] the world's first Series Compensation on transmission level, counted nowadays by the manufacturers as a FACTS-device, went into operation in 1950. Series Compensation is used in order to decrease the transfer reactance of a power line at rated frequency. A series capacitor installation generates reactive power that in a self-regulating manner balances a fraction of the line's transfer reactance. The result is that the line is electrically shortened, which improves angular stability, voltage stability and power sharing between parallel lines**.**

Shailendra Kumar Jain et al [7] The TCSC concept is that it uses an extremely simple main circuit. The capacitor is inserted directly in series with the transmission line and the thyristor-controlled inductor is mounted directly in parallel with the capacitor. Thus no interfacing equipment like e.g. high voltage transformers is required. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation.

Padiyar K. R.,et al [8] The electricity is an everyday, as it were an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Transmission of electricity in the interconnected, cooperating electricity systems is steadily increasing due to increasing growth in consumption and electricity generation. While occur to excessive burden of transmission equipment, which leads ultimately to a disruption in electricity end-user. In addition, there are other unforeseen disturbances and situations of power system operation.

Arindam Ghosh,et al [12] This paper discusses the application of trajectory sensitivity analysis (TSA) of power systems containing FACTS compensators. Thyristor controlled series compensator (TCSC) and static synchronous compensator (STATCOM) are the devices considered. The TCSC is modeled by a variable capacitor, the value of which changes with the firing angle. The STATCOM is modeled by a voltage source connected to the system through a transformer. The effect of their individual and simultaneous use on the system transient stability is studied by applying TSA. Two different test systems are considered. It is shown that TSA can be used to determine the best possible locations of the two devices for transient stability improvement as well as to predict the critical clearing time.

Jianguo Zhao, Chenghui Zhang, and Wei-Jen Lee, et al [13] the mode-switching control method of thyristor-controlled series capacitor is of great importance to power system stability. It is very difficult, if not impossible, to realize mode-switching only by changing firing angles. A method of predicting current zero-crossing time is proposed first to provide line current synchronization signals for switching control in time. In the switching strategy from capacitive mode to inductive vernier mode, the thyristor conditional firing is put forward. The thyristor will be fired and conducted on condition that both line current and capacitor voltage are in phase. Simulation and experimental results show that the proposed switching method can make the switching process faster with improved dynamic performance.

Priyanath Das, and Ajoy Kumar Chakraborty et al[21] Modelling and simulation of Fixed Capacitor Thyristor Controlled Reactor (FC-TCR), Static synchronous compensator (STATCOM), Thyristor controlled Series Capacitor (TCSC), Static synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) for power system stability enhancement and improvement of power transfer capability have been presented in this paper. First, power flow results are obtained and then power (real and reactive power) profiles have been studied for an uncompensated system and then compared with the results obtained after compensating the system using the above-mentioned FACTS devices. The simulation results demonstrate the performance of the system for each of the FACTS devices in improving the power profile and thereby voltage stability of the same.

1.3 Scope of work

From the literature reviews, it is observed that the work on the investigation on voltage in transmission system large voltage drop occur in nonlinear and sensitive load condition system performance is very much diversified. It is observed that there is a scope to investigate the effectiveness of compensating device for different load and with different loading condition in transmission system. The objective of the proposed work is to improve the power quality or reliability in the transmission system with the used of FACTS device is series compensation TCSC device. In the nonlinear load and sensitive load considered with different load to analyze the operation of TCSC for the voltage quality improvement and voltage sag reduction in the transmission system.

II. Power Quality

2.1.1 Power Quality

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power qualities "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems.

The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms. Along with definitions of the terms, explanations are included in parentheses where necessary. This chapter also attempts to explain how power quality factors interact in an electrical system.

2.1.2 Power Quality Progression

Why is power quality a concern, and when did the concern begin? Since the discovery of electricity 400 years ago, the generation, distribution, and use of electricity have steadily evolved. New and innovative means to generate and use electricity fueled the industrial revolution, and since then scientists, engineers, and hobbyists have contributed to its continuing evolution. In the beginning, electrical machines and devices were crude at best but nonetheless very utilitarian. They consumed large amounts of electricity and performed quite well. The machines were conservatively designed with cost concerns only secondary to performance considerations. They were probably susceptible to whatever power quality anomalies existed at the time, but the effects were not readily discernible, due partly to the robustness of the machines and partly to the lack of effective ways to measure power quality parameters. However, in the last 50 years or so, the industrial age led to the need for products to be economically competitive, which meant that electrical machines were becoming smaller and more efficient and were designed without performance margins.

At the same time, other factors were coming into play. Increased demands for electricity created extensive power generation and distribution grids. Industries demanded larger and larger shares of the generated power, which, along with the growing use of electricity in the residential sector, stretched electricity generation to the limit. Today, electrical utilities are no longer independently operated entities; they are part of a large network of utilities tied together in a complex grid. The combination of these factors has created electrical systems requiring power quality.

The difficulty in quantifying power quality concerns is explained by the nature of the interaction between power quality and susceptible equipment. What is “good” power for one piece of equipment could be “bad” power for another one. Two identical devices or pieces of equipment might react differently to the same power quality parameters due to differences in their manufacturing or component tolerance. Electrical devices are becoming smaller and more sensitive to power quality aberrations due to the proliferation of electronics. For example, an electronic controller about the size of a shoebox can efficiently control the performance of a 1000-hp motor; while the motor might be somewhat immune to power quality problems, the controller is not.

The net effect is that we have a motor system that is very sensitive to power quality. Another factor that makes power quality issues difficult to grasp is that in some instances electrical equipment causes its own power quality problems. Such a problem might not be apparent at the manufacturing plant; however, once the equipment is installed in an unfriendly electrical environment the problem could surface and performance suffers. Given the nature of the electrical operating boundaries and the need for electrical equipment to perform satisfactorily in such an environment, it is increasingly necessary for engineers, technicians, and facility operators to become familiar with power quality issues. It is hoped that this book will help in this direction.

2.2 Power Quality Terminology

Webster’s New World Dictionary defines terminology as the “the terms used in a specific science, art, etc.” Understanding the terms used in any branch of science or humanities is basic to developing a sense of familiarity with the subject matter. The science of power quality is no exception. More commonly used power quality terms are defined and explained below:

Bonding
Intentional electrical interconnecting of conductive parts to ensure common electrical potential between the bonded parts. Bonding is done primarily for two reasons. Conductive parts, when bonded using low impedance connections, would tend to be at the same electrical potential, meaning that the voltage difference between the bonded parts would be minimal or negligible.
Bonding also ensures that any fault current likely imposed on a metal part will be safely conducted to ground or other grid systems serving as ground.

Capacitance
Property of a circuit element characterized by an insulating medium contained between two conductive parts. The unit of capacitance is a farad (F), named for the English scientist Michael Faraday. Capacitance values are more commonly expressed in microfarad (μF), which is 10–6 of a farad. Capacitance is one means by which energy or electrical noise can couple from one electrical circuit to another. Capacitance between two conductive parts can be made infinitesimally small but may not be completely eliminated.

Coupling
Process by which energy or electrical noise in one circuit can be transferred to another circuit that may or may not be electrically connected to it.

Crest factor
Ratio between the peak value and the root mean square (RMS) value of a periodic waveform. Figure 1.1 indicates the crest factor of two periodic waveforms. Crest factor is one indication of the distortion of a periodic waveform from its ideal characteristics.

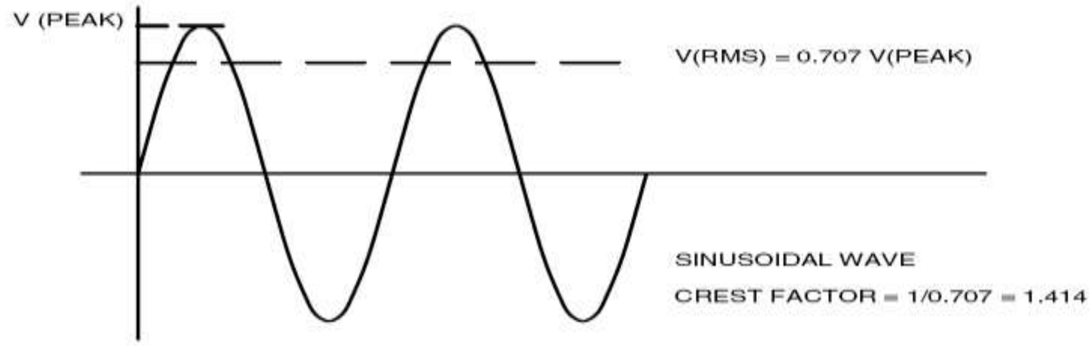


FIGURE 2.1 Crest factor for sinusoidal waveforms

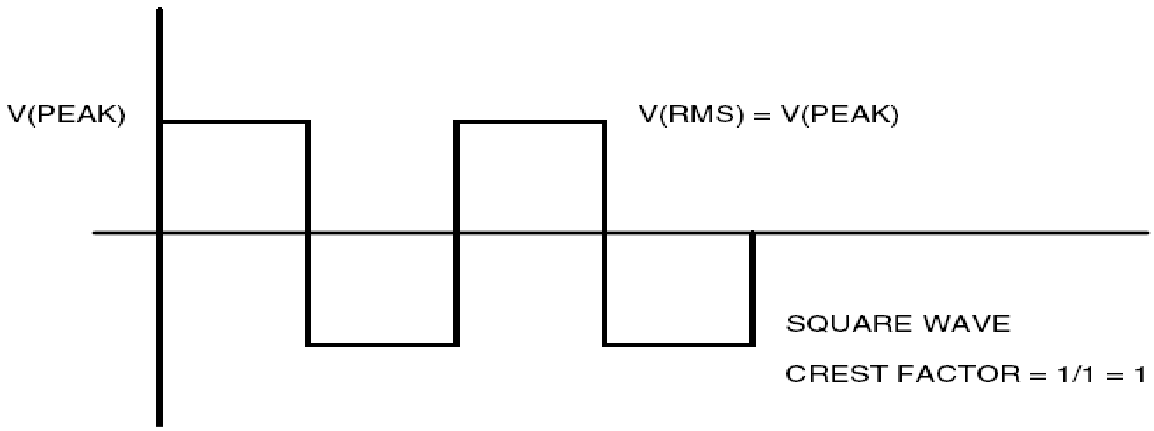


FIGURE 2.2 Crest factor for Square Waveforms

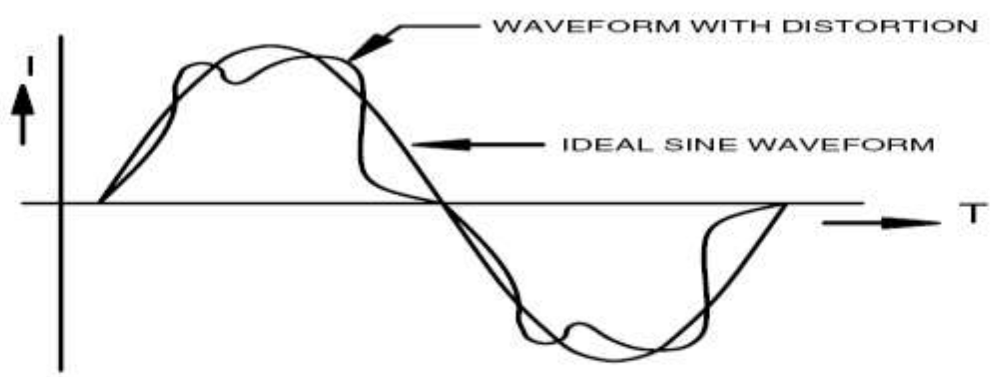


FIGURE 2.3 Waveform with Distortion

Distortion

Qualitative term indicating the deviation of a periodic wave from its ideal waveform characteristics.fig.1.2 contains an ideal sinusoidal wave along with a distorted wave. The distortion introduced in a wave can create waveform deformity as well as phase shift.

