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A Control Strategy for Combined Series-Parallel Active Filter System under Non-Periodic Conditions

M. Ucar, S. Ozdemir and E. Ozdemir

Electrical Education Department
Technical Education Faculty, Kocaeli University
41380, Umuttepe, Turkey
Phone/Fax number:+90262 3032275 / :+90262 3032203
e-mail: mucar@kocaeli.edu.tr, sozaslan@kocaeli.edu.tr, eozdemir@kocaeli.edu.tr

Abstract. In this study, generalized non-active power theory based control strategy is proposed for a 3-phase 4-wire Combined Series-Parallel Active Filter (CSPAF) system using a Three-Dimensional (3D) Space Vector Pulse Width Modulation (SVPWM). The CSPAF system consists of a Series Active Filter (SAF) and a Parallel Active Filter (PAF) combination connected a common Direct Current (DC) link for simultaneous compensating the source voltage and the load current. The generalized non-active power theory was applied in previous studies for the PAF control, in this study the theory is used for the CSPAF system control under non-sinusoidal and non-periodic current and voltage conditions. The closed loop control algorithm for the proposed CSPAF system has been described to direct control of filtering performance by measuring source currents and load voltages for the PAF and the SAF, respectively. The proposed control strategy has been verified by simulating the CSPAF system in Matlab/Simulink environment.

Key words

Harmonics, unbalance, reactive power compensation, non-periodic, active filter, 3D-SVPWM.

1. Introduction

The large use of non-linear loads and power electronic converters has increased the generation of non-sinusoidal and non-periodic currents and voltages in electric power systems. Generally, power electronic converters generate harmonic components which frequencies that are integer multiplies of the line frequency. However, in some cases, such as line commutated three-phase thyristor based rectifiers, arc furnaces and welding machines, the line currents may contain both frequency lower and higher than the line frequency but not the integer multiple of line frequency. These currents interact with the impedance of the power distribution system and disturb voltage waveforms at Point of Common Coupling (PCC) that can affect other loads. These waveforms are considered as non-periodic, although mathematically the currents may still have a periodic waveform, but in any event, the period of the currents is not equal to the period of the line voltage [1].

In this paper, the generalised instantaneous non-active power theory is used for the CSPAF system under non-sinusoidal and non-periodic load current and source voltage conditions. The CSPAF system consists of back-to-back connection of SAF and PAF with a common DC link. While the PAF compensates current quality problems of load and regulating of DC link, the SAF compensates voltage quality problems of utility [2]. Fig. 1 shows the general power circuit configuration of CSPAF system.

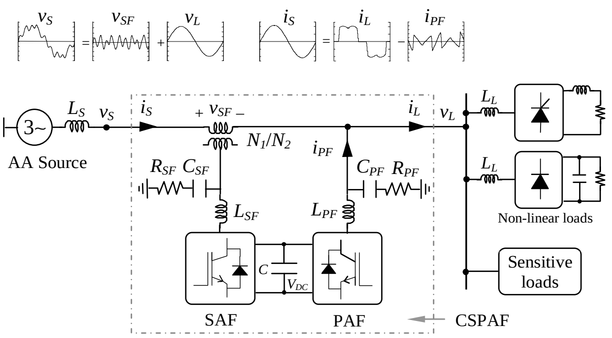


Fig. 1. General power circuit configuration of CSPAF system.

In 3-phase 3-wire systems, conventional SVPWM method, which is based on alpha-beta plane, has been widely used to reduce ripples and to get fixed switching frequency. In this study, the 3D-SVPWM scheme is used for controlling the CSPAF system, which uses two 3-leg 4-wire Voltage Source Inverter (VSI) because the zero sequence components must be controlled [3].

2. Generalized Non-Active Power Theory

The generalized non-active power theory [1] is based on Fryze's theory of non-active power/current. The instantaneous power $p(t)$ and the average power $P(t)$ is defined as the average value of the instantaneous power $p(t)$ over the averaging interval $[t\text{-}T_c, t]$, that is

$$p(t) = v^T(t)\, i(t) = \sum_{p=1}^{3} v_p(t)\, i_p(t) \tag{1}$$

$$P(t)=\frac{1}{T_c}\int_{t-T_c}^{t} p(\tau)\,d\tau \qquad (2)$$

The averaging time interval T_c can be chosen arbitrarily from zero to infinity for compensation of periodic or non-periodic waveforms, and for different T_c's, the resulting active current and non-active current will have different characteristics. The instantaneous active current $i_a(t)$ and non-active current $i_n(t)$ are given in (3) and (4).

