4-레그 PWM 컨버터/인버터와 AC 리액터를 사용한 새로운 3상 라인 인터렉티브 무정전전원장치의 개발

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Development of Novel 3-Phase Line-interactive UPS System using 4-leg PWM Converter/Inverter and AC Reactor

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ABSTRACT

In this paper a novel line interactive UPS (Uninterruptible Power Supply) using the two 4-leg VSCs and AC line reactor is proposed. The 4-leg Voltage Source Converter(VSC) can use the DC link voltage effectively by the 3-D SVPWM method. Hence the DC battery voltage can be reduced by 15% in comparison to that of the conventional line-interactive UPS system. One VSC is in parallel with the AC line reactor of the power source side, and the other is in series with the load. The parallel 4-leg voltage source inverter controls three-phase line voltage independently in order to control the line reactor current indirectly. It eliminates the neutral line current and the active ripple power of the source side using the pqr theory so that unity power factor and the sinusoidal source current can be achieved even though both the source and the load voltages have zero sequence components. The series 4-leg voltage source inverter compensates the line voltage and allows the load voltage to be balanced and harmonic-free. Both of parallel and series 4-leg voltage source inverters always act as independently controllable voltage sources, so that three-phase output voltage shows a seamless transition to the backup mode. The feasibility of the proposed UPS system has been investigated and verified through computer simulation results.

1. Introduction

The line interactive UPS systems have been widely used to improve the power source quality as well as to maintain the desired load voltage waveform for critical loads such as computers, medical equipment, and industrial control systems, despite the various power line faults and the voltage deviation condition[1]. Generally there are only a few situations where the UPS system feeds the three-phase balanced load. Most of the loads are single-phase nonlinear and three-phase unbalanced loads such as single-phase rectifier loads for the switched mode power supply, three-phase rectifiers with dc-side LC filters, etc. Therefore a zero sequence voltage should be controllable in the three-phase UPS system. However in much research, the controllability of the zero sequence voltage has been ignored[2-4]. For the controllability of the zero sequence voltage, the half-bridge converter topology, with the output nodes of the three legs connected to the center point of DC link, has been used widely for many industry applications[5]. However in the case of the half-bridge topology, the UPS system requires the DC link voltage to be maintained to be at least twice as large as the peak value of the nominal output voltage. The battery voltage should ascend along with the DC link voltage, which brings about the increase of the material and maintenance cost, since the number of the batteries increases.

The UPS system using the 4-leg voltage source converter proposed in this papercan use the DC link voltage effectively by the carrier-based 3-D SVPWM method[6,7] and also has the controllability of the zero sequence voltage as well as the instantaneous symmetrical component voltages. The DC battery voltage can be reduced by 15% in comparison with that of the conventional half-bridge converter type UPS system. This paper describes the novel UPS system with two 4-leg VSCs and AC line reactor, and its control strategy is described. The simulations have been performed for the verification of the feasibility of the proposed UPS system.

2. The proposed UPS system

Fig. 1 shows the configuration of the proposed line interactive UPS system. As shown in Fig.1 the two 4-leg voltage source converters are employed for power line conditioning. One is in parallel with the AC reactor of the power source side and the other is in series with the load. The 4-leg inverters, parallel with the ac reactor and series with the load, will be referred to as a shunt inverter and a series inverter, respectively. Note that the ac line reactor exists between the power source and the shunt inverter. The shunt inverter acts as a voltage source so as to control the reactor current indirectly. The series inverter acts as a direct voltage restorer so as to eliminate the harmonics and the unbalanced component of the output voltage.

By understanding the carrier-based 3-D SVPWM method, the 4-leg VSC can be completely modified into three single-phase full-bridge converters with an available voltage limited by $0.933V_{dc}$[6]. That is to say, the 4-leg voltage source converter is equivalent to three-independently-controllable voltage sources. Hence the proposed system can be simplified by the single phase equivalent circuit as shown in Fig. 2.