Distortion factor

Ratio of the RMS of the harmonic content of a periodic wave to the RMS of the fundamental content of the wave, expressed as a percent. This is also known as the total harmonic distortion (THD).

Flicker
Variation of input voltage sufficient in duration to allow visual observation of a change in electric light source intensity. Quantitatively, flicker may be expressed as the change in voltage over nominal expressed as a percent.

Form factor
Ratio between the RMS value and the average value of a periodic waveform. Form factor is another indicator of the deviation of a periodic waveform from the ideal characteristics. For example, the average value of a pure sinusoidal wave averaged over a cycle is 0.637 times the peak value. The RMS value of the sinusoidal wave is 0.707 times the peak value. The form factor, *FF*, is calculated as $FF = 0.707/0.637 = 1.11$.

Frequency
Number of complete cycles of a periodic wave in a unit time, usually 1 sec. The frequency of electrical quantities such as voltage and current is expressed in hertz (Hz).

Ground electrode
Conductor or a body of conductors in intimate contact with earth for the purpose of providing a connection with the ground.

Ground grid
System of interconnected bare conductors arranged in a pattern over a specified area and buried below the surface of the earth.

Ground loop
Potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.

Harmonic
Sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. If the fundamental frequency is 60 Hz, then the second harmonic is a sinusoidal wave of 120 Hz, the fifth harmonic is a sinusoidal wave of 300 Hz.

Harmonic distortion
Quantitative representation of the distortion from a pure sinusoidal waveform.

Impulse
Traditionally used to indicate a short duration overvoltage event with certain rise and fall characteristics. Standards have moved toward including the term impulse in the category of transients.

Inductance
Inductance is the relationship between the magnetic lines of flux (Ø) linking a circuit due to the current (I) producing the flux. If I is the current in a wire that produces a magnetic flux of Ø lines, then the self inductance of the wire, L , is equal to Ø/ I. Mutual inductance (M) is the relationship between the magnetic flux Ø 2 linking an adjacent circuit 2 due to current I 1in circuit 1. This can be stated as M= Ø2/I1.points out the two inductances. The unit of inductance is the henry [H], named for the American scientist Joseph Henry. The practical unit of inductance is the millihenry [mH], which is equal to 10 –3 H. Self inductance of a circuit is important for determining the characteristics of impulse voltage transients and waveform notches. In power quality studies, we also are concerned with the mutual inductance as it relates to how current in one circuit can induce noise and disturbance in an adjacent circuit.

Inrush
Large current that a load draws when initially turned on.

Interruption
Complete loss of voltage or current for a time period.

Isolation
Means by which energized electrical circuits are uncoupled from each other. Two-winding transformers with primary and secondary windings are one example of isolation between circuits. In actuality, some coupling still exists in a two-winding transformer due to capacitance between the primary and the secondary windings.

Linear loads
Electrical load which in steady-state operation presents essentially constant impedance to the power source throughout the cycle of applied voltage. A purely linear load has only the fundamental component of the current present.

Noises
Electrical noise is unwanted electrical signals that produce undesirable effects in the circuits of control systems in which they occur.

Nonlinear load
Electrical load that draws currents discontinuously or whose impedance varies during each cycle of the input AC voltage waveform.

2.3 Power Quality Issues

Power quality is a simple term, yet it describes a multitude of issues that are found in any electrical power system and is a subjective term. The concept of good and bad power depends on the end user. If a piece of equipment functions satisfactorily, the user feels that the power is good. If the equipment does not function as intended or fails prematurely, there is a feeling that the power is bad. In between these limits, several grades or layers of power quality may exist, depending on the perspective of the power user. Understanding power quality issues is a good starting point for solving any power quality problem.

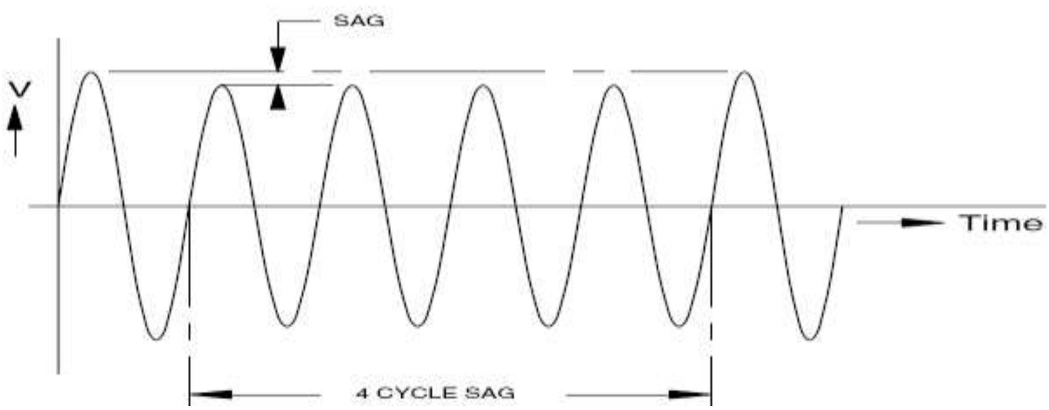


FIGURE 2.4 Voltage Sag

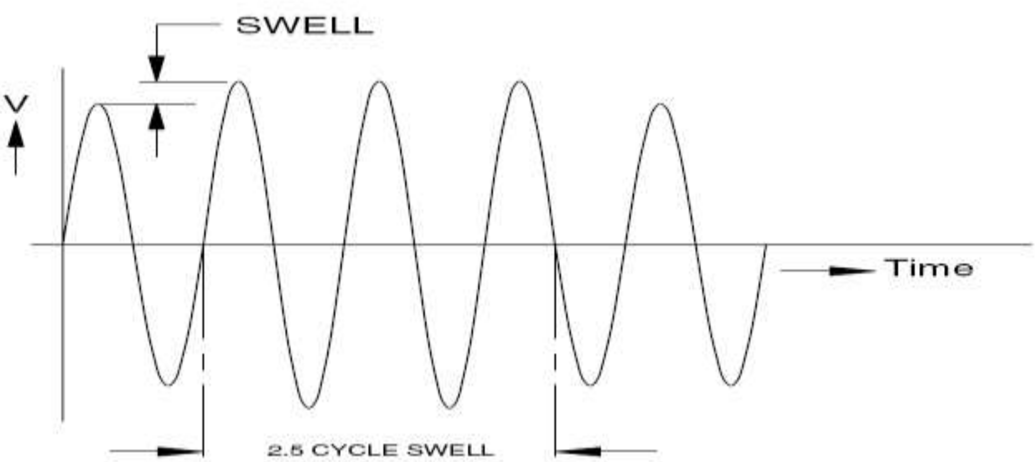


FIGURE 2.5 Voltage Swell

Power frequency disturbances are low-frequency phenomena that result in voltage sags or swells. These may be source or load generated due to faults or switching operations in a power system. The end results are the same as far as the susceptibility of electrical equipment is concerned. Power system transients are fast, short-duration events that produce distortions such as notching, ringing, and impulse. The mechanisms by which transient energy is propagated in power lines, transferred to other electrical circuits, and eventually dissipated are different from the factors that affect power frequency disturbances.

Power system harmonics are low-frequency phenomena characterized by waveform distortion, which introduces harmonic frequency components. Voltage and current harmonics have undesirable effects on power system operation and power system components. In some instances, interaction between the harmonics and the power system parameters (*R–L–C*) can cause harmonics to multiply with severe consequences. The subject of grounding and bonding is one of the more critical issues in power quality studies. Grounding is done for three reasons. The fundamental objective of grounding is safety, and nothing that is done in an electrical system should compromise the safety of people who work in the environment; in the U.S., safety grounding is mandated by the National Electrical Code (NEC). The second objective of grounding and bonding is to provide a low-impedance path for the flow of fault current in case of a ground fault so that the protective device could isolate the faulted circuit from the power source. The third use of grounding is to create a ground reference plane for sensitive electrical equipment. This is known as the signal reference ground (SRG). The configuration of the SRG may vary from user to user and from facility to facility. The SRG cannot be an isolated entity. It must be bonded to the safety ground of the facility to create a total ground system.

Power Quality is a term used to broadly encompass the entire scope of interaction among electrical suppliers, the environment, the systems and products energized, and the users of those systems and products. It is more than the delivery of "clean" electric power that complies with industry standards. It involves the maintainability of that power, the design, selection, and the installation of every piece of hardware and software in the electrical energy system. Stretching from the generation plant to the utility customer, power quality is a measure of how the elements affect the system as a whole. Graphic used with permission from Electrotek Concepts, Inc.

In The Beginning, Power Quality has been a problem ever since the conception of electricity, but only over the last two decades has it gotten considerable attention. The `80s brought about the move of computers from the office to the home and to just about everywhere else. The '90s brought the network revolution and ever increasing equipment capability. More importantly, both of these decades brought the potential for more interference.

Presently Today's environment brings with it the possibility of many new problems. With ever increasing integrated circuit densities, faster processor speeds, and increasingly sensitive equipment, the chance of interference occurring will undoubtedly rise unless something is done. With all this new technology, we are still faced with many of the basic power quality problems that have been with us for years: loose connections, neutral to ground bonds, and poor construction practices. In fighting these problems, the screwdriver can be a very useful tool.

Insight, Power Quality affects everyone, and there are hundreds of examples of power quality problems and solutions. One simple example of a power quality problem is the dishwasher in the kitchen disrupting the computer in the den. Conversely, if a bottle manufacturing plant is able to continue operating as high winds cause intermittent arcing of overhead lines; the power quality industry has achieved its goal.

2.4 Power Quality Problems

Sags

Sags are under-voltages on the power system and commonly caused by power failures, downed lines, utility reclose operations, and storms. They can be corrected by using backup power sources such as UPSs, generators or similar voltage restoration technologies.

Surges

Surges are caused by over-voltages resulting from lightning, switching on the utility power system and other causes without forewarning. Surges normally can be filtered out of the power system at the customer level.

Harmonics

Harmonics result from distortions to the voltage and/or current sine waves. Harmonics are commonly caused by ASDs, industrial processes, certain electronic loads, and wiring connections. Harmonic problems often can be corrected by filtering or resizing power system components.