$$i_a(t)=\frac{P(t)}{V_r^2(t)}v_r(t) \qquad (3)$$

$$i_n(t)=i(t)-i_a(t) \qquad (4)$$

In closed loop current control strategy, (3) is used and (5) is obtained similarly for closed loop voltage control strategy. The reference voltage $v_r(t)$ and current $i_r(t)$, which are chosen on the basis of the characteristics of the system and the desired compensation results. $V_r(t)$ and $I_r(t)$ are the corresponding effective value of the reference voltage and current. The switching signals of both VSI are produced by 3D-SVPWM technique.

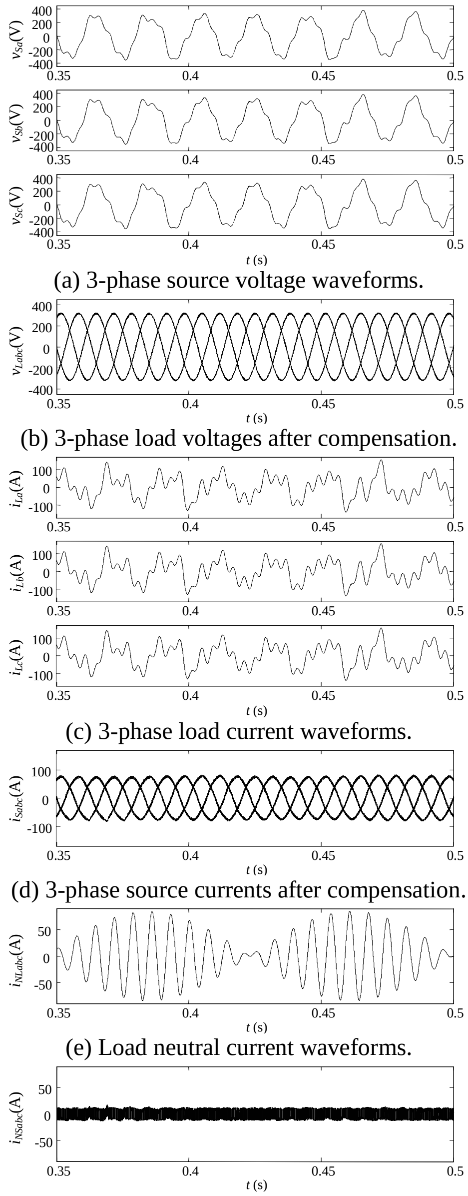
$$v_a(t)=\frac{P(t)}{I_r^2(t)}i_r(t) \qquad (5)$$

3. Non-Periodic Currents and Voltages Compensation

For compensation of periodic currents and voltages with fundamental period T, using a compensation period T_c that is a multiple of $T/2$ is enough for complete compensation. Whereas, the current of arc furnace loads is typically quite irregular. The non-active components in these types of loads cannot be completely compensated by choosing T_c as $T/2$ or T, or even several multiples of T. Choosing that period as may result in an acceptable both source current and load voltage which are quite close to a sine wave. If T_c is large enough, increasing T_c further will not typically improve the compensation results significantly [4]. Fig. 3 shows the non-periodic voltage and current compensation choosing the period as T_c=5T. After compensation, load voltages and source currents are balanced and almost sinusoidal with low THD. Additionally, source neutral current have been reduced considerably.

4. Conclusion

In this paper, the generalized non-active power theory, which is applicable to sinusoidal or non-sinusoidal, periodic or non-periodic, balanced or unbalanced electrical systems, is presented. It has been applied to the 3-phase 4-wire CSPAF system with the 3D-SVPWM to get fixed switching frequency. The theory is adapted to different compensation objectives by changing the averaging interval T_c. The closed loop control algorithm has been described by measuring source currents and load voltages in the proposed CSPAF system to direct control of filtering performance. The simulation results based on Matlab/Simulink software are presented to show the effectiveness of the CSPAF system for the compensation of a variety of non-sinusoidal and non-periodic voltages and currents in power systems.



(a) 3-phase source voltage waveforms.

(b) 3-phase load voltages after compensation.

(c) 3-phase load current waveforms.

(d) 3-phase source currents after compensation.

(e) Load neutral current waveforms.

(f) Source neutral current after compensation.

Fig. 3. Non-periodic voltage and current compensation.

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