3. Control Strategy

The output voltage reference of the shunt inverter(V_{pcap}^*) can be written as eq. (1) using the desired line reactor current(I_{src}^*), which is also the desired source current. The source current is determined by the compensation current reference(I_{comp}^*) which is given by the pqr instantaneous power theory[8], so that the sinusoidal source currents are maintained, and the neutral line current is eliminated even when the zero sequence component exists in the source and load side.

$$V_{pcap}^* = V_{src} - sL_{line} I_{src}^* \quad (1)$$

$$I_{src}^* = I_{load} - I_{comp}^* \quad (2)$$

The shunt inverter controls the three-phase line voltage so as to control the line reactor current indirectly. The series 4-leg voltage source inverter compensates the load voltage to be balanced and harmonic-free. Both of the series and parallel 4-leg voltage source inverters always act as independently controllable voltage sources, so that three-phase output voltage shows a seamless transition to the back-up mode with the battery. The conceptual view of the control strategy for the UPS system is shown in Fig. 3. The phase diagram of the controlled voltages(V_{pcap} and V_{scap}) during the normal operation is shown in Fig. 4. If the resistance of ac line reactor(R_{line}) is neglected, V_{line} will be orthogonal to the source current. Therefore the output voltage of the shunt inverter controlled by V_{pcap}^*, shown in Fig. 4, makes the power source keep the unity power factor.

4. Simulation Results

The simulation has been performed to verify the feasibility of the control strategy for the proposed UPS system. Considering a grid voltage variation of ±10% fundamental component with 5% third, fifth, and seventh harmonics voltage contents, the proposed UPS system provides a linear unbalanced and nonlinear combined load. The major parameters of the UPS system used in the simulation are summarized in Table I.

Fig. 5 represents the simulation results under the condition that the UPS system feeds the unbalanced and nonlinear combined loads, and that the A-phase 10% sag occursat 5.5 sec during 3 cycles. The load currents have zero sequence due to the unbalanced load, and the zero sequence voltage appears in the source voltage

