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Control Scheme for a UPQC With Integration of Series-and Shunt-Active Filters

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ABSTRACT
This paper deals with UPQC with integration of series-and shunt – active filters. The UPQC is one of the major custom power solutions capable of mitigating the effect supply voltage sags at the point of common coupling (PCC) or load. A UPQC employs a control method in which the series compensator injects a voltage that leads the supply current by 90^0. So that the series compensator at steady state consume no active power. However, the UPQC has some disadvantages. First, there is limitation in rating when using upqc for series compensation.
Second, there is a phase difference between the input and output voltage in proportion to the severity of voltage sags. As a result, it cannot offer effective compensation for voltage drops. This paper discusses the control strategy of the UPQC with a focus on the flow of instantaneous active and reactive power inside the UPQC. The validity of proposed control scheme has been investigated by simulation using matlab/simulink.

***Keywords* - voltage sag, reactive power, UPQC, power injection, voltage Capacity**

I. INTRODUCTION
With significant development of power electronics technology, the proliferation of nonlinear loads such as static power converters has deteriorated power quality in power transmission/distribution systems. Notably, voltage harmonics resulting from current harmonics produced by the nonlinear loads have become a serious problem in many countries to cause power quality decrease. The harmonic currents flowing through the source impedance of the utility supply can cause voltage distortion at the point of common coupling (PCC). This results in a malfunction of control, protection and system monitoring devices.
Loads that operate with a poor power factor show ineffective use of the volt-ampere rating of utility equipments.
To solve these problems, passive power filters have been widely used for a long time[1].although they are simple in structure they can cause unwanted resonance and amplify harmonic currents.
To overcome the disadvantage of passive power filter, research in active power filters has been carried out actively [2]-[5]. Active power filters can be classified as series or parallel according to their system configuration. The combination of series and parallel active power filter is called the unified power-quality compensator (UPQC). The UPQC employs a quadrature injection method which controls voltage sags and offers economical compensation.

The required energy for compensation can be reduced if the reactive power is used when injecting a voltage that has an phase difference with the source current. Therefore, this paper proposed the status of active series and shunt filter to the UPQC for power conditioning in industrial plants and distribution systems, and simulation results are carried out by using matlab/simulink. Moreover, in following sections theoretical analysis and control method are described.

II. UPQC

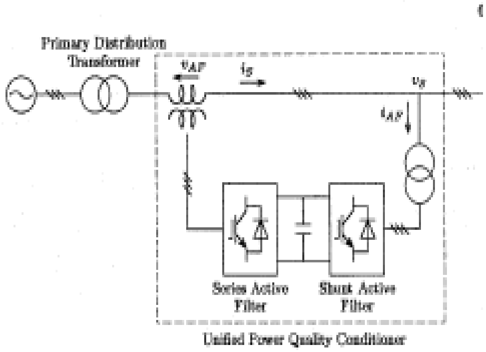

Fig.1. Integration of UPQC with series active and shunt active filter.

Fig. 1 shows the integration of a series active filter and a shunt active filter is referred to as “the unified power quality conditioner”,and is due to its similarity in power circuit configuration to the “upfc”, proposed by Gyugyi[6].
Fig.2. shows a simple configuration of the UPQC. The series compensator controls voltage sag by injecting V_{inj} which leads the source current by 90^0. The parallel compensator performs power factor correction through reactive power compensation, harmonic elimination, and DC link charging

