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Interline Power Quality Conditioner for Power Quality Improvement

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Abstract: ***Power quality is one of the major concerns in the present era. It has become important with the introduction of sophisticated devices, whose performance is very sensitive to quality of power supply. To solve this problem custom power devices are used. One of these devices is Interline Power Quality Conditioner (IUPQC), which is the most efficient and effective modern custom power device and addresses the problem of compensating a number of transmission lines at a given substation. This paper presents modeling, analysis and simulation of a Interline Power Quality Conditioner (IUPQC).***

Keywords: about four key words separated by commas

1. INTRODUCTION

Quality power supply is essential for proper operation of industrial processes which contain critical and sensitive loads. For Power Quality improvement, the developments of power electronics devices such as FACTS and Custom Power Devices have introduced an emerging branch of technology providing the power system with versatile new control capabilities. Like Flexible AC Transmission Systems (FACTS) for transmission systems, the new technology known as Custom Power pertains to the use of power electronics controllers in a distribution systems. Just as FACTS improves the power transfer capability and stability margins, custom power makes sure consumers get pre-specified quality and reliability of supply. Voltage sags and swells in the medium and low voltage grid are considered to be the most frequent type of Power Quality problems. Their impact on sensitive loads is severe. Different solutions have been developed to protect sensitive loads against such disturbances. Among these IUPQC is most effective device.

2. CUSTOM POWER TECHNOLOGY

As the power quality problems are originated from utility and customer side, the solutions should come from both and are named as utility based solutions and customer based solutions respectively. The best examples for those two types of solutions are FACTS devices (Flexible AC Transmission Systems) and Custom power devices. FACTS devices are those controlled by the utility, whereas the Custom power devices are operated, maintained and controlled by the customer itself and installed at the customer premises. Both the FACTS devices and Custom power devices are based on solid state power electronic components. As the new technologies emerged, the manufacturing cost and the reliability of those solid state devices are improved; hence the protection devices which incorporate such solid state devices can be purchased at a reasonable price with better performance than the other electrical or pneumatic devices available in the market. Some of these Custom Power Devices are: Series-connected compensator like DVR (Dynamic Voltage Restorer), Shunt-connected compensator like DSTATCOM (Distribution STATic COMpensator), Series and shunt compensator like UPQC (Unified Power Quality Conditioner) , IUPQC (Interline Unified Power Quality Conditioner) and SSTS (Solid State Transfer Switch). Among these, the IUPQC is an effective custom power solution which consists of two back to back connected IGBT based voltage sourced bidirectional converters with a common DC bus.

3. INTERLINE POWER QUALITY CONDITIONER (IUPQC)

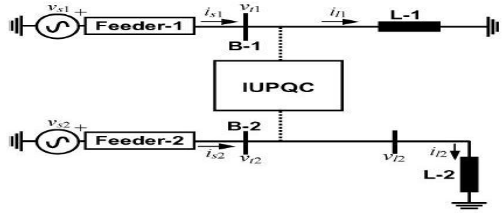

Figure 1 Single-line diagram of an IUPQC.

The single-line diagram of an IUPQC is shown in Fig.1. Two feeders, Feeder-1 and Feeder-2, which are connected to two different substations, supply the system loads L-1 and L-2. The supply voltages are denoted by V_{s1} and V_{s2}. It is assumed that the IUPQC is connected to two buses B-1 and B-2, the voltages of which are denoted by V_{t1} and V_{t2}, respectively. Further two feeder currents are denoted by i_{s1} and i_{s2} while the load currents are denoted by i_{l1} and i_{l2}. The load L-2 voltage is denoted by V_{l2}. The purpose of the IUPQC is to hold the voltages V_{t1} and V_{l2} constant against voltage sag/swell, temporary interruption and momentary interruption etc. in either of the two feeders. It has been demonstrated that the IUPQC can absorb power from one feeder (say Feeder-1) to hold V_{l2} constant in case of a sag in the voltage V_{s1}. This can be accomplished as the two VSCs are supplied by a common dc capacitor. But basically IUPQC is nothing but the device UPQC kept in between two individual feeders, (called feeder-1 and feeder-2). UPQC consists of two back to back connected IGBT based voltage source bi-directional converters or Voltage Source Converters (VSCs) (called VSC-1 and VSC-2) with a common DC bus. VSC-1 is connected in shunt with feeder-1 while VSC-2 is placed in series with the feeder-2.

