Harmonic Reduction in an Isolated Power System through Series Compensator

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Abstract— Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. This paper discusses the design and simulation of series compensator for improving power quality and reduces the harmonic distortion of sensitive load. The role of the series 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. The series compensator consists of injection transformer, filter, ESS, VSI, control and protection system. In series compensator LC filter is used to eliminate the unwanted harmonics. At the end the effectiveness of result is investigated through computer simulation by using MATLAB/SIMULINK software.

Key words: Isolated Power Systems, Series Compensator, Harmonics, Power quality, ESS, VSI, Filter, injection transformer, MATLAB

I. Introduction

Isolated power systems are commonly found in rural and remote areas of the world. These systems represent the alternative to grid connection, where

Interconnection to a large grid is not viable due to

High cost and/or geographical obstacles. Power quality problem occurs due to non-standard voltage, current and frequency. The power quality has serious economic consideration for customers, utilities and electrical equipment manufacturers. Modernization and automation of industry involves increasing use of computers, microprocessors and power electronic systems such as adjustable speed drives. Power System may also contain sensitive loads such as computers or electronic controllers which consume less power are connected in parallel with nonlinear loads. The harmonics generated by this nonlinear load may be harmful to sensitive loads and could even damage the sensitive loads. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problem such as voltage sags, swells and harmonics. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. The occurrence of harmonics in the system can cause excessive losses and heating in motors, capacitors and transformers connected to the system. This paper analyses the key issues in the power quality problems, In the proposed system Voltage sag occurs due to the three phase fault in the transmission line and harmonics occurs due to the connection of controlled six pulse converter (rectifier) to the main drive load(non linear load). All these factors affect the sensitive load which is connected in parallel to the main drive load. So the proposed system protects the sensitive load by mitigating the voltage sags and harmonics using series compensation technique.

II. Problem associated with power quality problem

A. *Transients:*

These are undesirable but decay with time and hence not a steady state problem. A broad definition is that a transient is that part of the change in a variable that disappears during transition from one steady state operating condition to the other. Another synonymous term is `surge'. Transients are classified into two categories

1) Impulsive
2) Oscillatory

B. *Long Duration Voltage Variations:*

A long-duration variation means rms deviation at power frequencies for longer than 1 minute. Long duration variation can be sustained interruptions over voltage or under voltage and are generally caused by load variations on the system and switching operations. Sustained Interruptions: If the supply voltage becomes zero for a period of time which is than one minute, then we can say that it is a sustained interruption. Normally voltage interruption lasting for more than one minute is often unending and requires human intervention to restore the supply. The term “outage” is also used for long interruption. However it does not bring out the true impact of the power interruption. Even an interruption of half a cycle can be disastrous for a customer with a sensitive load.

C. *Short Duration Voltage Variations*

Short duration variations are deviations at power frequency for less than 1 minute. The short duration voltage variations are generally caused by fault conditions like single line ground or double line to ground and starting of large induction motors. This voltage variation can be instantaneous, momentary or temporary depending on its duration.

D. *Voltage Sags*

Voltage sag is a brief decrease in the rms voltage at power frequency of 1 to 0.9pu of the nominal voltage value. The duration of voltage sag is 0.5 to 1 minute. Voltage sags as a voltage dip. Voltage sags are mainly due to system faults and last for durations ranging from 3 cycles to 30 cycles depending on the fault clearing time. The magnitudes of the voltages sags caused by faults depend upon the distance of the fault location from the bus where the sag is measured. Starting of large induction motors can result in voltage sags as the motor draws a current up to 10 times the full load current during the starting. Also, the power factor of the starting current is generally poor.

E. *Voltage Swells*

A voltage swell is opposite to the sag**.** A voltage swell is defined as an increase to between 1.1 and 1.8 p.u.in RMS voltage at the power frequency for duration between 0.5 cycles to 1minute. But voltage swell are not as common as voltage sags. A swell can occur on the healthy phases during a single line ground fault. A voltage swell caused by an SLG fault. Swell can also be caused by switching off large load, energizing a large capacitor bank, incorrect setting of tap changer etc. Swell are characterized by their magnitude and duration which depends in the fault location, system impendence and grounding. However in a grounded system, there will be negligible voltage rise on the un-faulted phases close to a substation where the delta connected windings of the transformer (usually connected delta-wye) provide low impendence paths for the zero sequence current during the SLG fault.

F. Interruption

If the supply voltage or load current decrease to less than 0.1 pu for a period of time not more than one minute is known as interruption .Interruption can be caused either by system faults, equipment failures or control malfunction .The interruption are measured by their duration alone. The duration due to a fault is determined by the operating time of the protective devices. Duration of an interruption due to equipment malfunction can be irregular. Some interruption may also be caused by voltage sag conditions when there are faults in the source side.

