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DOUBLE-SOURCE ALTERNATE BACKUP TYPE UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT

A double-source alternate backup type unified power quality conditioner (DS-UPQC) is proposed in this paper, which consists of two shunt inverters and two series inverters, the shunt inverters are connected alternately to the series inverters through the dc links, and a simple effective control scheme is also proposed. DS-UPQC can compensate harmonic voltage, voltage sag and swell, voltage interruption, three-phase voltage unbalance, harmonic current and reactive power current. The proposed system can realize the desired power alternate backup among different sources, and provide uninterrupted power supply，thereby improve power system reliability effectively. Simulation results based on MATLAB/SIMULINK are presented to verify the good performance

Key words- *Double-source, alternate backup, unified power quality conditioner (UPQC), Voltage interruption, three-phase voltage unbalance*

1. INTRODUCTION

Ideal power system is that the power network is "supplying a pure-resistive equivalent load". But the augment of nonlinear loads results in the deterioration of the quality of both the voltage waveforms and the current waveforms. Not only the power electronic devices but the power system itself, like the transformer, is the source of the harmonics. Therefore they draw considerable reactive volt-amperes from the utility and inject harmonics in the power networks. The power quality problem is now cared by the power customer and the one must be settled [1-3].

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To settle the power quality problem, the passive filters were used firstly. Subsequently, the active filters were introduced which have been known as the best tool for harmonics mitigation as well as reactive power compensation [4, 5]. They were developed since 1983, when one of the first prototypes based on instantaneous power theory was reported. Many configurations such as shunt, series, hybrid (a combination of shunt and series active filters) have been introduced and improved [6-8].

The unified power quality conditioner is firstly introduced in [9]. Traditionally, it was used to mitigate current and voltage disturbances. Some

modification are made to enable UPQC to perform more than one function such as reactive current compensation and harmonic current mitigation, and harmonic voltage mitigation and balanced voltage sags compensation [10-12].
However, traditional UPQC cannot compensate the voltage interruption because it has no energy storage in the dc link. Even if it has energy storage in the dc link, no matter storage cell or super capacitor, whose compensation time and compensation capacity and serve life are finite. Furthermore, the maintenance charge is high and the maintenance amount is frequent for storage cell.

This paper proposes a double-source alternate backup unified power quality conditioner (DS-UPQC), which consists of two shunt inverters and two series inverters, the shunt inverters are connected alternately to the series inverters through the dc links. The advantage of the proposed system over the conventional UPQC is to compensate the voltage interruption, as well as the voltage sag, voltage swell, harmonics, reactive power, and three-phase voltage unbalance. The operation of the proposed system was verified through simulations based on the proposed simple control scheme.

2. PROPOSED SYSTEM

Normally, UPQC has two voltage-source inverters in three-phase four-wire or three-phase three-wire configuration. One inverter called the series inverter is connected through transformer between the source and the common connection point. The other called the shunt inverter is connected in parallel with the common connection through transformers.
This paper proposes a new configuration of UPQC named double-source alternate backup unified power quality conditioner (DS-UPQC) that consists of two shunt inverters and two series inverters, the series inverter 1 is connected through the series T2 between the source 2 and the capacitor 1, and the shunt inverter 1 is connected through the shunt T1 between the capacitor 1 and the non-linear load 1, and the series inverter 2 is connected through the series T1 between the source 1 and the capacitor 2, and the shunt inverter 2 is connected through the shunt T2 between the capacitor 2 and the non-linear load 2 as shown in Fig. 1. Based on double-source alternate backup, additional features of the DS-UPQC are as follows:

- ♦ DS-UPQC can realize the power alternate backup among different sources, and provide uninterrupted power supply, thereby improve power system reliability effectively.
- ♦ DS-UPQC can compensate voltage sag and swell in depth because the power of compensating voltage is from the other source, and compensation time and compensation capacity are improved, also the serve life is prolonged.