Wiring and Grounding

Wiring and grounding problems come in the form of intermittent network failures, buzzing sounds (corona effect), scooted insulation, intermittent voltages at equipment, and burned panel or junction boxes. Wiring and grounding problems can often be fixed by checking to see that everything is properly connected and that there are no bad wires being used.

2.5 Power Quality Parameters

Even the best distribution systems are subject to changes in system voltage from time-to-time. Voltage changes can range from small voltage fluctuations of short duration to a complete outage for an extended period of time. The following industry terms can be used to describe given voltage conditions.

Voltage dip

A voltage dip is used to refer to short-term reduction in voltage of less than half a second.

Voltage sag

Voltage sag is used to relate long-term reduction in voltage .voltage sag is a brief decrease in the rms voltage at power frequency of 0.1 to 0.9 pu of the nominal voltage value. the duration of a voltage sag is 0.5 cycle to 1 minute. voltage sag obtained in the system when low voltage (less than 80%),for more than one period.

Voltage swell

Voltage swell is an increase in voltage outside normal rated tolerance of an equipment.

Voltage ‘spikes’, ‘impulses’ or ‘surges’**:** These are terms used to describe abrupt, very brief increases in voltage value.

Voltage transients**:** They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time (milliseconds or nanoseconds). Hence, the term ‘spike’ can also be used.

Harmonics

The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency. The following sections will discuss the causes and symptoms of each power disturbance parameter and the methods of preventing/minimizing their effects on power equipment.

Voltage dips, sags and surges

Most electrical power generating authorities have an obligation to supply consumers from the grid at a constant voltage (typically within +/- 6% of nominal). However, sometimes this is not practical, particularly in rural locations. Sometimes voltage sags are caused by the power supplier during times of heavy demand, while dips are often caused by auto closers, operating within one second of fault detection. It is also possible for heavy plant to pull down the supply voltage during start-up. Compressors and pumps are good examples of loads, which require a high start-up current and switch in and out on a frequent basis, causing the supply voltage to dip. A dip is used to refer to a short term reduction of less than half a second, whilst sag relates to a long-term voltage reduction.

2.6 Causes of Dip, Sags and Surges

1. Rural location remote from power source

2. Long distance from a distribution transformer with interposed loads

3. Unreliable grid system

4. Power distributor’s tolerances not suitable for voltage sensitive equipment

5. Switching of heavy loads and nonlinear load.

6. Unbalanced load on a three phase system

7. Equipment not suitable for local supply.

2.7 Implication of Poor Power Quality

Some of the implications of power quality especially related to power factor and harmonics are:

1. Increase in line & equipment current leading to additional ohmic losses.

2. Increase in line & equipment current leading to blocked capacity and/or increased capital investment.

2.**8 General Benefits of Power Quality Improvement**

1. Reduction in line & equipment currents and losses and hence lower energy bills

2. Release of blocked capacity and consequent avoided cost of capital investment

3. Improvement in power factor and avoided penalty for low power factor or incentive for high power factor.

4. Reduction in maximum demand and reduction in demand charges.

5. Tax benefits such as accelerated depreciation benefits for installation of power conditioning /energy saving devices.

6. Improvement in voltage profile and consequent efficient operation of power equipment.

7. Reduction in harmonic distortion and consequent reduction in copper loss, core loss and stray loss.

8. Prevention of malfunction of equipment and avoided loss of production.

9. Elimination of unplanned outages and reduction in loss of production and revenue.

10. Reduction / elimination of failure of equipment due to reduced electrical and thermal stress.

11. Enhanced life / reliability of equipment due to lower operating temperature due to lower losses

2.9 Power Quality Solutions

The need for solutions to power quality problems grows with every passing second. Currently many projects are under way and they are looking at how to collect data to find and analyze power quality problems. Presently, the analysis ;of power quality problems is often difficult due to the fact that the source of a problem can be a few feet away in the form of a loose connection, or a hundred miles away in the form of a power system fault. If we look back at the stated power quality problems of sags, surges, harmonics, and wiring and grounding, one can see that each one has possible solutions to correcting these problems.

Power quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

2.10 Flexible AC Transmission Systems (FACTS)

2.10.1 Introduction

In the past few years the demand for electrical energy has increased significantly and as a result energy transmission systems are facing power transmission limitation crisis. The limitations occur due to keeping a balance between maintaining stability and supplying the allowed level of voltage. As a result of this the practical operation capacity of the system is far less than the real capacity. This results in non-optimal operation of the energy transmission systems. One among the solutions to this problem of increasing power transmission capacity is construction of new transmission lines. This is not feasible both economically and practically. Due to the developing semiconductor industry and its applications in power systems, the concept of FACTS is offered, to enhance the real capacity of transmission lines without having to construct any new transmission lines. The major drawback in using thyristor switches is that the control for turn-off capability is not possible. Hence in a cycle, switching more than once is not possible. After the invention of IGBT and GTO which are semiconductor devices with controlled turn-off capability the transmission system was revolutionized. This development resulted in the use of VSCs in the field of energy transmission. The advantage of this is the generation and absorption of reactive power without the use of devices like capacitor or reactor. All FACTS equipment designed by Voltage Source Converters are known as FACTS new generation devices. The approach of engineers towards planning and operation of power systems will be changed by the implementation of FACTS devices. The equipments can be applied in series, shunt or shunt-series in transmission lines, and the control of the operation parameters in transmission systems in steady state and system dynamic behavior in transient state can be achieved.

FACTS devices have the following applications [1]

- Power flow control
- Increase of transmission capability
- Voltage control
- Reactive power compensation
- Stability improvement
- Power quality improvement
- Power conditioning
- Flicker mitigation
- Interconnection of renewable and distributed generation and storages.

The use of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The reaction time allowed by power electronic is very short and goes down to far below one second. A structured overview on FACTS-devices is given ahead. The devices are mapped to their different fields of applications.

2.10.2 Configuration of FACTS Devices

Shunt Devices

The most used FACTS-device in the power system. These devices operate as reactive power compensators. The following are the major applications of the shunt devices in transmission, distribution and industrial networks [1]:

- Reduced network losses by reduction of unwanted reactive power flows
- Maintaining contractual power exchanges with balanced reactive power
- Compensation of consumers and improvement of power quality especially with huge demand
- fluctuations like industrial machines, metal melting plants, railway or underground train systems
- Compensation of Thyristor converters e.g. in conventional HVDC lines
- Improvement of static or transient stability.

In industrial applications almost half of the SVC and more than half of the STATCOMs are used. Power quality is the requirement of industry as well as commercial and domestic groups of users. The interruptions of industrial processes due to insufficient power quality or flickering lamps are not anymore entertained. Weak network connections with severe voltage support problems are given a special attention.

Series Devices

From fixed or mechanically switched compensations the series devices have further developed to the Thyristor Controlled Series Compensation (TCSC) and Voltage Source Converter based devices. The major applications are given below

- Reduction of series voltage decline in magnitude and angle over a power line.
- Reduction of voltage fluctuations within defined limits during changing power transmissions.
- Improvement of system damping resp. damping of oscillations.
- Power quality improvment in power system.
- Limitation of short circuit currents in networks or substations avoidance of loop flows resp. power flow adjustments.

III. Voltage Sags

3.1 Introduction

A Voltage Sag as defined by IEEE Standard 1159-1995, IEEE Recommended Practice For Monitoring Electric Power Quality, is a decrease in RMS voltage at the Power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage. The measurement of a Voltage Sag is stated as a percentage of the nominal voltage, it is a measurement of the remaining voltage and is stated as a sag TO a percentage value. Thus a Voltage Sag to 60% is equivalent to 60% of nominal voltage, or 288 Volts for a nominal 480 Volt system.

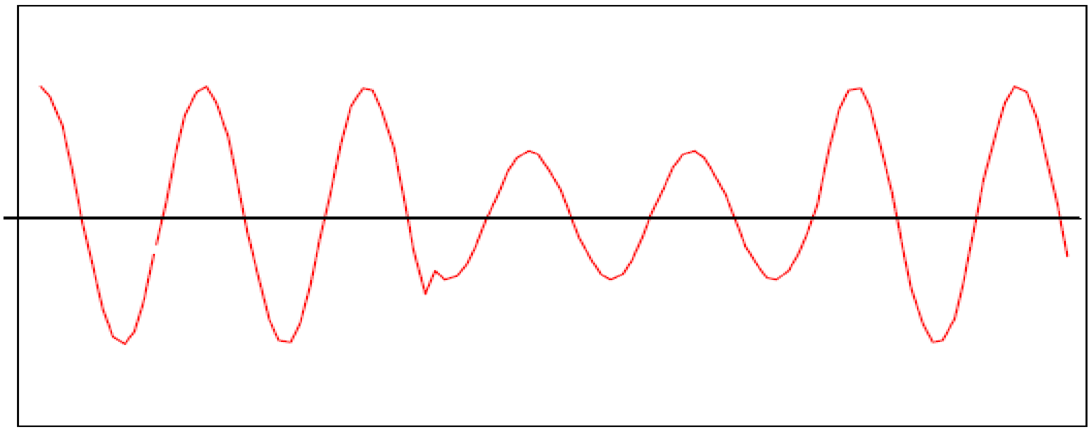
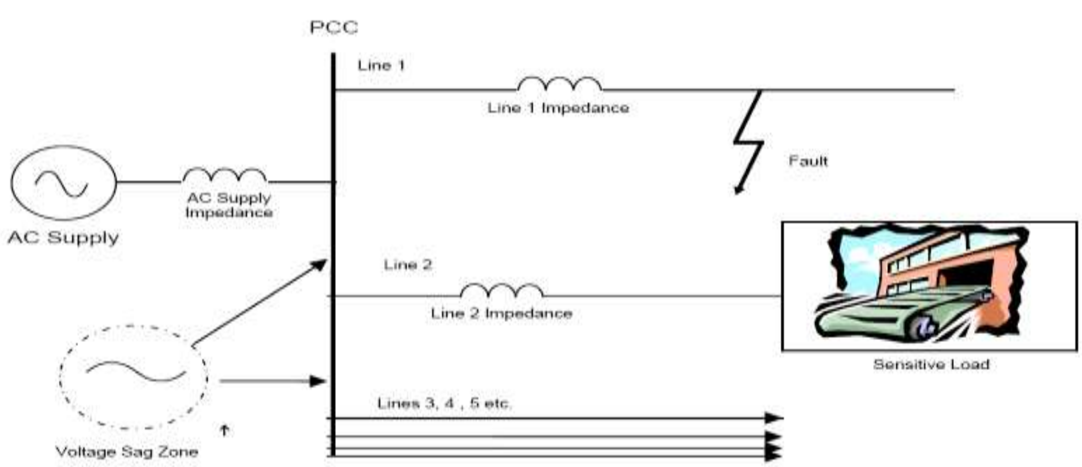


FIGURE 3.1 Voltage Sag- A reduced voltage for a limited period

Voltage Dip
In North America a Voltage Dip is usually understood to mean the amount by which the Nominal voltage declines - in percentage terms this is 100-Voltage Sag. Thus a voltage Dip of 40% equates to a Voltage Sag TO 60% Unfortunately in practice there is confusion and the terms Voltage Sag and Voltage Dip are sometimes interchanged. It is therefore important that data is clarified.

