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ENHANCEMENT OF VOLTAGE QUALITY IN ISOLATED POWER SYSTEM

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Abstract - *In rural and outlying areas of the world, isolated power system are most commonly in use. The power systems are often considered weak as they possess relatively low short-circuit ratio, as compared to a grid. Thus, network voltage control becomes challenging.*
A traditional method to achieve improved power quality (PQ) is to use passive filters which connected at the sensitive load terminals, but this method has some disadvantages:
o the effectiveness of the scheme could decrease as the source impedance or load condition changes
o it can also lead to resonance between the filter and the source impedance.
Thus, the use of series compensators (SCs) is preferred for improving the quality of voltage of isolated power systems. The role of the compensators are to reduce the effects of momentary voltage sags/swells, and to control the harmonic distortions level in the network. A control strategy for the series compensator is developed to regulate the flow of power. This is achieved by adjusting the phase of load terminal voltage. This control leads to an increase in the ride through capability of loads to the voltage sags/swells.
This control concept is thoroughly studied by using MATLAB/Simulink simulation.

Key Words: SC (series compensator), VSI (voltage source inverter), THD (total harmonic distortion), ESS (energy storage system), PQ (power quality), PWM (pulse width modulation), PI (proportional integral)

1. INTRODUCTION

The isolated power systems are most commonly found in the rural and outlying areas of the world. These systems represents a substitute to grid connection, where interconnection to a large grid is not possible due to high cost and geographical barriers. Furthermore, power systems such as those onboard of ships, in oil exploration areas and isolated mining districts are characterized by limited capacity of generation, supplying loads which can consist of remarkable amount of motor drives and power converters. The power systems are usually acknowledged as weak, as they possess relatively low short-circuit ratio, as compared with a grid. As a result network voltage control becomes a challenging work. The power-quality (PQ) problem is associated as the drive-converter loads are likely to fluctuate in addition with the mining or exploration activities. In addition to the drive load, one can also await the presence of capacity-sensitive loads of lower power, such as computers or any electronic controllers present in the power system. Series voltage compensation methods have been discussed for the minimization of short-duration voltages/swells but the presence of harmonic voltages/current in the networks has been ignored. This project intends to fill this gap. Specifically, the investigation is to develop a method to control the basic component of VL. The control is achieved by regulating the flow of power by adjusting the phase angle. Unlike the previous methods, the investigation also shows that the voltage-sag ride through capability of the sensitive load can be improved by carrying harmonic power from the external system into the SC.

Methodology of thesis

The objectives of the project are:

• Relevant literature is collected form the IEEE explorer, magazines and books .
• Problem recognized is "Quality of Voltage".
• Series compensator based on VSI is identified to Solve the above mentioned problem.
• Simulink model will be developed for the above concept results will be compared with the reference paper

2. THEORY OF HARMONICS

The general definition for a harmonic is "a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Some references refer to "clean" or "pure" power as those having no harmonics. But such clean waveforms typically only exist in a laboratory. When transformers are first energized, the current which is drawn is different from that of the steady state condition. This is caused by the inflow of the magnetizing current. The harmonics during this period varies over time. Some harmonics have zero value for part of the time, and before returning to zero increases for a while. An unbalanced transformer (where either the output current, winding impedance or input voltage on each leg are not equal) will cause harmonics, as will overvoltage saturation of a transformer.

What are harmonics filters?

Harmonic filters are used to eliminate the harmonic distortion caused by loads which are no linear in nature. Particularly, harmonic filters are designed to attenuate or in some filters remove the potentially dangerous effects of harmonic currents functioning inside the system of power distribution. Filters are constructed to trap these currents and, through the use of capacitors, coils, and resistors in series and shunt them to ground. Several of these elements may be contained in filters, each designed to compensate a significant frequency or an array of frequencies.

Types of Harmonic Filters involved in Harmonic Compensation

- Passive filters
- Active power filters
- Shunt active filters
- Series active filters

3. HARMONIC MITIGATION AND POWER FLOW

With respect to the present problem, it is assumed that there is balance between nonlinear converter and the sensitive loads. This follows, symbols with the subscript "S" which denote quantities that are correlated with the upstream source, "L" for those conjoined with the sensitive load, "D" with the downstream main converter drive and "C" with the series compensator. Subscript "h" represents the hth harmonic component and "1" that of the fundamental. The phasor of voltage and current are denoted with a symbol on the top of the corresponding quantities. Their magnitudes (r m s) are shown as capital letters while their peak values are denoted with "^" on top. Vectors are denoted by bold letters.

