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Enhancement of Voltage Quality in Power System Using Series Compensation

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ABSTRACT: The power quality requirement is one of the most important issues especially with the introduction of sophisticated device whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in failure of end user equipment. One of the major problem deal with sag and harmonics. Voltage sags are one of the most important power quality problems challenging the utility industry voltage sags can be compensated for by voltage and power injection in to the distribution system The use of series compensators (SCs) in improving voltage quality of isolated power systems is considered. The roles of the compensators are to mitigate the The use of series compensators (SCs) in improving voltage quality of isolated power systems is considered. The roles of the compensators are to mitigate the effects of momentary voltage sags or swells, and to control the level of harmonic distortions in the networks. A control strategy for the SC is developed to regulate power flow. 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. Validity of the technique is illustrated through simulation.

KEYWORDS: Harmonics, Power quality problem, Voltage sag, isolated power system, phase shift, series compensation, voltage restoration

I. INTRODUCTION

Power quality problems have increasingly become a concern over the last decade or so because they impact greatly on the operations of electrical equipment. Often the consequence would be significant economic losses to customers. While enhancing power quality in interconnected systems has attracted much research interest, unfortunately much less attention has been directed toward solving the same problems in isolated power systems. This is despite the fact that one can still encounter situations where loads are supplied by a relatively small capacity power system which is not part of a grid. Examples of such isolated power systems include small networks in oil exploration areas and remote mining districts. The main focus of this project is to examine issues closely related to power quality enhancement in such an isolated power system. These isolated power systems are typically characterized by generation capacity of up to a few MVA. The electrical source can be in the form of diesel generator-sets and the p.u. equivalent source impedances tend to be high because of the sparsity of the networks. The loads are often relatively large DC or AC motor-drives: the variable-speed drives or machinery would be supplied by the generators via power converters. The loads are nonlinear and would involve the commutation process of the converters. The consequence would be distortions in the voltage/current waveforms in the supply systems, the extent of which are likely to fluctuate as the loads change. Hence under such a situation, any attempt to enhance power quality will need to take into consideration the presence of harmonic distortions in the network. In an attempt to address the growing concern on power quality much research attention have been directed toward the design of so-called Custom Power devices. Among such devices are those which are based on series compensation technique, applied to interconnected or grid systems. A series compensator (SC) is intended for use in a distribution system, with rating of between a few hundred kVA to 2 MVA typically. Central to its design is a voltage-source inverter connected to a DC energy storage system. The SC is designed to be installed upstream of loads which are to be protected against short-duration voltage disturbances. The basic operating principle of a SC is by injecting a voltage component in series with the load voltage so that the load-side voltage is maintained at its nominal level during a voltage disturbance. Due to its quick response and high reliability, the SC is considered to be an effective device in mitigating the impacts of voltage sags/swells and can provide good power quality for customers. Currently, most studies on series compensation are focused on applying the technique in mitigating the effects of voltage sags. However harmonic voltages/currents in the network have been ignored. This paper therefore begins with a detailed analysis concerning the mitigation of the effects of voltage sags under distorted conditions



through series compensation. A method to control the injection voltage of the SC that can mitigate the effects of the harmonics on voltage compensation is proposed. The method is based on the control of the SC branch impedance. In the process of harmonic voltage compensation, it is shown that power exchange exists between the SC and the external network. It would then result in a variation in the terminal voltage of the energy storage system (ESS) within the SC. Permitting the phase adjustment of the fundamental frequency component of the reference voltage of the SC, a method to control the voltage of ESS is proposed. Simulation results indicate that using the suggested method, harmonic distortion in an isolated power system can be mitigated.