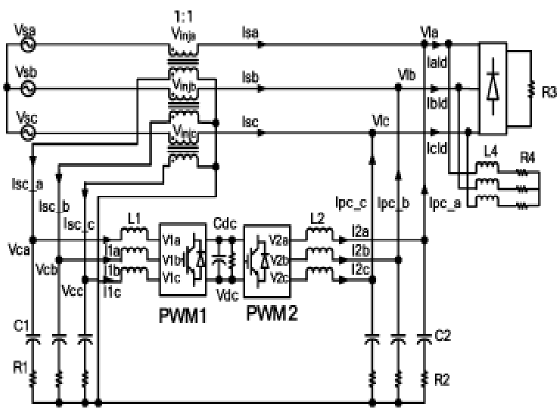

Fig.2. Configuration of the UPQC

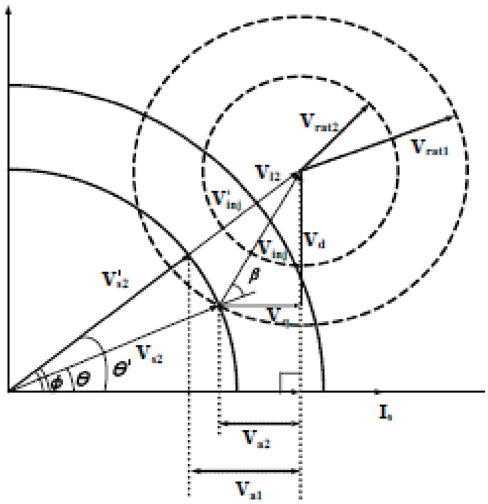

Fig.3. Voltage compensation of reactive power without parallel compensator

Fig.3. shows the energy saving of voltage compensation using reactive power without a parallel compensator. Each of the abbreviations refers to the following:

V_s : Source voltage phasor

V_{inj} : Injected voltage

V_l : Load side voltage phasor

V_{rat} : Voltage injection limit of series compensator

I_s : Load current phasor

V_{a1} : Active power component of in-phase injection voltage V_{inj}

V_{a2} : Active power component of V_{inj}, injected by a phase advance of β with respect to V_s

β : Phase advance angle of V_{inj}, with respect to V_s

θ : Phase angle difference between V_s and V_l without a parallel compensator

ϕ : Load power factor

The phasor diagram shows that voltage compensation is possible, when β increases, the needed active power decreases with minimum power. Active power $V_{a1}I_S$ is required when V_{inj} is injected in phase with load voltage V_{l2} If a voltage that leads the source voltage by β is injected, only $V_{a2}I_s$ which is smaller than $V_{a1}I_s$ is consumed. V_{s2} and $V_{s2}^{'}$ are source voltages according to the two cases. However, there is a phase difference between the input and output voltages, a transient state will occur when the source voltage decreases or returns to a normal value. The magnitude of the injected voltage must be larger than that used for in-phase injection.

Therefore, considering the limits of series compensator as shown in Fig.3, voltage compensation is possible V_{inj} which leads the source voltage by β with minimum energy consumption. In this case the problem of a phase difference between input and output voltage will be overcome because β is calculated, and the time to reach a calculated value can be controlled.

In Fig. 3 when β increases, θ decreases and the injected active power decreases. β Depends on the level of voltage sag and the limits of the series compensator, but the power factor θ can be controlled by a parallel compensator. Therefore, if the parallel compensator controls the power factor, the effective power can be reduced.

III. PHASOR DIAGRAM

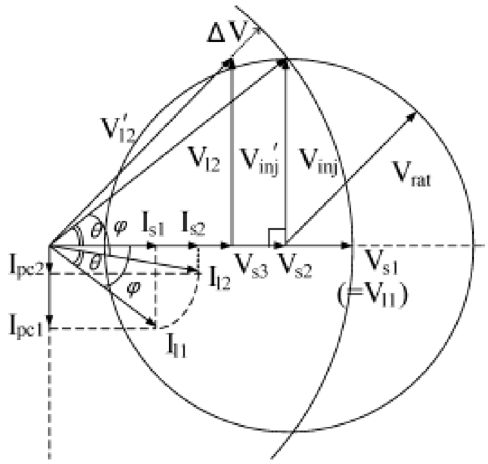

Fig.4. Phasor diagram of UPQC

Fig.4. is a phasor diagram showing the UPQC performance. When the source voltage is the rated voltage V_{s1}, load voltage V_{l1} equals to V_{s1} the load current I_{ll} flows with power factor θ with respect to the output voltage V_{l1} . This current is supplied by the parallel compensator current I_{c1} and source current I_{s1}.

When voltage sag occurs, V_{s1} becomes V_{s2} and V_{inj} injected from the series compensator compensates output voltage which has the same amplitude as V_{s1} . At this moment V_{l1}, the load voltage before the voltage sag, has a phase difference of θ with V_{L2}, the load voltage after compensation. The load current I_{l2} is also supplied by the parallel compensator current I_{c2}, and source current I_{s2}.Voltage compensation is possible with minimum energy.