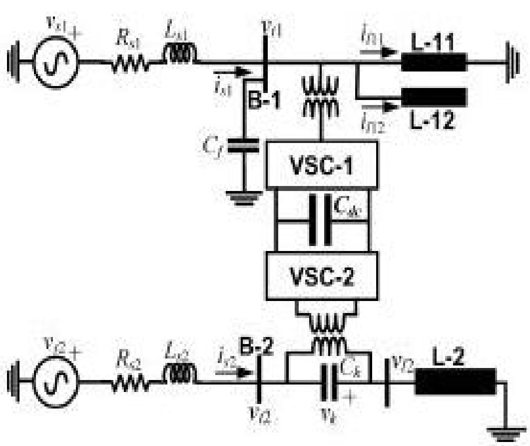

Figure 2 Typical IUPQC connected in a distribution system.

An IUPQC connected to a distribution system is shown in Fig.2. In this Figure, the feeder impedances are denoted by the pairs (R_{s1}, L_{s1}) and (R_{s2}, L_{s2}). It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by i_{l11} and i_{l12}, respectively. It is further assumed that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage.

3. CONTROL STRATEGY OF IUPQC

The aim of control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The important issues in the design of the control strategy are the generation of reference currents/voltages for compensation and the generation of the compensating current/voltage based on the reference currents/voltages.

3.1 Series Control

The series inverter, which is operated in current control mode, isolates the load from the supply by introducing a voltage source in between. This voltage source compensates supply voltage deviations such as sag and swell. The three phase reference voltages (V_{la}^*, V_{lb}^*, V_{lc}^*) are generated by subtracting the three phase load voltage (V_{la}, V_{lb}, V_{lc}) from three phase supply voltages (V_{sa}, V_{sb}, V_{sc}). In closed loop control scheme of the series inverter, the three phase load voltages (V_{la}, V_{lb}, V_{lc}) are subtracted from the three phase supply voltages (V_{sa}, V_{sb}, V_{sc}), and are also compared with reference supply voltage which results in three phase reference voltages (V_{la}^*, V_{lb}^*, V_{lc}^*). These reference voltages are to be injected in series with the load. By taking recourse to a suitable transformation, the three phase reference currents (i_{sea}^*, i_{seb}^*, i_{sec}^*) of the series inverter are obtained from the three phase reference voltages (V_{la}^*, V_{lb}^*, V_{lc}^*). These reference currents (i_{sea}^*, i_{seb}^*, i_{sec}^*) are fed to a PWM current controller along with the actual series currents (i_{sea}, i_{seb}, i_{sec}). The gating signals obtained from PWM current controller ensure that the series inverter meets the demand of voltage sag and swell, by injecting the compensating voltage in series with source voltage, thereby providing sinusoidal voltage to load. Thus series inverter plays an important role in increasing the reliability of quality of supply voltage at the load. The series inverter acts as a load to the common DC link (provided by a capacitor) between the two inverters. When sag occurs series inverter exhausts the energy of the DC link.

3.2 Shunt Control

Shunt control is used to inject compensating currents to eliminate harmonics at the load end and also charge the capacitor to the required value to drive the VSC. This involves generation of the required compensating currents.