G. Steady State Phenomena:

Waveform Distortion is steady state phenomena and it is defined as steady state deviations from an ideal sine wave of power frequency. There are five type of waveform distortion.

1) DC offset
2) Harmonic
3) Inter harmonics
4) Notching
5) Noise

H. Voltage Fluctuations and Flicker:

Voltage fluctuations are systematic variations of the voltage envelope or a series of random changes in the voltage magnitude (which lies in the range of 0.9 to 1.1pu) High power loads that draw fluctuating current, such as large motor drives and arc furnaces, cause low frequency cyclic voltage variations that result in flickering of light sources (incandescent and fluorescent lamps) which can cause significant physiological discomfort or irritation in human beings. The voltage flicker can also stable operation of electrical and electronic devices such as motors and CRT devices. The typical frequency spectrum of voltage flicker lies in the range from 1 Hz to 30 Hz.

III. SYSTEM MODEL

The series compensator is most recently method for improvement of power quality. There are several power quality problems (sags, swells, harmonic) in which voltage sags are the most severe disturbances. The SC is connected in series with sensitive load. The function of the SC is to ensure that the voltage across the sensitive load terminals is of high quality. The central part of the SC is an energy storage system (ESS) and a VSI where a PWM switching scheme is often used. The ESS can be a capacitor of suitable capacity. Because of the switching, harmonics are generated, and filtering is required.

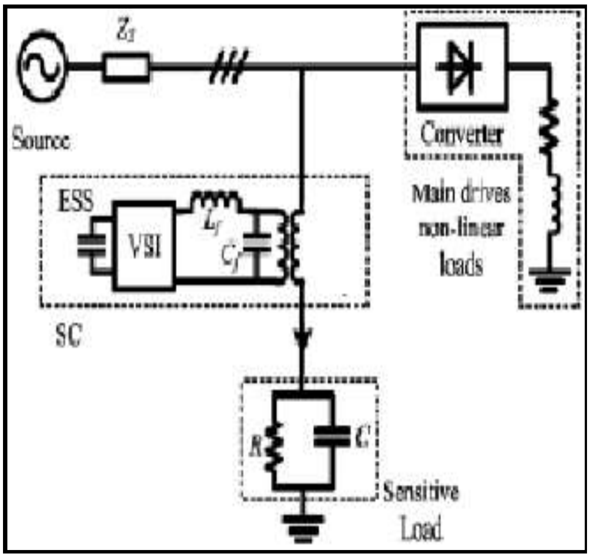

Fig. 1: The Basic Structure of Series Compensator

IV. BASIC CONFIGURATION OF SERIES COMPENSATION

The general configuration of the SC consists of:

1) An Injection Transformer
2) A Harmonic filter
3) Storage Devices/ESS
4) A Voltage Source Converter (VSC)/VSI
5) By-pass switch
6) A Control and Protection system

A. An Injection Transformer

An injection transformer may either three single-phase transformer units or one three phase transformer unit can be used for voltage injection purpose. The injection transformer comprises of two side voltages namely the high voltage side and low voltage side. The voltage sag problems occur due to the three phase fault in the transmission line and harmonics occurs due to non linear load. So the proposed system mitigates the voltage Sag and reduces harmonic of an isolated power system.

B. A Harmonic filter

Basically harmonic filter unit consists of inductor and capacitor. The harmonic filters can be placed either on the high voltage side or the converter side of the injection transformers. In this system filters are used to convert the inverted PWM waveform into a sinusoidal waveform which is possible only by eliminating the unwanted harmonic components generated by the VSI action. Higher orders harmonic components distort the compensated output voltage. The unnecessary switching harmonics generated by the VSI must be removed from the injected voltage waveform in order to maintain an acceptable Total Harmonics Distortion (THD) level.

C. Storage Device

This is required to provide active power to the load during deep voltage sags. Lead-acid batteries, flywheel etc. can be used for energy storage. It is also possible to provide the required power on the DC side of the VSI by an auxiliary bridge converter that is fed from an auxiliary AC supply. The series compensator need real power for compensation purpose during voltage disturbance in the distribution system. In this case the real power of the series compensator must be supplied by energy storage when the voltage disturbance occurs. The energy storage such as battery is responsible to supply an energy source in D.C form.

D. A Voltage source Converter

VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. This voltage source inverter system is used to convert from dc storage to ac. Rating of the VSI converter is of low
voltage and high current type due to injection transformer in the series compensation technique.