3.1.1 Where Do Voltage Sags Occur

Utility Systems
Voltage sags can occur on Utility systems both at distribution voltages and transmission voltages. Voltage sags which occur at higher voltages will normally spread through a utility system and will be transmitted to lower voltage systems via transformers.



Inside Industrial Plants
Voltage sags can be created within an industrial complex without any influence from the Utility system. These sags are typically caused by starting large motors or by electrical faults inside the facility.

Operation of Reclosers and Circuit breakers
If for any reason a sub-station circuit breaker or a reclosed is tripped, then the line which it is feeding will be temporarily disconnected. All other feeder lines from the same substation system will see this disconnection event as a voltage sag which will spread to consumers on these other lines (See Fig.2). The depth of the voltage sag at the consumer's site will vary depending on the supply line voltage and the distance from the fault. Typically a higher supply voltage will have larger sag affected zone.

Equipment Failure
If electrical equipment fails due to overloading, cable faults etc., protective equipment will operate at the sub-station and voltage sags will be seen on other feeder lines across the utility system.

Bad Weather
Thunderstorms and lightning strikes cause a significant number of voltage sags. If lightning strikes a power line and continues to ground, this creates a line to ground fault. The line to ground fault in turn creates voltage sag and this reduced voltage can be seen over a wide area. Note the lightning strike to ground causes Voltage Sags on all other lines. Circuit breakers and recloses operate more frequently in poor weather conditions High winds can blow tree branches into power lines. As the tree branch strikes the line, a line to ground fault occurs which creates voltage sag.

If the line protection system does not operate immediately, a series of sags will occur if the branch repeatedly touches the power line. Broken branches landing on power lines cause phase to phase and phase to ground faults Snow and Ice build up on power line insulators can cause flash-over, either phase to ground or phase to phase. Similarly snow or ice falling from one line can cause it to rebound and strike another line. These events cause voltage sags to spread through other feeders on the system.

Pollution
Salt spray builds up on power line insulators over time in coastal areas, even many miles inland, can cause flash over especially in stormy weather. Dust in arid inland areas can cause similar problems. As circuit protector devices operate voltage sags appear on other feeders.

Animals & Birds
Animals particularly squirrels, raccoons and snakes occasionally find their way onto power lines or transformers and can cause a short circuit either phase to phase or phase to ground. Large birds, geese and swans, fly into power lines and cause similar faults. While the creature rarely survives, the protective circuit breaker operates and voltage sag is created on other feeders.

Vehicle Problems
Utility power lines frequently run alongside public roads. Vehicles occasionally collide with utility poles causing lines to touch, protective devices trip and voltage sags occur.

Construction Activity
Even when all power lines are underground, digging foundations for new building construction can result in damage to underground power lines and create voltage sags.

3.2 Industrial Plants
Voltage sags can be caused within an industrial facility or a group of facilities by the starting of large electric motors either individually or in groups. The large current inrush on starting can cause voltage sags in the local or adjacent areas even if the utility line voltage remains at a constant nominal value.

3.2.1 Single Phase Sags and Multi Phase Sags
Single Phase Sags
The most common voltage sags, over 70%, are single phase events which are typically due to a phase to ground fault occurring somewhere on the system. This phase to ground fault appears as single phase voltage sag on other feeders from the

same substation. Typical causes are lightning strikes, tree branches, animal contact etc. It is not uncommon to see single phase voltage sags to 30% of nominal voltage or even lower in industrial plants.

Phase to Phase Sags

Two Phase, phase to phase sags may be caused by tree branches, adverse weather, animals or vehicle collision with utility poles. The two phase voltage sag will typically appear on other feeders from the same substation.

Phase Sags

Symmetrical 3 phase sags account for less than 20% of all sag events and are caused either by switching or tripping of a 3 phase circuit breaker, switch or recloses which will create 3 phase voltage sag on other lines fed from the same substation. 3 phase sags will also be caused by starting large motors but this type of event typically causes voltage sags to approximately 80% of nominal voltage and is usually confined to an industrial plant or its immediate neighbors.

3.3 Voltage Sags Affect Production

Both single phase and multiphase voltage sags can cause unplanned production stoppages but single phase (120V) control devices and electronic sensors can be very vulnerable to voltage sags. Modern electronic equipment requires more precise voltage regulation than traditional devices such as induction motors. When manufacturing industry used mechanical devices and gearboxes to control the speed of its processes, many of which were relatively slow and required manual operation or intervention by operators, voltage variations were not such a serious issue.

Automation has lead to high speed processes, automatic electronic sensing and controls; precision machine tools have sophisticated electronic controls, variable speed drives have replaced many gearboxes and any unplanned manufacturing stoppage can be very expensive.

Electronic process controls, sensors, computer controls, PLC’s and variable speed drives, even conventional electrical relays are all to some degree susceptible to voltage sags. In many cases one or more of these devices may trip if there is a voltage sag to less than 90% of nominal voltage even if the duration is only for one or two cycles i.e. less than 100 milliseconds. The time to restart production after such an unplanned stoppage can typically be measured in minutes, hours or even days. Costs per event can be many tens of thousands of dollars.

3.3.1 Cost of Voltage Sags

An EPRI study in 2005 (Ref 2)suggests that the cost to North American industry of production stoppages caused by voltage sags now exceeds U$250 billion per annum.

3.3.2 Who is to Blame

Frequently industrial customers blame their local electrical supply utility for unplanned production stoppages and claim that other jurisdictions have “much better power quality”. Unfortunately in many cases there is little or nothing the utility can do. It is true that certain parts of North America experience more storms than others so voltage sags are more prevalent in some areas. Even in desert areas devoid of trees, storms and lightning strikes occur. Given the large distances between power plants and consumers in North America the cost of underground conductors at all voltages would be prohibitive, even if underground rights of way were available. Few consumers would wish to see their utility power bill increase several fold in order to pay for this. Very few utilities, anywhere in the world, escape voltage sags. Even those with total underground systems in a small geographic area such as Singapore suffer voltage sags. These may be due to damage to cables by digging for new construction or due to failure of electrical equipment from cable faults, overloads etc.

3.3.3 Industrial Responsibility

Industrial customers who have invested heavily in production equipment which is susceptible to voltage sags must take responsibility for their own solutions to voltage sags or lose some benefit from their investment.

Voltage sags are a fact of life they cannot readily be eliminated from regular utility systems. For the industrial customer the solution may involve replacement of components or devices, which are especially sensitive, with less voltage sensitive substitutes or installation of some form of protection against voltage sags.

3.3.4 The Solution

First Identify the Problem

Equipment Identification

In order to provide a optimal and cost effective solution to voltage sag problems it is necessary to determine which equipment is susceptible to unplanned stoppages. In most industries there is still a significant amount of electrical equipment which is not sensitive to voltage variation or which can be restarted at little or no cost. Usually it is not necessary to protect an entire industrial facility, it is sufficient to protect the key sensitive equipment.

Identify the Voltage Sags

The next stage is to determine the frequency, depth and duration of the voltage sags. These can vary widely even in apparently similar industrial facilities. Collection of this data is essential if the optimal solution is to be identified. In North America, only a small proportion of manufacturing businesses have installed electrical metering which is capable of measuring and recording the voltage variations which are responsible for the majority of their very costly Unplanned Production Stoppages.

Measure the Problem

Install Metering

To identify the depth of the voltage sags and their duration, the sag events need to be measured and recorded for subsequent analysis. As a typical voltage sag events last only a few cycles, the most cost effective way to measure these is by installation of an electronic meter with wave form capture capability. As and when voltage sag occurs, these devices capture the 3 phase voltages values throughout the sag event, the duration of the event in cycles, and can time stamp the start and or finish of the event. The data is captured automatically and is downloaded to a computer for later analysis.

Record Unplanned Production Stoppages

It is extremely helpful to record precisely the time and date of unplanned production stoppages and then to compare these against voltage variations recorded by the meter, as not all voltage sags lead to stoppages. This analysis will show the value of the sag voltage which typically causes production problems and equally those events which have not caused problems. Surprisingly in many industries, people are so busy trying to restart the process they fail to record the time of the stoppage with any formal system. Even in large companies precise data on the number and duration of unplanned stoppages is often difficult to find.

Meter Cost vs. Cost of Unplanned Production Stoppage

The cost of an installation with a meter capable of wave form capture and its software is typically a few thousand dollars. This is often only a small fraction of the cost of even one unplanned production stoppage. Unfortunately installation of such meters has not become commonplace in many industries as “there is no money in the budget for this”.

Choose a Solution

Once the characteristics of typical voltage sag have been determined by examining recorded data from the wave-form capture meter over a period of time, it is possible to calculate the type of voltage sag correction required to cover the depth and duration of expected future voltage sag events. If it is possible to correct the problem by changing some sensitive components, this may well be the least expensive solution. This approach has been widely adopted in the semi-conductor industry and it is notable that this industry has invested heavily in high quality meters to identify the problems. This is an industry where an unplanned stoppage may cost $1 million per event or more. If component substitution is not practical, it is necessary to identify the size of the load to be protected in KVA and its supply voltage. This may be an entire plant at medium voltage or a critical machine at low voltage or anything in between.

3.3.5 Voltage Sag Correction Devices

Traditional Solutions

Traditional methods of facts device available for the reduction of voltage sag in power system. In some cases and for some applications these traditional technologies may still be applicable and work well but in many cases they were designed to correct problems other than voltage sags.

3.4 Transmission system sag performance evaluation

The voltage sag performance for a given customer facility will depend on whether the customer is supplied from the transmission system or from the distribution system. For a customer supplied from the transmission system, the voltage sag performance will depend on only the transmission system fault performance. On the other hand, for a customer supplied from the distribution system, the voltage sag performance will depend on the fault performance on both the transmission and distribution systems. This section discusses procedures to estimate the transmission system contribution to the overall voltage sag performance at a facility.

Transmission line faults and the subsequent opening of the protective devices rarely cause an interruption for any customer because of the interconnected nature of most modern-day transmission networks.
These faults, cause voltage sags. Depending on the equipment sensitivity, the unit may trip off, resulting in substantial monetary losses. The ability to estimate the expected voltage sags at an end-user location is therefore very important.

Most utilities have detailed short-circuit models of the interconnected transmission system available. These programs can calculate the voltage throughout the system resulting from faults around the system. Many of them can also apply faults at locations along the transmission lines to help calculate the area of vulnerability at a specific location. The area of vulnerability describes all the fault locations that can cause equipment to misoperate. The type of fault must also be considered in this analysis. Single-line-to-ground faults will not result in the same voltage sag at the customer equipment as a three-phase fault. The characteristics at the end-use equipment also depend on how the voltages are changed by transformer connections and how the equipment is connected, i.e., phase-to-ground or phase-to-phase.

- Equipment connected line-to-line would experience a minimum voltage of 33 percent.
- Equipment connected line-to-neutral would experience a minimum voltage of 58 percent.

