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엑티브 필터 기능을 가지는 단상 태양광 PCS의 운전특성 해석

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Operational Characteristic Analysis of a Single-Phase PCS for PV Power Generation System with Active Filter Function

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Abstract - This paper deals with operational characteristic analysis of a single-phase PCS (Power Conditioning System) for PV (Photovoltaic) power generation system with AF (Active Filter) function. The theory of *dq* transformation has been applied to the control strategy of a single-phase PV power generation system to implement the AF function. Application of the virtual two-phase using phase-shift makes it possible to use the *dq* theory for the single-phase PV power generation system. The authors are sure that the proposed system is a very useful to compensate harmonics caused by nonlinear loads in a single-phase utility system. In this paper, not only a theoretical aspect of the single-phase PV-AF system is discussed, but also the DSP (Digital Signal Processor) based experiment results are presented to demonstrate the effectiveness of the single-phase PV-AF system.

1. INTRODUCTION

With some advantages of the limitless resources and pollution free characteristic, the PV power generation systems have been extensively studied and implemented [1], [2]. However, it's a drawback that the PV array loses the output capability when the insolation is weak or it is night. To overcome the disadvantage of the PV power generation system, the three-phase PV-AF system have been proposed by the authors [3].

The grid-connected single-phase PV-AF system is accomplished, in this paper, to compensate the harmonics caused by the nonlinear loads in a single-phase utility system. The virtual two-phase is used to implement the single-phase active filter. By using the phase shift, the ordinary single-phase system is transformed into the virtual two-phase system. The algorithm of virtual two-phase system allows that the theory of *dq* transformation can be applied to the single-phase system. The active filter function using the virtual two-phase is adapted to inverter control of the single-phase PV-AF system.

2. PRINCIPLES OF THE SINGLE-PHASE PV-AF SYSTEM

2.1 Single-Phase AF System

The theory of instantaneous reactive power and *dq* transformation are adopted to extract the harmonic components in this paper [4].

In this paper, an algorithm of virtual two-phase using phase shift is implemented for the single-phase AF function. This algorithm can be performed as follows:

In the single-phase system, the feedback current can be defined as phase_α in (1). And more than one forth cycle of the sampled feedback current is stored in the buffer memory. The memory indexes for the estimated phase_β can be calculated, which correspond to the phase-shift equal to -π/2 as (1).

$$I_{load\_\alpha}(t) = I_1\sin(\omega t) + I_3\sin(3\omega t) + I_5\sin(5\omega t) + I_7\sin(7\omega t) + \dots \quad (1)$$
$$I_{load\_\beta}(t) = I_1\cos(\omega t) - I_3\cos(3\omega t) + I_5\cos(5\omega t) - I_7\sin(7\omega t) + \dots$$

With the virtual two-phase, the general *dq* transformation described in (2) can be utilized for the single-phase system as follows.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

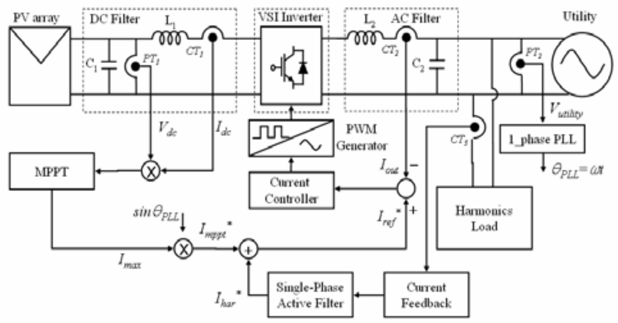
Using the *dq* transformation, the virtual two-phase is transformed into the two-axes orthogonal rotating coordinate system as given in (3).

$$i_d(t) = (I_3 + I_5)\sin(4\omega t) + (I_7 + I_9)\sin(8\omega t) + \dots \quad (3)$$
$$i_q(t) = I_1 + (I_3 + I_5)\sin(4\omega t) + (I_7 + I_9)\sin(8\omega t) + \dots$$

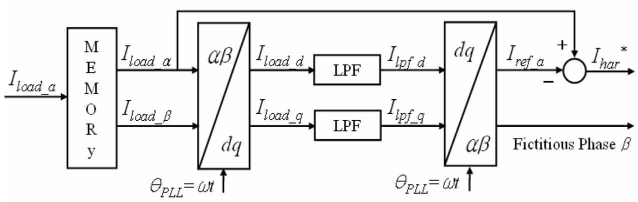
The fundamental component is shown as dc component, and the harmonic components are expressed as 4kf Hz component(f = fundamental wave, k = 1, 2, 3, …). Therefore, with a low pass filter (LPF), the fundamental components can be extracted [4]. After the inverse *dq* transformation, the harmonic reference currents of the virtual two-phase are defined as in (4) after removing the fundamental components.

$$I_{load\_\alpha}(t) = I_3\sin(3\omega t) + I_5\sin(5\omega t) + I_7\sin(7\omega t) + \dots \quad (4)$$
$$I_{load\_\beta}(t) = -I_3\cos(3\omega t) + I_5\cos(5\omega t) - I_7\sin(7\omega t) + \dots$$

The phase_α of the above virtual two-phase is only used as the reference current for the single-phase PV-AF system.



