Power Quality Compensating System Using Series Active Power Filter

Hyoung-Nam Kwon, Jae-Sok Gho, Gyu-Ha Choe, Hong-Sung Kim*, Suk-Woo Han**
Dept. of E.E. Konkuk Univ., LG Industrial Systems Co.*, Dept. of E.E. Kyung-Moon College**
E-mail : hnkwon@konkuk.ac.kr

ABSTRACT - Voltage harmonics resulting from current harmonics produced by the nonlinear loads have become a serious problem in many systems. Moreover momentary interruptions and voltage sags are responsible for many of the power quality problems found in typical industrial plants. In this paper, proposed power system using series active power filter is not only harmonic compensation but also harmonic isolation between supply and load, and voltage regulation and unbalance compensation. The effectiveness of the proposed system is verified through computer simulations and experiments

1. Introduction

As a demand in the electric power increases and becomes various, the consumers are asking for more stabilized high quality of electric power. The power supply troubles occurring on the power suppliers side are largely divided as a problems with the power failure or momentary voltage fluctuation by the power suppliers defect or malfunctioning, and the harmonic problem caused as many of the nonlinear loads become connected to the power source system. The momentary source voltage fluctuations such as the voltage increase or voltage decrease on power suppliers side exists as one of the constant power source problem. Owing to the continuous tendency to increase in the usage of semiconductor power converter-like nonlinear loads as the harmonic current source, it can be viewed that a harmonic current problem, too, is one of the power source trouble continuing to provoke on the power source side [1-2].

Traditionally, the UPS for the voltage error appearance as its compensator about the above power source side problems and for the harmonic current, the passive or active current filters were used therein.

Although the UPS can be used as a unified solution including the power failure as well as other various troubles occurring upon the power source, in viewing from the power source side, it is applied as the nonlinear loads causing the harmonic and as though the passive or active power filter works in compensating the harmonic, it cannot be a solution for the voltage fluctuation of power source side.

For this paper, the problem said above is solved. Accomplished the effective management of energy and generated high quality of electric power in on the power suppliers side, Power Quality Compensating System Using Series Active Power Filter is composed. The proposed compensation system is copied with a harmonic current compensation generated nonlinear load and power source variation of abnormal power source. The 3-phase hybrid series active power filter system is made up of the combination construction of a parallel passive filter, series active power filter. As through the simulation and experiment, one is demonstrated that the suggested validity of the compensation system.

2. System Configuration

2.1 *System Configuration and Principles of Compensator*

The Fig. 1 shows the configuration of the proposed voltage compensation system. The system is divided into the passive and active form of which the space vector modulation method is used by the IGBT-built within voltage source inverter with a passive filter, the high pass filter connected parallel to the system, and the active power filter connected in series. DC terminal of compensation system is connected the diode rectifier. A System parameters is Table 1

The converter actively compensates the harmonic current generated a nonlinear load, the variation of source voltage that caused the matter of source voltage. In order to combine the compensating output voltage with the power system, it combines in series with the source impedance through three voltage injection transformers.

By preventing a harmonic current, the active power filter sustains the load terminals voltage regularly while

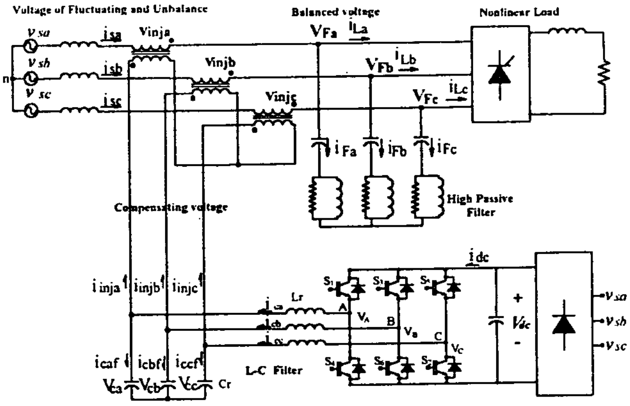


Fig. 1 Configuration of compensator.

compensating an insulation with the system and the source voltage deviation, and the passive filter runs in that low impedance circuit to absorption the load harmonic current. In following, the harmonic current compensation and the source voltage fluctuation is simultaneously compensated which increases the utilization factor of the compensator.