3.5 Voltage sag statistical indices

For many years, electricity companies have used sustained interruption indices as indicators describing the quality and reliability of the services they provide. In order to compare power quality in different networks, regulators need to have common, standardized quality indices. The number of these indices should be kept at a minimum, easy to assess, and be representative of the disturbance they characterize. This section briefly discusses various voltage sag indices proposed by electrical association organizations and indices suggested by recent researchers. These indices are used to characterize any voltage sag, according to the individual index point of view. The procedure to evaluate the quality of supply, reference to non-rectangular events and equipment compatibility issues are also discussed.

3.5.1 Types of indices

Any available voltage sag index can be classified within the following three categories (Bollen, 2000).

a. Single-event index: a parameter indicating the severity of a voltage or current event, or otherwise describing the event. Each type of event has a specific single-event index.

b. Single-site index: a parameter indicating the voltage or current quality or a certain aspect of voltage or current quality at a specific site.

c. System index: a parameter indicating the voltage or current quality or a certain aspect of voltage or current quality for a whole or part of a power system.

IV. Thyristor Controlled Series Capacitor (TCSC)

4.1 Introduction

It is obvious that power transfer between areas can be affected by adjusting the net series impedance. One such conventional and established method of increasing transmission line capability is to install a series capacitor, which reduces the net series impedance, thus allowing additional power to be transferred. Although this method s well known, slow switching times is the limitation of its use. Thyristor controllers, on the other hand, are able to rapidly and continuously control the line compensation over a continuous range with resulting flexibility. Controller used for series compensation is the Thyristor Controlled Series Compensator (TCSC). Nowadays, it is becoming increasingly difficult to build new transmission lines, due to restrictions regarding environment and financial issues. One important benefit of FACTS (Flexible AC Transmission Systems) technology is that it makes it possible to improve the use of the existing the existing power transmission system and to postpone or avoid the construction of new transmission facilities.

TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line.

4.2 Operation OF Thyristor Controlled Series Capacitor

(TCSC) is a series FACTS device which allows rapid and continuous changes of the transmission line impedance. It has great application potential in accurately regulating the power flow on a transmission line, damping inter-area power oscillations, mitigating sub synchronous resonance (SSR) and improving transient stability. TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank (Figure4.1). The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert an inductive reactance into the line. According to IEEE definition, “A TCSC is a capacitive reactance compensator which consists of a series capacitor bank shunted by a Thyristor Controlled Reactor (TCR) in order to provide a smooth variation in series capacitive reactance.” TCSC controllers use TCR in parallel with segments of series capacitor bank. The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert appropriate reactance into the line.

This thyristor controlled series capacitor is type of series compensator. This TCSC controller is design only for reduction of voltage sags in transmission system and the TCSC controller is controlled with the help of pulse width generator its work when gate pulse are given in this system then capacitor and inductor through control the voltage sags in the system.

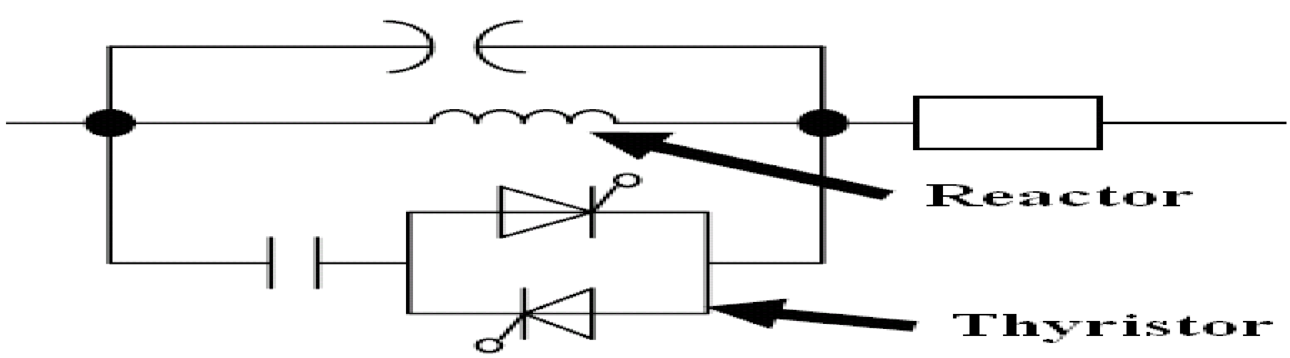


FIGURE 4.1 Simple diagram of TCSC

FIGURE 4.1 shows the simple diagram of TCSC comprised of a series capacitor bank, shunted by a Thyristor Controlled Reactor (TCR), to provide a smoothly variable series capacitive reactance. It is a one-port circuit in series with transmission line; it uses natural commutation; its switching frequency is low; it contains insignificant energy storage and has no DC port.

Insertion of a capacitive reactance in series with the line's inherent inductive reactance lowers the total, effective impedance of the line and thus virtually reduces its length. As a result, both angular and voltage stability gets improved.

TCSC - Thyristor Controlled Series Capacitor compensator consisting of the series compensating capacitor, whereto is parallel connected thyristors controlled reactor (TCR), and it is one of FACTS devices which are mainly used to control active power flow in power system and increase the transmission power lines capacity.

TCSC is involved in a series to line (in terminal) and allows changing impedance of the transmission path and thus affecting the power flows. Control is fast, efficient and increased between the transmitted powers. Basic scheme of TCSC device is shown in the follows figure.

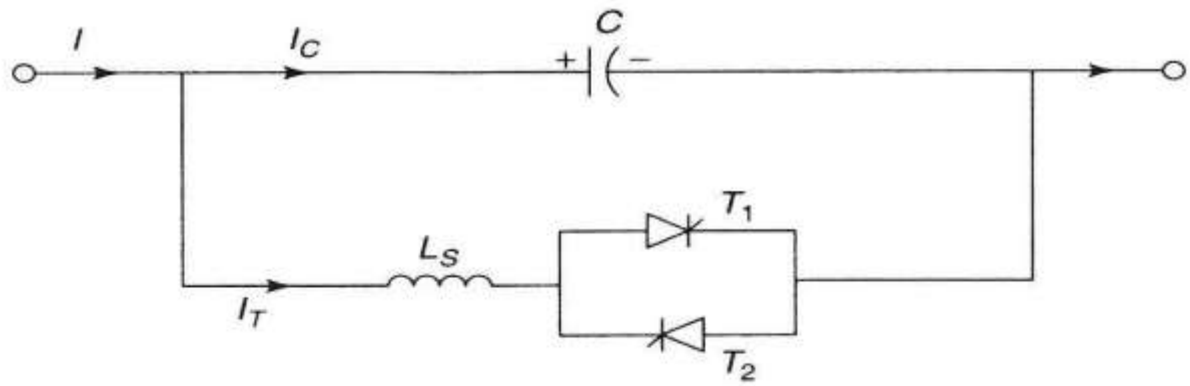


FIGURE 4.2 Basic diagram of TCSC

Change of impedance of TCSC is achieved by changing the thyristor controlled inductive reactance of inductors connected in parallel to the capacitor. The magnitude of inductive reactance is determined by angle switching thyristors, which can also be controlled continuously flowing amplitude of current reactor from the maximum value to zero. Angle switching thyristors can change inductive reactance controlled choke from a minimum value (_ = 0, *X*TCR= *XL*) theoretically to infinity (_ = _/2, *X*TCR = _). [1][2] Magnitude of inductance this compensator is given by:

$$X_{\text{TCSC}}(\alpha) = \frac{X_C \cdot X_{\text{TCR}}(\alpha)}{X_{\text{TCR}}(\alpha) - X_C},$$

Where *X*C = 1/_*C* is capacitive reactance of capacitor and *C* its capacity [1][2].
For sufficiently small inductive reactance of reactor towards capacitive reactance of capacitor (*XL* < *XC*), the operating diagram of TCSC contains inductive and capacitive mode operation of TCSC and the transition between areas is the resonance region. Under normal operating conditions TCSC can operate in four modes of operation, namely: blocked mode, bypassed mode, capacitive and inductive mode.

Thyristor-Controlled Series Compensation (TCSC) is used in power systems to dynamically control the reactance of a transmission line in order to provide sufficient load compensation. The benefits of TCSC are seen in its ability to control the amount of compensation of a transmission line, and in its ability to operate in different modes. These traits are very desirable since loads are constantly changing and cannot always be predicted.TCSC designs operate in the same way as Fixed Series Compensation, but provide variable control of the reactance absorbed by the capacitor device. A thyristor-controlled series compensator is composed of a series capacitance which has a parallel branch including a thyristor-controlled reactor.

TCSC operates in different modes depending on when the thyristors for the inductive branch are triggered. The modes of operation are as listed:

- Blocking mode: Thyristor valve is always off, opening inductive branch, and effectively causing the TCSC to operate as FSC.
- Bypass mode: Thyristor valve is always on, causing TCSC to operate as capacitor and inductor in parallel, reducing current through TCSC.

- Capacitive boost mode: Forward voltage thyristor valve is triggered slightly before capacitor voltage crosses zero to allow current to flow through inductive branch, adding to capacitive current. This effectively increases the observed capacitance of the TCSC without requiring a larger capacitor within the TCSC.

Because of TCSC allowing different operating modes depending on system requirements, TCSC is desired for several reasons. In addition to all of the benefits of FSC, TCSC allows for increased compensation simply by using a different mode of operation, as well as limitation of line current in the event of a fault. A benefit of using TCSC is the damping of sub synchronous resonance caused by torsional oscillations and inter-area oscillations. The ability to dampen these oscillations is due to the control system controlling the compensator. This results in the ability to transfer more power, and the possibility of connecting the power systems of several areas over long distances.

4.3 Possibilities of using TCSC

Using of the TCSC has many benefits that result from its substance, and for which its use is justified. Possibilities and advantages of the TCSC are:
• increased dynamic stability of power transmission systems,
• Improved voltage regulation and reactive power balance,
• Improved load sharing between parallel lines,
• Elimination of subsynchronous resonance risks (SSR),
• damping of active power oscillations,
• improved stability,
• Dynamic power flow control,
• minimizing system losses,
• Reduction of loop flows,
• Elimination of line overloads,
• optimizing load sharing between parallel circuits,
• Reduction of the gap between commercial and physical flows.

The aforementioned benefits are typically seen to increase transmission lines capacity. Benefits of TCSC are not subject only to newly built TCSC installation but they can also be achieved by upgrading existing series compensation on the thyristors controlled series compensation or only its part, thus considerably extended its influence and usefulness.

4.4Control system of TCSC

4.4.1 PWM Generator six pulses

PWM is a modulation technique that conforms the width of the pulse, formally the pulse duration, based on modulator signal information. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load.

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. In this control system in thyristor controlled series capacitor is controlled through discrete PWM Generator six pulses when gate pulses are given in thyristor then thyristor triggering.