E. By-pass Switch

By -pass switch play very important role during voltage sag appear in the power system, it is used to protect the inverter from high current. Whenever any fault or short circuit occur on downstream of distribution system, the series compensator change in to the bypass condition where the VSI inverter is protected against over current flowing through the power semiconductor devices

F. A Control and Protection System

The main function of the control and protection system is to maintain constant voltage magnitude under the disturbances at the point where a sensitive load is connected. The harmonics is generated by using six pulse converters with fixed firing angle are connected to the main drive non linear load which is parallel to the sensitive load and voltage sag is created at load terminals due to three phase fault. The above voltage problems are sensed separately and passed through the sequence analyzer the magnitude component is compared with reference voltage (Vref). Pulse width Modulation (PWM) control technique is applied for inverter switching so as to produce a three phase 50 Hz Sinusoidal voltage at the load terminals. Chopping frequency is in the range of few KHz. The IGBT inverter Controlled with PI controller maintains 1per unit voltage at the load terminals. PI controller is a closed loop controller which drives the plant to be controlled with a weighted sum of the error (difference between the output and the desired set point) and the integral of that value .One advantage of a proportional plus integral controller is that the integral term in a PI controller causes the steady-state error to be zero for a step input.

V. PRINCIPLE OF HARMONICS COMPENSATION

Fig. 2 shows a typical scheme of series compensator, through which injection of the voltage V_{out}, compensates the harmonic voltage. In this study, the resistance and leakage inductance of injection transformer is assumed negligible. The transformer turns-ratio is 1:n. Only the network branch pertaining to the sensitive load is included. The distorted source-side voltage V_L is represented as a harmonic voltage source. Z_{Load} *denotes* the parallel RC load shown in Fig. 1 and the line current is I_{Load}.

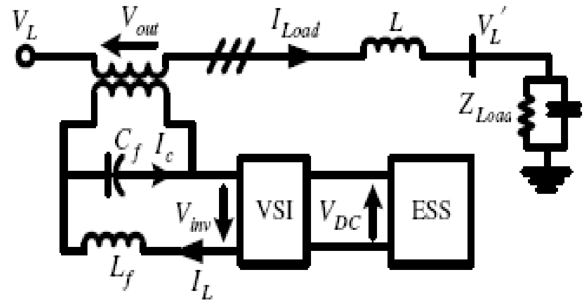

Fig. 2: Schematic Diagram Showing the Interconnection of the SC with the Sensitive Load

The block diagram of the control scheme for a conventional SC designed for load ride-through enhancement function during a voltage-sag is given in Fig. 3. As an initial attempt, the same scheme may be considered for adoption herewith for the purpose of mitigating harmonic distortions. In this scheme, the injection voltage Vout is regulated to follow the reference voltage V*. Thus it requires Vout to be compared with V*. The error is multiplied by the voltage error feedback gain K2Cf and fed to the second stage as the reference for the inductor current. This virtual inductor current reference is compared with the actual inductor current and the error is multiplied with the current error gain K1Lf to form the inner feedback loop. The resulting quantity of this loop is subsequently fed to the PWM generator of the inverter