<Fig. 1> Control diagram of single-phase PV-AF system



<Fig. 2> Algorithm of single-phase active filter

<Fig. 3> Manufactured 3kw single-phase PCS

<Table 1> Specifications of manufactured PCS

Capacity	L_{DC}	C_{DC}	L_{AC}	C_{AC}	G	Trans.
3kW	1mH	2200μF	6mH	5μF	IGBT	220/50V 60Hz

<Table 2> Load conditions

LOAD	L	C	R
Rectifier with RLC	5mH	2200μF	20Ω

2.2 Single-Phase PV-AF System

Fig. 1 represents the main circuit diagram and the control schemes of the single-phase PV-AF system. As shown in Fig. 1, the compensation theory of AF is adopted in the inverter control of conventional PV power generation system. With the algorithm of single phase AF function shown in Fig. 2, the harmonic components can be extracted through the process explained in section 2.1. The harmonic components are applied to the control strategy of inverter as the reference current of AF function. The inverter is used to realize the MPPT (Maximum Power Point Tracking) control of the PV array output in the single-phase PV-AF system. Therefore there exist two reference currents in the single-phase PV-AF system. One is used as the reference current of MPPT controller for making maximum power output to the grid, and the other is used as the reference current to perform the active filter function. Even at night time, the inverter of single-phase PV-AF system can still be operated as an active filter.

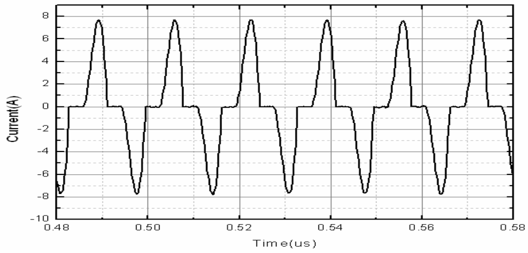
3. EXPERIMENT RESULTS

3.1 Experiment Conditions

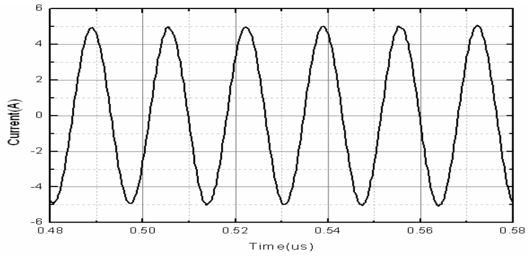
In order to demonstrate the effectiveness of the proposed single-phase PV-AF system, a DSP based experiment is performed and the results are discussed. A diode bridge rectifier with RL load is adopted to verify the harmonics compensation properties. Fig. 3 shows a manufactured 3KW single-phase PCS, and table 1 and 2 show the specifications of manufactured PCS and load condition, respectively.

3.2 Experiment Results

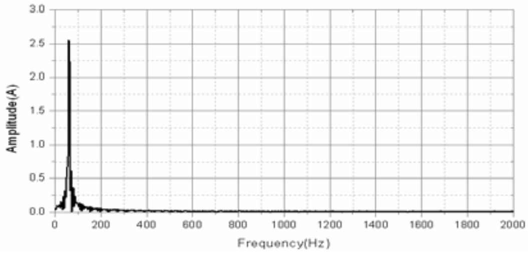
The utility current without active filter function is shown in Fig. 4. The utility current contains harmonic currents due to the nonlinear loads. This non-sinusoidal current causes a serious problem of power quality in the utility system. Fig. 5 depicts the utility current in which the harmonic current is provided by the inverter. The utility current is sinusoidal because of the PV-AF system performance. The Fast Fourier Transform (FFT) analysis of utility current with AF function is shown in Fig. 6. There are no serious harmonics. All of the experiment results agree with theoretical analysis. The experiment results verify that the single-phase PV-AF system can effectively reduce the harmonic current without any instability problem.



<Fig. 4> Utility current without AF function



<Fig. 5> Utility current with AF function



<Fig. 6> FFT result of utility current with AF function

4. CONCLUSIONS

In this paper, a single-phase PCS for PV power generation system with AF function is developed and the operational characteristic of the system is represented. The active filter function using the virtual two-phase is applied to the inverter control of the single-phase PV-AF system. The single-phase PV-AF system not only delivers the active power produced by PV array to the grid but also compensates the harmonic current even under low insolation weather conditions or at night time. The experiment results indicate that the proposed system with active filter function contributes to the enhancement of utility power quality.

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[REFERENCES]

[1] E. Roman, R. Alonso, P. Ibanez, S. Elorduizapatarietxe, and D. Goitia, "Intelligent PV module for grid-connected PV systems," IEEE Trans. on Industrial Electronics, vol. 53, no. 4, pp. 1066-1073, 2006

[2] A. Fernandez-Infantes, J. Contreras, and J. L. Bernal-Agustin, "Design of grid connected PV systems considering electrical, economical and environmental aspects: A practical case,"Elsevier Trans. on Renewable Energy, vol. 31, no. 13, pp. 2042-2062, 2006

[3] Seong Nak-gueon, Lee Jae-deuk, Kim Bong-tae, Park Min-won and Yu In-keun, "Novel concept of a PV power generation system adding the function of shunt active filter" Trans, IEEE/PES, vol. 3, pp. 1658-1663, 2002

[4] S. Srianthumrong, H. Fujita, and Akagi, "Stability Analysis of a Series Active Filter Integrated with a Double-Series Diode Rectifier,"IEEE Trans. on Power Electronics, vol. 17, no. 1, pp. 117-124, 2002