In case of there having no source voltage fluctuation, the converter changes to zero in impedance from the fundamental wave frequency, and it would obtain a pure resistance value from the load harmonic frequency. A Fig. 2 represents compensation principles of compensator. The compensator operates as a blocking resistance of the harmonic current, and when it takes the infinity resistance value, obtains an idealistic compensating characteristic. The compensating voltage deviation and harmonic current compensation, the compensating voltage, v_{inj}, is produces as (3) by using (1) and (2).

$$i_{sh} = i_s - i_{s1} \tag{1}$$

$$\Delta v = v_F^* - v_s \tag{2}$$

$$v_{inj} = \Delta v - k(i_s - i_{s1}) \tag{3}$$

where :

i_{sh} : harmonic element of power source current
i_s : power source current
i_{sl} : fundamental element of power source current
Δv: source voltage deviation
v_s : source voltage
v_F^*: load terminal reference voltage
v_{inj} : compensation or injection voltage
k : gain of compensator

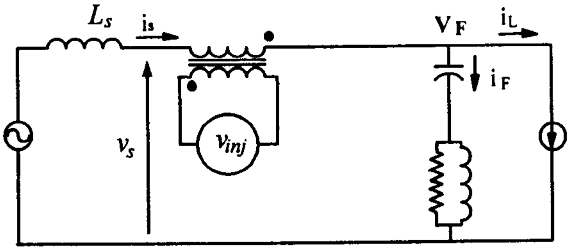


Fig. 2. Operation principles of compensator.

2.2 *Control Algorithm*

The control algorithm controls by separating the harmonic current and voltage deviation while the harmonic detection uses the p-q coordinates transforming. First in α−β coordinates transforming the phase voltage and current, is produced

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos 0 & \cos\left(-\frac{2\pi}{3}\right) & \cos\left(\frac{2\pi}{3}\right) \\ \sin 0 & \sin\left(-\frac{2\pi}{3}\right) & \sin\left(\frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \tag{4}$$

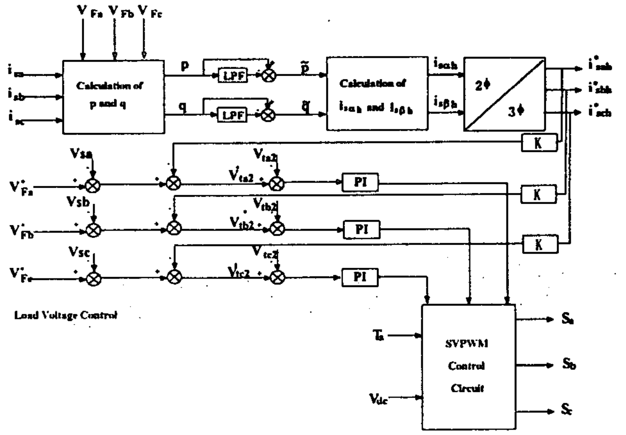


Fig. 3. Control block diagram.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos 0 & \cos\left(-\frac{2\pi}{3}\right) & \cos\left(\frac{2\pi}{3}\right) \\ \sin 0 & \sin\left(-\frac{2\pi}{3}\right) & \sin\left(\frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} \tag{5}$$

Here, v_{an}, v_{bn}, v_{cn} are the phase voltages detected from a load terminal, and i_{sa}, i_{sb}, i_{sc} are the source current. In illustrating p-q transformation as in equation (6) about p and q of Fig 3, can be shown.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \bar{p} \\ \bar{q} \end{bmatrix} + \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \tag{6}$$

Here, $\bar{p},\bar{q}$ as the DC component multiply fundamental voltage by fundamental current, and $\tilde{p},\tilde{q}$ are the AC component of the p, q. A p of the instantaneous active power and a q of the instantaneous reactive power may be expressed as in (7) through having a p_h and, q_h, the harmonic components, to be passed through their each high pass filter, and the harmonic component of source current, i_{sh} is shown as (8).

$$\begin{bmatrix} p_h \\ q_h \end{bmatrix} = G_{HPF}(j\omega) \begin{bmatrix} p \\ q \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} i_{s\alpha h} \\ i_{s\beta h} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_h \\ q_h \end{bmatrix} \tag{8}$$

As indicated above, the compensating voltage, v_{hc}^* of the harmonic current is produced as (9) [2].

$$v_{hc}^* = k\ i_{sh} \tag{9}$$

If the nonlinear load is connected to the system, instantaneous voltage fluctuation of the power source and the unbalanced voltage affects the function and the capacity of various systems connected to a power system originating that low harmonic frequency of non-characteristics. Thus the compensating voltage Δv_c, following after a source voltage fluctuation, is produced in between the loads reference voltage, v_F^* and source voltage, v_s^* as (10).

$$\Delta v_c = \dot{v}_F - v_s \qquad (10)$$

The Eq.(11) shows the value of subtracting the compensation voltage about harmonic current from the deviation of source voltage, the v_{inj}^*, which should be injected finally into the injection transformer, and it is injected to be added on the system voltage through the injection transformer.

