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A NOVEL ANTI-ISLANDING METHOD IN THE THREE PHASE PV-AF POWER GENERATION SYSTEM

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ABSTRACT
Islanding is the electrical phenomenon in a part of a power network disconnected from the utility, where the loads are entirely supplied by PV(Photovoltaic) systems, and the voltage and frequency are maintained around nominal values. But the probability of islanding is extremely low, and it may never occur in practice. At the point of disconnection of an islanding, it is essential that the active power of PV system is very close to the active power of the loads, and that the reactive power of PV-system is very close to zero. But unintentional islanding may result in power-quality issues, interference to grid-protection devices, equipment damage, and even personnel safety hazards. This paper proposes that the three phase PV-AF (Photovoltaic and active filter) system fundamentally has the anti-islanding function. So, in this paper, anti-islanding function of this system is explained. And it is evaluated by simulations, using PSCAD/EMTDC.

KEY WORDS
Islanding, Active filter, PV-AF Generation system, Photovoltaic(PV), PSCAD/EMTDC

LIST OF SYMBOLS

e_a, e_b, e_c = utility voltage [*V*]
e_{dc} = output voltage of PV array [*V*]
e^*_{dc} = voltage reference of PV array [*V*]
i_{out} = inverter output current [*A*]
i^*_{power}= current reference of active power[*A*]
i_{load_a}, i_{load_b}, i_{load_c} = load current [*A*]
i_{load_d} = d-axis component of load current [*A*]
i_{load_q} = q-axis component of load current [*A*]
i_{d_lpf} = dc component of i_{load_d} [*A*]
i_{q_lpf} = dc component of i_{load_q} [*A*]
$i_{har\_d\_ref}$ = d-axis component of harmonics current [*A*]
$i_{har\_q\_ref}$ = q-axis component of harmonics current [*A*]
i_d = d-axis component of inverter output current [*A*]
i_q = q-axis component of inverter output current [*A*]
v_{qs} = beta component of utility voltage [*V*]
i_{power_q} = q-axis current reference of MPPT(Maximum Power Point Tracking) [*A*]
I_a, I_b, I_c = inverter output current [*A*]
I_R, I_S, I_T = harmonics components of inverter output current [*A*]

1. Introduction

When many PV(Photovoltaic) generation systems are connected to a low voltage network, it is possible for the power generated by the PV-systems to be exactly equal to the power consumed by the loads in that network. In this situation there is no power flow from the main supply at the distribution transformer. If the power transformer is disconnected, it may be possible that the PV systems maintain the voltage in the network feeding all connected loads. This situation is called islanding. An unintentional islanding is not acceptable by any power utility [1]. Unintentional islanding of PV system may result in power-quality issues, interference to grid-protection devices, equipment damage, and even personnel safety hazards [2]. So, anti-islanding method is needed in the PV generation systems.

There are generally two types of anti-islanding methods. One is passive method. And the other is active method. The conventional passive method just measures voltage, frequency, phase, and harmonics. If a suspicious value is detected, it will stop operating. Conventional active methods drift a little frequency. So, if the utility is disconnected at the power matching condition, it will stop operating because of change of the frequency.

Passive methods have wide non-detection zone (NDZ). And, active methods have small size of NDZ and power quality degradation.

The PV-AF(Photovoltaic and active filter) system is a particular photovoltaic generation system that is added the active filter function. That compensates harmonics current for power quality of utility [3].

The paper proposes that the PV-AF system fundamentally has the anti-islanding method. So, this system doesn't have any NDZ, moreover, the active filter function improves the power quality.

In the first part of this paper, the PV-AF system is introduced, and why the PV-AF system fundamentally has the anti-islanding function is explained. Finally, this method is analyzed and evaluated by computer simulations, using PSCAD/EMTDC that is used for power system and power electronics modeling.

2. PV-AF System

The basic hardware system of the PV power generation adding the function of AF (Active Filter) is very similar and almost close to the general PV generation system. The compensation theory of the AF system is adapted to the inverter control. Including the function of AF in the PV power generation system connected to the utility system would be very helpful for the improvement of power quality for individual consumers rather than for utility system. Fig. 1 shows the control block diagram of the PV-AF system. In this system, constant voltage control for MPPT is applied [3].

