A New Control Scheme for Series-Parallel Compensated UPS System

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Abstract- **This paper describes a new control scheme using Synchronous Reference Frame (SRF) of a three-phase series-parallel compensated UPS system in detail. By controlling the series converter as a sinusoidal current source in phase with the input voltage and the parallel converter as a sinusoidal voltage source in phase with the input voltage, the proposed control scheme can make this kind of UPS carry out all of the control goals: sinusoidal input current with $\cos\phi = 1$ and sinusoidal output voltage with normal value in the case of non-sinusoidal, non-normal supply voltage and non-linear load. Digital simulation results are presented to verify the good performance of the UPS system and the effectiveness of the new control scheme.**

I. INTRODUCTION

To improve the power source quality, UPS systems have been employed, providing clean and uninterruptible power to critical loads. Few three-phase line-interactive UPS systems with series-parallel active power-line conditioning have been proposed in literature [1,2]. In these line-interactive UPS systems, an effective power factor correction is carried out. The output voltages are controlled to have constant RMS values and low total harmonic distortion (THD) and the source currents are controlled to be sinusoidal quantities with low THD, too.

In this paper, a new control scheme using SRF for a three-phase series-parallel compensated UPS system is presented. In this control scheme, the series converter acts as a sinusoidal current source and the parallel converter acts as a sinusoidal voltage source. Different from the control algorithms in [1,2], the new control scheme obtains better performance of source current and output voltage by means of establishing the voltage and current equations of series-parallel converters under dq coordinate and considering the influence of series-parallel converters caused by decoupled voltage, decoupled current, feedforward voltage and feedforward current. Digital simulations are performed to verify the performance of the proposed UPS system and Simulation results also verify the proposed control scheme is effectiveness.

II. THE PROPOSED TOPOLOGY

The power circuit of the proposed series-parallel compensated UPS topology is shown in Fig.1.

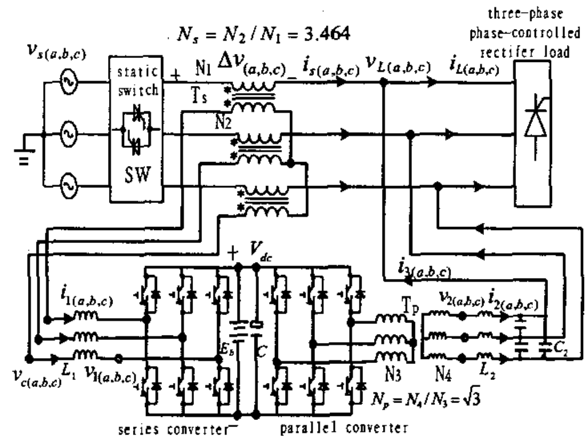

Fig.1 Proposed series-parallel compensated UPS system topology

In Fig.1, both series converter and parallel converter are reversible AC $\leftrightarrow$ DC SPWM converters, which are connected to a common dc bus with a capacitance C. A battery bank E_b is placed in the dc bus and a static switch 'sw' is used to provide a fast disconnection between the UPS system and the power supply when an occasional interruption of the incoming power occurs. Series converter injects a voltage Δv between source voltage v_s and load voltage v_L through inductance L_1 and series transformer Ts. Parallel converter shunts to load side through parallel transformer Tp, filter reactor L_2 and filter capacitor C_2.

III. CONTROL SCHEME

The new control scheme of series-parallel compensated UPS system using SRF is shown in Fig.2.

A. Source current control

Series converter is controlled as a sinusoidal current source, and its output current i_1 is pure sine wave. As a result, the source current i_s is sinusoidal waveform in phase with the fundamental supply voltage v_{s1} and the power factor is one.