IV. VA REQUIREMENT OF UPQC

From the phasor diagram of Fig. 4, it can be found that for each phase of fundamental power frequency [7].

$$V_{l1} = V_{l2} = V_{s1} = \text{constant.} \quad (1)$$

If load current are assumed $I_l = I_{l1} = I_{l2}$ =constant, with fundamental power factor equal to $\cos\phi$, active power demand in the load remains the same

$$V_{s1} I_{s1} = V_{l1} I_{l1} \cos\phi = \text{constant} \quad (2)$$

In the case of sag, when $V_{s2} < V_{s1}$, if x denotes the rate of sag ($0 \le x \le 1$), then

$$V_{s2} = (1-x) V_{s1} \quad (3)$$

Now, to maintain constant active power

$$V_{s1} I_{s1} = V_{s2} I_{s2} \quad (4)$$

$$I_{s2} = \frac{I_l \cos\phi}{1-x} \quad (5)$$

As the injected voltage is produced in the quadrature with the supply, the resulting load voltage V_{l2} makes the angle θ with the supply V_{s2}.

$$V_{inj} = \sqrt{V_{s1}^2 - V_{s2}^2} \quad (6)$$

$$\frac{V_{inj}}{V_{s2}} = \tan\theta, V_{inj} = V_{s2} \tan\theta, V_{inj} = (1-x) V_{s1} \tan\theta \quad (7)$$

The series VA rating is given by

$$V_{inj} I_{s2} = V_{s1} I_l \cos\phi \tan\theta \quad (8)$$

The parallel compensator current rating is

$$I_{pc} = \frac{\sqrt{((1-x)^2 + \cos^2\phi - 2\cos\phi\cos(\phi-\theta)(1-x)}}{(1-x)} I_{l2} \quad (9)$$

The parallel VA rating is given by

$$V_{l2} I_{pc} = \frac{\sqrt{((1-x)^2 + \cos^2\phi - 2\cos\phi\cos(\phi-\theta)(1-x)}}{(1-x)} V_{l2} I_{l2} \quad (10)$$

V. PROPOSED METHOD

Compensation with active power and minimum power injection

As shown in Fig.4, when compensation of voltage sag is not possible using only reactive power, when voltage sag occurs, V_{s1}, becomes V_{s2}, and V_{inj} injected from the series compensator voltage rating V_{rat} and voltage sag V_{s2} determine whether the active power will be used or not. Sags of all ranges can be compensated for using only reactive power. In this case, $\beta = 90^0$, injected voltage from the series compensator V_{inj} is

$$V_{inj} = \sqrt{V_{l2}^2 - V_{s2}^2} \quad (11)$$

If $V_{rat} < \sqrt{V_{l2}^2 - V_{s2}^2}$, the level of voltage sags V_{s2} must be consider.

$$V_{inj} = V_{rat} \quad (12)$$

$$\beta = \pi - \cos^{-1}((V_{s2}^2 + V_{inj}^2 - V_l^2) / 2V_{s2} V_{inj}) \quad (13)$$

$$V_{inj} = \sqrt{V_{l2}^2 + V_{s2}^2 - 2V_{l2} V_{s2} \cos\theta} \quad (14)$$

The active and reactive power of the series compensator is as follows:

$$P = V_{inj} I_{s2} \cos\beta \quad (15)$$

$$Q = V_{inj} I_{s2} \sin\beta \quad (16)$$

The series compensator is able to compensate with minimum active power and maximum reactive power [7],[8].

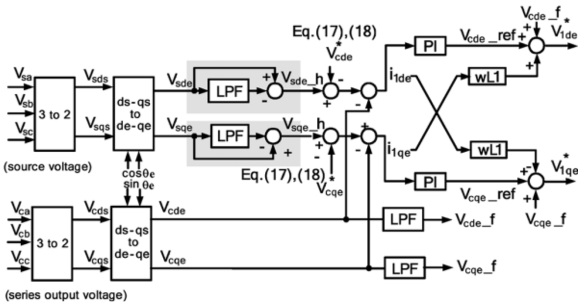

Fig.5. Synchronous reference frame controller for a series active compensator.

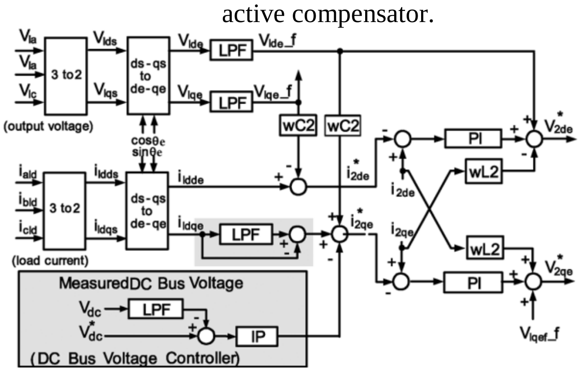

Fig.6. Synchronous reference frame controller for a parallel active compensator.