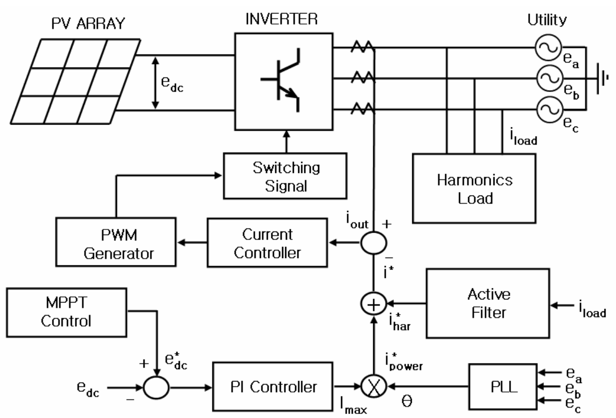


Fig. 1 Control Block diagram of the PV-AF system

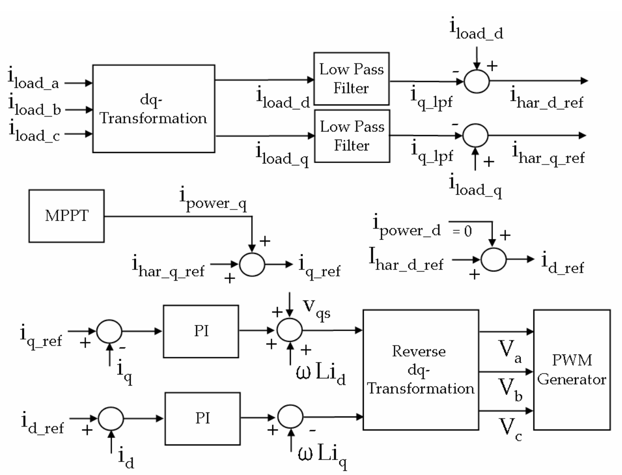


Fig. 2 Control block diagram of the active filter and current control

The PV-AF System has two references. One is the current reference of the PV output power control (MPPT control, Constant voltage control, etc) [4]-[5], and the other is the current reference of active filter function. The active filter function detects harmonics currents of load. Then the inverter compensates harmonics currents instead of utility.

The control block diagram of the active-filter function and current control is shown in Fig. 2, which consists of a Park's transformation, a low pass filter (LPF), PI control and a reverse Park's transformation [6]-[10].

As shown in Fig. 2, Load currents (i_{load_a}, i_{load_b}, i_{load_c}) are transformed into d, q axis component of load current. As this result, a fundamental of load current is transformed into dc-component. So, d, q axis component of load current minus dc-component of it are d, q axis component of harmonics current ($i_{har\_d\_ref}$, $i_{har\_q\_ref}$).

Sum of q axis component of harmonics current and it of a current for active-power ($i_{har\_q\_ref} + i_{power\_q}$) is total q-axis reference of inverter output current. And d-axis reference is also sum of d axis component of harmonics current and a current reactive-power ($i_{har\_d\_ref} + i_{power\_d}$). But in this system, i_{power_d} is zero.

Current control is used to the linear rotating frame current controller.

3. Anti-islanding Method in PV-AF System

The three phase PV-AF power generation system fundamentally may have the anti-islanding function, because if the utility is disconnected at the power matching condition, the active filter function compensates harmonics currents more and more. Therefore, islanding is prevented. In this section, why active filter function compensates harmonics currents and islanding is prevented are explained.

For three-phase inverters, the harmonics numbers are

$$n = 6c \pm 1, where\ c = 1,2,3,... \qquad (1)$$

So, the output current of inverter is

$$I_{out} = I_1 \cos\theta + I_5 \cos 5\theta + I_7 \cos 7\theta + I_{11} \cos 11\theta + I_{13} \cos 13\theta + ... \qquad (2)$$

For parallel R-L-C Loads, low order harmonics currents flow mostly into the utility from the PV-AF system. But if the utility is disconnected, these currents will flow into loads from the inverter.

$$I_{load} = I_{out} \text{ (Because utility is disconnected)}$$

So,

$$I_{load} = I_1 \sin\theta + I_5 \sin 5\theta + I_7 \sin 7\theta + I_{11} \sin 11\theta + I_{13} \sin 13\theta \cdots \qquad (3)$$