In Fig.1, neglecting the resistance of inductance L_1, the current equation of series converter in static three-phase system is found as (1):

$$L_1(d_{i_1}/dt) = v_c - v_1 \qquad (1)$$

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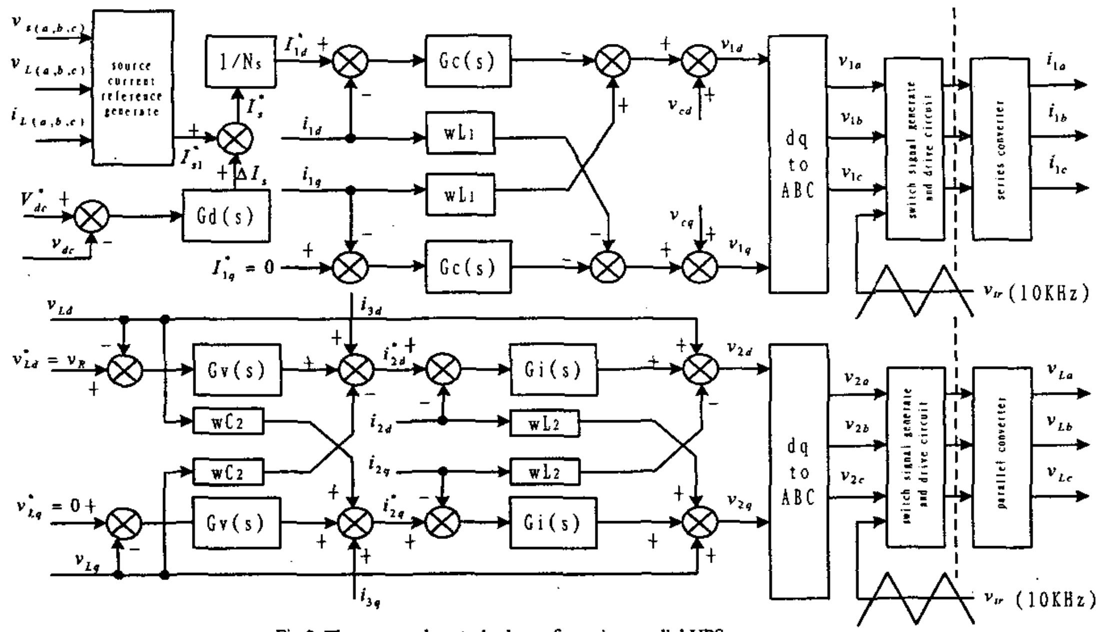

Fig.2. The proposed control scheme for series-parallel UPS

With the transformation from three-phase reference frame to two-phase synchronous rotating reference frame (ABC/dq)[2], the equation (1) can be written as follow:

$$L_1(di_{1d}/dt) = \omega L_1 i_{1q} + v_{cd} - v_{1d} \quad (2)$$

$$L_1(di_{1q}/dt) = -\omega L_1 i_{1d} + v_{cq} - v_{1q} \quad (3)$$

Where, i_{1d} and i_{1q} represent the d and q axes component of series converter's output current $i_{1(a,b,c)}$ respectively under SRF. In similar manner, v_{cd} and v_{cq} are the d and q axes component of input voltage $v_{c(a,b,c)}$. v_{1d} and v_{1q} are control variables (namely output voltage of series converter). As shown in (2) and (3), the d and q axes component of output current $i_{1(a,b,c)}$ is not only effected by the control variables v_{1d} and v_{1q}, but also by decoupled voltage ($\omega L_1 i_{1q}, \omega L_1 i_{1d}$) and series converter's input voltage (v_{cd}, v_{cq}). Therefor, for eliminating their influences, the decoupled voltage and feedforward voltage are introduced in the control system.

According to (2) and (3), the source current control system is found in Fig.2. The three-phase load voltages $v_{L(a,b,c)}$, load currents $i_{L(a,b,c)}$ and source voltages $v_{s(a,b,c)}$ are measured as the input variables of source current reference generating mode and transformed into two-phase synchronous rotating reference frame quantities ($v_{Ld}, v_{Lq}, i_{Ld}, i_{Lq}, v_{sd}, v_{sq}$) with (ABC/dq) transformation. And the dc components of the synchronous reference frame ($V_{Ld}, V_{Lq}, I_{Ld}, I_{Lq}, V_{sd}, V_{sq}$) are obtained by using a low pass filter (LPF).