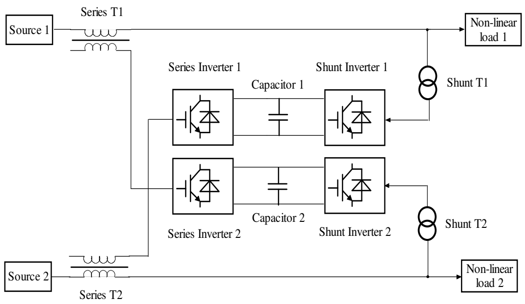


Figure 1. Block diagram of DS-UPQC.

3. CONTROLLER DESIGN

The proposed control scheme is as follows, the series inverter operates as a voltage source to compensate harmonic voltage, voltage sag and swell, three-phase voltage unbalance and voltage interruption. The shunt inverter operates as a current source to compensate harmonic current and reactive power current.

3.1. Voltage Reference Generator

The voltage reference generator has a configuration shown in Fig.2. The source voltage is detected to calculate the fundamental current component $i'_{s\alpha}$ and $i'_{s\beta}$ using the phase-locked loop (PLL) and the sine-wave generator. The source voltage is used to calculate the instantaneous active and reactive power p'_s and q'_s using the source current $i'_{s\alpha}$ and $i'_{s\beta}$. These values are passed through the low-pass filter to obtain the constant components of

$\overline{p}'_s$ and $\overline{q}'_s$. The calculated $\overline{p}'_s$ and $\overline{q}'_s$ include only the positive-sequence fundamental component of the source voltage V_s. The reference voltage $V'_{s\alpha}$ and $V'_{s\beta}$ is calculated using (1)

$$\begin{bmatrix} V'_{s\alpha} \\ V'_{s\beta} \end{bmatrix} = \frac{1}{i'^2_\alpha + i'^2_\beta} \begin{bmatrix} i'_\alpha & i'_\beta \\ i'_\beta & -i'_\alpha \end{bmatrix} \begin{bmatrix} \overline{p}'_s \\ \overline{q}'_s \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} p'_s \\ q'_s \end{bmatrix} = \begin{bmatrix} i'_{s\alpha} & i'_{s\beta} \\ i'_{s\beta} & -i'_{s\alpha} \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (2)$$

The reference voltage V^*_{ra}, V^*_{rb} and V^*_{rc} are

derived from the nominal instantaneous active and reactive power p^*_s and q^*_s, using (1) and inverse $\alpha-\beta-0$ transformation.

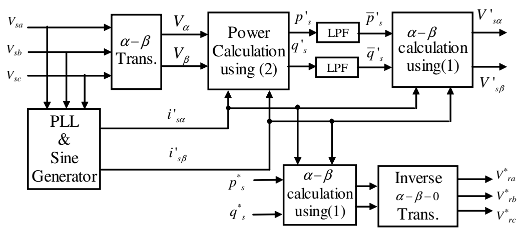


Figure. 2 Voltage reference generator.

3.2. Series Inverter Control

The function of series inverter is to compensate the voltage disturbance in the source side, which is due to the fault in the distribution line. The series inverter control calculates the reference value to be injected by the series inverter, comparing the positive sequence component with the disturbed source voltages V_{sa}, V_{sb} and V_{sc}. Here, the voltage disturbances include harmonic voltage, voltage sag and swell, voltage interruption and three-phase voltage unbalance in the source side. The control scheme is simple and effective because of not distinguishing the disturbance from harmonic voltage and fundamental voltage.

Fig.3 shows the configuration of series inverter decoupling control. Here, double decoupling multiloop feedback control scheme is applied in order to achieve good dynamic performance and static performance. The multiloop feedback controller consists of two inner current-feedback loops, an outer voltage-feedback loop, and a voltage-feedforward loop. By introducing the capacitor-current-feedback loop, the sensitivity to parameter variations is reduced and the robustness is much improved. Moreover, the system can have a fast dynamic response. Here, the voltage-feedback loop employs a traditional PI controller to regulate the output voltage. Since the PI controller will introduce phase errors, a voltage-feedforward loop is employed to reduce the phase error and to provide a high tracking accuracy to the reference. Although this arrangement may cause large overshoot in the dynamic response, the drawback can be overcome by optimizing the parameters of the voltage-feedback loop. Because PLL circuit can realize the synchronism of control signal, the output compensation voltage of the series inverter is synchronized with the disturbed source voltage. Therefore, the series inverter can compensate harmonic voltage, voltage sag and swell, voltage interruption and three-phase voltage unbalance in the source side. In Fig. 3, L_2 is the filter inductance, C_2 is the filter capacitor, i_{3d} is the active power component of output current, i_{3q} is the reactive power component of output current, i_{2d} is the active power component of inductance current, i_{2q} is the reactive power component of inductance current, i_{2d}^* *is* the active power component of reference inductance current, i_{2q}^* is the reactive power component of reference inductance current, u_{c2d} is the active power component of compensation voltage, u_{c2q} is the reactive power component of compensation voltage, u_{c2d}^* is the active power component of reference compen- sation voltage, u_{c2q}^* is the reactive power component of reference compensation voltage.

