Letters

Confirmation of Photovoltaic Generation Through Recognition of Inverter Output Signals

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***Abstract*—This letter proposes a method to help confirm the existence of photovoltaic (PV) generation through the characteristic recognition of inverter output signal. While the approach helps to identify the power generation sources, it not only benefits the engineers to grasp the operation scenario of the supplying-power, but also contributes to prevent the inappropriate financial support of government funding due to the intrusion of non-PV generation.**

***Index Terms*—Current injection, inverter output, photovoltaic generation.**

I. Introduction

MORE photovoltaic (PV) generation equipment is increasingly installed in industrial and residential areas in Taiwan today. Because PV is often installed at the top-floor roofs of buildings, it is found to be difficult to justify the existence of PV operation. Scenario recognition of PV generation, from the perspectives of utility engineers, remains a challenging work. Particularly, facing the high possibility that PV owners may get the profit from selling the power by use of nonphotovoltaic generation, this PV scenario recognition problem becomes more imperative than ever [1]. Under the lack of PV generation information, not only that the financial support to faked PV energy providers is inappropriate, the affected degree of electric power quality caused by PV output is hard to clarify. In view of such critical importance, this study has proposed an alternative measure to distinguish the PV generation pattern by tracking the inverter output signal of photovoltaic systems [2]–[4]. This method has been validated with the technical assistance of utility engineers. Test results are anticipated serving as a useful aid to confirm the PV resource with a higher confidence.

II. Paradigm and Methodology

This letter is an extension of [5] that has been effectively applied to several factories of Taiwan. The concept in this study was motivated from the monitoring of waveform variation after a signal injection. In this method, a short duration of dead time appeared between the utility output voltage and the inverter output current is served as a handy reference to justify the mode of operation. This dead time is measured between $T_{\rm IPV}$ and $T_{V,{\rm utility}}$, where $T_{\rm IPV}$ and $T_{V,{\rm utility}}$ individually stand for half a cycle of PV inverter output current and utility voltage. The ratio of T_Z to $T_{V,{\rm utility}}$ is referred to as the chopping fraction (cf), which is expressed as

$$\mathrm{cf} = \frac{T_z}{T_{v\mathrm{utility}}}. \tag{1}$$

Equation (1) helps comprehend the disturbance degree of current injection, where the IEEE Std. 519–1992 needs to be satisfied.

This inverter output current waveform can be written as

$$I_{\rm PV}(t) = \begin{cases} \sqrt{2} I_{\rm PV} \sin(2\pi f_{\rm iPV} t), & 0 \le T_{\rm iPV} \\ 0, & T_{\rm iPV} \le t T_{V,\,\rm utility} \end{cases} \tag{2}$$

where $f_{\rm iPV}$ is the frequency of inverter output current. Through the discussions with utility engineers in Taiwan, we have found that features exhibited by this inverter output current can be utilized to enhance the PV source identification. The field measurements are made at the point of common coupling. The main steps are listed as follows:

Step 1) Validate that the total harmonic distortion of current (THDi) is within 5%. This step is considered because if the load is sufficiently nonlinear to distort the current, then the first priority for maintenance personnel should be a prudent inspection at that demand side.

Step 2) Ensure that the current waveform comes with a dead time inside. This step is considered because the appearance of dead time may imply that the supplying power is possibly mixed with other unknown resources.

Step 3) Check the dead time to see if it appears cyclically. If it does, then the PV generation at this location can be highly confirmed.

Explanations on the above steps are further described here. For Step 1, it is proposed because only if the quality of supplying power is well ensured, then it becomes meaningful to further investigate the PV generation. For Step 2, it is suggested since the dead time appears in most PV inverter outputs. If this scenario is not found, then a further inspection may need to be carried out. It is worth mentioning that if the generation output at that time is not fully delivered by the PV system, then for that power to be sold to an electric utility to gain financial support will be inappropriate. Finally, for Step 3, it is recommended because the dead time often appears periodically once the PV generation is joined. All of the aforementioned steps have been

Manuscript received August 24, 2011; revised March 17, 2012; accepted May 09, 2012. Date of publication July 19, 2012; date of current version December 12, 2012.

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Digital Object Identifier 10.1109/TSTE.2012.2202202

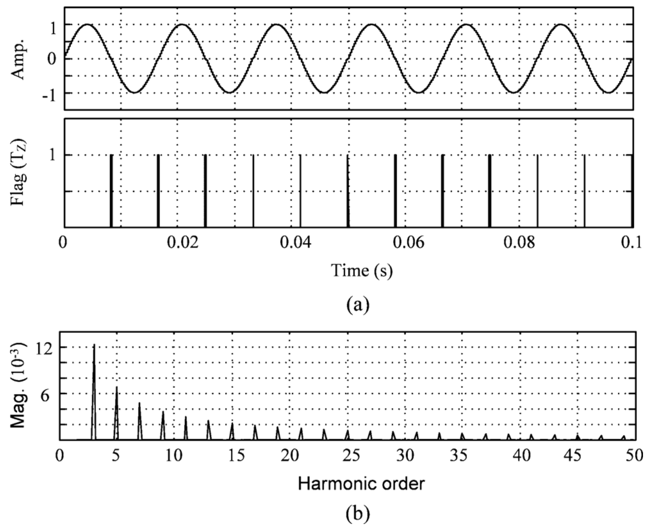

Fig. 1. (a) PV output current and the dead time mark, (b) spectrum.