Fig.5 and 6 show the control block diagram of the series compensator and parallel compensator in synchronous reference frame. Series compensator is the implemented voltage control scheme that receives three phase input and output voltage and supplies reference [6][7].

Three phase input voltage is transformed to a stationary reference frame, and to the synchronous reference frame, which is through HPF (1-LPF). Harmonics are separated, and a reference for harmonics compensation is provided. Through PI control of reference of compensation of input voltage harmonics and EQ (17,(18)) controlling portion of reactive and active power and feedback of output voltage, reference of series compensator is provided.

$$V_c^* d^e = V_{rat} \sin\beta \quad (17)$$

$$V_c^* q^e = V_{rat} \cos\beta \quad (18)$$

$$V_{inj}^2 = (V_c^* d^e)^2 + (V_c^* q^e)^2 \quad (19)$$

$$\beta = \arctan(V_c^* d^e / V_c^* q^e) \quad (20)$$

Cut-off frequency of source voltage and output voltage of serial converter are 5Hz, and 100Hz, respectively. PI gains are 1, 150. Parallel compensators are implemented using a current control scheme that receives load voltage, current and supply reference The load current is transformed to the stationary reference frame, the synchronous reference frame, which is through the HPF (1-LPF). Harmonics are separated, and a reference for harmonics compensation is provided.
Cut-off frequency of load voltage and current are 100Hz, and 100Hz, respectively. PI gains are 1.23, 150. Additionally, through the feed-forward term of *wL2* and *wC2*, decoupling between d axis and q axis is possible. The IP controller for DC voltage control is used.
Fig. 7 shows the flow chart of series compensator control

VI. SIMULATION RESULTS

The proposed algorithms were studied by simulation tools ACSL (Advanced Continuous Simulation Language).
System parameters are shown in Table. 1. and Fig 8 shows the simulink model of system implementation

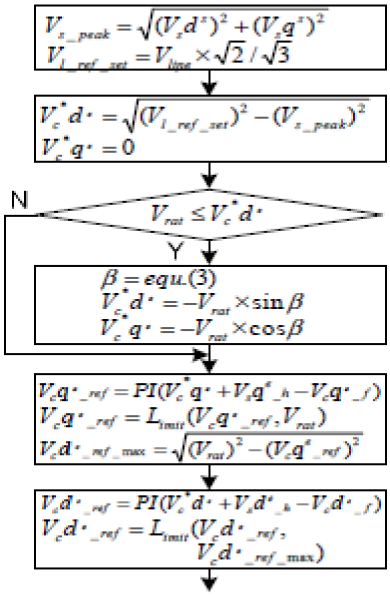

Fig.7. Flow chart of series compensator control

Table.1. SYSTEM PARAMETERS

Parameters	Value
Source Voltage(V_{sa}, V_{sb}, V_{sc})	**220[V],60[HZ]**
Line Impedance (L_s)	**0[μH]**
DC-link Capacitor(C_{dc})	**6800[μF)**
DC-link Voltage(V_{dc})	**400[V]**
L_1	**0.35[mH]**
L_2	**1.3[Mh]**
R_3	**25[Ω]**
R_4, R_5	**10[Ω],5mH**
C_1, R_1	**50[μF],1[Ω]**
C_2, R_2	**50[μF],1[Ω]**

Figure .8 shows the simulation diagram of the implemented system.

From Fig10 to Fig 11. Show the simulation results of the UPQC In the simulation, is the input voltage, is the input current, is the output voltage, and is the active power and reactive power of the series compensator.

