A NEW INSTANTANEOUS VOLTAGE COMPENSATOR WITH FUNCTION OF ACTIVE POWER FILTERING

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Abstract - A novel active input unbalance voltage compensator with harmonic current compensating capability is proposed and the operating principle of the proposed system is presented in the 3-phase power system. The proposed system performs both the voltage regulation of the load and the compensation of the harmonic currents generated due to nonlinear load such as diode rectifier. The system to compensate unbalanced voltage and harmonic currents is composed of a 3-phase voltage source inverter, LC filter, series transformer and passive devices at the load side of the line. The compensating voltage to regulate the load voltage and to remove the harmonic current components is transmitted to the line by the series transformer. The validity of the proposed system is proved by the results of computer simulation.

1. INTRODUCTION

In the three phase power systems, it is difficult to maintain the balanced condition due to the unbalanced load distribution in most cases. In addition to this, the harmonic interference problems generated by nonlinear loads such as rectifiers, inverters and cycloconverters is getting serious as they are widely used in industrial applications and distribution systems. To suppress harmonics produced by nonlinear power converters, active power filters as well as passive filters with specific frequencies that are usually connected as shunt filters in power systems have been researched and developed[1~4].

In addition, it has been noticed that the unbalanced 3-phase supplies generate the uncharacteristic low frequency harmonic components because of non-linear loads such as static converter in the unbalanced input condition and this results in increasing the power rating of filter or switches in power conversion systems. Moreover, in case of ac electric machines supplied by unbalanced voltage sources, large negative sequence current components, which increase the machine losses and reduce the net torque, are generated by the low negative sequencce impedance[5,6]. In comprehensive unbalance researches, the proposed limits on continuous voltage unbalance is 5 percent[8,9]. Therefore, the efforts to solve the problems by unbalanced source voltages have been reported in the literatures[6~8].

However, both researches on harmonic current and unbalance voltage compensation have been carried out separately by this time. In this paper, a novel control algorithm, which is capable of both alleviating the problems of harmonic interference and voltage regulation at the load side. is proposed in the unbalanced condition of input source. The results by simulation proves the validity of the proposed system. The simulation is carried out with 10[kVA] diode rectifier nonlinear load and experiment of laboratory version is being executed in this writing time.

2. SYSTEM CONFIGURATION

Overall system configuration of the proposed voltage compensator with harmonic compensating capability is represented in Fig. 1. The compensating system is composed of 3-phase voltage source inverter, LC filter to suppress switching ripples, series transformers and capacitors as a voltage buffer used to compensate the unbalanced voltage. The capacitor provides path of the harmonic currents but it is not passive filter pre-calculated for specific harmonic frequencies. The compensating voltage through LC filter is transmitted by the series transformers to the line. In this paper, the 3-phase full-bridge diode rectifier is used as a nonlinear load generating the harmonic currents and the L_s, R_s at ac source side in Fig. 1 are the line impedances.

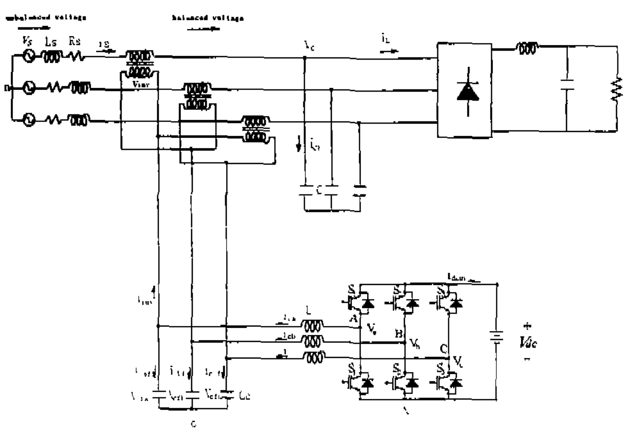


Fig. 1. Overall configuration of proposed voltage compensator with harmonic compensating capability.

