ENHANCEMENT OF POWER QUALITY IN GRID CONNECTED ISOLATED POWER SYSTEM

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ABSTRACT

In Isolated power systems the power quality problem is compounded as the drive converter loads are likely to fluctuate in conjunction with mining or exploration areas. Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads. Adequate reactive power control solves power quality problems like flat voltage profile maintenance at all power transmission levels, and improvement of power factor, transmission efficiency and system stability. 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. The proposed series compensator consists of Energy Storage System (ESS) and Voltage Source Inverter (VSI), Injection Transformer. The ESS can be a capacitor of suitable capacity. ESS would act as a buffer and generally provides the energy needed for load ride-through during voltage sag. A control strategy for the SC is developed to regulate power flow. This is achieved through phase adjustment of load terminal voltage. Validity of the technique is illustrated through simulation.

Keywords: Isolated Power Systems, Series Compensator, Harmonics compensation, Energy Storage System, VSI, Harmonics; Voltage Sag; MATLAB.

I.INTRODUCTION

Isolated power systems are commonly found in rural and remote areas of the world. Isolated power systems are characterized by limiting generating capacity. The sensitive loads which are present in the isolated power systems are much more affected by the power quality problems. Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Power quality problems encompass a wide range of disturbances such as voltage sags/swells, flickers, harmonics distortion, impulse transient, and interruptions.

Among power system disturbances, voltage sags, swells and harmonics are some of the severe problems to the sensitive loads, because (i) the occurrence of voltage sag in the system can cause devices/process down time, effect on product quality, failure/malfunction of equipments etc., (ii) 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.

An alternative method to improving the power quality of the isolated systems is through the use of series compensators (SC). A SC is viable because it is of smaller capacity compared to a shunt compensator to achieve the same level of voltage quality control. It is based on the well-established voltage-source inverter (VSI) technology. Also, as reported in [6, 7], the SC can function to mitigate the effects of voltage sag/swell although in these previous works; harmonic voltages/current distortions in the networks have been ignored.

II.EFFECTS OF ELECTRICAL POWER QUALITY PROBLEMS

Power Quality is "Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipments"[1]. Power systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the isolated systems, some of the primary source of distortion [2] can be identified as Non – Linear Loads, Power Electronic Devices, IT and Office Equipments, Arcing Devices, Load Switching, Large Motor Starting, Larger capacitor bank energies, Embedded Generation, Electromagnetic radiations and Cables, Storm and Environment Related Causes etc.

III.SYSTEM MODEL

The simple isolated power system model shown in Fig. 1 is used to explain the principle of the proposed harmonics compensation method of the SC. The upstream generators are represented as an ideal voltage source and *ZS* represents the equivalent source impedance. The main drives or machinery loads are modeled as a lumped resistance-inductance load connected to the source through a power converter which is assumed to be an uncontrolled six-pulse rectifier in this study.

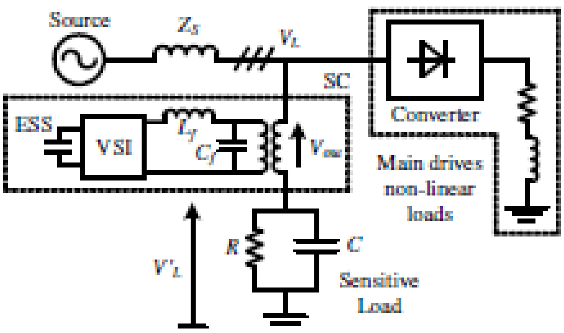

Fig 1: A typical isolated power system with Series Compensator

The main drives or machinery loads are modeled as a lumped resistive-inductive load connected to the source through a power converter, assumed to be a six-pulse rectifier. The much smaller capacity sensitive loads are assumed to be supplied through point of common coupling and are modeled by the resistor R in parallel with the capacitor C. The SC is connected upstream from the sensitive load through an injection transformer. It is series connected with the 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[5]. The ESS can be a capacitor of suitable capacity. Because of the switching, harmonics are generated, and filtering is required.