4.4.2 Firing angle control

The basic circuit of TCSC is illustrated in Figure4.1. It consists of a capacitor in parallel with a thyristor-controlled inductor. The control variable is the firing angles α of the thyristors, with reference to the capacitor voltage zero crossings. The thyristors are fired when the capacitor voltage and current are opposite in polarity. This is equivalent to thyristor firing angles between 90° and 180°.The TCSC can operate in three different modes. In the bypassed mode, the thyristor path is conducting continuously, the capacitor is bypassed and the apparent impedance becomes inductive. In the blocked mode, the thyristor path is blocked continuously, which is equivalent to the fixed capacitor reactance. Finally in the Vernier mode, the thyristor path is partially conducting resulting in a flow current circulating in the TCSC loop. Depending on the conduction time of the thyristors, this current may have the same or opposite direction with the internal capacitor current.

In this way the TCSC appears as an apparent reactance that may be capacitive or inductive. When TCSC operates in the constant impedance mode it uses voltage and current feedback for calculating the TCSC impedance. The reference impedance indirectly determines the power level, although an automatic power control mode could also be introduced. A separate PI controller is used in each operating mode. The capacitive mode also employs a phase lead compensator. Each controller further includes an adaptive control loop to improve performance over a wide operating range. The controller gain scheduling compensates for the gain changes in the system, caused by the variations in the impedance. The firing circuit uses three single-phase PLL units for synchronization with the line current. Line current is used for synchronization, rather than line voltage, since the TCSC voltage can vary widely during the operation.

V. Modeling of TCSC Controller

5.1 Simulation of Transmission Line without TCSC Device

5.1.1 Modeling of Thyristor controlled series capacitor in MATLAB/SIMULINK

The model of electrical network with TCSC device was prepared and simulated in Simulink For demonstration of action TCSC device, from the viewpoint of voltage sag control has been created a simple model of electrical network, this electrical network implemented in MATLAB/SIMULINK.

The model of simple electrical network consists of a voltage source, load, two parallel lines and units for measuring and displaying measured electric variables. Among the power quality problems (sags, swells, harmonics) voltage sags are the most severe disturbances. In order to overcome these problems the concept of series compensator devices TCSC is introduced recently. The function of series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage. Series inductance exists in all AC transmission lines. On long lines, when a large current flows, this causes a large voltage drop. To compensate, series capacitors are connected, decreasing the effect of the inductance. The simple power system model shown in Figure 5.1 is used to explain the principle of the proposed represents the equivalent source impedance.

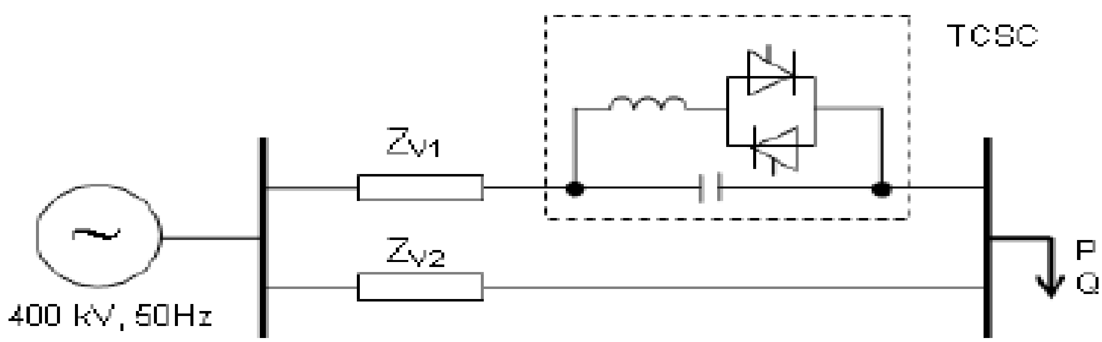


FIGURE 5. 1: General block diagram of the model of electrical network with TCSC

The parameters of the model are as follows:

Ideal Three-Phase Voltage Source
Line to-line voltage UN = 400 kV,
Phase angle L1 _ = 0°,
Frequency f = 50 Hz,

Three-Phase RL Load
Active power P = 50 MW,
Reactive power Q = 10 MVAr,
Configuration Y (grounded),

Three-Phase transmission line
Line resistance R = 0.028 _/km,
Line inductance L = 0.904 mH/km,,

This TCSC device are designed in matlab simulink ,firstly design the three phase voltage source 400 KV voltage are consider in this system than transmission line design with R L parameter are taken in the system. TCSC device design in Matlab Simulink two anti parallel connection thyristor with series connection of inductance and capacitor connected in parallel of the thyristor and inductance. Then connection of the heavy load three phase breaker with series connection of R L load. After that measure the transmission line voltage and current though the discrete PWM Generator 6 pulses, are observed voltage sag in the power system. Check the effect of heavy load then voltage sag and losses occur in the system and the reduction of voltage sag. In the fig. 5. 2 Series Compensator is absent .It is observed that voltage and current across the sensitive load are not pure sinusoidal. Fig. 5.3 shows the matlab simulink model of transmission line with series compensator thyristor controlled series capacitor for reduction voltage sag is to connected at the sensitive load terminals. The challenge is to regulate the sensitive load terminal voltage so that magnitude is increase and voltage sag is reduced to an acceptable level.

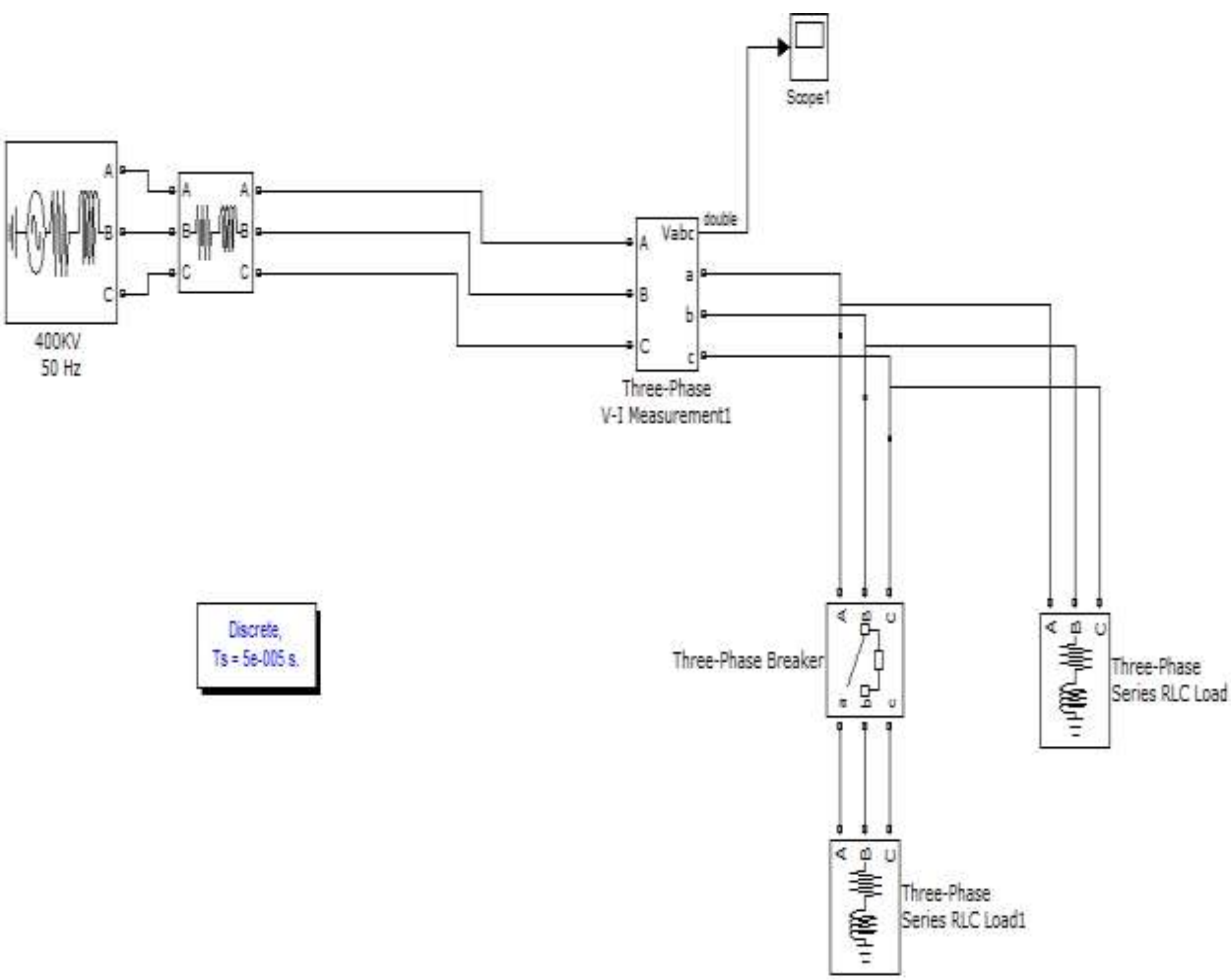


FIGURE 5.2: Simulink diagram of transmission line without thyristor controlled series capacitor series compensator

5.2 Simulation of Transmission Line with TCSC Device

The designing of Thyristor controlled series capacitor for the reduction of voltage sag in transmission line. The AC source supply of system 400 KV in transmission line . In this thesis work discuss in MATLAB designing of thyristor controlled series capacitor device for reduction of voltage sag using PWM Generator six pulse controller. TCSC controller through reduction of voltage sag in the system and minimize system losses. This paper present an work on MATLAB/SIMULINK. Modeling of TCSC for reduction of voltage sag in transmission line system. The result given in simulation results. This thesis work discuss design and simulation of transmission system in use in power electronics switching device series compensator in thyristor controlled series capacitor for reduction of voltage sags issues due to the presence of nonlinear loads and heavy load condition. In simulink model when the fault is introduced at the point of common coupling, sag appears at the period 0.6 to 0.7 secs in all the three phases is shown in figure 5.2. When the series compensator is connected to the system the appeared sag is mitigated is shown in figure 5.3.