3. PRINCIPLE OF THE PROPOSED COMPENSATING SYSTEM

Operating Principle

Fig. 2 shows the single phase equivalent circuit for the compensating system. Assuming that the voltage source inverter is an ideal controllable voltage source, the equivalent circuit of system shown in Fig. 1 is corresponded to Fig. 2(b). The variables L_s, R_s are the line impedance components or the inductance and resistance inserted for the sake of control.

Fig. 2(a) shows the case that has not the voltage compensator, and therefore this case can not obtain the harmonic current compensation as well as voltage compensation characteristics by active method. This case is only used, in this paper, for the comparison of the active harmonic current filter operation with Fig. 2(b). In the Fig. 2(b), the voltage source V_{inv} controls the voltage components to be compensated and forces the fundamental currents to flow through the source side of the line. In this case, although the source has the unbalanced conditions, the terminal voltages(V_c) of the capacitor are maintained with the balanced voltages by the active operation of PWM inverter. However, the balanced voltages after compensation comprise the harmonic voltage components because the harmonic currents are absorbed into the capacitor by the active operation of the compensator. To improve this defect, the passive filter can be added like Fig. 2(c). By this way, the compensated voltages become more sinusoidal waveforms, and also the currents at the source side are improved increasingly.

Control of Voltage Compensator with Harmonic Current Compensating Capability

If the fundamental component of current flows at the source side, the voltage equation about a phase is described like Eq. (1) from Fig. 2(b) and (c).

$$v_{inv} = v_c + (R_S + L_S \frac{d}{dt}) i_{s1} - v_s . \quad (1)$$

The reference capacitor voltage(v_c^*) is pre-fixed with the balanced sinusoidal waveforms and the reference current of the source with fundamental component can be extracted from the load current i_L by Bandpass filter $G_b(s)$.

$$i_{s1} = G(s)_b \, i_L . \quad (2)$$

Therefore the reference compensating voltage to be

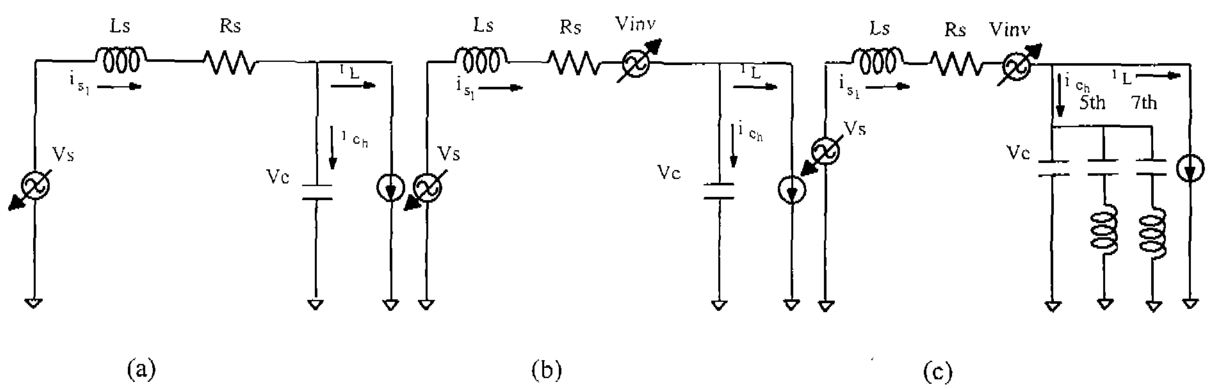


Fig. 2. Equivalent circuit per phase. (a) without voltage compensator. (b) with voltage compensator. (c) with voltage compensator and 5, 7th harmonic passive filter.

provided by PWM inverter is calculated as follows :

$$v_{inv}^* = v_c^* + (R_S + L_S\frac{d}{dt})(K_{Pi} + \frac{K_{Ii}}{s}) \cdot (i_{s1}^* - i_{s1}) - v_s \qquad (3)$$

In here, in order to become fundamental current component, the current control of source current is executed. And then the voltage control is carried out by using the compensating reference voltage v_{inv}^*. The control signal of voltage controller is compared with a triangle wave carrier and the PWM switching patterns are produced. The overall control block diagram is shown in Fig. 3.