IV.PRINCIPLE OF HARMONICS COMPENSATION

The underlying principle when the SC is used to compensate for upstream voltage sag/swell has been discussed in [8]. In Fig. 2, distorted voltage V_L will appear on the upstream source-side of the sensitive load and the phase voltages can be expressed as

$$V_{La}(t) = \sum_{n=1}[V_{0n} + V_{1n}\sin(nwt + \phi_{\ln}) + V_{2n}\sin(nwt + \phi_{2n})] \tag{1}$$

$$V_{Lb}(t) = \sum_{n=1}^{n}[V_{0n} + V_{1n}\sin(nwt + \phi_{\ln} - 2n\pi/3) + V_{2n}\sin(nwt + \phi_{2n} + 2n\pi/3)] \tag{2}$$

$$V_{Lb}(t) = \sum_{n=1}^{n}[V_{0n} + V_{1n}\sin(nwt - \phi_{\ln} + 2n\pi/3) + V_{2n}\sin(nwt + \phi_{2n} - 2n\pi/3)] \tag{3}$$

where n is the harmonic order; V_{0n} is the zero phase sequence voltage component; V_{1n} and φ_{1n} are the magnitude and phase of the positive phase sequence voltage components; V_{2n} and φ_{2n} are the magnitude and phase of the negative phase sequence voltage components. Clearly, the distorted voltage is undesirable at the sensitive load terminals.

The proposed voltage injection method is to compensate for the difference between V_L and the desired voltage described by (1)-(3). This is achieved by injecting an ac voltage component in series with the incoming three-phase network. Hence from (1)-(3), the desired injection voltages are,

$$V_{inja}(t) = V_{la}(t) - V_{La}(t) = \sum_{n=1} V_{on} - \sum_{n=2} V_{in}\sin(nwt + \phi_{\ln}) - \sum_{n=1}^{\infty} V_{2n}\sin(nwt + \phi_{2n})$$

(4)

$$V_{injb}(t) = V_{lb}(t) - V_{Lb}(t) = \sum_{n=1} V_{on} - \sum_{n=2} V_{in}\sin(nwt + \phi_{\ln} + 2\pi/3) - \sum_{n=1}^{\infty} V_{2n}\sin(nwt + \phi_{2n} + 2\pi/3)$$

(5)

$$V_{injc}(t) = V_{lc}(t) - V_{Lc}(t) = \sum_{n=1} V_{on} - \sum_{n=2} V_{in}\sin(nwt + \phi_{\ln} - 2\pi/3) - \sum_{n=1}^{\infty} V_{2n}\sin(nwt + \phi_{2n} - 2\pi/3)$$

(6)

The above equations can be written in a compact form. From (4)-(6), define V_{Lf} =[V_{la}(t), V_{lb} (t), V_{lc} (t)]^T and from (1)-(3), denote as,

V_{Lf} =[V_{la}(t), V_{lb} (t), V_{lc} (t)]^T, Let V_{Lh} be the vector containing all the harmonic components in (1)-(3). Hence, from (7)-(9), the injection voltage of the SC would be

$$V^{*}=V_{Lf}-V_{L}=V_{Lh} \tag{i}$$

V_L can be measured online and its fundamental voltage V_{Lf} can be obtained using, for example, a Phase Locked Loop (PLL) scheme. Hence the injection voltage V*can be generated online and used to mitigate the harmonic distortions in the manner described below.

V.SERIES COMPENSATOR CONTROLLER

The harmonics is generated in the load terminals using six pulse converters with fixed firing angle are connected to the main drive non linear load which is parallel to the sensitive load. Voltage sag is created at load terminals via a 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 [6] 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 is controlled with PI controller in order to maintain 1 per unit voltage at the load terminals. PI controller (Proportional Integral 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.

For the convenience of analysis and to avoid complicated mathematical expressions, a single-phase equivalent system is used to describe the three-phase system shown in Fig. If the function of the SC is solely for the purpose of harmonics compensation, the instantaneous power at the SC output will be of the form

$$V_{out}(t)=V_{L1}\sin(wt+\phi_{11}\alpha)-V_{s1}(t)+V_{sh}{}^{1}(t) \tag{7}$$

$$p(t)=V(t)I_{Load(t)}=\sum_{k=2}^{\infty}V_k\sin(k\omega t+\varphi_k)\sum_{k=2}^{\infty}I_k\sin(k\omega t+\varphi_k) \tag{8}$$

