Islanding Detection for PV System Connected to a Utility Grid

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Abstract - Prevention of the islanding phenomena is one of the most important issues because it can damage electrical equipment connected to the utility system and endanger human life.

It is very difficult to detect an islanding condition of a power distribution line with conventional voltage of frequency relays, while the output power and the load power of utility interactive PV inverter units are in nearly balanced state in both active power and reactive power.

This paper describes the protective equipment that prevents the PV system connected to the utility grid from starting islanding.

Both predictive control method and harmonic injection method are used for a current control and islanding detection for operating safety.

1. Introduction

With today's global environmental and energy problems high expectations exist for solar power generation to reduce So_x and Co_2 generated by the consumption fossil fuels[1].

On the other hand, power consumption in residential homes is increasing every year, resulting in a need to develop energy - efficient system for home use.

Therefore, photovoltaic and fuel cell generation systems be watched as a reinforcement of large scale power source and green energy.

Power supply of the former is accommodated supply by development of large power source, but demand control with load management consideration or demand-side management need progressive in future and that development and introduction of dispersed generation system necessary efficiency application of various energy source.

"Dispersed storage and generation system" means that possible power source on small scale consumption area nearness dispersion arrangement unlike large scale power source of existing a power corporation.

Development and introduction of dispersed generation system effective variously energy saving, improvement of energy security Co_2 exhaust suppression on environment, local unbalanced settle of power demand and supply, stiffened relaxation of power demand and supply, both stability power source expectation with utility interactive PV inverter and send excess power to the utility system, and so on.

Dispersed generation system means that dispersion in itself, because power system of utility interactive system has many difficult problem of management, etc.

Many problems is voltage fluctuation of power system, protection coordination, islanding, harmonics, increment of power system short capacity, and so on.

Therefore, system is requested below item in utility interactive system.

1) quality maintenance of power (voltage fluctuation, power factor, harmonics, etc)
2) protection coordination of system side
3) safety security of the human body, equipment connected with the system

The importance of islanding protection is increasing together with the spread of PV systems and the increase of PV systems connected to the utility grid.

Islanding is a phenomenon with the PV power station continues to operate during a power failure as long as the output of the power station is balanced with the power consumption of the load.

Therefore, technology to prevent islanding is necessary to assure maintenance personnel's safety.

In this paper, the method to inject arbitrary order harmonics into controlled current is proposed. In this method islanding can be detected by measuring the amount of load voltage of injected harmonics order.

And then, the proposed method is verified by experiment.

2. Circuit configuration of PV inverter

The PV inverter consists of solar cell, the line-side isolation transformer, intermediate inductor between inverter and utility and controller implemented by the DSP.

Block diagram of main circuit configuration is shown in Fig. 1. The control unit has the functions of the current control, the islanding detection and the system protection.

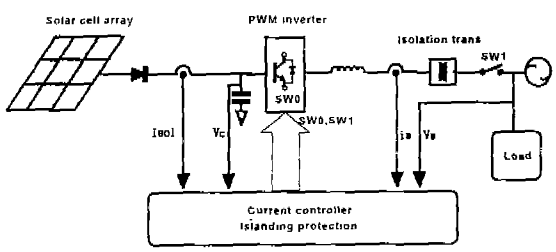

Fig. 1. System configuration of utility interactive photovoltaic system

2-1. Current controller

Inverter output must be controlled by unit factor and sin wave. It used CCS for generation power of high quality and high efficiency. Therefore, in this study, we applied prediction current control technique that has advantage of current ripple being little and transient response being rapid.

Inverter voltage V_{inv} of prediction current control technique show Fig. 2.

In inverter of equivalent circuit, real current for following reference current per sampling period be calculated by instantaneous voltage of inverter. Power source voltage is supposed to be constant while sampling time T_{samp}.

Reference current was given in order to follow the present current and the next one.