If that is expressed in the three phase,

$$I_a = I_1 \sin\theta + I_5 \sin 5\theta + I_7 \sin 7\theta + I_{11} \sin 11\theta + I_{13} \sin 13\theta \cdots$$

$$I_b = I_1 \sin\left(\theta - \frac{2}{3}\pi\right) + I_5 \sin 5\left(\theta - \frac{2}{3}\pi\right) + I_7 \sin 7\left(\theta - \frac{2}{3}\pi\right) + I_{11} \sin 11\left(\theta - \frac{2}{3}\pi\right) + I_{13} \sin 13\left(\theta - \frac{2}{3}\pi\right) \cdots$$

$$I_c = I_1 \sin\left(\theta + \frac{2}{3}\pi\right) + I_5 \sin 5\left(\theta + \frac{2}{3}\pi\right) + I_7 \sin 7\left(\theta + \frac{2}{3}\pi\right) + I_{11} \sin 11\left(\theta + \frac{2}{3}\pi\right) + I_{13} \sin 13\left(\theta + \frac{2}{3}\pi\right) \cdot$$

α-β transformation is

$$\begin{aligned} I_\alpha &= I_1 \sin\theta + I_5 \sin 5\theta + I_7 \sin 7\theta + I_{11} \sin 11\theta + I_{13} \sin 13\theta \cdots \\ I_\beta &= -I_1 \cos\theta - I_5 \cos 5\theta - I_7 \cos 7\theta - I_{11} \cos 11\theta - I_{13} \cos 13\theta \cdots \end{aligned} \quad (4)$$

DQ transformation is

$$\begin{aligned} I_D &= (I_5 - I_7)\sin 6\theta + (I_{11} - I_{13})\sin 12\theta \\ I_Q &= I_1 + (I_7 - I_5)\sin 6\theta + (I_{13} - I_{11})\sin 12\theta \end{aligned} \quad (5)$$

If DC component is disregarded

$$\begin{aligned} I_{D\_ref} &= (I_5 - I_7)\sin 6\theta + (I_{11} - I_{13})\sin 12\theta \\ I_{Q\_ref} &= (I_7 - I_5)\sin 6\theta + (I_{13} - I_{11})\sin 12\theta \end{aligned} \quad (6)$$

Reverse transformation is

$$\begin{aligned} I_R &= I_5 \sin 5\theta + I_7 \sin 7\theta + I_{11} \sin 11\theta + I_{13} \sin 13\theta \cdots \\ I_S &= I_5 \sin 5\left(\theta - \frac{2\pi}{3}\right) + I_7 \sin 7\left(\theta - \frac{2\pi}{3}\right) + I_{11} \sin 11\left(\theta - \frac{2\pi}{3}\right) + I_{13} \sin 13\left(\theta - \frac{2\pi}{3}\right) \cdots \\ I_T &= I_5 \sin 5\left(\theta + \frac{2\pi}{3}\right) + I_7 \sin 7\left(\theta + \frac{2\pi}{3}\right) + I_{11} \sin 11\left(\theta + \frac{2\pi}{3}\right) + I_{13} \sin 13\left(\theta + \frac{2\pi}{3}\right) \cdots \end{aligned} \quad (7)$$

So, current reference is

$$\begin{aligned} i_a^* &= I_{mppt} \sin\theta + I_5 \sin 5\theta + I_7 \sin 7\theta + I_{11} \sin 11\theta + I_{13} \sin 13\theta \cdots \\ i_b^* &= I_{mppt} \sin\left(\theta - \frac{2\pi}{3}\right) + I_5 \sin 5\left(\theta - \frac{2\pi}{3}\right) + I_7 \sin 7\left(\theta - \frac{2\pi}{3}\right) + I_{11} \sin 11\left(\theta - \frac{2\pi}{3}\right) + I_{13} \sin 13\left(\theta - \frac{2\pi}{3}\right) \cdots \\ i_c^* &= I_{mppt} \sin\left(\theta + \frac{2\pi}{3}\right) + I_5 \sin 5\left(\theta + \frac{2\pi}{3}\right) + I_7 \sin 7\left(\theta + \frac{2\pi}{3}\right) + I_{11} \sin 11\left(\theta + \frac{2\pi}{3}\right) + I_{13} \sin 13\left(\theta + \frac{2\pi}{3}\right) \cdots \end{aligned} \quad (8)$$

Generally, the PV-AF system detects harmonics currents that flow into the loads. Then it compensates harmonics currents. So, if the utility is disconnected at almost 100% power matching and passive RLC load condition, harmonics currents of the inverter will flow into the load, and the PV-AF system will compensate these harmonics currents. Then harmonics currents that flow into the loads will increase continuously. Therefore, frequency of system will be changed. And the system will be stopped by the relays for abnormal frequency conditions.