Neglecting the battery charged power and the losses of inductances, capacitances and switch devices, the equation (4) can be obtained based on the balance of system power.

$$P_{sdc} = V_{S1} I_{S1}^{*} = P_{Ldc} = V_{Ld} I_{Ld} + V_{Lq} I_{Lq} \quad (4)$$

Then the source current reference is given by:

$$I_{S1}^{*} = P_{Ldc} / V_{s1} \quad (5)$$

Where, P_{sdc} is AC input supply power. P_{Ldc} is load active power. $V_{s1} = \sqrt{V_{sd}^2 + V_{sq}^2}$ represents the magnitude of fundamental input source voltage.

Considering the power losses in the system, an increment ΔI_s which is generated from DC bus voltage regulator $G_d(s)$ must be added into I_{S1}^{*}. Source current reference I_S^{*} which represents the active power need of load divided by series transformer voltage ratio N_s acts as the d axes current control reference I_{1d}^{*}. Because of no requiring reactive component in the source current, q axes current control reference I_{1q}^{*} is set to zero. With (dq/ABC) transformation [2], control variables v_{1d} and v_{1q} are transformed into three-phase reference frame quantities (v_{1a}, v_{1b}, v_{1c}), and they are respectively compared with triangular carrier wave v_{tr} to obtain the PWM switching signal for series converter. Consequently, it is realizable that source current i_s pursues the reference I_S^{*}.

Because of heavy harmonic components in the series converter input voltage, current regulator $G_c(s)$ in Fig.2 is a

PID controller. Derivative action improves the steady and dynamic behavior of the system.

B. Output voltage control

Parallel converter is controlled as a sinusoidal voltage source, and its output voltage v_L equals to normal sine voltage v_R in phase with v_{s1}.

From Fig.1, the current and voltage equations of parallel converter in static three-phase system are found as (6) and (7):

$$L_2(d_{i_2}/dt) = v_2 - v_L \qquad (6)$$

$$c_2(d_{v_L}/dt) = i_c = i_2 - i_3 \qquad (7)$$

With (ABC/dq) transformation [2], the two-phase synchronous rotating reference frame equations can be given by:

$$v_{2d} = v_{Ld} - \omega L_2 i_{2q} + L_2(di_{2d}/dt) \qquad (8)$$

$$v_{2q} = v_{Lq} + \omega L_2 i_{2d} + L_2(di_{2q}/dt) \qquad (9)$$

$$i_{2d} = i_{3d} - \omega c_2 v_{Lq} + c_2(dv_{Ld}/dt) \qquad (10)$$

$$i_{2q} = i_{3q} + \omega c_2 v_{Ld} + c_2(dv_{Lq}/dt) \qquad (11)$$

Equation (8), (9), (10), (11) construct the control system for parallel converter with voltage-current loop, as shown in Fig.2. In the voltage loop $V_{Ld}^* = v_R$, $V_{Lq}^* = 0$, while in the current loop the current references i_{2d}^*, i_{2q}^* are the combination of voltage regulator $G_v(s)$ output, feedforward compensated current (i_{3d}, i_{3q}) and the decoupled current ωC_2. And control variables (v_{2d}, v_{2q}) involve current regulator $G_i(s)$ output, feedforward load voltage (v_{Ld}, v_{Lq}) and the decoupled voltage ωL_2. With (dq/ABC) transformation [2], (v_{2d}, v_{2q}) are transformed into three-phase reference frame quantities (v_{2a}, v_{2b}, v_{2c}), and they are respectively compared with triangular carrier wave v_{tr} to obtain the PWM switching signal for parallel converter. Consequently, it is realizable that output voltage v_L pursues the reference V_{Ld}^*.