There are two methods for finding compensating current. They are Direct Method and Indirect Method. The Direct Method is used in the present study. The output I_{sp} is considered as magnitude of three phase reference currents. Three phase unit current vectors (U_{sa}, U_{sb}, U_{sc}) are derived in phase with the three phase supply voltages (V_{sa}, V_{sb}, V_{sc}). These unit current vectors (U_{sa}, U_{sb}, U_{sc}) form the phases of three phase reference currents. Multiplication of magnitude i_{sp} with phases (U_{sa}, U_{sb}, U_{sc}) results in the three phase reference supply currents (i_{sa}^*, i_{sb}^*, i_{sc}^*). Subtraction of load currents (i_{la}^*, i_{lb}^*, i_{lc}^*) from the reference supply currents (i_{sa}^*, i_{sb}^*, i_{sc}^*) results in three phase reference currents (i_{sha}^*, i_{shb}^*, i_{shc}^*) for the shunt inverter. These reference currents I_{ref} (i_{sha}^*, i_{shb}^*, i_{shc}^*) are compared with actual shunt currents I_{act} (i_{sha}, i_{shb}, i_{shc}) and the error signals are then converted into (or processed to give) switching pulses using PWM technique which are further used to drive shunt inverter. In response to the PWM gating signals the shunt inverter supplies harmonic currents required by load. (In addition to this it also supplies the reactive power demand of the load). In effect, the shunt bi-directional converter that is connected through an inductor in parallel with the load terminals accomplishes three functions simultaneously. It injects reactive current to compensate current harmonics of the load. It provides reactive power for the load and thereby improves power factor of the system and also draws the fundamental current to compensate the power loss of the system and makes the voltage of DC capacitor constant. The control quantities have to be computed.

The amplitude of the supply voltage is computed from the three phase sensed voltages as

$$V_{sm} = \left[\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)\right]^{\frac{1}{2}}$$

The three phases per unit current vectors are computed as under:

$$U_{sa} = \frac{V_{sa}}{V_{sm}}$$
$$U_{sb} = \frac{V_{sb}}{V_{sm}}$$
$$U_{sc} = \frac{V_{sc}}{V_{sm}}$$

Multiplication of three phase per unit current vectors (U_{sa}, U_{sb}, U_{sc}) with the amplitude of the supply current (i_{sp}) results in the three-phase reference supply currents as

$$i_{sa}^* = i_{sp}.U_{sa}$$
$$i_{sb}^* = i_{sp}.U_{sb}$$
$$i_{sc}^* = i_{sp}.U_{sc}$$

To obtain reference currents, three phase load currents are subtracted from three phase reference supply currents:

$$i_{sha}^* = i_{sa}^* - i_{la}$$
$$i_{shb}^* = i_{sb}^* - i_{lb}$$
$$i_{shc}^* = i_{sc}^* - i_{lc}$$

These are the I_{ref} for shunt inverter. The I_{ref} are compared with I_{act} in PWM current controller to obtain the switching signals for the devices.

4. RESULTS

4.1 Mitigation of Momentary Sag of 0.07p.u. Using Series Voltage Control

A 3-phase supply voltage (11kv, 50Hz) with mometary sag of 0.2 pu magnitude with the duration about 20 to 30 cycles is taken. With the system operating in the steady state, a 20-30 cycle momentary sag of 0.2 pu magnitude is occurring at 8 msec for which the peak of the supply reduces from its nominal value of 11kv to 9kv. The Total Harmonic Distortion (THD) at load side is found to be 1.65%. The source voltage THD is effectively found to be 0.045%.

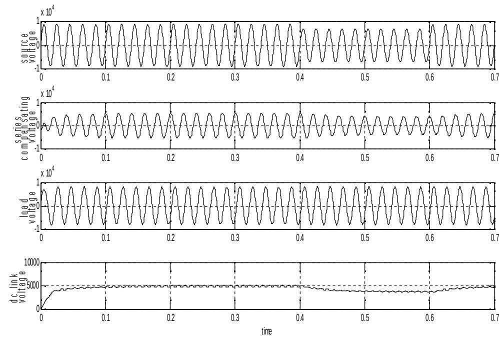

Figure 3 Mitigating the effect of momentary sag of 0.2 p.u. with duration 0.4sec. to 0.6 sec. using series voltage controller. ….. (3.8)

4.2 Compensating Load Current Harmonics Using Direct Current Control Technique for mitigating sag of 0.2 p.u.

In order to supply the balanced power required to the load, the DC capacitor voltage drops as soon as the sag occurs. As the sag is removed the capacitor voltage returns to the steady state.The Total Harmonic Distortion (THD) at load side is found to be 0.496%. The source current THD was effectively found to be 14.44% .