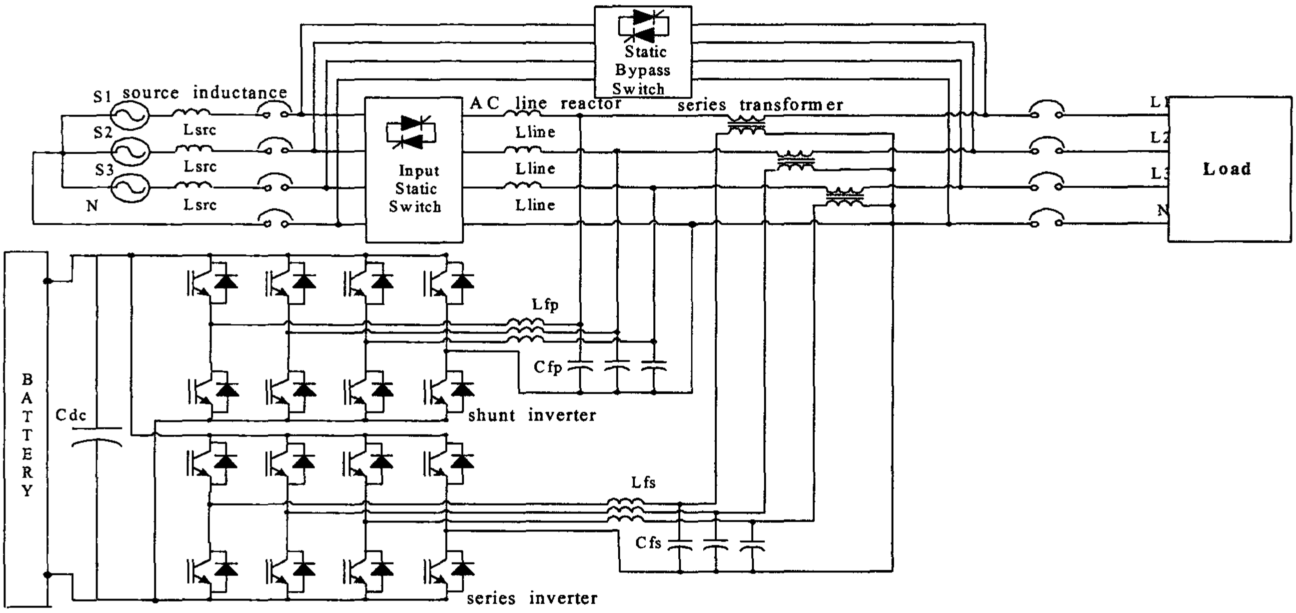


Fig. 1 Configuration of proposed UPS system

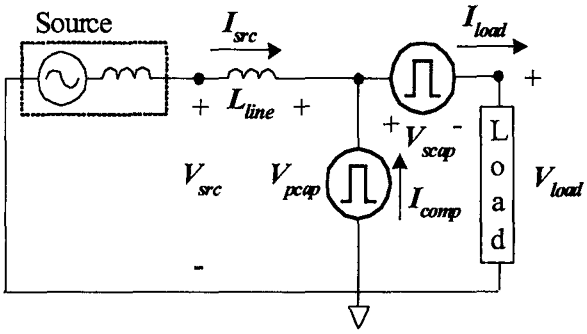


Fig. 2 Single phase equivalent circuit of Fig. 1

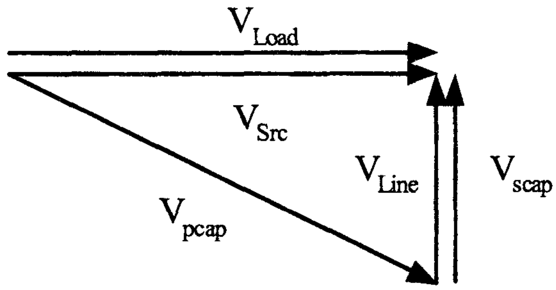