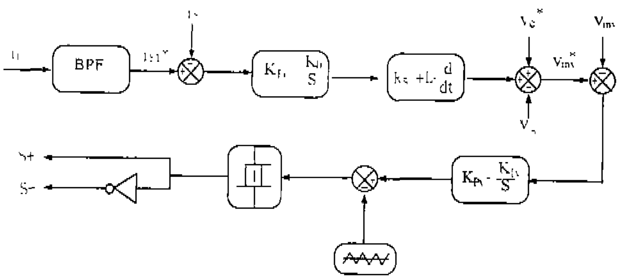


Fig. 3. Overall control block diagram.

4. SIMULATION AND RESULTS

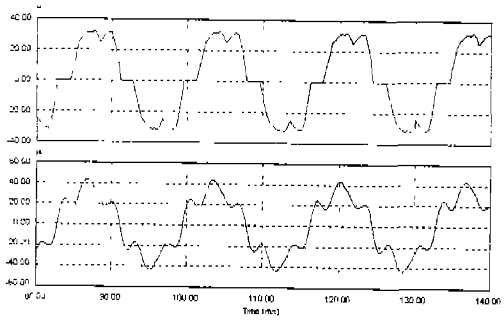
The system parameters for simulation are shown in table 1. The switching frequency is 10[kHz] and the LC filter(notation of inductance : L, notation of capacitance : Cc) for removal of switching ripple are designed in the view of THD(Total Harmonic Distortion) of the output voltage of the inverter. For smoothing filtering, the resonant frequency has to be lower than the switching frequency and also the resonant frequency must exist between source frequency and switching frequency. Therefore, in this paper, the resonant frequency of 600[Hz] is selected and selected value of L, Cc is 0.28[mH] and 250[μF], respectively. And the resistance and inductance inserted for the system control as line impedance are 0.001[Ω] and 1.5[mH], respectively. And the line capacitance(C) used as voltage buffer is 200[μF] in each phase.

Fig. 4 represents the simulation results in case that voltage compensator does not exist. This case is correspondent to the results of Fig. 2(a). Fig. 4(a) shows the currents at load side(upper figure) and

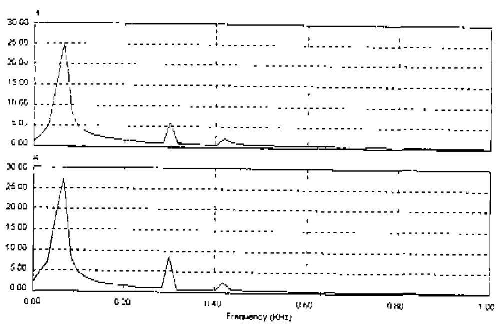
Table 1. System parameters

Ripple Filter Inductance : L	0.28[mH]
Ripple Filter Capacitance:Cc	250[μF]
Line Capacitance : C	200[μF]
Source Voltage	220[V]
DC-Link Voltage	300[V]
Switching Frequency	10[kHz]
Load Power Rating	10[kVA]

source side(lower figure) and Fig. 4(b) represents th harmonic spectrums of Fig. 4(a) in each case. It noticed that the current harmonics are not reduced the source side. The simulation results in case th voltage compensator exists are depicted in Fig. 5. A Fig. 4. Fig. 5(a) shows the currents at loa side(upper figure) and source side(lower figure) an Fig. 5(b) shows the harmonic spectrums in each cas In this case, we can know that the harmonic curre components at source side are largely reduced.

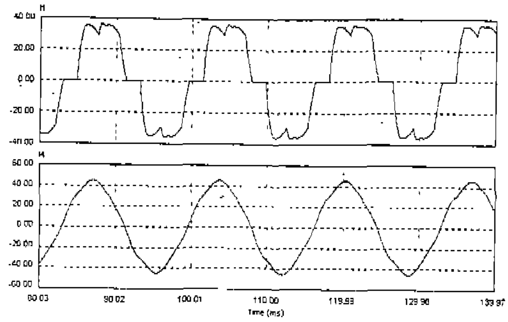


(a)