The average power is

$$P=\frac{1}{2}\sum_{k=2}^{\infty}V_kI_k\cos\varphi_k \tag{9}$$

Note that only power components associated with the harmonics are contained in *P*. *P* is either imported into or exported from the SC to the external system. The losses in the VSI would be low and can be ignored. Hence the energy exchange between the SC and the external power system is

$$E = \frac{T}{2}\sum_{k=2}^{\infty} V_k I_k \cos\varphi_k \qquad (10)$$

over the time interval *T*. The SC supplies energy to the external system when *E>0*. As the only significant source of energy storage in the SC is the ESS, the export of the energy to the external system will result in a decrease in the voltage V_{DC}. Hence V_{DC} has to be controlled within certain range. In order to achieve this, there must be control on the energy flow. This can be achieved by adjusting the phase of the fundamental component of the reference voltage of the SC. If a phase shift α is introduced to the reference voltage for, say phase "a" of (1), one obtains

$$V_L(t) = V_1 \sin(wt + \varphi_1 + \alpha) \qquad (11)$$

Since only the fundamental voltage component is involved in the phase shift, the second subscript "1" in (4) has been omitted in (11). Furthermore, notice that the intention is not to change the magnitude of the fundamental component of the load-side voltage V_L. Hence V_L has the same magnitude as without the phase shift. With an assumed constant impedance load model, *I1* will also remain constant following the phase shift. It then follows that the new injection voltage is

$$V_{inj}(t) = V_1 \sin(\omega t + \varphi_1 + \alpha) - V_1 \sin(\omega t + \varphi_1) - V_{Lh} \qquad (12)$$

Refer to above equations, the energy flow between the ESS and the external power system now becomes

$$E = \frac{T}{2}(V_1 I \cos(\phi_1 + \alpha) - \sum_{k=2}^{\infty} V_k I \cos\phi_k) \qquad (13)$$

From (13), it can be seen that *E* could be forced to be zero if α is selected to be α_0 where

$$\alpha_0 = ar\cos(\frac{1}{V_1 I_1}\sum_{k=2}^{\infty} V_k I_k \cos\phi_k) - \varphi_1 \qquad (14)$$

VI.SIMULATION RESULTS AND DISCUSSIONS

The example shown on Fig. 1 may now be used to verify the effectiveness of the SC in enhancing the voltage quality of the power system. The upstream generator is represented as a 220-V voltage source, with its AVR action ignored. The source impedance is assumed to be 0.05 p.u. and q=20. The main load converter is assumed to be a six-pulse controlled rectifier.

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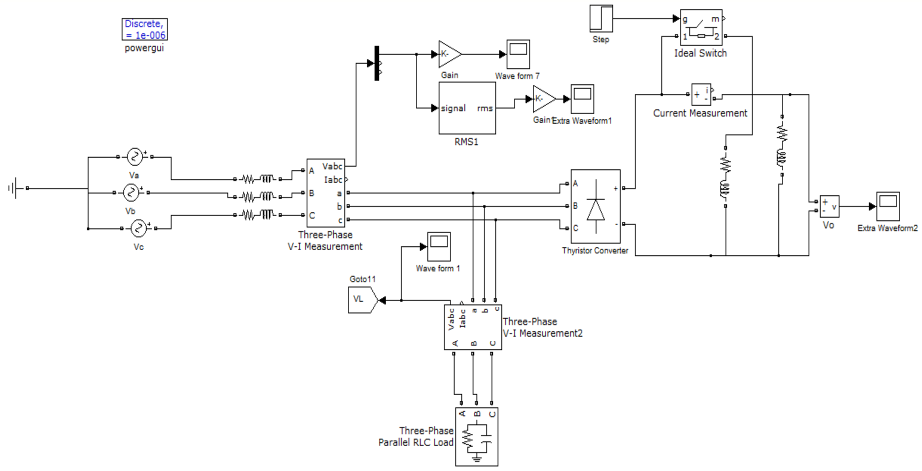