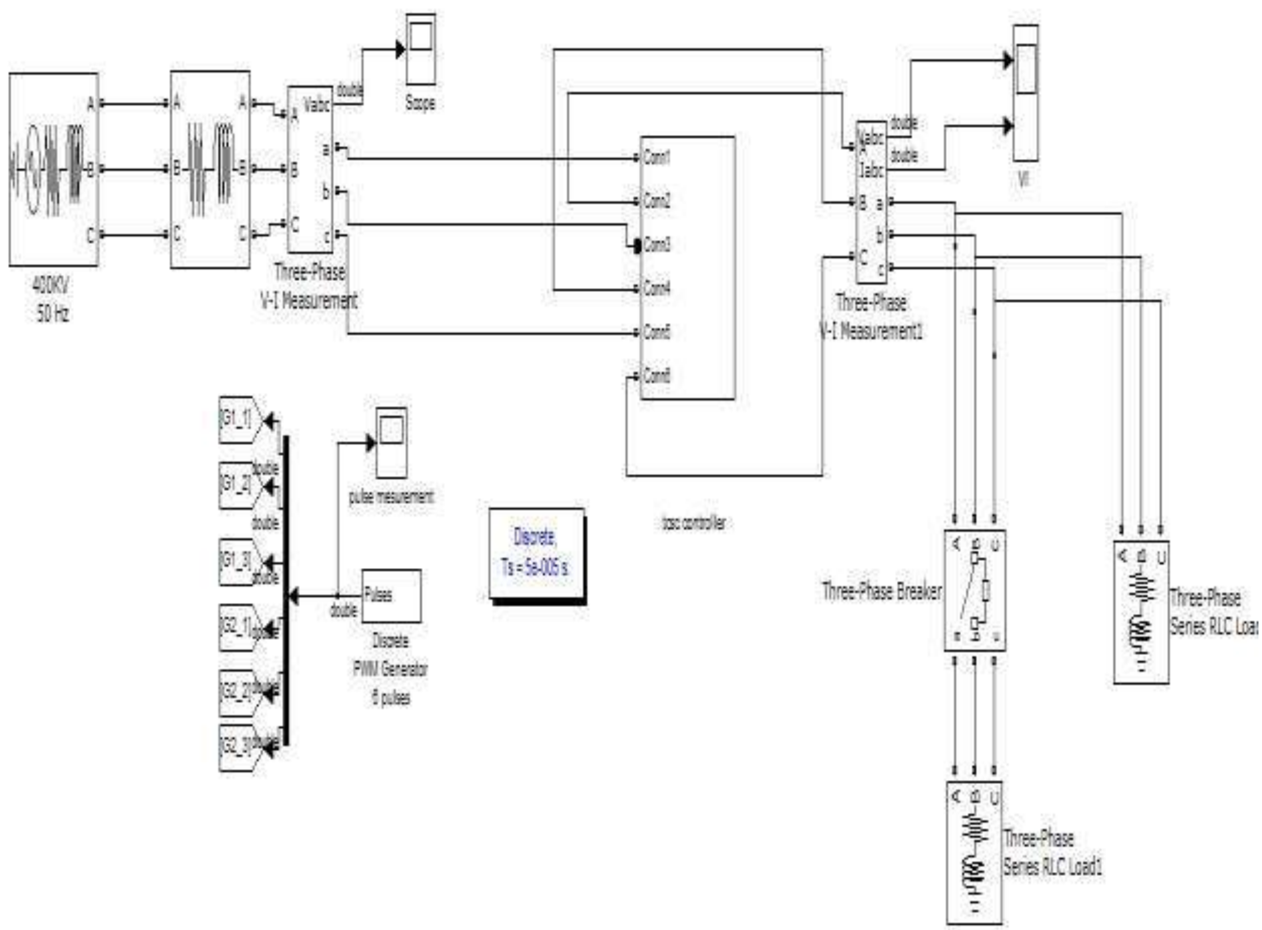


FIGURE 5.3: Simulink diagram of transmission line with thyristor controlled series capacitor series compensator

5.3 Designing of TCSC in Transmission Line with Firing Angle Controller

This TCSC device are designed in MATLAB/SIMULINK, firstly design the three phase voltage source 400 KV voltage are consider in this system than transmission line design with R L parameter are taken in the system. TCSC device design in

Matlab two anti parallel connection thyristor with series connection of inductance and capacitor connected in parallel of the thyristor and inductance. Then connection of the nonlinear load three phase bridge rectifier are parallel connected of R L load and series connection of R L load in the transmission system. After that measure the transmission line voltage through the firing angle through TCSC control system, are observed voltage sag reduction in the transmission line. Check the effect of nonlinear load then voltage sag and losses occur in the system and the reduction of voltage sag.

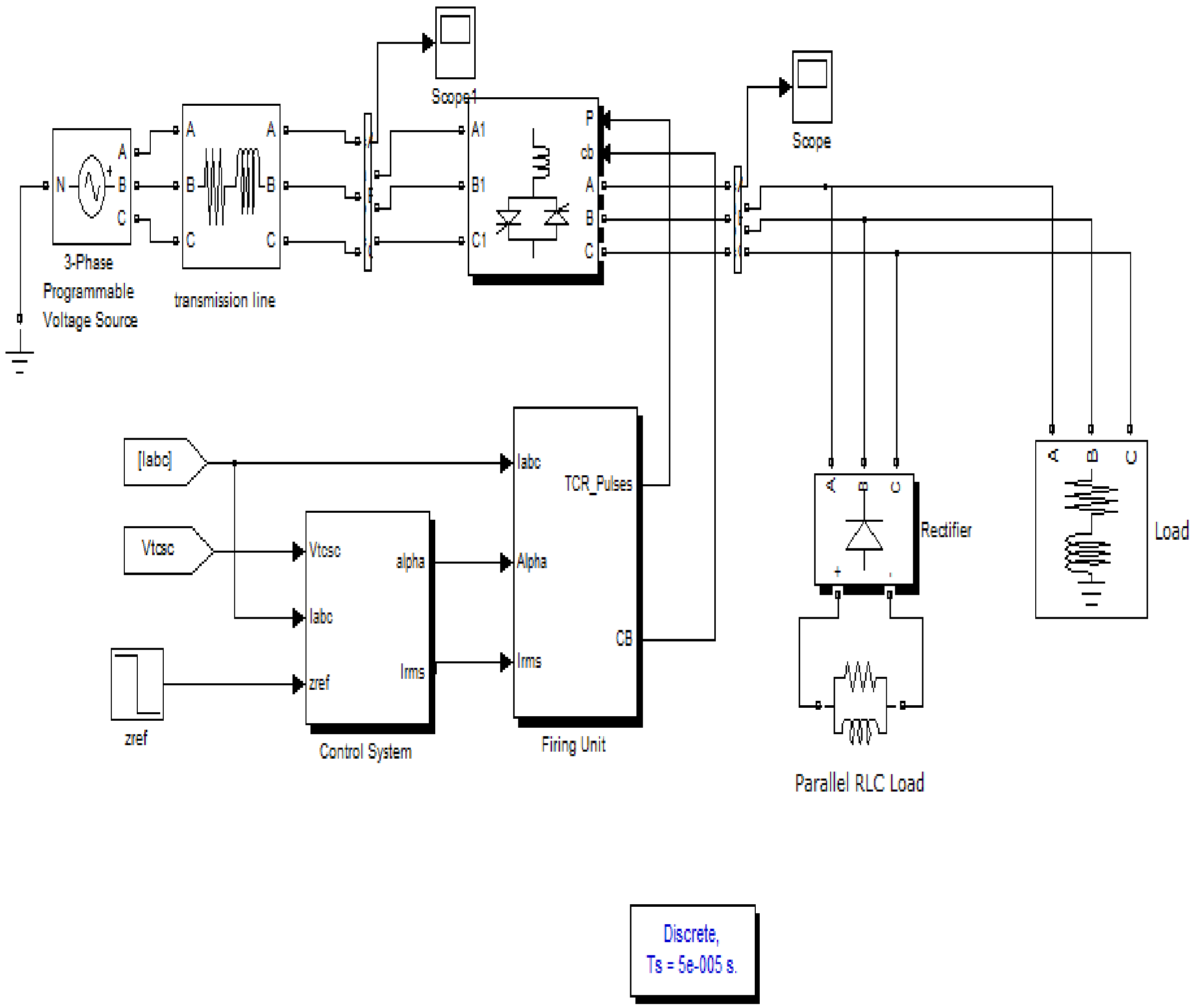


FIGURE 5.4: Simulink diagram of transmission line with firing angle thyristor controlled series capacitor series compensator

5.4 Designing of TCSC in Transmission Line with Discrete PWM Generator Six Pulses Controller

This TCSC device are designed in Matlab/Simulink, firstly design the three phase voltage source 400 KV voltage are consider in this system than transmission line design with R L parameter are taken in the system. TCSC device design in Matlab two anti parallel connection thyristor with series connection of inductance and capacitor connected in parallel of the thyristor and inductance. Then connection of the nonlinear load three phase bridge rectifier are parallel connected of R L load and series connection of R L load in the transmission system. After that measure the transmission line voltage through the discrete PWM generator six pulses TCSC control system, are observed voltage sag reduction in the transmission line. Check the effect of nonlinear load then voltage sag and losses occur in the system and the reduction of voltage sag.

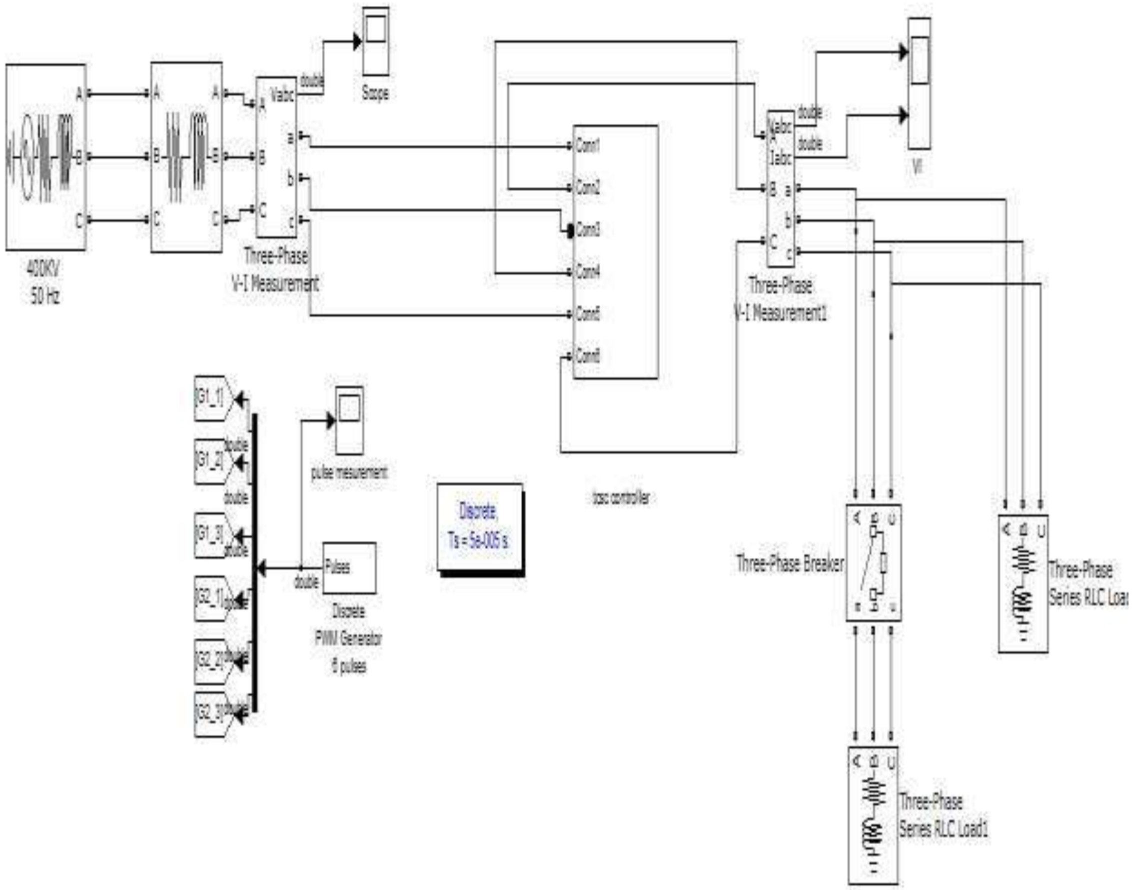


FIGURE 5.5 Simulink diagram of transmission line with discrete PWM Generator 6 pulses thyristor controlled series capacitor series compensator

5.5 Comparative Analysis of TCSC with Firing Angle Controller and Discrete PWM Generator Six Pulses Controller in MATLAB/SIMULINK

The model of electrical network with TCSC device was prepared and simulated in Simulink For demonstration of action TCSC device, from the viewpoint of voltage sag control has been created a simple model of electrical network, in which was subsequently implemented TCSC device. The model of simple electrical network consists of a voltage source, load, two parallel lines and units for measuring and displaying measured electric variables. In this paper Comparative performance of thyristor controlled series capacitor with firing angle control system and TCSC device with Discrete PWM Generator six pulses controller for the mitigation of voltage sag in transmission system.