$$\dot{v}_{inj} = \Delta v_c - \dot{v}_{hc} \qquad (11)$$

In illustrating v_{inj}^* as a matrix, is earned as (12).

$$\begin{bmatrix} \dot{v}_{inja} \\ \dot{v}_{injb} \\ \dot{v}_{injc} \end{bmatrix} = \begin{bmatrix} \dot{v}_{Fan} & - & v_{san} \\ \dot{v}_{Fbn} & - & v_{sbn} \\ \dot{v}_{Fcn} & - & v_{scn} \end{bmatrix} - k \begin{bmatrix} \dot{i}_{sah} \\ \dot{i}_{sbh} \\ \dot{i}_{sch} \end{bmatrix} \qquad (12)$$

Here, i_{sah}, i_{sbh}, i_{sch} are expressed as (13).

$$\begin{bmatrix} \dot{i}_{sah} \\ \dot{i}_{sbh} \\ \dot{i}_{sch} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \dot{i}_{s\alpha h} \\ \dot{i}_{s\beta h} \end{bmatrix} \qquad (13)$$

2.3 *The phase angle information*

he phase angle information is needed for generating the reference voltage in order to compensate the source voltages deviation. When the phase angle information is distorted, it creates a problem where the volume of the compensation system increases.

Because the 2nd order harmonic element exists at the negative-phase sequence component when the sources phase angle is detected, it holds a fault of being slow in responding specificity while detecting the phase angle information of the same period as the positive-phase sequence component in using 120[Hz] band pass filter. In addition, when the 3-phase source becomes unbalanced, there comes a problem of distorting the phase angle information as in case of using the d-q voltage variable to derive the phase angle information after the 3-phase voltage transforms into the stationary frame. In this paper, one uses a method of detecting the phase angle of the synchronized as an actual positive-phase sequence component through applying the method of symmetrical coordinates claimed in 1918 by C. L. Fortescue in the United States of America in order to resolve the indicated problems.

Therefore, only according to the positive-phase sequence component, the stationary frame d-q component is as the (14), and the phase angle of synchronized positive-phase sequence component can be shown as the (15).

$$E_{qp}^s = \frac{\left(2E_{pa} - E_{pb} - E_{pc}\right)}{3} \qquad (14a)$$

$$E_{dp}^s = \frac{E\left(E_{pc} - E_{pb}\right)}{\sqrt{3}} \qquad (14b)$$

$$\theta = \tan^{-1}\left(\frac{-E_{dp}^s}{E_{qp}^s}\right) \qquad (15)$$

As the method suggested before, the Fig 4 (a) is an a-phase source voltage with an occurrence of voltage drop, (b) is the a-phase source voltages of positive-phase sequence component. (c) is a phase angle information synchronized by the (b) thereof. (d) is a reference voltage that must be sustained in load terminal of a-phase as it was produced by using the phase angle information.

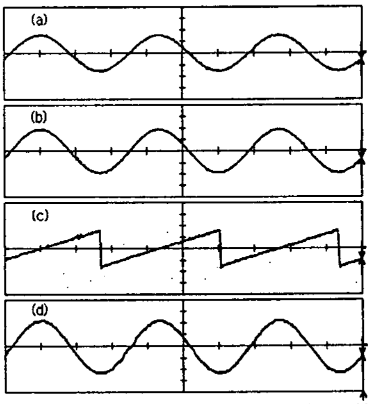


Fig. 4. Phase angle detection. (a) a-phase source voltage (56[%] [80V/div 5ms/div]) (b) positive sequence for a-phase source voltage ([80V/div 5ms/div]) (c) phase angle ([5ms/div]) (d) reference voltage for a-phase load terminal voltage (100[%] [80V/div 5ms/div])

3. SIMULATION AND EXPERIMENTAL RESULT

The proposed compensating system, by using the PSIM as a parameter in table 1, proved its validity, and as for the load, the R-L load is connected to 6-pulses thyrister rectifier.

Table 1. System parameters.

Items	Values
high pass filter	R=3[Ω] L=260[μH] C=300[μF]
Power source	3ϕ 220[V] 60[Hz]
Output filter	L=760[uH] C=2[uF]
Load	5[kVA]
Switching frequency	10[kHz]

The Fig.5 studies the specificity of firing angle 60° as the source voltage of 3-phase balanced. As in Fig. 6, the harmonic current is eliminated over 10 order as through the high pass filter installation, and on the 5th and 7th, it had resulted in greatly existent simulation outcome.