II. SUPPLY QUALITY ISSUES PERTAINING TO ISOLATED POWER SYSTEMS

Despite wide coverage of the land area of the earth by electricity networks, not all consumers are served by large interconnected systems. A small power system that is not connected to a much larger grid is often called an isolated power system and such a network can be found in rural and remote areas of the world. The system represents the alternative to grid connection, where interconnection to a large grid is not viable due to high costs and/or geographical obstacles. Isolated power systems are gaining importance because of the push by governments and utilities on the electrification of rural and remote areas. From a utility perspective, the construction and maintenance of ever increasing interconnected grids can become both economically and environmentally less attractive. Operational and administrative costs associated with providing power to remote locations may not compensate the gains of bulk production. Thus, utilities may not opt for grid expansion and large-scale, centralized generating plants. Instead, it may be more attractive to adopt decentralized small-scale generation policy, with the generation sited near the loads. The opportunity to optimize resources and reduce costs can be significant. The above factors have created a new situation in which large scale centralized systems may become less prevalent, even in some of the most developed countries. In general, it can be concluded that isolated power systems, which have relatively low inertia and short-circuit levels, and/or experience relatively large load variations, tend to result in higher levels of power quality degradation. Harmonics, voltage variations, voltage unbalance and frequency variations are some of the most important issues on power quality in such system and could be of much concern. Since voltage sags/swells and harmonic distortion are considered the most common power quality occurrences in an isolated power system and could significantly impact the electric utility customers [4], an understanding of the causes will help one to search for effective solutions to these problems. An underlying cause of sags or swells is a sudden change of current flow through source impedance. Application of Ohm's Law and Kirchoff's Equations, as they related to real life, non-ideal sources, is necessary to understanding the effect of such an event. A sudden increase in current can be due to a downstream fault. For instance, one of the important causes of the voltage sag is the occurrence of a fault within an industrial facility or on parallel feeders in the electrical neighborhood. Fluctuations of large loads such as motors in isolated power systems will also result in voltage sags/swells. As individual load capacity can be relatively large in an isolated power system, load changes would result in appreciable current fluctuations in the system. Electricity generation is normally produced at constant frequencies of 50 Hz or 60 Hz and the generators' e.m.f. can be considered practically sinusoidal. However, when a source of sinusoidal voltage is applied to a non-linear device or load, the resulting current is not perfectly sinusoidal. In the presence of system impedance, this current causes a nonsinusoidal voltage drop. Therefore, it produces voltage distortion at the load terminals, i.e. the latter contains harmonics. As the system impedance can be of relatively high value in an isolated power system, one can expect harmonic distortions to appear even more prevalently in such a system. Harmonic distortion is common because of the presence of non-linear devices in the systems such as transformer, rotating machine and power electronic device. If an isolated power system supplies industrial or mining activities, it can be envisaged that there will be a large number of AC or DC motor loads. The machineries are usually of the form of adjustable-speed AC or DC drives. One would also find electronic devices such as computers and process control systems within the loads. These loads are often found to be sensitive to the power quality disturbances.

III. PROPOSED SYSTEM MODEL

Among the novel Custom Power devices, the Series Compensator (SC) is the most technically advanced and promising device developed so far for mitigating voltage sag/swell. With the increase in interest and the necessity in mitigating voltage sags in power systems, ABB has also introduced a SC composed of newly developed Integrated Gate Commutated Thyristors (IGCT) [76]. The basic design criteria of the ABB SC, IGCT technology and protection measures of the SC have all been well addressed in this paper. As a general observation, the SC shares a similar hardware structure to the DSTATCOM. The major difference is that this controller is connected in series with the distribution feeder and the protected sensitive load through an injection transformer. A typical SC schematic is shown in Fig.1. The power system upstream to the SC is represented herewith by a voltage source V_s and a series impedance Z_s , calculated based on the fault level at the point of common coupling (PCC). Both V_s and Z_s can substantially vary during fault condition. When

the PCC voltage is under voltage disturbance condition, the role of the SC is to restore the load-side voltage to its nominal level through injecting a voltage V_{sc} in series with the incoming supply voltage. Thus V_{sc} can be expressed as

$$V_{sc} = V_L - V_P$$

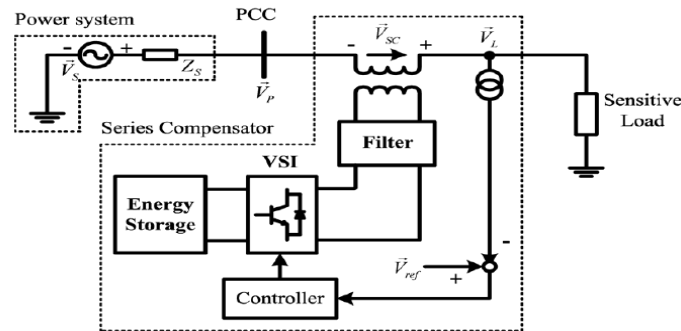


Fig. 1. Schematic diagram of a typical SC.