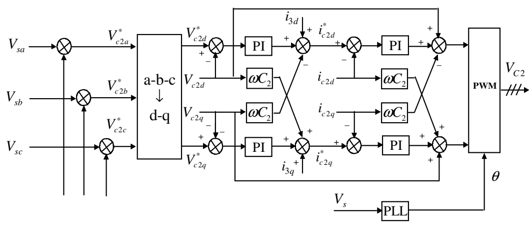


Figure 3. Series inverter control block diagram.

3.3. Shunt Inverter Control

The shunt inverter described in this paper has two major functions. One is to compensate the current harmonics generated in the nonlinear load and the reactive power. The other is to supply the power to the load if necessary. The advantage of the control method is simplicity, because the stability of load voltage is not considered. The control strategy for the shunt inverter requires real-time detecting harmonic current and reactive power current and is based on the instantaneous reactive power theory. The method has good steady-state accuracy and dynamic response performance.

Fig.4 shows the configuration of current compensation command generator of the shunt side. Three phase load currents i_{la}, i_{lb}, and i_{lc} are used to calculate two phase currents i_{ld}, i_{lq} using Park transformation(*abc to dq0*). These values are passed through the low-pass filter to obtain the fundamental active current i_d and reactive current i_q. The reactive current compensation command i_{cq}^* is obtained by comparing i_{lq} and i_q. Whether compensating fundamental reactive current or not is controlled by the switch *K* in Fig.4. When *K* is on, the fundamental reactive current is not compensated; when *K* is off, the fundamental reactive current is compensated successfully. The active current compensation command i_{cd1}^* is obtained by comparing i_{ld} and i_d. In order to keep the DC voltage be a constant, the DC voltage regulator is used in Fig.4. It is used to generate an active current compensation command i_{cd2}^*. Therefore, the whole active current compensation command signal i_{cd}^* consists of i_{cd1}^* and i_{cd2}^*. In Fig.4, v_{dc}^* is DC reference voltage, v_{dcf} is DC feedback voltage.

In compensation process, the DC side voltage will change because DS-UPQC compensates the active power and the losses of switches, etc. If the DC voltage is not the same as the rating value, the output voltage of the series inverter will not equal to the compensation value. The compensation will not correct. When the series inverter 1 requires consuming active power due to compensating voltage sag and swell, voltage interruption and three-phase voltage unbalance, the DC voltage regulator forces the shunt inverter 2 to draw additional active power from the power supply 2. When the series inverter 2 requires consuming active power due to compensating voltage sag and swell, voltage interruption and three-phase voltage unbalance, the DC voltage regulator forces the shunt inverter 1 to draw additional active power from the power supply 1. Therefore, the power alternate backup is realized between the two different sources.

Fig.5 shows the configuration of shunt inverter decoupling control. In order to achieve good steady-state performance and suppress the disturbance and parameter deviation effectively, the decoupling control scheme is employed to relief the coupling between *d* axes and *q* axes, the state feedback decoupling and the voltage feedforward compensation are introduced to simplify the design of control strategy. After the state feedback decoupling and the voltage feedforward compensation, the input voltage disturbance is erased, the *d* axes and the q axes may be deal with as an independent second-order system, and the collocation of the regulator's parameter becomes easy. Because the synchronism of control signal is realized by PLL circuit, the output compensation current of the shunt inverter is synchronized with load current. Therefore, the shunt inverter can compensate the current harmonics generated in the nonlinear load and the reactive power. In Fig.5, L_l is the ac side inductance of the shunt inverter, V_{Ld} is the active power component of ac side voltage of the shunt inverter, V_{Lq} is the reactive power component of ac side voltage of the shunt inverter.