As for the load, R-L is connected to the 6-pulses thyrister rectifier. One study the character of source voltage, current, load voltage. As for the detection circuit, one detected the source voltage, source current, individual detection of an injection transformer secondary voltage, and the DC terminal voltage. Executing a simulation with having the source voltage unbalanced of 56, 78, 89[%] after the percentage unbalance rated of 25[%], the Fig.7,8 show the system character while operating the unbalanced 3-phase source voltage in 50-70[ms]. During the source trouble, one can observe that the source current can be the sinusoidal wave. The load voltage sustains regularly through from the unbalanced 3-phase voltage as well. At this point, the current THD is driven under 3[%]. As the Fig. 9 accounting for largely in the source trouble, one can observe that the source current can be the sinusoidal wave as well by having the loads voltage sustained regularly though from the 1-phase fault. A malfunction causing the unbalanced 3-phase drive occurs in 50-100[ms] during the balanced 3-phase voltage drive. At this point, the current THD, too, is driven under 3[%] and the source current FFT wave appearance is shown as the Fig. 10.

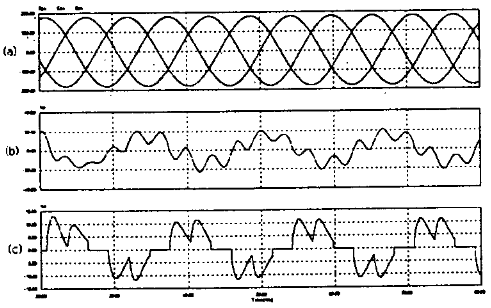


Fig. 5. simulation result for a phase controlled 3-phase bridge rectifier with high pass filter (voltage : 100[%], 3-phase balanced, α =60°). (a) source voltage (b) a-phase source current (c) a-phase load current

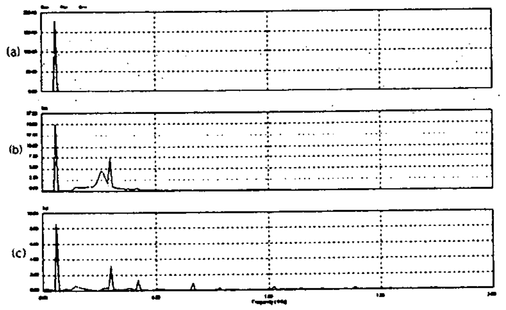


Fig. 6 FFT result of Fig. 5.
(a) source voltage (b) a-phase source current (c) a-phase load current

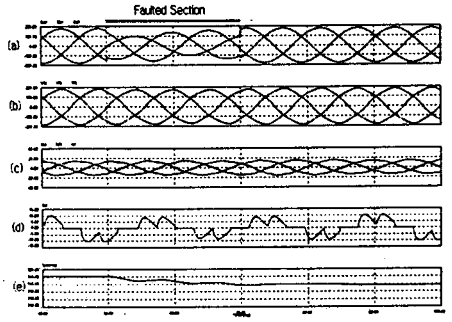


Fig. 7. Simulation result for a phase controlled 3-phase bridge rectifier with proposed compensator (voltage of faulted section : 56, 78, 89[%], 3-phase fault, α =60°). (a) source voltage (b) load voltage (c) source current (d) a-phase load current (e) DC link voltage

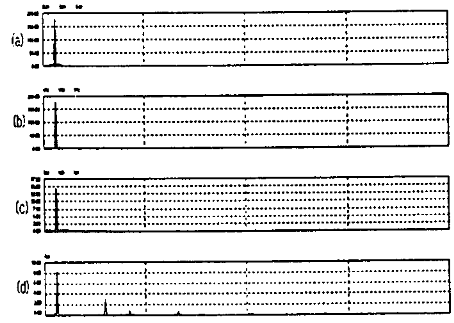


Fig. 8. FFT result of Fig. 7. (a) source voltage (b) load voltage (c) a-phase source current (d) a-phase load current

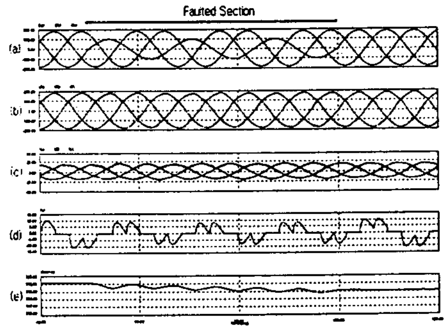


Fig. 9. Simulation result for a phase controlled 3-phase bridge rectifier with proposed compensator (voltage of faulted section : 56, 100, 100[%], 1-phase fault, α =60°). (a) source voltage (b) load voltage (c) source current (d) a-phase load current (e) DC link voltage