This TCSC device are designed in MATLAB/SIMULINK, firstly design the three phase voltage source 400 KV voltage are consider in this system than transmission line design with R L parameter are taken in the system. TCSC device design in MATLAB/SIMULINK, two anti parallel connection thyristor with series connection of inductance and capacitor connected in parallel of the thyristor and inductance. Then connection of the nonlinear load three phase bridge rectifier are parallel connected of R L load and series connection of R L load in the transmission system. After that measure the transmission line voltage through the discrete PWM generator 6 pulses and firing angle through TCSC control system ,are observed voltage sag reduction in the transmission line. check the effect of nonlinear load then voltage sag and losses occur in the system and the reduction of voltage sag.

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Then Comparative effect are observed in system. It is observed that voltage across the nonlinear load are pure sinusoidal. Figure shows the matlab/simulink model of power system with series compensator thyristor controlled series capacitor for reduction voltage sag is to connected at the nonlinear load terminals. The challenge is to regulated the nonlinear load terminal voltage so that magnitude is increase and voltage sag is reduced to an acceptable level.

5.6 Simulation Results

5.6.1 Simulation Result of transmission line without TCSC controller device

The waveforms of the voltage in 400KV transmission line using thyristor controlled series capacitor for reduction of voltage sag. In this paper discuss in MATLAB designing of thyristor controlled series capacitor device to reduction of voltage sag using PWM generator pulse controller. TCSC controllers through reduction of voltage sag in the system and minimize system losses. This thesis presents a work on matlab simulink modeling of tcsc for reduction of voltage sag in transmission line system. the result waveform are given below.

This thesis work discuss design and simulation of transmission system in use in power electronics switching device series compensator in thyristor controlled series capacitor for reduction of voltage sags issues due to the presence of nonlinear loads and heavy load condition. In simulink model when the fault is introduced at the point of common coupling, sag appears at the period 0.6 to 0.7 secs in all the three phases is shown in figure 5.6.

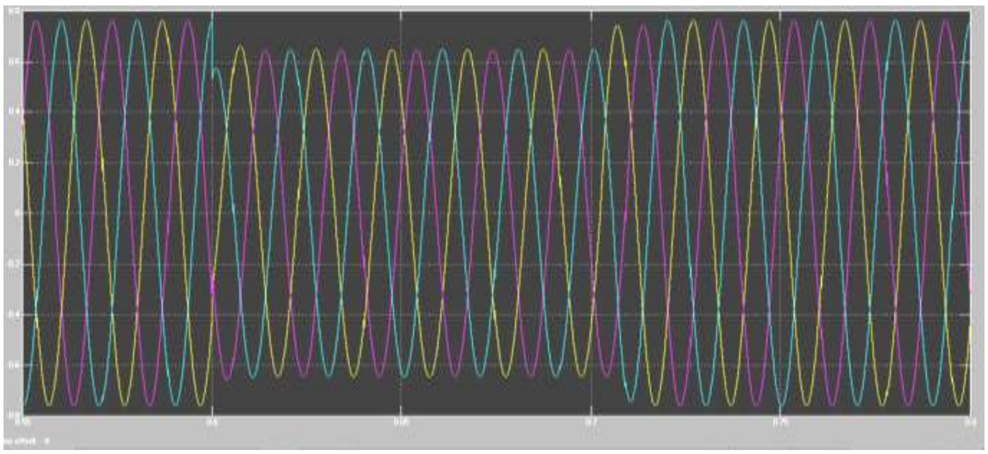

FIGURE 5.6 Three phase voltage sag

5.6.2 Simulation Result of transmission line with TCSC controller device

In simulink model when the fault is introduced at the point of common coupling, voltage appear in magnitude of 0.62 pu. from 0.6 to 0.7 sec in all the three phases. When the series compensator is connected to the system the appeared voltage sag is mitigated to 0.62 pu to 0.9pu is shown in figure 5.7.

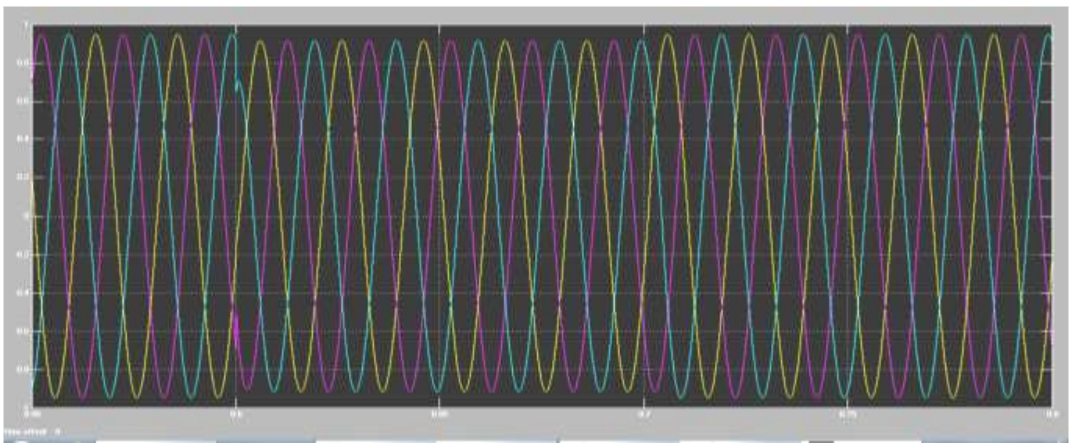

FIGURE 5.7 Three phase voltage Sag mitigation

5.6.3 Comparative Performance of TCSC controllers

The waveforms of the voltage in 400 KV transmission line using thyristor controlled series capacitor for reduction of voltage sag. In this paper discuss in matlab designing of thyristor controlled series capacitor device to reduction of voltage sag using PWM Generator six pulse controllers. TCSC controller through reduction of voltage sags in the system and minimize system losses. This Paper present an work on matlab/simulink model of TCSC firing angle controller and discrete PWM generator six pluses controller for the comparison of the both controller performance in matlab simulink for reduction of voltage sag in transmission line system. The result waveform are given below this paper discuss design and simulation of transmission system in use in power electronics switching device series compensator in thyristor controlled series capacitor for reduction of voltage sags issues due to the presence of nonlinear loads and heavy load condition and the output results waveform in Comparative performance of firing angle TCSC controller and Discrete PWM Generator six pluses controller. Output results waveform are below:

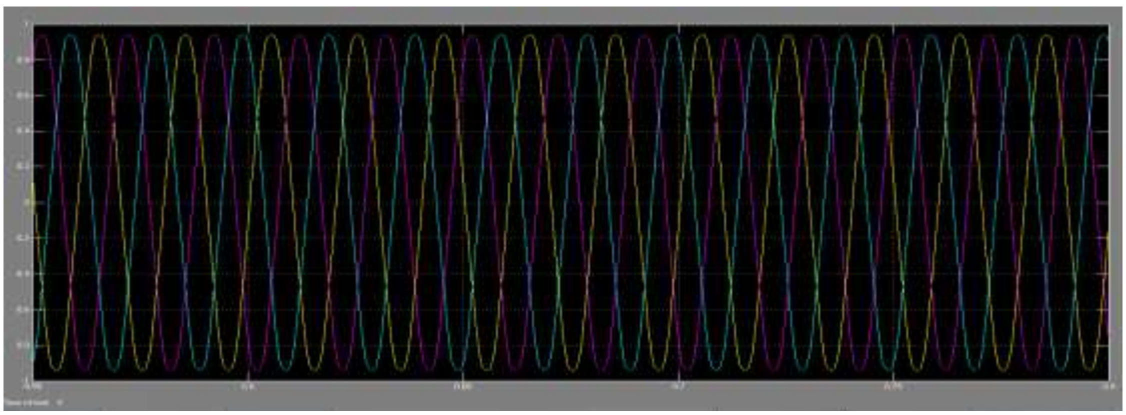

FIGURE 5.8 : Three phase voltage sag reduction through the firing angle thyristor controlled series capacitor series compensator

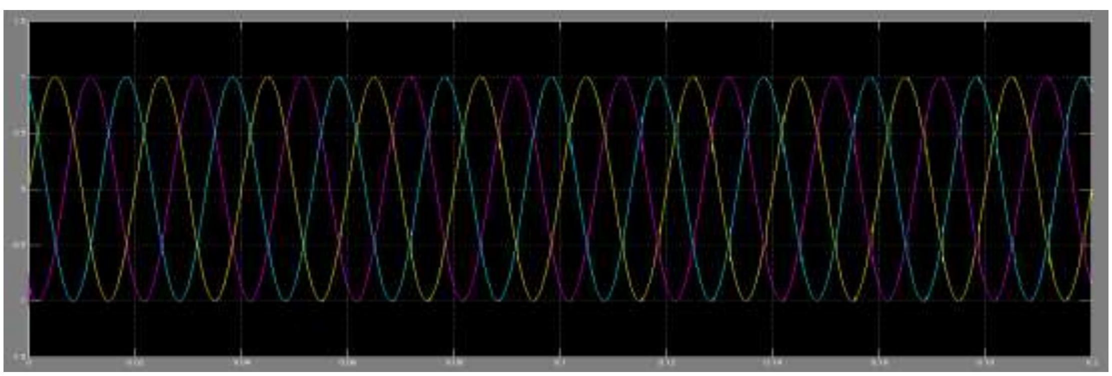

FIGURE 5.9: Three phase voltage sag reduction through the Discrete PWM Generator six pluses thyristor controlled series capacitor series compensator

VI. Conclusion & Recommendation

6.1 Conclusion

Voltage Sag is defined as a short reduction in rms voltage magnitude from 0.1 to 0.9 per unit (pu), for a duration of 0.5 cycle to 1 minute. In transmission line, voltage sag is occurred due to unreliable grid system, switching of heavy loads and nonlinear loads, unbalanced load on a three phase system and faults on the system. In This thesis work, TCSC Controller is used to reduce the Voltage Sag and to improve the Voltage Quality of a Transmission line. Here TCSC is controlled by two methods (1) By controlling the Firing angle and (2) By Discrete PWM six pulses Generator. Both methods are Simulated in MATLAB and Results are compared. It is found that Discrete PWM Generator method of TCSC controller is more effective than the other method.

6.2 Future Recommendations

This approach is different from conventional methods and provides effective solution. If this method is enhanced in future could provide much more improved power quality.

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