Combined Operation of Unified Power-Quality Conditioner With Distributed Generation

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***Abstract*—This paper describes analysis results of a combined operation of the unified power quality conditioner with the distributed generation. The proposed system consists of a series inverter, a shunt inverter, and a distributed generator connected in the dc link through rectifier. The proposed system can compensate voltage sag and swell, voltage interruption, harmonics, and reactive power in both interconnected mode and islanding mode. The performance of proposed system was analyzed using simulations with power system computer aided design/electromagnetic transients dc analysis program, and experimental results with the hardware prototype. The proposed system can improve the power quality at the point of installation on power distribution systems or industrial power systems.**

***Index Terms*—Distributed generation (DG), power system computer-aided design/electromagnetic transients dc analysis program (PSCAD/EMTDC), unified power-quality conditioner (UPQC).**

I. Introduction

UNIFIED power-quality control was widely studied by many researchers as an ultimate method to improve power quality [1]–[5]. The function of unified power-quality conditioner (UPQC) is to mitigate the disturbance that affects the performance of the critical load. The UPQC, which has two inverters that share one dc link capacitor, can compensate the voltage sag and swell, the harmonic current and voltage, and control the power flow and voltage stability. However, UPQC cannot compensate the voltage interruption because it has no energy storage in the dc link.

The interest in distributed generation (DG) has been increasing rapidly because DG might play an important role in the future power system [6]–[8]. DG can solve many typical problems that the conventional ac power system has. For example, an energy security problem occurs in the large-scale power system because a few transmission facilities are responsible for serving electric power to a great number of customers. This security problem caused by some transmission-line trip can be alleviated if a large number of DGs are installed in the power system. Moreover, DG can yield economic benefits, such as reducing the loss of transmission line and the cost of high-voltage equipment. However, a small DG has some significant problems of frequency and voltage variation when it is operated in stand-alone mode. Therefore, a small DG should be interconnected with the power system in order to maintain the frequency and the voltage. Several studies proposed an interconnection system for DG with the power system through the inverter because the inverter gives versatile functions improving the ability of DG [9], [10].

This paper proposes a combined operation system of UPQC and DG, which is connected to the dc link through a rectifier. The advantage of the proposed system over the UPQC in [4] is to compensate the voltage interruption, as well as the voltage sag, voltage swell, harmonics, and reactive power. The operation of the proposed system was verified through simulations with power system computer-aided design/electromagnetic transients dc analysis program (PSCAD/EMTDC). The feasibility of hardware development was confirmed though experimental works with a prototype.

II. 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 transformers between the source and the common connection point. The other inverter called the shunt inverter is connected in parallel with the common connection point through transformers. The series inverter operates as a voltage source, while the shunt inverter operates as a current source.

UPQC has compensation capabilities for the harmonic current, the reactive power compensation, the voltage disturbances, and the power-flow control. But UPQC has no capability in compensating the voltage interruption because there is no energy storage.

This paper proposes a new configuration of UPQC that has a DG connected to the dc link through the rectifier as shown in Fig. 1. The UPQC can compensate the voltage interruption in the source, while the DG supplies power to the source and load or the load only. There are two operation modes in the proposed system. One is called the interconnected mode, in which the DG provides power to the source and the load. The other is called the islanding mode, in which the DG provides power to the load only within its power rating.

III. Controller Design

The control structure of proposed system is shown in Fig. 2. Three major elements are the positive sequence detector, the series inverter control, and the shunt inverter control. The control strategy was designed for implementing the interconnected

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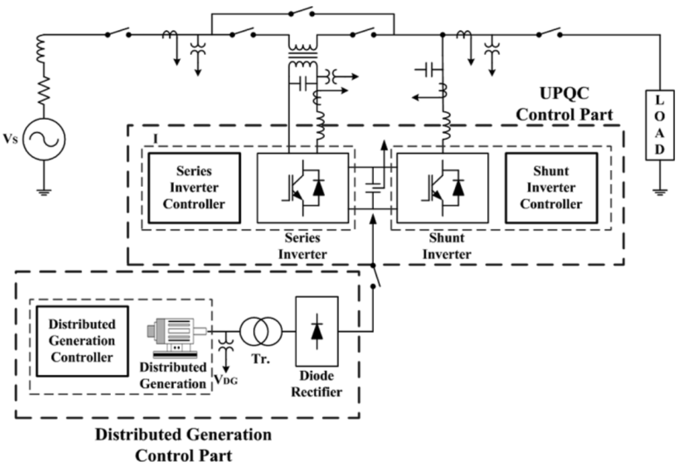

Fig. 1. Proposed UPQC system with DG.