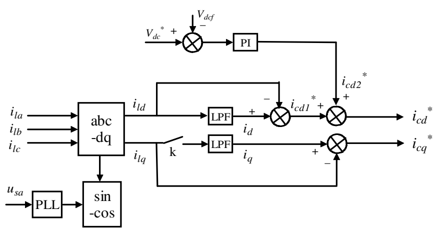


Figure 4. Current compensation command generator.

4. SIMULATION RESULTS

The simulation system of the DS-UPQC with the proposed control strategy is implemented by using MATLAB/SIMULINK software package. The power circuit is modeled as a three-phase system with non-linear loads. The circuit parameters that were used in the simulation are shown in Table 1.

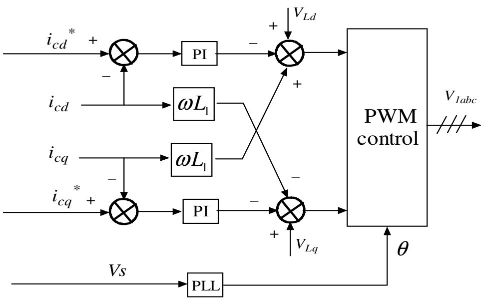


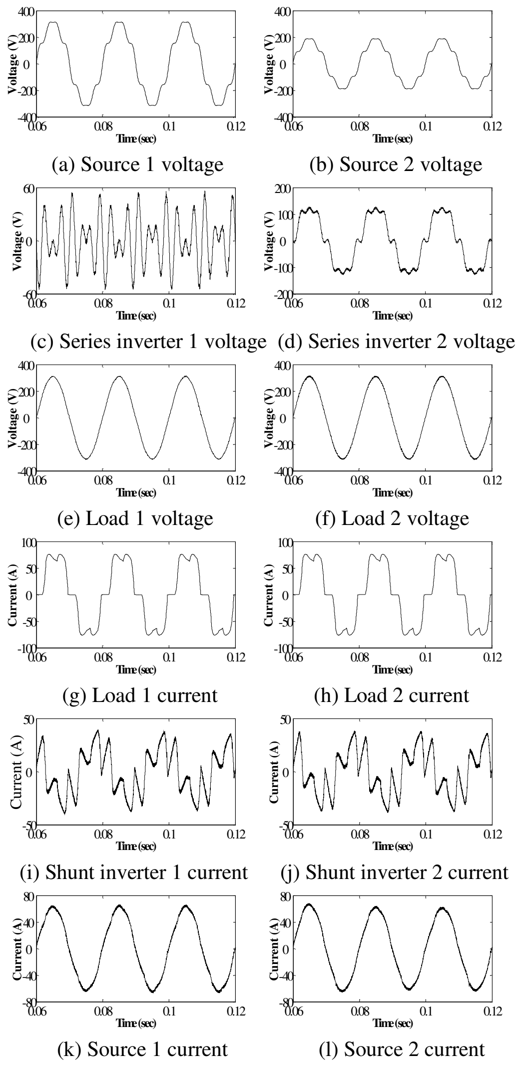
Figure 5. Decoupling control diagram of shunt side.

Table 1. Simulation Parameters

Source	Voltage	380V, 50Hz
DC-Link	Capacitor	3500uF
	Reference Voltage	800V
Shunt Inverter	Filter L, C	2.5mH, 2uF
	Switching Freq.	8kHz
Series Inverter	Filter L, C	0.2mH,1.5mF
	Switching Freq.	8kHz
Load	Non-linear Load	24kVA

In order to simulate the distortion in the source voltage, the source 1 voltage and the source 2 voltage are introduced by connecting a 5th and a 7th (8% of the fundamental input). Fig.6 shows the simulation results when the source 1 has only the harmonics distortion, and the source 2 has both the harmonics distortion and 40% of the voltage sag. Fig.7 shows the simulation results when the source 1 has both the harmonics distortion and 30% of the voltage swell, and the source 2 has only the harmonics distortion.