The reference voltage of the inverter is calculated by following Eq. 1.

$$V^*_{inv}(k+1) = R_s i_s(k) + L\frac{i^*s(k+1) - i_s(k)}{T_{samp}} + v_s(k) \quad (1)$$

And switch on time show Fig. 3. Eq. 2 is calculated like this space(A) of inverter reference voltage being equal to space (B) of pulse width in one sampling period.

$$T_{on} = \frac{|v^*_{con}(K)|}{V_c(K)} T_s \quad (2)$$

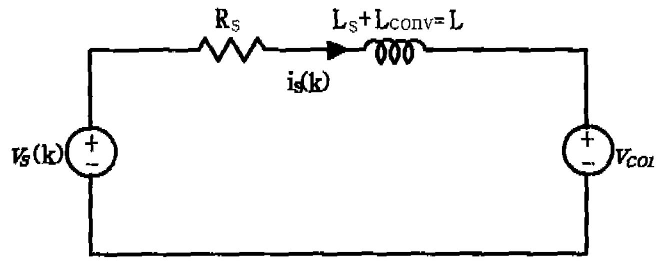

Fig. 2. Equivalent circuit of inverter

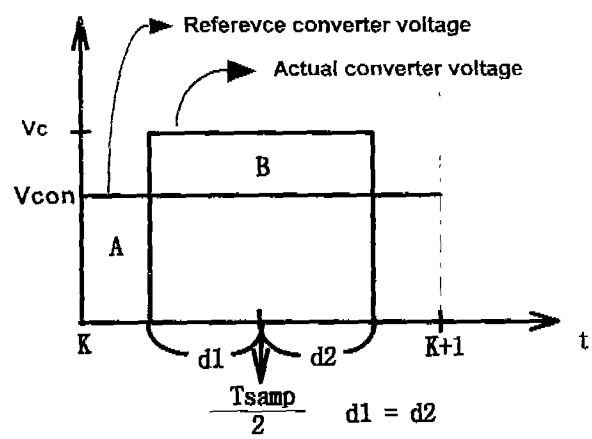

Fig. 3. Modulation method by calculation

If switch ON time decide, off time T_{off} is calculated by Eq. 3.

$$T_{off} = T_s - T_{on} \tag{3}$$

If ON time T_{on} increase more than sampling time, ON time are in accord with sampling time.

3. Islanding detection

Protection system of interconnected with the electric utility system supervise the voltage and frequency in interconnection of utility grid.

The system is disconnected from islanding detection in utility power failure. That is, if generation power of system and load capacity are unbalance, voltage and frequency of interconnection vary largely while system is islanding. In this reason, it be out of normal range. Therefore, we can detect islanding.

But, if generation power of system and load capacity is nearly balanced, voltage and frequency of interconnection are little changed while system is islanding.

Due to this result, islanding detection is difficult.

The function of islanding detection is necessary in this case. The function of islanding detection is active mainly by inverter control, which is passive and active method [2, 3].

Nowadays, proposed islanding detection method summarize table 1. - passive and active method.

Methods		Principle
Passive Method	Voltage phase jumping	Detecting abrupt phase change of voltage caused by unbalanced between generating power and load.
	Frequency change rate	Detecting abrupt frequency change caused by unbalanced between generating power and load.
	Increase of 3rd harmonics voltage	Detecting 3rd harmonics caused by the magnetizing characteristics of pole transformer. Applicable for current controlled inverter for mono phase circuit.
Active Method	Frequency shift	Adding frequency bias or oscillation for inverter control circuit which causes frequency shift at islanding state.
	Active power variation	Adding periodic variation for active power reference which causes frequency and voltage variation at islanding state.
	Reactive power variation	Adding periodic variation for reactive power reference which causes frequency and voltage variation at islanding state.
	Load variation	Inserting parallel impedance momentary and periodically and detecting the rapid change of voltage and current at islanding state.

Table 1. Proposed islanding detection for PV generation systems

Islanding detection can increase reliability with combination of passive and active method.

3.1 Dead zone of islanding detection

As islanding detection system used in the past, there are voltage and frequency relay.

By this, PV inverter disconnect from utility power system when the trouble of voltage and frequency detect.

This is based on protection function.

It is very difficult to detect an islanding condition of a power distribution line with conventional voltage or frequency relays, while the output power and the load power of utility interactive PV inverter units are in nearly balanced stats in both active power and reactive power, because a big enough voltage or frequency change can not be expected at such a balanced state.

If active power and reactive power flow are ΔP, ΔQ about before disconnect, voltage and frequency relays can not detect in $\Delta P=0$, $\Delta Q=0$, because dead zone exist[1].