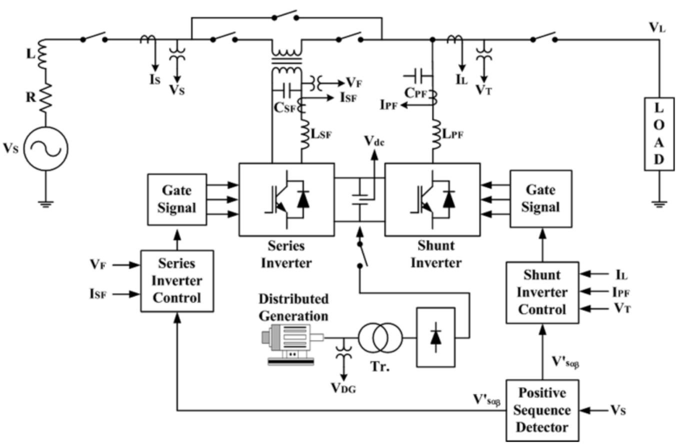

Fig. 2. Control block diagram.

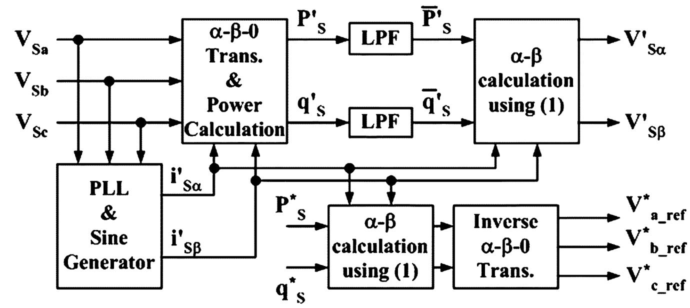

Fig. 3. Positive-sequence detector and voltage reference generator.

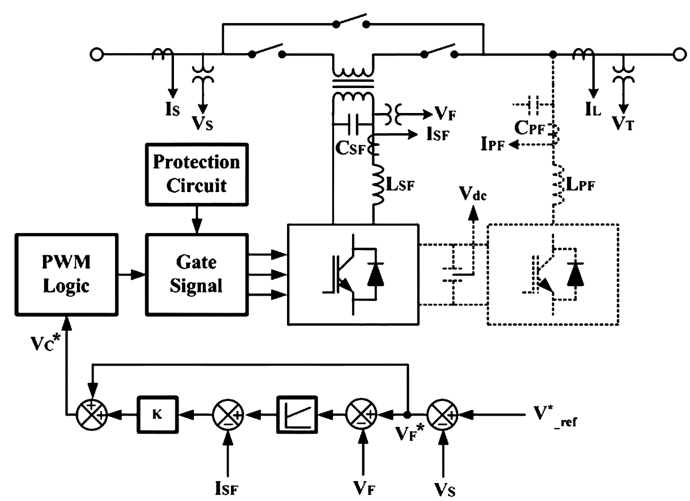

Fig. 4. Series inverter control block diagram.

mode and the islanding mode. The system works in interconnected mode when the DG and the main source supply power to the load in parallel. But it works in islanding mode when the voltage interruption occurs. Once the voltage interruption is removed, the system operation transfers from the islanding mode to the interconnected mode.

A. Positive-Sequence Detector and Voltage Reference Generator

The positive-sequence detector has a configuration shown in Fig. 3. The source voltage is detected to calculate the fundamental current component $i'_{S\alpha} = \sin(\omega_1 t)$ and $i'_{S\beta} = \cos(\omega_1 t)$ passing through 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 $i'_{S\beta}$, and $\alpha - \beta - 0$ transform. These values are passed through the low-pass filter to obtain the constant components of $\bar{p}'_S$ and $\bar{q}'_S$. The calculated $\bar{p}'_S$ and $\bar{q}'_S$ 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)

$$\begin{bmatrix} V'_{S\alpha} \\ V'_{S\beta} \end{bmatrix} = \frac{1}{i'^2_\alpha + i'^2_\beta} \begin{bmatrix} i'_\alpha & i'_\beta \\ i'_\beta & -i'_\alpha \end{bmatrix} \begin{bmatrix} \bar{p}'_S \\ \bar{q}'_S \end{bmatrix}. \quad (1)$$

The reference voltage $V^*_{a\_\text{ref}}$, $V^*_{b\_\text{ref}}$, and $V^*_{c\_\text{ref}}$ are derived from the nominal instantaneous active and reactive powerp^*_S and q^*_S, using (1) and inverse $\alpha - \beta - 0$ transformation.

B. 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 voltage. Equation (2) shows the state equation of the series inverter

$$V^*_C = [K_{PI}\{(V^*_{\_\text{ref}} - V_S) - V_F\} - I_{SF}] * K + V^*_F. \quad (2)$$

Fig. 4 shows the configuration of series inverter control, which is based on (2).

Fig. 5 shows the simulation result of voltage control, which confirms the fact that the output voltage of each phase tracks the reference value without large transient and steady-state errors.

C. 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 when the voltage interruption occurs in the source side. The control system for the shunt inverter has to be designed to cover these two functions. In normal operation, the