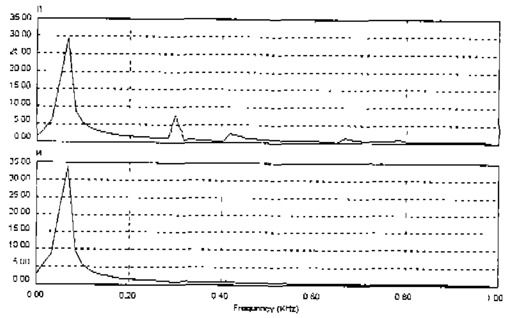


(b)

Fig. 4. Simulation results in case that voltag compensator does not exist. (a) the currents at loa side(upper) and source side(lower). (b) the harmoni spectrums of (a) in each case.



(a)



(b)

Fig. 5. Simulation results in case that voltage compensator exists. (a) the currents at load side(upper) and source side(lower). (b) the harmonic spectrums of (a) in each case.

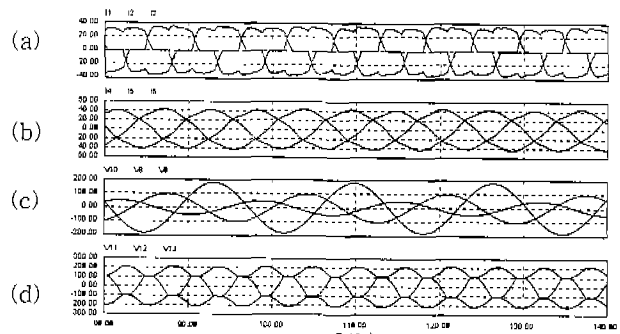


Fig. 6. Simulation results in case that the voltage unbalance is 34[%] and only voltage compensator exists. (a) currents at load side. (b) currents at source side. (c) unbalanced input voltage. (d) compensated voltage at the buffer capacitor.

The simulation results of the case that the voltage unbalance is 34[%] are shown in Fig. 6 and Fig. 7. Fig.6 is the case that only voltage compensator exists

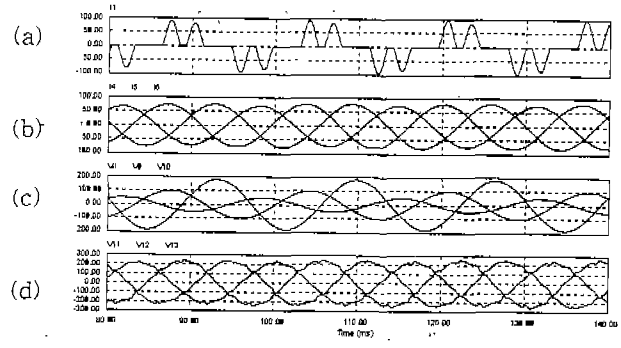


Fig. 7. Simulation results in case that the voltage unbalance is 34[%] and voltage compensator which 5th, 7th passive filter is added exists. (a) currents at load side. (b) currents at source side. (c) unbalanced input voltage. (d) compensated voltage at the buffer capacitor.

and Fig. 7 shows the case 5th, 7th passive filters are included. In each case of Fig. 6 and Fig. 7, (a) is the three phase currents at load side and (b) is the currents of three phase at source side. Each (c) of Fig. 6 and Fig. 7 represents the input source voltage contains the voltage unbalance of 34[%] and (d) shows the voltage waveforms after compensation at inserted line capacitors. We can notice that the voltage waveforms after compensation are maintained with the balanced constant values in each case. And also, it can be known that if the passive filter is included in the compensation system the effect of the unbalance compensation is improved.

5. CONCLUSION

A novel active input unbalance voltage compensator with harmonic current compensating capability is proposed and the operating principle of the proposed system is presented in the 3-phase power system. The proposed compensator to compensate unbalance voltages and harmonic currents comprises the series transformer and compensating operation is achieved through this transformer. It is known that the satisfactory compensation for harmonic currents and unbalance voltages are obtained through the proposed system. By the simulation results, the validity of the proposed system has been proved and also the experiment will be carried out to verify the compensating characteristics.

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