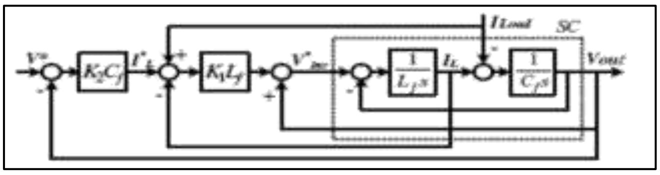

Fig. 3: Closed-Loop Control Scheme for the SC

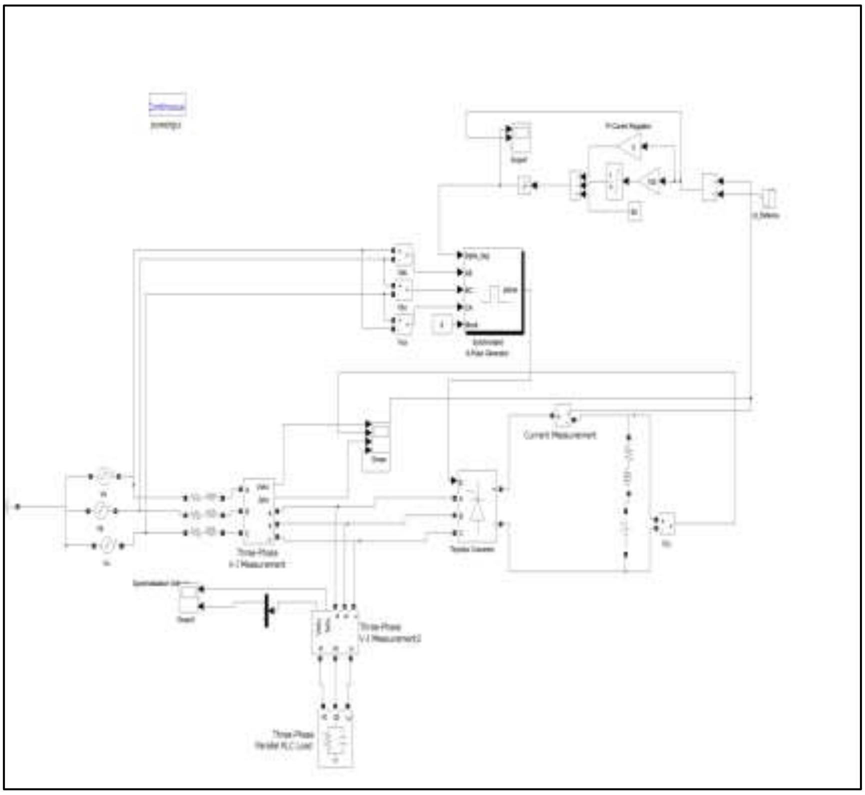

Fig. 4: Simulink Diagram of Isolated Power System without Series Compensator

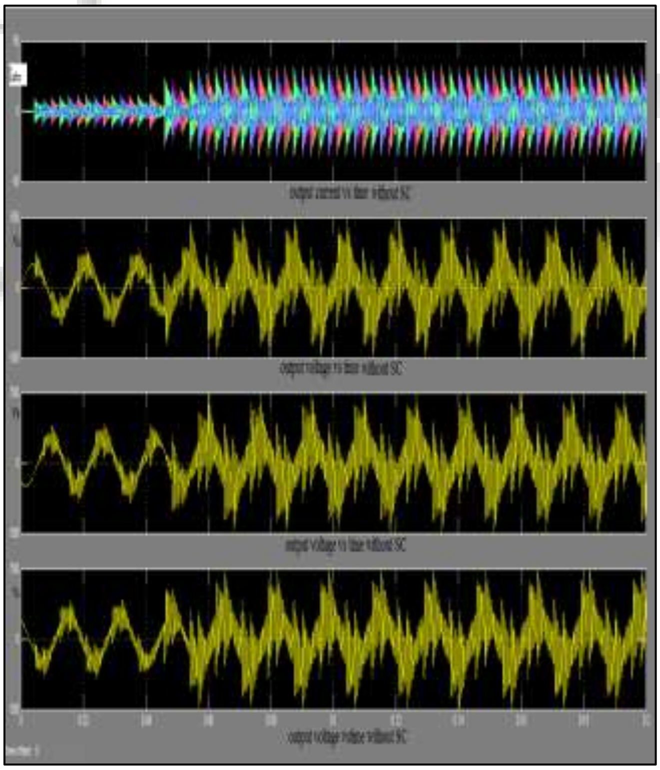

Fig. 5: Output Current & Voltage Waveforms without Series Compensator

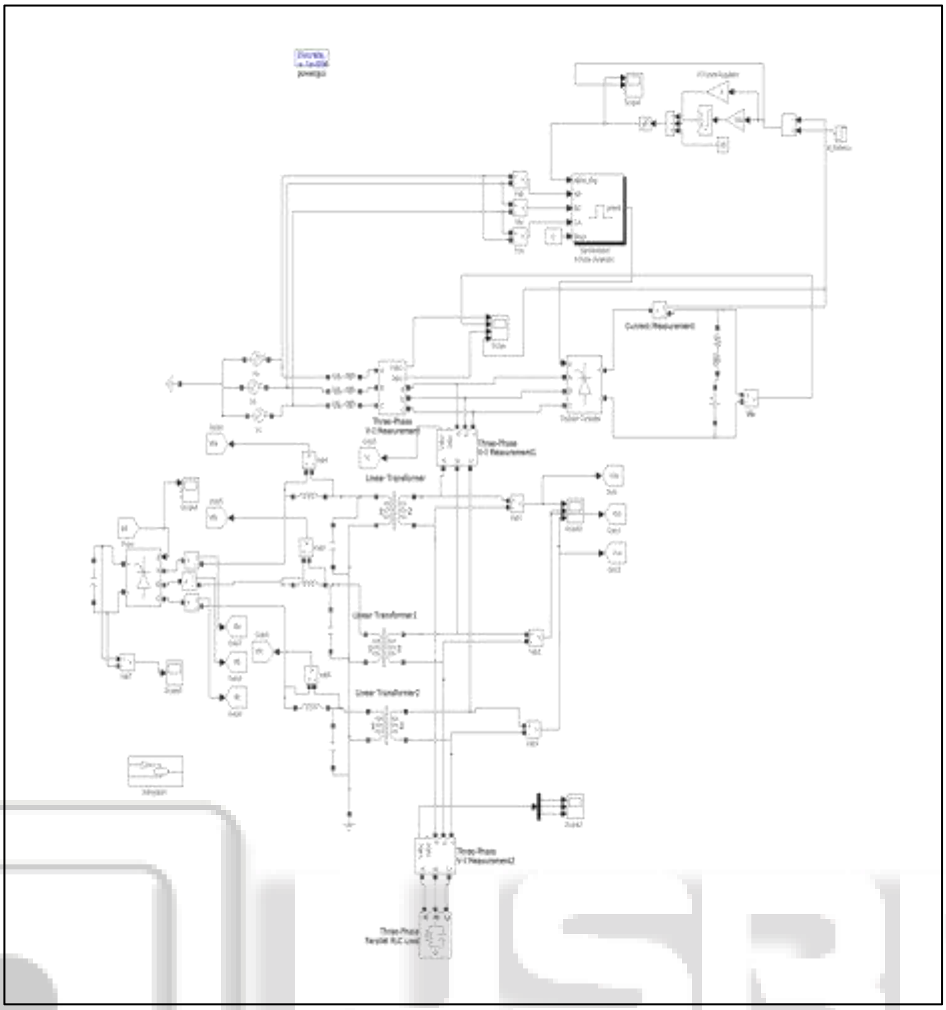

Fig. 6: Simulink Diagram of Isolated Power System with Series Compensator

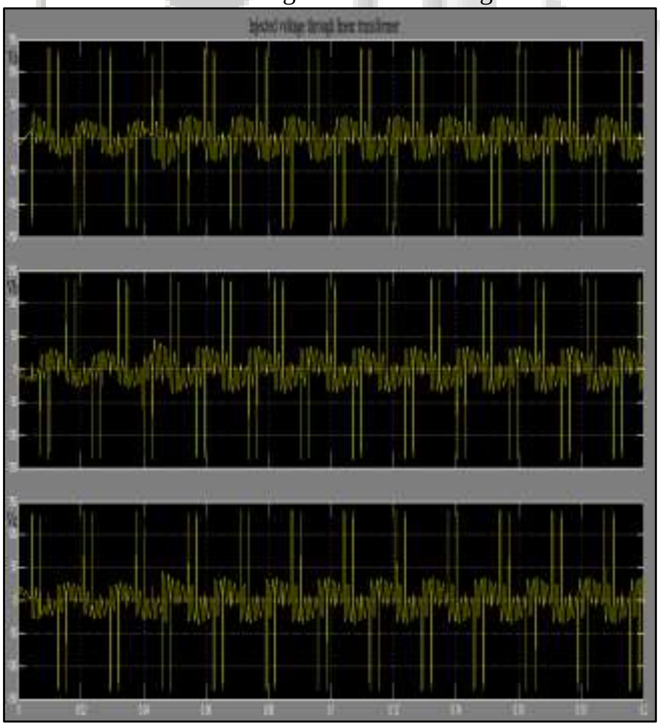

Fig. 7: Voltage Waveforms with Series Compensator Va, Vb & Vc

VI. EXPERIMENTAL RESULTS

In simulink model shows the harmonics is generated in the transmission line using six pulse converters connected to the main drive non linear load which is parallel to the sensitive load. Matlab simulation is carried out with compensation technique. The simulation results show that the harmonics in the sensitive load side is decreased approximately to 50%. The sensitive load is protected against the distortion introduced by the main drive load and the total harmonic distortion is reduced up to 50%. The simulation results carried out with series compensator generated harmonics are reduced.

VII. CONCLUSION

Power quality improvement in an isolated power system through series compensation has been investigated. Harmonic produced by the nonlinear load are harmful to the sensitive load which are connected in parallel with the non linear load .In this paper a method to reduce harmonic & increase voltage quality using series compensation is considered. VSI based series Compensator is used to reduce the harmonic produced by non linear loads. The SC is also designed to maintain the fundamental frequency component of the terminal voltage of protected sensitive load. In this paper, a complete simulated series compensator system has been developed by using Matlab/ Simulink software. It is shown that the simulated SC developed works successfully to improve power quality. The proposed system performs better than the traditional methods in mitigating harmonics and voltage sags.

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