When the sag occurs, the SC will inject voltage and sensitive load voltage (V_L) is then restored to the pre-sag voltage. The SC is a voltage source inverter (VSI) which produces the required voltage V_{sc} to be injected in series with the incoming supply voltage. Pulse width modulation (PWM) technique is usually used in the VSI, due to the flexibility of controlling the ratio between the fundamental frequency component of output voltage and the DC-link voltage, its fast response to load and source changes, elimination of low order harmonic which results in reduction of output filter rating and the simplicity of implementation. The series injection transformer is used to boost and couple the injection voltage generated by VSI into the feeder circuit. The output of the PWM-controlled VSI will include a large amount of high-order harmonics due to the high switching frequency of the VSI. Therefore, a harmonic filtering system is necessary to offer a clean injected voltage on the primary-side of the injection transformer. Generally, the filter system will consist of a L-C section. The values of the filter components will depend on the switching frequency of VSI. The filtering system can be placed either on the primary side (line-side filter system) or on the secondary side (inverter-side filtering system). In this thesis and where relevant, inverter-side filter is adopted in the design of the SC. The controller is also needed to provide the necessary signal in order to generate the PWM gating pulse for the SC inverter. The scheme can be in the form of open loop control or closed-loop control. In the open loop control, the control signal is derived by comparing the load voltage against a desired reference. The output voltage is sensed and fed back to be compared with a desired reference in the closed-loop control technique. During voltage compensation, the SC would supply (or absorb) real and reactive power to (from) the system. Thus energy storage system is required to provide the needed real power buffer. Large capacitors are used as the storage medium in most of the commercially available SC. Other possible energy storage devices are battery bank, supercapacitor, superconducting magnetic energy storage (SMES) and flywheel.

IV. SIMULATION RESULTS AND DISCUSSIONS

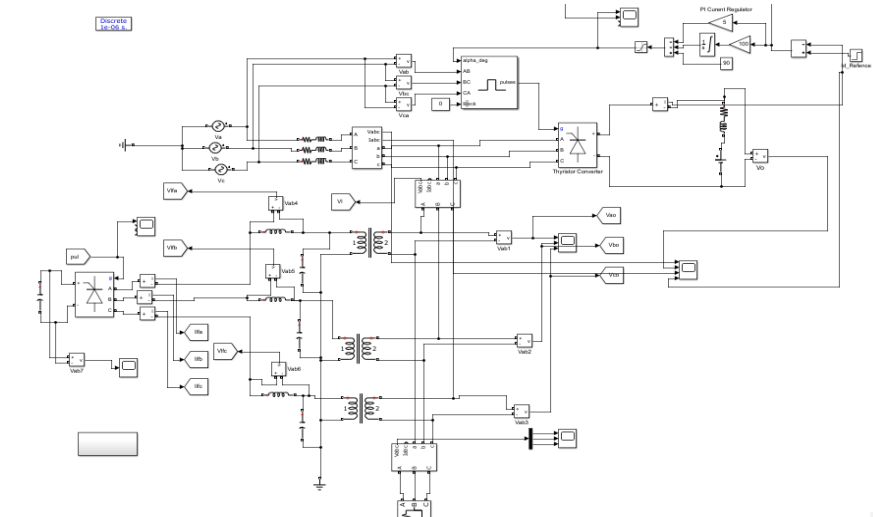


Fig.2. Simulink model with series compensation



Simulink model of Fig. 2 is used to verify the effectiveness of the SC and its control strategy and simulations are accomplished using MATLAB. The injection transformer is assumed to have a turns-ratio of 1:1. This is a reasonable assumption as the focus of the study is to demonstrate the principle of operation of the SC and not on the detailed design of the compensator. With this turns-ratio and in order to be able to achieve the maximum injected voltage equal to the PCC rated voltage.