Based on the control scheme shown above, due to series converter being controlled as a sinusoidal current source, source current i_s is a sine wave form in phase with the fundamental source voltage. So parallel converter compensates the harmonic and reactive components of nonlinear load. At the same time parallel converter is controlled as a sinusoidal voltage source and makes the output voltage v_L a sinusoidal wave form in phase with the

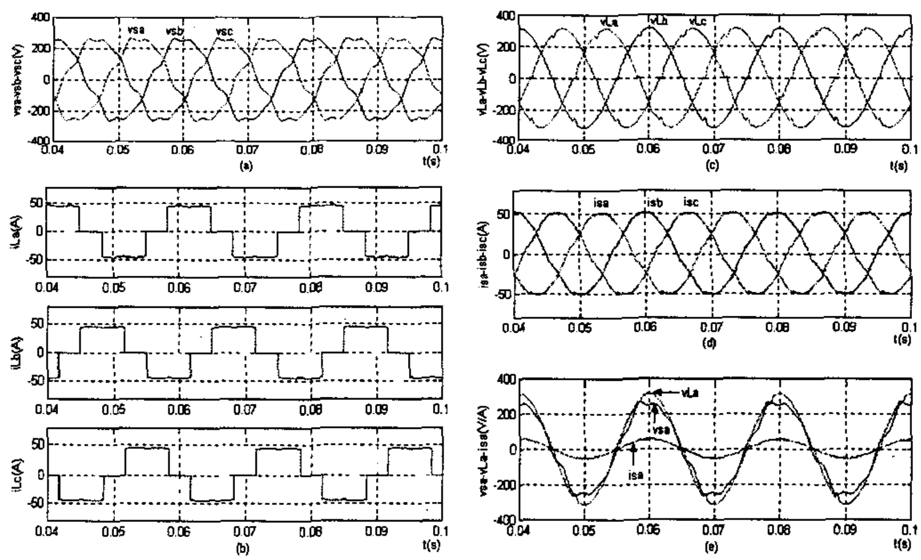

Fig.3. The standby mode waves in case of $v_{s1} = 0.85v_R$ (a)Input source voltage,(b)Load current (c)Output load voltage(d)Input source current,(e)Input voltage,output voltage and input current

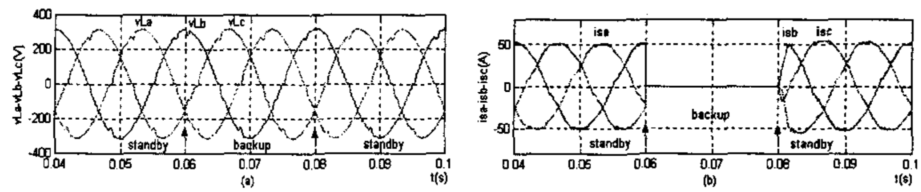

Fig.4. Output voltage and input current waves for Standby to backup mode transition and vice versa

fundamental utility voltage, so the voltage error (involving voltage harmonics and fundamental voltage deviation) between the utility and the load is compensated by the series converter.

IV. SIMULATION RESULTS

Based on the proposed control scheme, the digital simulation model of series-parallel compensated UPS system is made up in MATLAB SIMULINK and some simulation results are obtained to verify the feasibility of the control scheme. In Fig.1, the UPS system considers a ±15% fundamental input source voltage deviation under non-sinusoidal voltage conditions with fifth and seventh harmonics contents. The amplitude of these voltage harmonics is 5% of normal input voltage. The UPS system feeds a 20KW three-phase phase-controlled rectifier. Battery bank voltage $E_b = 440V$, common side capacitance $C = 3300\mu f$, series transformer voltage ratio $N_s = 3.464$, parallel transformer voltage ratio $N_p = \sqrt{3}$, $L_1 = 7mH$, $L_2 = 0.45mH$, $C_2 = 100\mu f$, system sampling frequency 10KHz.

In Fig.3, input source voltage v_s, load current i_L, output voltage v_L and input source current i_s are shown in the case of $v_{s1} = 0.85v_R$ for standby mode. Fig.4 shows the three-phase output voltage and input source current waves during the transition from the standby mode to backup mode (0.06s) and vice versa (0.08s).

V. CONCLUSION

This paper presents a new control scheme based on SRF for series-parallel compensated UPS system. The digital simulation results in Fig.3 prove that the proposed control scheme can make this kind of UPS carry out all of the control goals: sinusoidal input current with $\cos\phi = 1$ and sinusoidal output voltage with normal value in the case of non-sinusoidal, non-normal supply voltage and non-linear load with reactive power. The results in Fig.4 indicate the proposed UPS provided seamless transition from the standby mode to backup mode and vice versa.

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