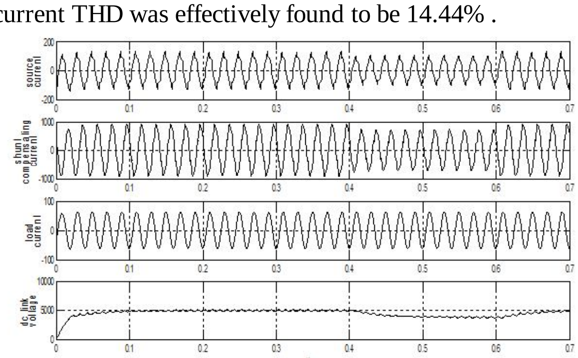

Figure 4 Mitigating the effect of momentary sag of 0.2 p.u. with duration 0.4 sec. to 0.6 sec. using direct current control technique with PI controller. ……. (3.11)

4.3 Mitigation of Momentary Swell of 0.3p.u. Using Series Voltage Control

A 3-phase supply voltage (11kv, 50Hz) with momentary swell of 0.3 pu magnitude with the duration about 20 to 30 cycles is taken. With the system operating in the steady state, a 20-30 cycle momentary swell of 0.3 pu magnitude is occurring at 8 msec for which the peak of the supply raises from its nominal value of 11kv to 14kv. The Total Harmonic Distortion (THD) at load side is found to be 1.71%. The source voltage THD is effectively found to be 0.045%.

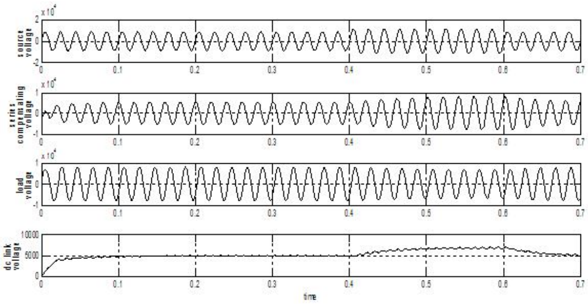

Figure 6 Simulation results – mitigating the effect of momentary swell of 0.3 pu with duration 20 to 30 cycles using series voltage controller.

4.4 Compensating Load Current Harmonics Using Direct Current Control Technique for mitigating swell of 0.3 p.u.

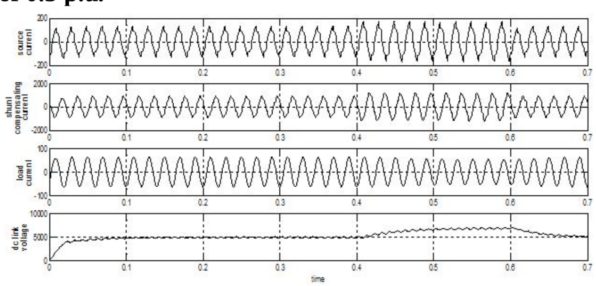

Figure6 Simulation results- mitigating the effect of momentary swell of 0.3 pu with duration 20 to 30 cycles using direct current control technique with PI controller.

The Total Harmonic Distortion (THD) at load side is found to be 0.567%. The source current THD was effectively found to be 14.60% .

Table 1: Total Harmonic Distortion

Cases	Type of interruption	TOTAL HARMONIC DISTORTION (THD) In %			
		VS	IS	VL	IL
Momentary	Sag, 0.4 sec. - 0.6 sec.	0.045	14.44	1.65	0.49
	Swell, 0.4sec. – 60sec.	0.045	14.60	1.70	0.56

5. Conclusion

The closed loop control schemes of Direct current control, series voltage converter for the proposed IUPQC have been described. A suitable mathematical model of the IUPQC has been developed with shunt (PI) controller and series voltage controller the simulated results have been described. The simulated results shows that PI controller of the shunt filter (current control mode), series filter (voltage control mode) compensates of all types of interruptions in the load current and source voltage, so as to maintain sinusoidal voltage and current at load side. For all the types of disturbances (interruptions) the Total Harmonic Distortion (THD) after compensation is to be less than 5% which is as per IEEE standards.

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