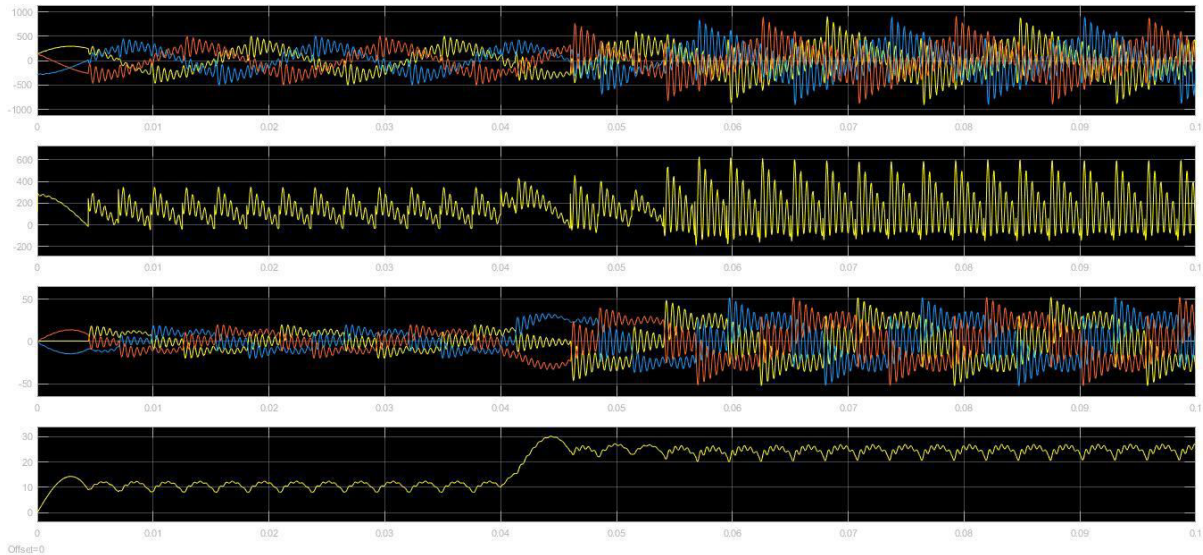


Figure 3. Load voltage and current After and Before RLE Load without compensation