Fig 2: Isolated Power System without Series Compensator

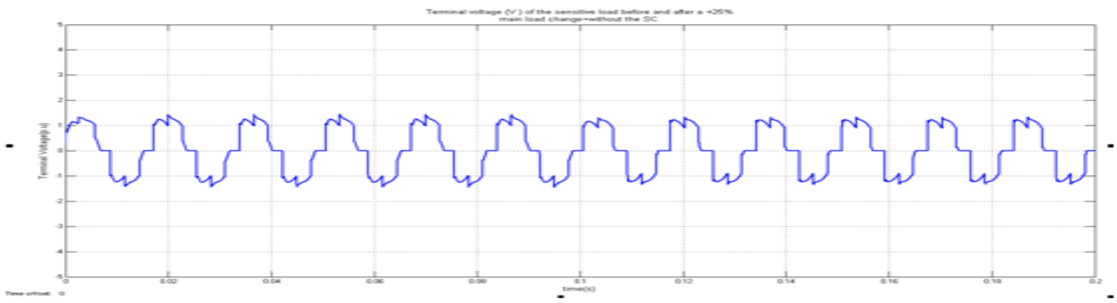

Fig 3: Terminal voltage (V) of the sensitive load before and after a 25% main load change: without SC

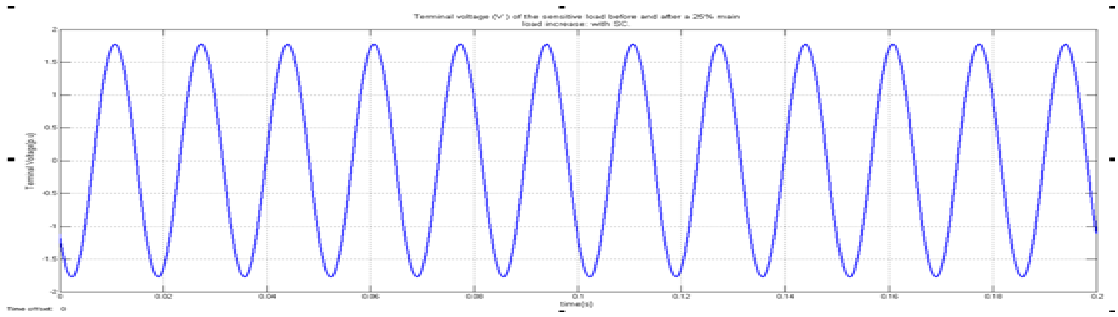

Fig 4: Terminal voltage (V) of the sensitive load before and after a 25% main load increase: with SC

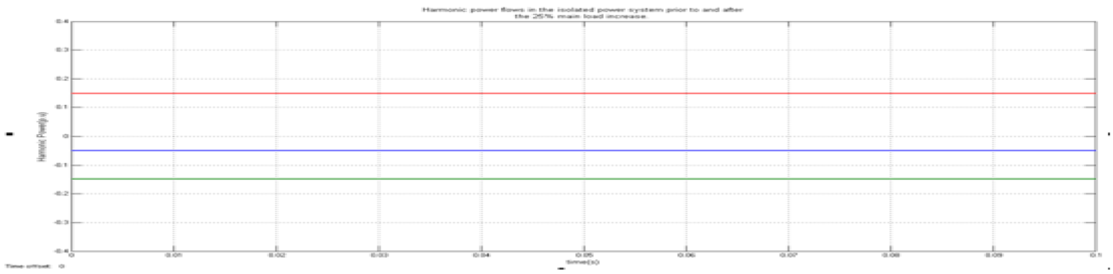

Fig.5. Harmonic power flows in the isolated p.s prior to and after the 25% main load increase.