4. Methods of Simulation

In this work, simulations are carried out by PSCAD/EMTDC.

Fig. 3 shows a brief configuration of the power system, which includes a PV-AF system and a passive RLC load. The PV-AF is connected to the utility, and the passive load for testing the islanding is connected near the terminal. And the PV array is replaced by a DC source. Because of causing islanding condition, the PCS is assumed to generate constant active power.

The specifications of the utility are listed in Table 1.

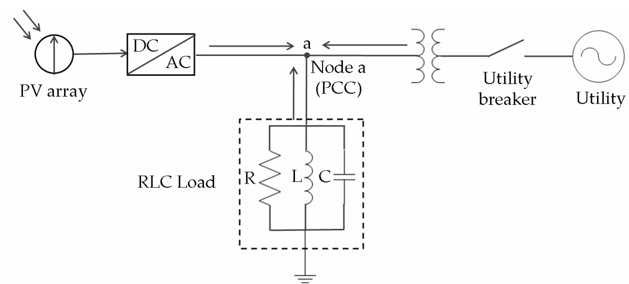


Fig. 3 Configuration of the power system

Table 1
Condition of the utility

Frequency	60[*Hz*]
Line to line voltage	380[*V*]
Line to neutral voltage	220[*V*]
Grid inductance	1E-5[*H*]

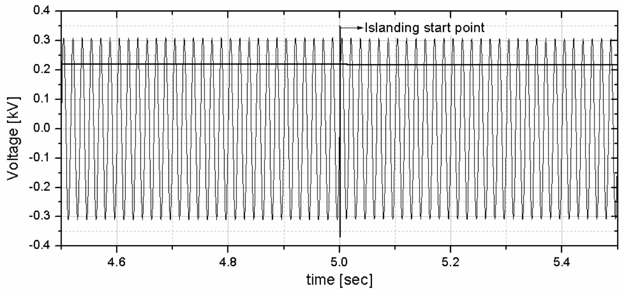
5. Simulation Results and Discussion

The PV system without anti-islanding method and PV-AF system is simulated using the same load condition, P=10[*kW*] and Qf=2.5.

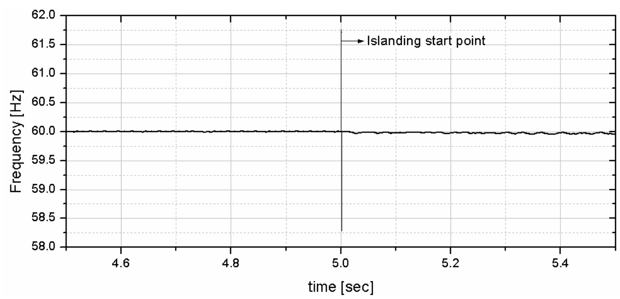
The three major output current controllers for a voltage source inverter are hysteresis control, ramp comparison control, linear rotating frame current control, and predictive current control. In this paper, the current controller used to linear rotating frame current control. And the inverter is operating at 10[*kW*].

5.1 Baseline case without active-filter function and anti-islanding method

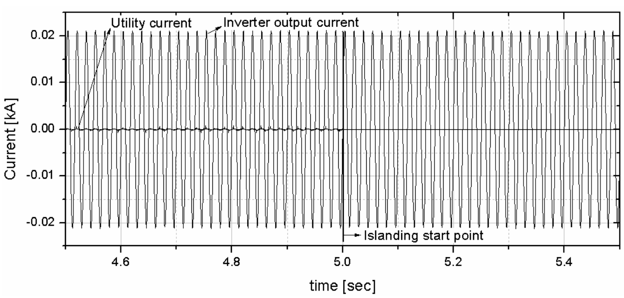
Before demonstrating the effectiveness of the proposed anti-islanding method in the PV-AF system, a baseline case without active-filter function and any anti-islanding method is simulated. Passive loads are selected as: R=14.67[*Ω*], L=15.46[*mH*], and C = 455[*uF*]. So, the load quality factor is 2.5. At 5 second from simulation, utility was disconnected. As shown in Fig. 4, the inverter can easily follow the nominal voltage and frequency despite of disconnecting the utility. Moreover, as shown in Fig. 4(b), a little deviation of the frequency is appeared because of a small reactive power mismatch.