Fig.4 UPS operation for unity power factor during the normal operation

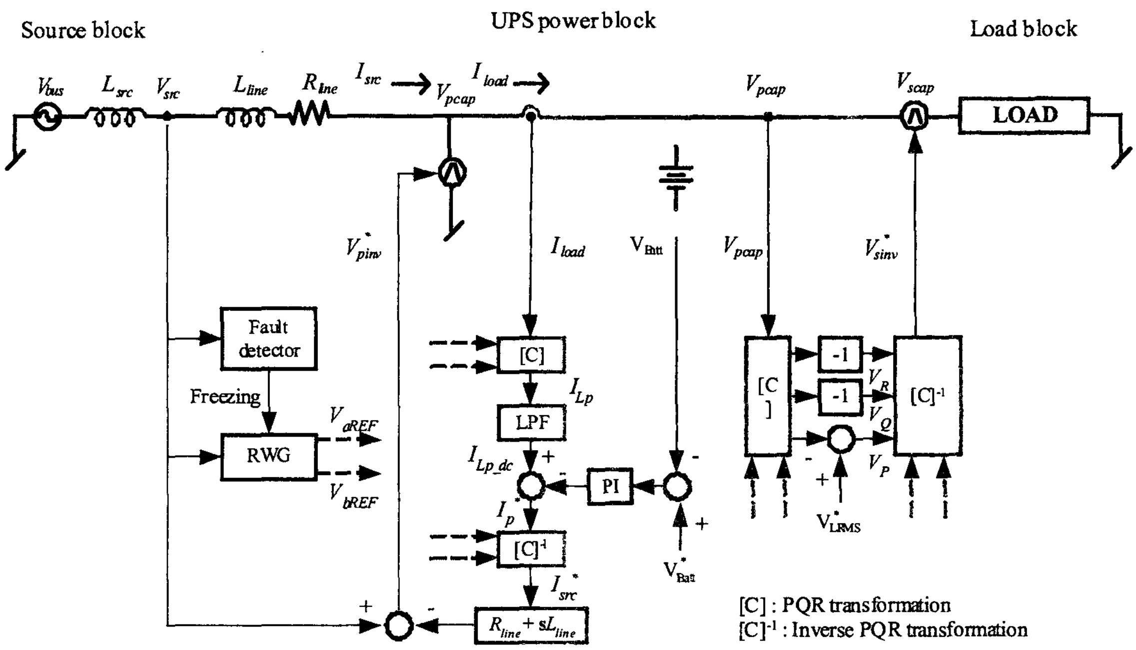
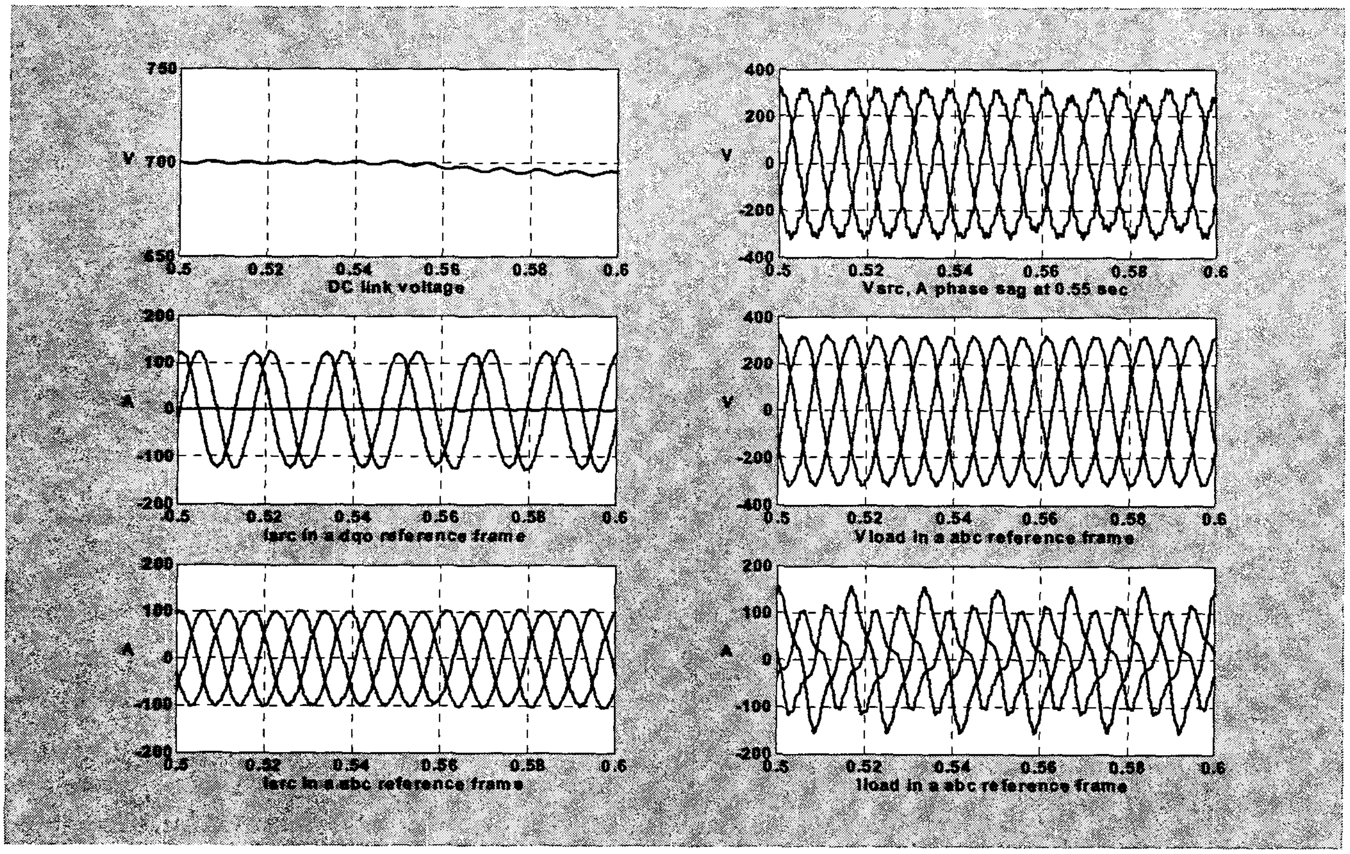
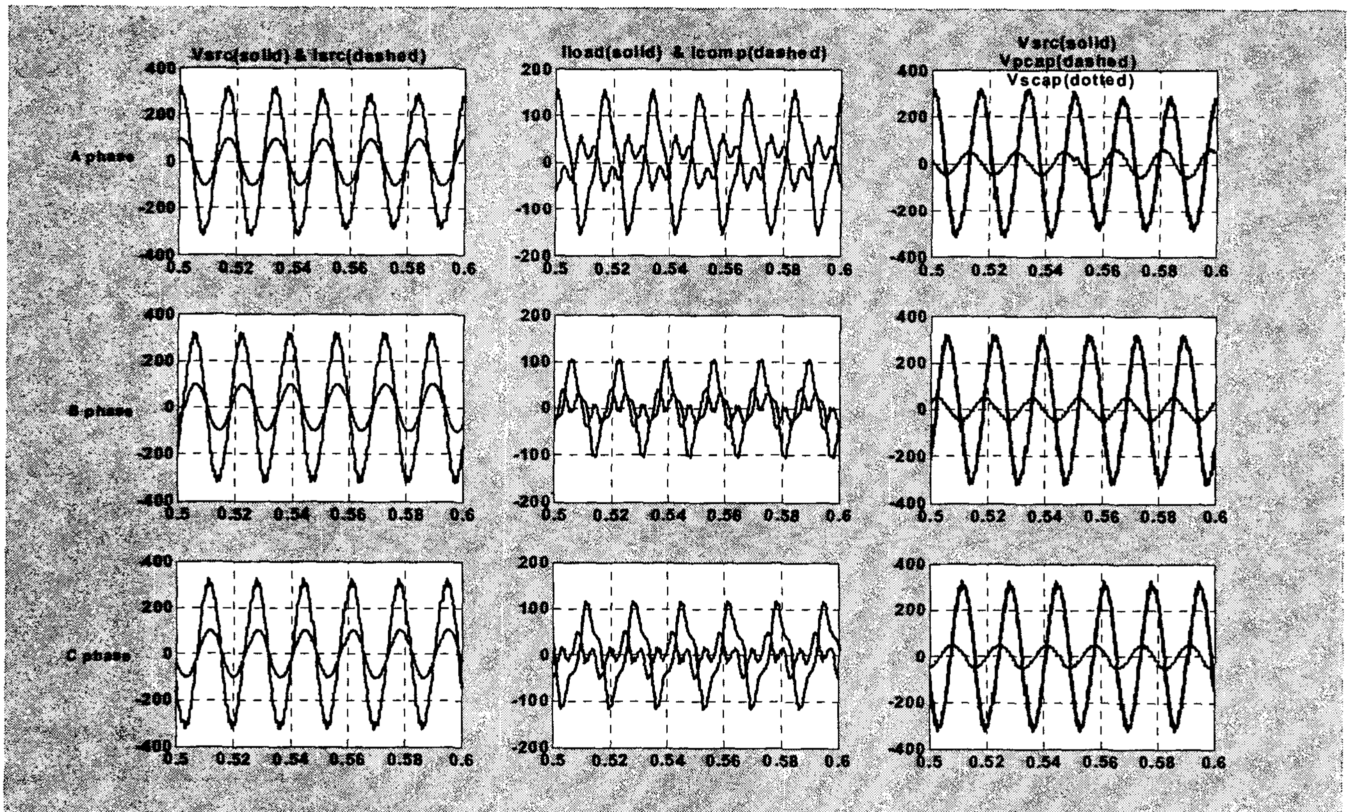