These days, proposed dead zone concept of islanding detection technique is shown in Fig. 4.

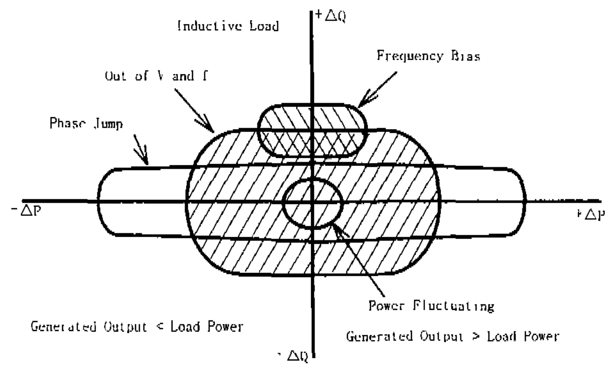

Fig. 4. Non detection zone

3.2 Voltage and frequency of islanding

Islanding equivalent circuit is shown in Fig. 5.

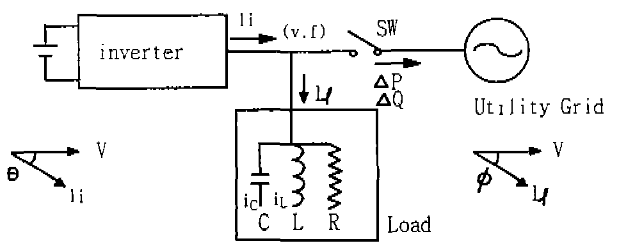

Fig. 5. Islanding equivalent circuit

(a) Voltage of islanding

Consumption power is decided only by resistance R in steady load side and is concluded Eq. 4. This relationship is shown in Fig. 6.

$$P = VI_i \cos\theta = \frac{V^2}{R} \quad (4)$$

P : Active Power

V : Voltage

I_i : Inverter current

θ : Phase angle of inverter current

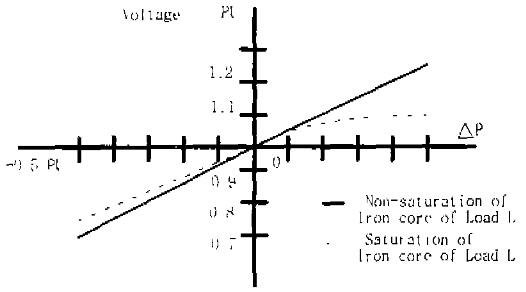

Fig. 6. Reverse power flow ΔP and voltage at islanding

(b) Frequency of islanding

Reactive of load in normal case is concluded Eq. 5 in circuit of condenser C and reactor L.

$$Q = VI_i \sin\theta = VI_l \sin\theta = V(|i_L| - |i_C|) \quad (5)$$

$$= V\left(\frac{V}{2\pi fL} - \frac{V}{\frac{1}{2\pi fC}}\right)$$

Q : Reactive power

Il : Load current

θ: Power factor angle of load

f : Frequency

From this equation, supply reactive power and necessary reactive power of load is necessary balance when inverter is islanding. Consequently, frequency f varies and balance complete.

If inverter operates, $\cos\theta = 1$, Q=0 and frequency f is changed.

In this result, $|i_L| = |i_C|$ complete and balance at $\theta = 0$.

4. The algorithm for islanding protection

If the line is normal, the line impedance is so small that the injected harmonics component of the load voltage will be very small. But if the line is fault, the harmonic component of load voltage is significant because the source side impedance is increased rapidly. The basic idea of this method is very simple, but it may cause high current THD. Therefore, small amplitude of harmonics is required for low THD.

Fig.7 is the block diagram of algorithm detecting the islanding phenomena, and in the algorithm, the transition of band pass filter which filter out the harmonics was considered. The filter transition may cause the malfunction of islanding detector. Namely, by applying other load, filter can go into transition state because of varied source side impedance which is seen from inverter side. It can misinform to the first filter transition, detector must examine the filter output again to decide whether it is a islanding or not.