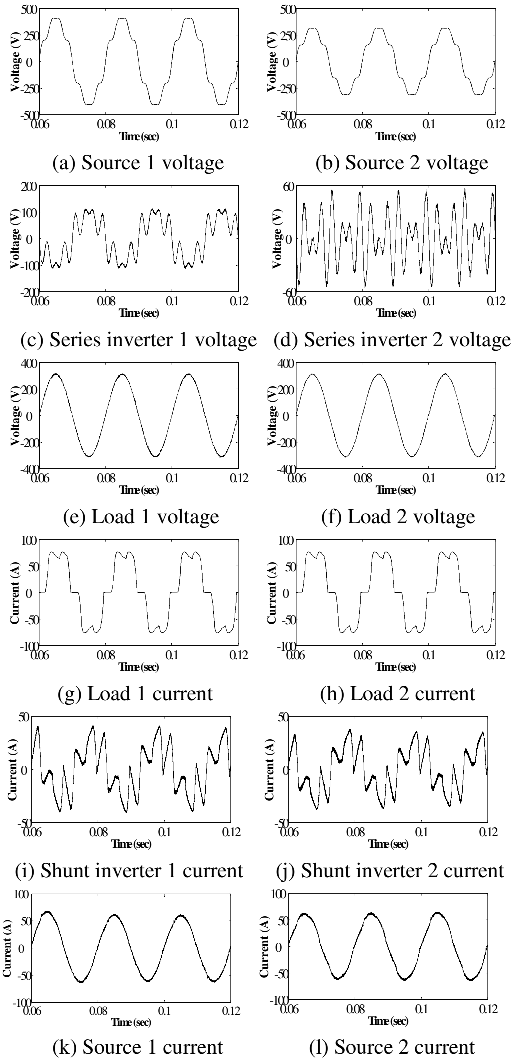
Simulation results indicate that, no matter the source voltage is sag or swell, the load 1 voltage and the load 2 voltage maintain a same constant value as expected after alternate compensation. Although both the source 1 and the source 2 voltage have the harmonics components, and both the load 1 and the load 2 are non-linear loads, the load voltage and the source current become sinusoidal by injecting the compensating components. The THDs of the source voltage and the load current are more than 11% and 31%, respectively. After alternate compensation, the THDs of the load voltage and the source current become less than 2% and 5%, respectively. Therefore, DS-UPQC based on the proposed control scheme not only compensates fundamental voltage and harmonic voltage in two different source sides simultaneously, but compensates harmonic current generated in two nonlinear loads and the reactive power current simultaneously.



(a) Source 1 voltage (b) Source 2 voltage
(c) Series inverter 1 voltage (d) Series inverter 2 voltage
(e) Load 1 voltage (f) Load 2 voltage
(g) Load 1 current (h) Load 2 current
(i) Shunt inverter 1 current (j) Shunt inverter 2 current
(k) Source 1 current (l) Source 2 current

Figure 6. V_{S1}=V_R, V_{S2}=0.6V_R, the voltage, current waveforms of phase A. (Where V_{S1} is the voltage of the source 1, V_{S2} is the voltage of the source 2, V_R is the RMS of the source reference voltage and equals to 220V).

Fig.8 shows the simulation results when the source 1 has a voltage interruption for 0.05s from 0.1 to 0.15 s and the source 2 has a voltage interruption for 0.05s from 0.2 to 0.25 s. Fig.8 (a), (b), (c), (d), (e), and (f) shows the source 1 voltage, the source 2 voltage, the series inverter 2 voltage, the series inverter 1 voltage, the load 1 voltage, and the load 2 voltage. The load 1 voltage and the load 2 voltage maintain a constant value after alternate compensation. Therefore, DS-UPQC can realize the desired power alternate backup among different sources, and provide uninterrupted power supply.