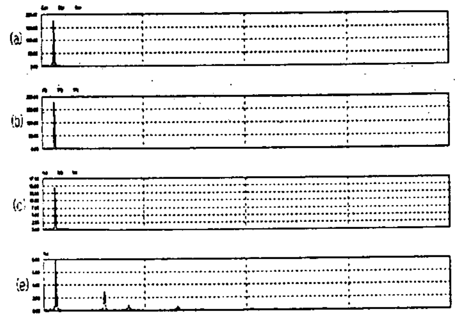
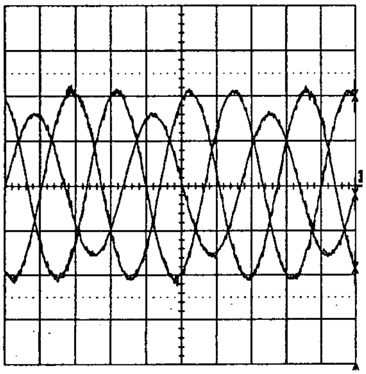
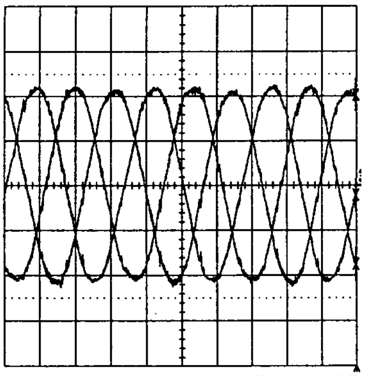


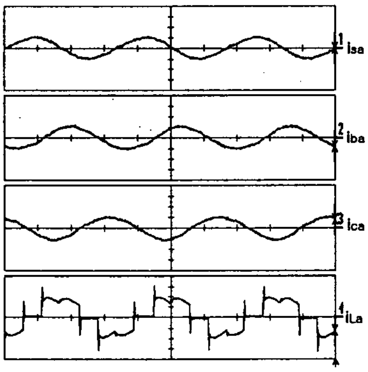
Fig. 10. FFT result of Fig. 5. (a) source voltage (b) load voltage (c) source current (d) a-phase load current



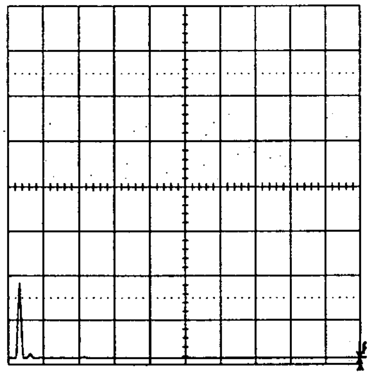
(a) source voltage [80V/div, 5ms/div]



(b) load terminal voltage [80V/div, 5ms/div]



(c) source[20A/div] / load current[10A/div, 5ms/div]



(d) FFT of the source current

Fig. 11 Experimental result of a-phase with proposed compensator. (voltage : 56, 100, 100[%], 3-phase unbalanced, α =60°)

Fig.11 (a), (b), (c), (d) show an experimental results when 1- phase voltage drops and, the firing angle of load is 60° . Fig.11(a) shows that unbalance wave form of 31% unbalanced rate. Fig.11(b) show that after compensated, load terminal voltage is sustained with 179[V]. Fig, 11(c) is source current and load current , source current is sustained as the sinusoidal wave by active power filter operation. Fig,11(d) is shown the current THD of 4.3%.

In 3-phase system, 1-phase fault is often occurred. At voltage drop of 1-phase, the compensator compensate both the voltage drop of 1-phase and the harmonic current of load. The active power filter improves the current THD from 31% to 4.3% and compensates the voltage drop of 1-phase fault up to 99%, therefore the power quality is improved.

4. CONCLUSION

When the compensator isn't installed, the current THD of a phase controlled 3-phase rectifier is 31[%]. The harmonics are the most of the 5th and 7th harmonics, and other harmonics are generated. The harmonic compensation algorithm proposed injects the difference of source voltage through a series transformers after creating the harmonic compensation voltage by detecting only the harmonics from the instantaneous active power and instantaneous reactive power passing through the high pass filter which had been applied with the p-q transformation. This series transformer compensates the source voltage at the same time, and which prevents the outflow and inflow of the harmonic in between the power source side and load side.

The proposed system is verified the application of the system that is compensated a variation of a source voltage, harmonics, and used series active power filter. By reducing the number of a passive filter, the generation of the reactive power and power of loss are reduced.

ACKNOWLEDGMENT

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