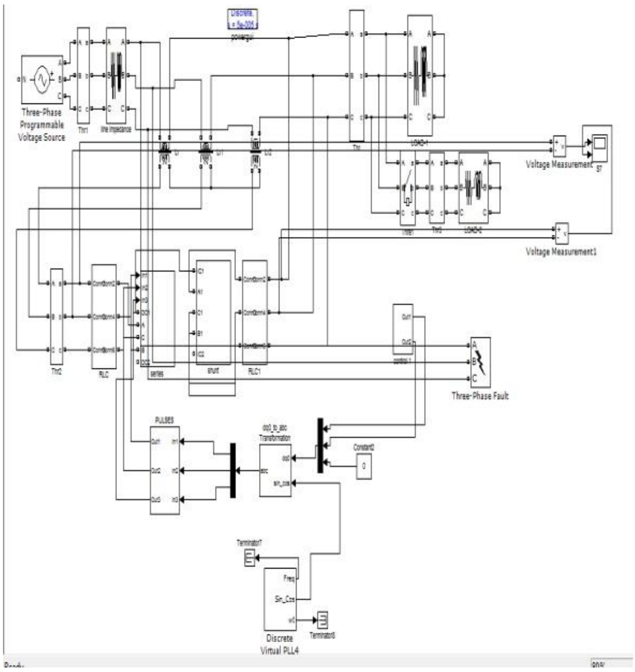

Fig.8. Diagram of test system with UPQC

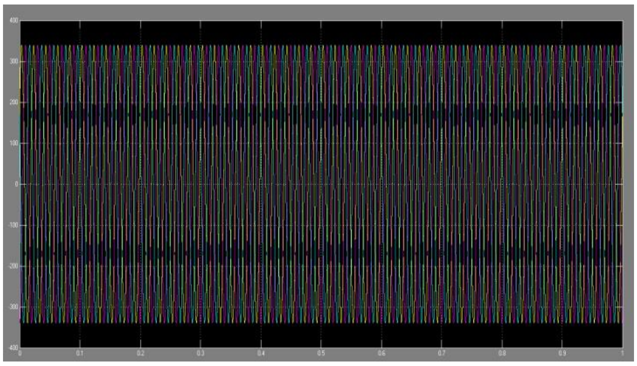

Fig.9. Output load voltage fully compensated

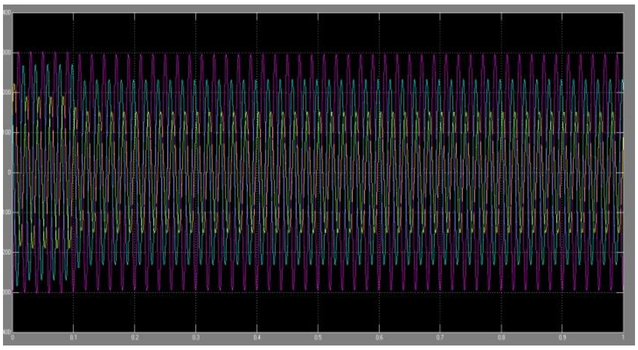

Fig.10. Source Voltage with fault

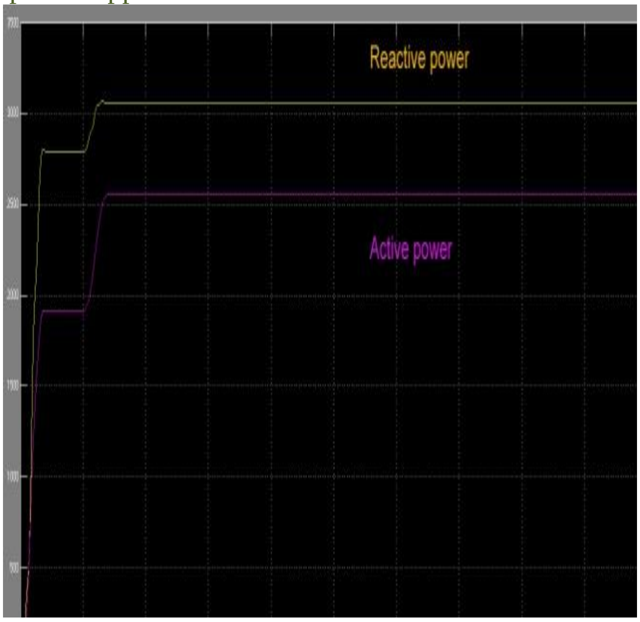

Fig.11.Reactive and Active power

Despite voltage sags, the output voltage is controlled to have constant magnitude. This is because the injected voltage from the series compensator is adequate to maintain the output voltage, and the transient state of the output voltage exists because of the phase difference of the input and output voltage.

VII. CONCULTION

This paper discussed the control methods for a UPQC The conventional UPQC-Q cannot compensate for the voltage sag effectively with limitations on the rating of the series compensator and a phase difference between the input and the output voltage. When there are limitations on the rating and a phase difference, the proposed control scheme can compensate for the voltage sag effectively and economically by using minimum active power. The control algorithm and mathematical models were proposed, and then simulation is done. Further we can replace RL load with ac induction motor and simulation can be done .

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