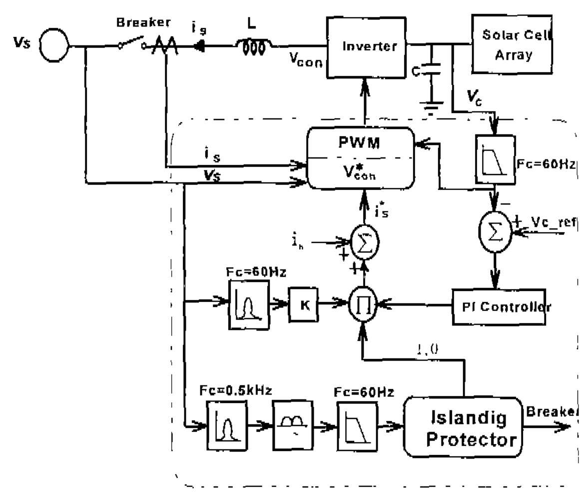

Fig. 7. Block diagram for islanding detection

5. Experimental results

Source voltage 40[V], solar cell output 133[W], AC side load 12[Ω], inverter output side inductance 5[mH], bandwidth of band pass filter for harmonics 40[Hz].

Fig. 8 shows that voltage and current are controlled in phase.

In Fig. 9(c), Harmonics are very small before line fault occurs because there is small source side impedance. But, harmonics are increased after line fault occurs. Fig. 9(c) presents the experimental results.

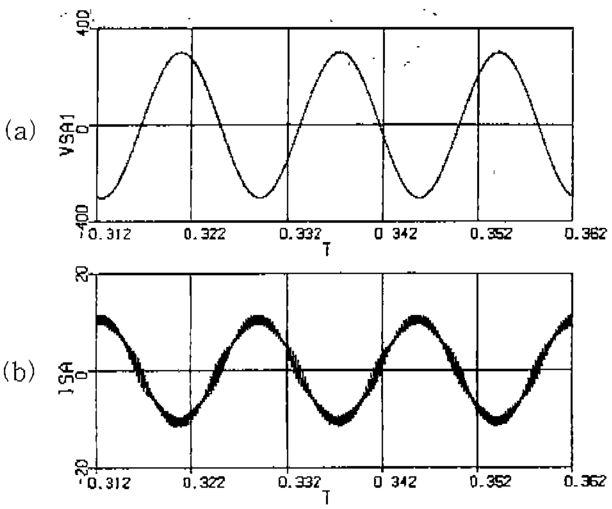

Fig. 8. Steady state source voltage and current waveform before power failure
(a) Source voltage (b) Current

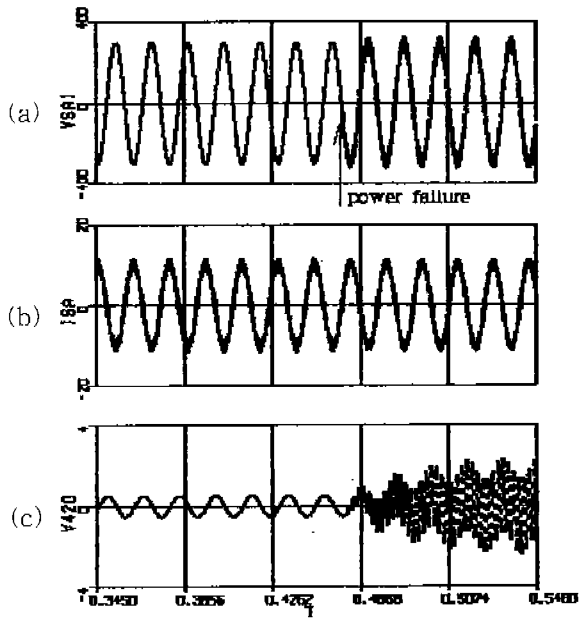

Fig. 9. System operating characteristics in power failure with harmonic current injection
(a) Source voltage (b) Current
(c) Harmonic voltage

6. Result

In this study, novel islanding algorithm and control technique is proposed by using digital controller for utility interactive photovoltaic system. Consumption power of load and output of PV system is balance and load is resistance, though power system occur trouble, we can find by experiment that voltage and current of phase fluctuations is not vary approximation.

The proposed method can detect islanding after 11 period in trouble.

If passive, active mode and proposed mode is combination, we can expect that detection reliability will increase.

[Reference]

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