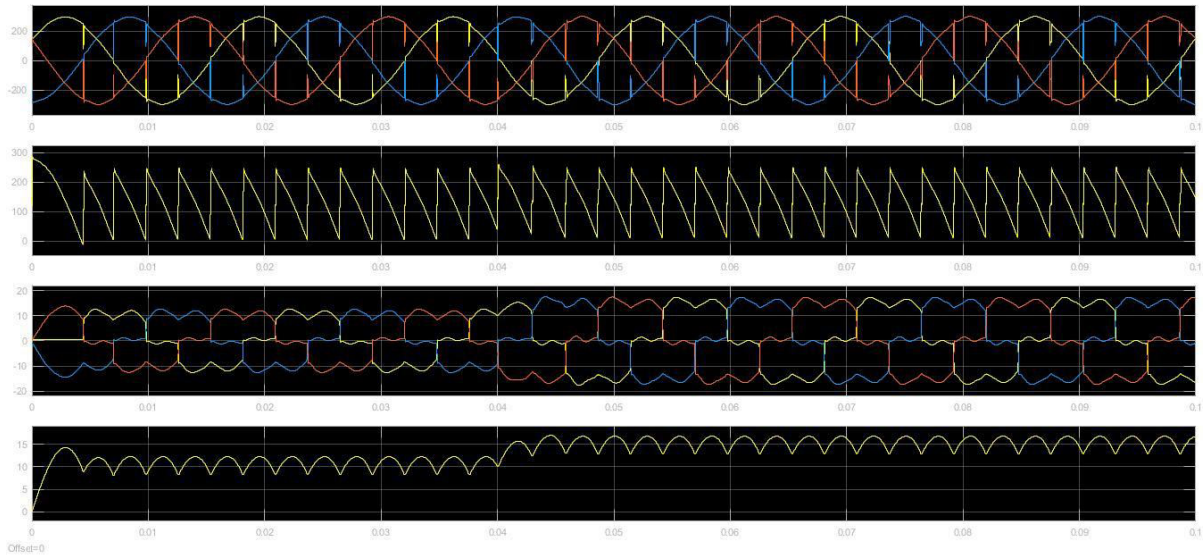


Figure 4. Load voltage and current After and Before RLE Load with series compensation

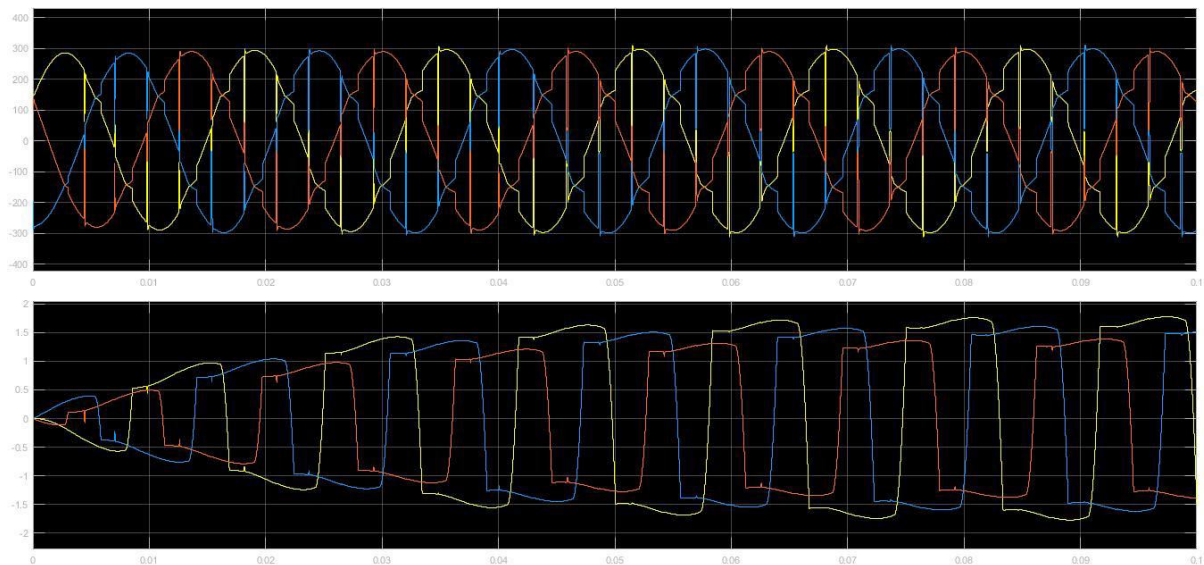


Figure 6. voltage and current of Three phase Nonlinear Load with Series Compensation

V. CONCLUSION

In this paper, power quality improvement in an isolated power system through series compensation has been investigated. The power system is assumed to contain a significant proportion of non-linear loads and a high level of harmonic distortions is observed. A method to control the injection voltage of the SC so that it can mitigate the effects of the harmonics has been proposed. The method is based on the control of the SC branch impedance. A load-current feedback scheme is incorporated in the control system of the SC, in conjunction with an inductive filter intended for mitigating the high-order harmonic currents. The design of the filter and feedback scheme has been described. In the process of harmonic voltage compensation, it is shown that power exchange exists between the SC and the external network. The function of the SC is then extended to control the terminal voltage of the protected sensitive load. The technique used is through the phase adjustment of the fundamental frequency component of the reference voltage of the SC. Through the analysis of the energy exchange, a strategy on the phase adjustment has been obtained. Simulation results have confirmed the effectiveness of the proposed method, as it is applied on the SC to achieve improved quality of supply in the power system.

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