(a) Source 1 voltage (b) Source 2 voltage

(c) Series inverter 1 voltage (d) Series inverter 2 voltage

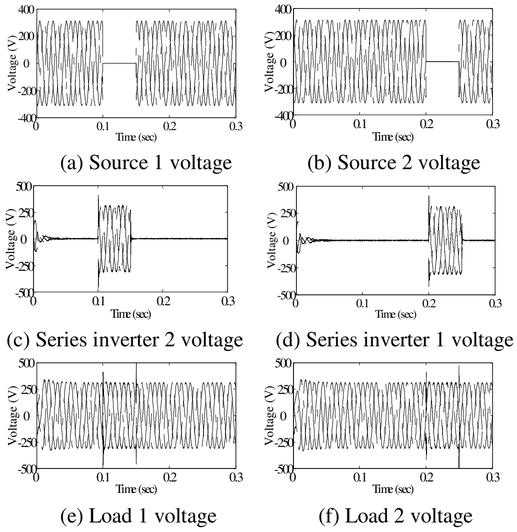
(e) Load 1 voltage (f) Load 2 voltage

(g) Load 1 current (h) Load 2 current

(i) Shunt inverter 1 current (j) Shunt inverter 2 current

(k) Source 1 current (l) Source 2 current

Figure 7. $V_{S1}=1.3V_R$, $V_{S2}=V_R$, the voltage, current waveforms of phase A.



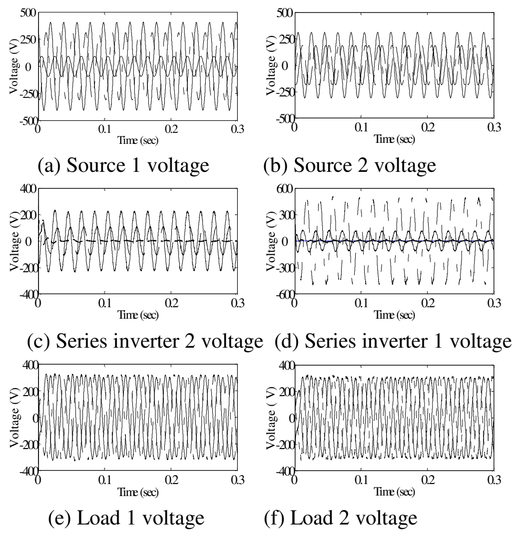
(a) Source 1 voltage (b) Source 2 voltage

(c) Series inverter 2 voltage (d) Series inverter 1 voltage

(e) Load 1 voltage (f) Load 2 voltage

Figure 8. Voltage waveforms of source and load voltage when voltage interruption compensation.

Fig.9 shows the simulation results when the source has an unbalanced voltage. In the source 1, phase A has 70% of sag, and phase C has 30% of swell, respectively. In the source 2, Phases B and C have 40% of sag, and the phase of phase C becomes -30^{o}. Fig.9 (a), (b), (c), (d), (e), and (f) shows the source 1 voltage, the source 2 voltage, the series inverter 2 voltage, the series inverter 1 voltage, the load 1 voltage, and the load 2 voltage.



(a) Source 1 voltage (b) Source 2 voltage

(c) Series inverter 2 voltage (d) Series inverter 1 voltage

(e) Load 1 voltage (f) Load 2 voltage

Figure 9. voltage waveforms when three-phase voltage unbalance compensation.

Although both the source 1 and the source 2 have a catastrophic unbalanced voltage, the load 1 voltage and the load 2 voltage maintain a constant as expected after alternate compensation. Therefore, DS-UPQC can alternately compensate three- phase voltage unbalance effectively.

5. CONCLUSION

This paper describes the analysis results of a double-source alternate backup unified power quality conditioner. The proposed system consists of two shunt inverters and two series inverters, the shunt inverters are connected alternately to the series inverters through the dc links. The proposed system based on the proposed control scheme can compensate harmonic voltage, voltage sag and swell and three-phase unbalance voltage in two different source sides simultaneously, and can compensate harmonic current generated in two nonlinear loads and the reactive power simultaneously. It also can realize the desired power alternate backup among different sources, and provide uninterrupted power supply. Therefore, DS-UPQC not only solves the most of power quality problems from two different systems, but improves power system power supply reliability effectively.

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