Fig. 3 Block diagram of control system



(a) Sinusoidal source current and elimination of zero sequence current



(b) The voltage and current waveform during the normal operation

Fig. 5 Simulation Results : Overall performance of the proposed line-interactive UPS system during the voltage sag period. The sinusoidal source currents and neutral current elimination are achieved even though both zero sequence voltage and current exist, as shown in Fig. 5(a). Fig. 5(b) shows that proposed UPS system operates at unity power factor. Through these simulation results, the feasibility of the proposed control strategy can be verified.

Table 1 Suggested UPS ystem parameters

Grid Rated Power		60kVA/380V	
L_{line}		0.1pu	
R_{line}		0.005pu	
$V_{battery}/V_{dc}$		650V/700V	
Turns Ratio of Series Transformer		1:5	
LC Filters			
Shunt(Parallel)		Series	
L_{fp}	C_{fp}	L_{fs}	C_{fs}
300uH	200uF	600uH	60uF

5. Conclusions

This paper has proposed a novel topology and its simple control strategy for three-phase line-interactive UPS system with parallel-series active power-line conditioning capability using two 4-leg voltage source converters and AC line reactor. The 4-leg VSC can use the DC link voltage effectively by the 3-D SVPWM method. Hence the DC battery voltage can be reduced by 15% in comparison to that of the conventional line-interactive UPS system. The shunt inverter eliminates the neutral line current and the active ripple power of the source side using the pqr transformation so that unity power factor and the sinusoidal source current can be achieved even though both source and load voltages have zero sequence components. The series inverter operating as dynamic voltage restorer(DVR) compensates the line voltage and allows the load voltage to be balanced and harmonic-free. Both of series and shunt inverters always act as independently controllable voltage sources, so that the three-phase output voltage can show a seamless transition to the backup mode in contrast to conventional parallel-series line interactive UPS system needing transition from current source to voltage source at backup mode.

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