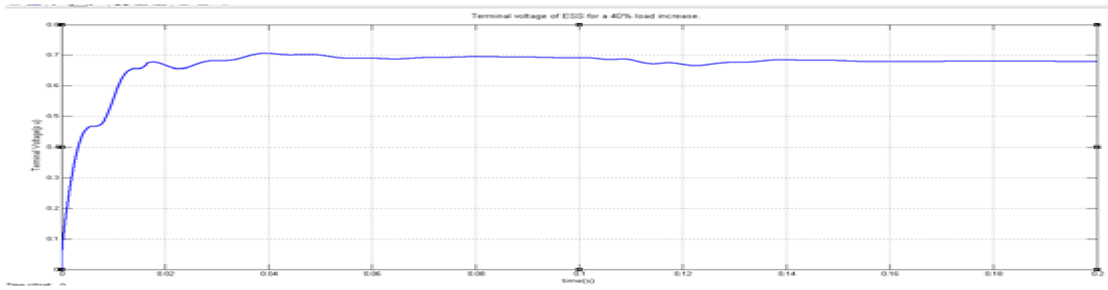

Fig: 6. Terminal voltage of ESS for a 40% load increase

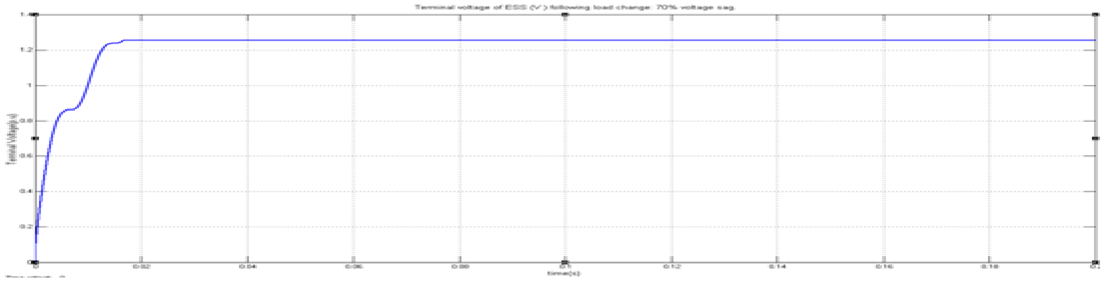

Fig: 7. Terminal voltage of ESS(v) following load change:70% voltage sag

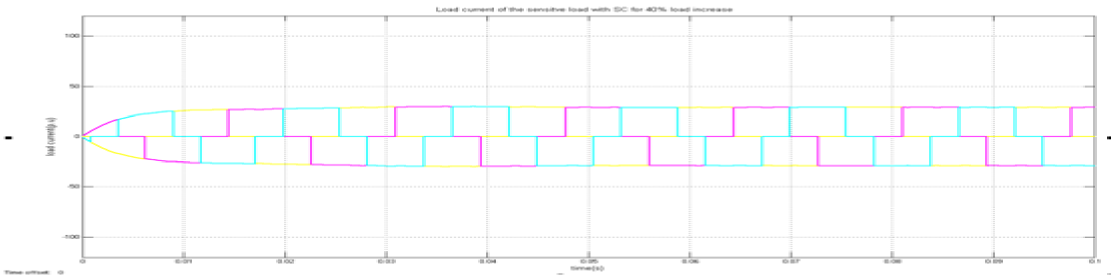

Fig 8.Load current of the sensitive load with sc for 40% load increase

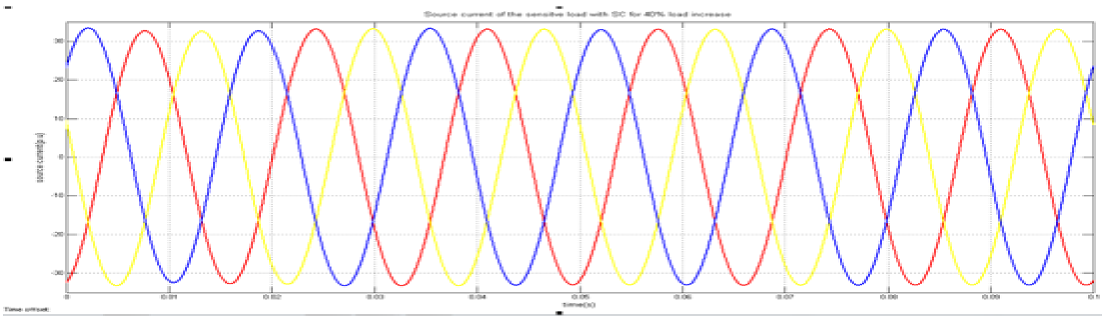

Fig 9.Source current of the sensitive load with sc for 40% load increase

VII.CONCLUSION

Voltage quality improvement in an isolated power system through series compensation has been investigated. The power system contains significant proportion of fluctuating nonlinear load and a high level of harmonic distortions is observed. 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. PWM technique is used to control the injection voltage of the SC so that it can mitigate the effects of the harmonics and voltage sag has been proposed. The proposed system performs better than the traditional methods in mitigating harmonics and voltage sags. The proposed SC can handle both balanced and unbalanced situations without any difficulties and would inject the appropriate voltage component to correct rapidly and anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value

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