(a) Inverter output voltage and RMS Value

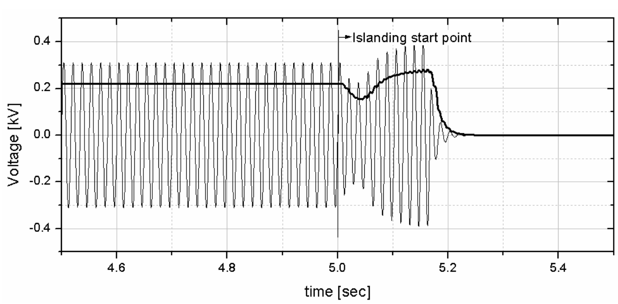


(b) Inverter measured frequency

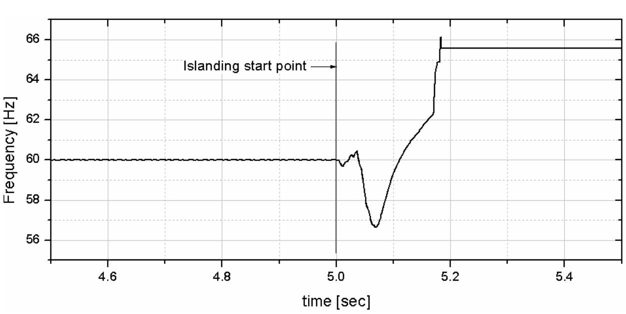


(c) Inverter output current and utility current

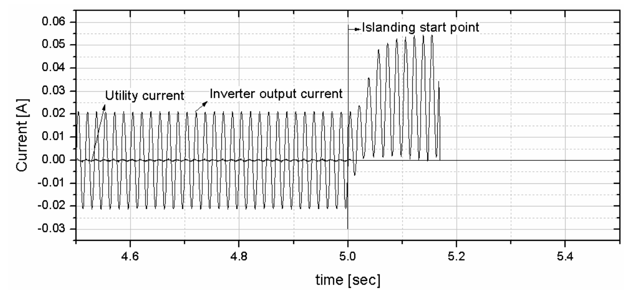
Fig. 4 Simulation results without active filter function and any anti-islanding function (P=10[*kW*], Qf = 2.5)



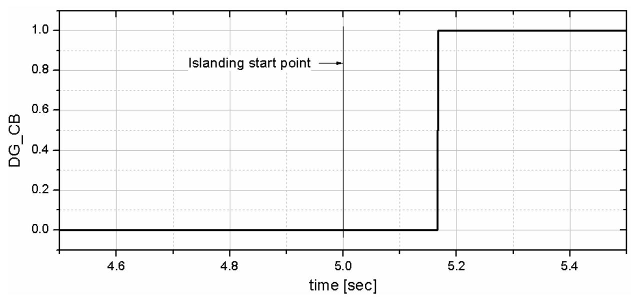
(a) Inverter output voltage and RMS Value



(b) Inverter measured frequency



(c) Inverter output current and utility current



(d) Inverter trip signal

Fig. 5 Simulation results with active filter function (P = 10[*KW*], Qf = 2.5)

5.2 PV system with active filter function in islanding with P = 10[*kW*], Qf = 2.5

In case of this simulation, PV system with active filter function in islanding was simulated. In this case, islanding is protected.

Fig. 5 (c) shows the PV-AF system under the same power level and load quality-factor conditions.

As shown in Fig. 5, when the utility is disconnected with the load matching condition, the voltage and frequency are changed. After 0.167[*sec*], the inverter is tripped by over-frequency relay as shown in Fig. 5 (d). The PV-AF system can be protected from islanding without anti-islanding method.

At 5[*sec*], the utility breaker is disconnected. So, the harmonics currents of inverter, described in equation (2) flow into the load. Active filter compensates these harmonics current continuously. And the current controller diverges.

6. Conclusion

This paper presents a novel anti-islanding method in the three phase PV-AF power generation system. The conventional passive method has widespread NDZ (Non-detection zone). The conventional active method doesn't have NDZ. But it has current distortion.

The PV-AF System has fundamentally anti-islanding protection function without any additional anti-islanding technologies. It doesn't any have NDZ moreover, it can compensate the harmonics current of load. So, it improves the power quality.

In the near future, we would make the real islanding hardware system and carry out the experiment using real hardware.

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