As displayed in Fig. 1. The central part of the SC (shunt compensation) is the voltage source inverter (VSI) and the energy storage system (ESS). In the VSI (voltage source

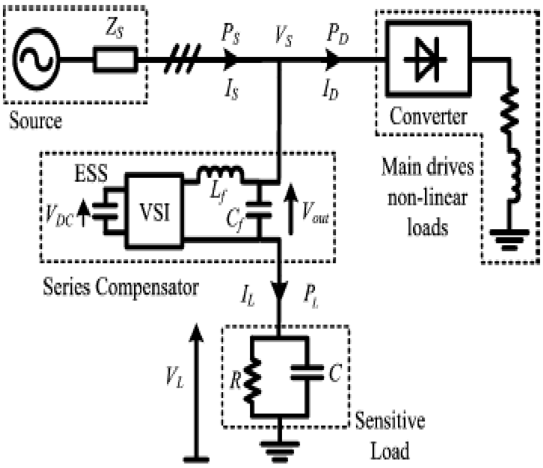

Fig 1: Typical Isolated Power System installed with an SC

inverter), PWM switching scheme is used frequently, which generates the harmonics and filtering is required. .Lf and Cf are the inductance and capacitance of the filter respectively. While the detailed function of the SC under voltage sag/swell suffice to state that the VSI integrates the required voltage quantity (Vout) which would be injected with VL in series.

The ESS would act as a buffer and provides the energy needed for load ride during a voltage-sag. Contrarily, during a voltage-swell, excess energy from the network would be stored in the ESS so that VL can be controlled.

4. CONTROL OF HARMONIC DISTORTIONS

On the upstream source-side of the sensitive load, distorted phase voltage Vs can be represented as displayed in fig(1) at the bottom of the page for phases a, b, and c where W0 is the fundamental frequency, n is the order of harmonics; Von is the zero phase sequence voltage component; and are the peak and phase of the positive phase sequence voltage component respectively; and are the peak and phase component of the negative phase sequence voltage respectively. When expressed in this manner, Vs would be completely general and would include network unbalances. Certainly, distorted voltage is undesirable at the sensitive load terminals. The fundamental components of the voltages contained in [1] are

$$V_S = \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} = \begin{bmatrix} \sum_{n=1}^{\infty}[V_{0n} + \hat{V}_{1n}\sin(n\omega_o t + \varphi_{1n}) + \hat{V}_{2n}\sin(n\omega_o t + \varphi_{2n})] \\ \sum_{n=1}^{\infty}[V_{0n} + \hat{V}_{1n}\sin(n\omega_o t + \varphi_{1n} - 2n\pi/3) \\ \qquad + \hat{V}_{2n}\sin(n\omega_o t + \varphi_{2n} + 2n\pi/3)] \\ \sum_{n=1}^{\infty}[V_{0n} + \hat{V}_{1n}\sin(n\omega_o t + \varphi_n + 2n\pi/3) \\ \qquad + \hat{V}_{2n}\sin(n\omega_o t + \varphi_{2n} - 2n\pi/3)] \end{bmatrix} \quad (1)$$

....(1)

$$\boldsymbol{V}_{S1} = \begin{bmatrix} V_{Sa1} \\ V_{Sb1} \\ V_{Sc1} \end{bmatrix} = \begin{bmatrix} \hat{V}_{11}\sin(\omega_o t + \varphi_{11}) \\ \hat{V}_{11}\sin(\omega_o t + \varphi_{11} - 2\pi/3) \\ \hat{V}_{11}\sin(\omega_o t + \varphi_{11} + 2\pi/3) \end{bmatrix}.$$

From (1) and (2), therefore

$$\boldsymbol{V}_S = \boldsymbol{V}_{S1} + \boldsymbol{V}_{Sh}$$

...(2)

...(3)

Where V_{sh} contains all the harmonic components in (1). The considered voltage injection method shown in [6] is to add voltage components in series with Vs and the desirable injected voltages would contain all the harmonic components in (1). Hence, from (1) and (2), the injected voltage from the SC would be

Vout= -Vsh =Vs1- Vs ... (4)

So far, it is only considered the condition that Vs consists of harmonic distortions. However, a voltage sag/swell may appear in Vs and therefore, Vs1 could differ from specified aggreable value. Assume the fundamental voltage components of desirable load side are

$$V_{L1} = \begin{bmatrix} V_{La1} \\ V_{Lb1} \\ V_{Lc1} \end{bmatrix} = \begin{bmatrix} \hat{V}_{L1} \sin(\omega_o t + \varphi_{11}) \\ \hat{V}_{L1} \sin(\omega_o t + \varphi_{11} - 2\pi/3) \\ \hat{V}_{L1} \sin(\omega_o t + \varphi_{11} + 2\pi/3) \end{bmatrix} \quad ...(5)$$

Vout =VL1-VS=VL1-VS-VSh ... (6)

