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 [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. 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.

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

\[
\begin{bmatrix}
    i_d \\
    i_q
\end{bmatrix} =
\begin{bmatrix}
    \cos(\theta) & \sin(\theta) \\
    -\sin(\theta) & \cos(\theta)
\end{bmatrix}
\begin{bmatrix}
    i_\alpha \\
    i_\beta
\end{bmatrix}
\]

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

\[
i_d(t) = (I_d + I_s \sin(4\omega t) + I_s \sin(8\omega t) + ... \\
i_q(t) = I_q + (I_d + I_s \sin(4\omega t) + I_s \sin(8\omega t) + ...)
\]

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.

\[
\begin{align*}
I_{\text{Harm, } \alpha} &= I_d \sin(3\omega t) + I_s \sin(5\omega t) + I_s \sin(7\omega t) + ... \\
I_{\text{Harm, } \beta} &= -I_d \cos(3\omega t) + I_s \cos(5\omega t) - I_s \sin(7\omega t) + ...
\end{align*}
\]

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

![Control diagram of single-phase PV-AF system](image1)

![Algorithm of single-phase active filter](image2)
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.

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