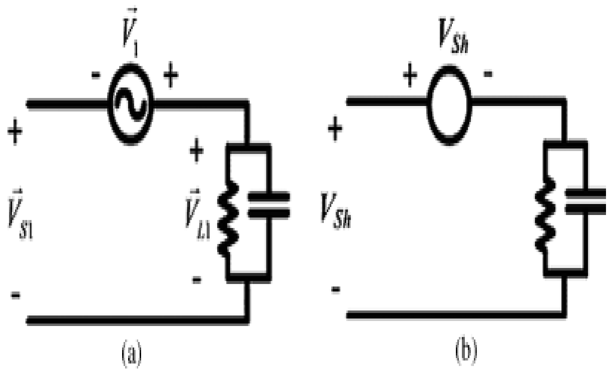

Fig 2: Equivalent Circuits of the Sensitive Load-SC branch for (a) Fundamental Component (b) hth Harmonic Component

$$\vec{V}_1 = \vec{V}_{L1} - \vec{V}_{S1}. \quad ...(7)$$

In such an ideal compensation situation, there will be no harmonic component in the sensitive load current IL and thus, no exchange of harmonic energy can exist between the SC and the external system. The exchange of energy is only due to the fundamental components of frequency of Vout and IL. In covenience, however, the SC has a finite bandwidth. Inescapably a phase lag exists between Vsh and the actual injected voltage from the SC. The lag results in voltage pulses arising at the terminals of the sensitive load. As the RC sensitive load impedance reduces with frequency, the voltage pulses will result in large harmonic current distortions to appear in IL . A practical method to limit the THD in IL to a pre-specified level has been advised in [6]. It involves a new strategy to control Vout and the use of a series filter. Essentially, Vout is obtained from IL, through a lead-lag feedback scheme while the series filter reduces high-frequency harmonics in IL. Hence, there will be harmonic current ILh in the circuit, as shown in Fig. 3(a).

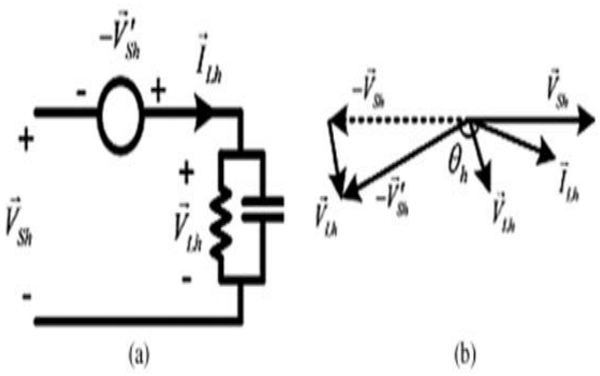

Fig 3: Sensitive Load SCBranch (a) Equivalent Load describimg Harmonic Compensation in practice (b)Phasor Diagram for the hth harmonic order

5. Power Flow Control Through SC

Having characterized the harmonic mitigation principle and noting that the flow of harmonic power would exist in the SC circuit, detailed study will be carried out next. For the availability of analysis and assuming negligible imbalances in the network, a single-phase equivalent system (phase "a") is used to describe the three-phase system displayed in Fig. 1. Let the fundamental component of frequency of the sensitive load current $\vec{I}_{L1}$ be taken as the reference phasor. Normally, the instantaneous SC output power is given by

$P_c(t)= V_{out}(t)\ I_l(t)$ ...(8)

6. VOLTAGE RESTORATION

Considering the flow of harmonic power in the isolated power system, voltage restoration will be tested next. As stated earlier, controlling the voltage of the ESS is necessary to ensure the proper operation of the SC and for the protection of the device. So it is desirable to regulate the transfer of power between the SC and the external system so that Vsh across the ESS of the SC can be maintained. Once this is attained, the SC will be able to exercise control of network voltage, in a manner described in [7] and [8]. The SC will consider this role of voltage control until such time when the excitation system of the upstream generator becomes effective in compelling the generator to share the voltage regulation duty. Though, if the slow-acting electromechanical type is chosen as the excitation system, the sensitive load would have to rely very much on the SC to achieve a constant VL . It is therefore necessary to examine the extent by which the SC can exercise such control. Moreover, in terms of voltage quality, it is the fundamental component VL . Hence in what follows, the focus is on retaining the magnitude of this voltage component , denoted as in Fig.

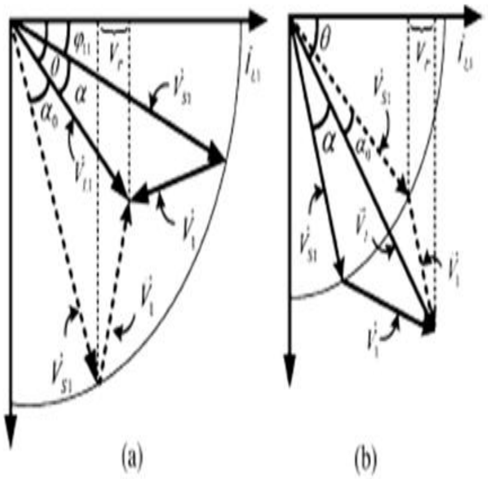

Fig 4: Phasor Diagram showing Voltage Restoration during (a) Voltage Swell (b) Voltage Sag : Fundamental Frequency Component

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7. CONCLUSIONS

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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