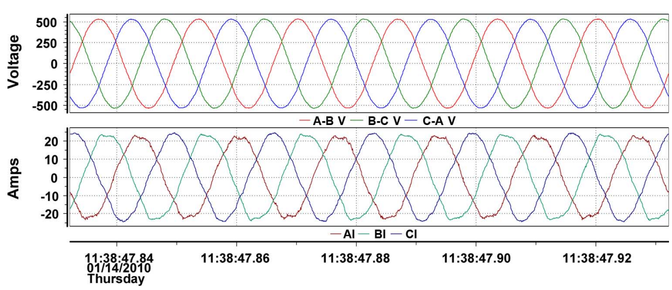

Fig. 2. Waveforms of field measurement.

consulted with local utilities and validated with their assistance. Data examined from PV inverter output current at several test sites of southern Taiwan have confirmed this proposed method with good agreement.

III. Test Results

Fig. 1 shows the simulated results using the proposed approach. In the test, the PV equipment is assumed to be installed previously, but is unknown to engineers in advance. The data sampling rate is 18 kHz. The main utility voltage frequency of f_0 is 60 Hz, and the signal frequency f_{ipv} of PV inverter output is 61 Hz by which the cf is 0.0164. With the plot of Fig. 1(b), the $_{\mathrm{THDi}}$ is found to be 1.64% that is smaller than 5%, indicating that electric power quality at that time is tolerated. Next, by observing the waveform of Fig. 1(a), the dead time of T_z is confirmed with the flag marked periodically at each half period, thereby reaching a good agreement with the scenario assumed.

To support the practicality of the method, it has been further tested through several practical measurements. As an example,Fig. 2 shows the waveform of PV output measurement at an industrial plant. This case was provided by local utility engineers, which is a three-phase system connected on a line voltage of 380 V. From the waveform display, it indicates that this output voltage is over 380 V, presuming that voltage rise is possibly caused by the PV operation.Fig. 3 shows one of three-phase current acquired from the field measurement. Through the plot of Fig. 3(b), the $_{\mathrm{THDi}}$ is calculated to be 4.23%. The electric power quality is acceptable, and the attention is next shifted to

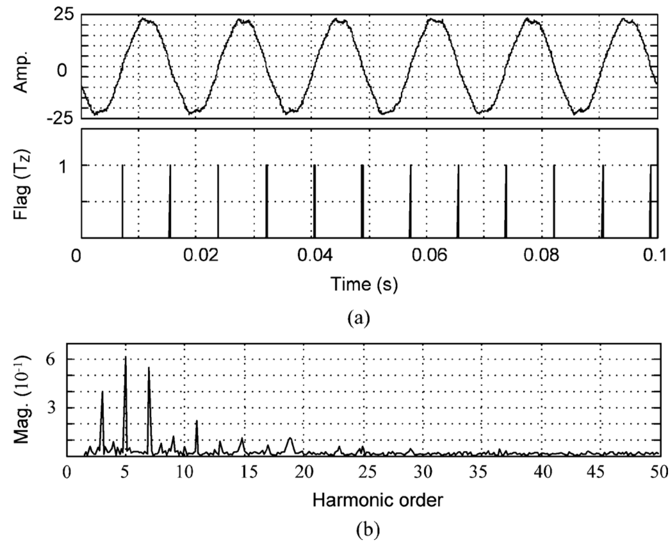

Fig. 3. (a) PV output current and the dead time mark, (b) spectrum.

the occurrence of dead time in the inverter output current I_{pv}. Now with the plot of Fig. 3(a), the existence of dead time is justified with the flags marked at each half period. Test results of this case again validate the consistence of the proposed method with real scenario investigated. Note that this method is developed based on the frequency drift after the signal injection, in which the dead time can be easily inspected once the PV generation is added; yet for other approaches where the dead time may be hard to observe, a comprehensive test is suggested to ensure their reliability.

IV. Conclusion

This letter tracks the signal of inverter output current in order to help confirm the existence of PV generation. The proposed method has been verified through both software simulations and field measurements. Not only can it be realized swiftly, but also owns an advantage of providing a quick grasp of the PV generation scenario. It is anticipated that through this proposed measure, a forewarning signal due to faked PV energy can be flagged at an early stage such that any inappropriate effect to the utility can be effectively restricted.

Acknowledgment

The authors would like to express their thanks to H. F. Lee, Motech Industries Inc., Taiwan, for his technical suggestions and measurement assistance.

References

[1] R. A. Prata, "Impact of distributed generation connection with distribution grids- two case studies," in *Proc. IEEE PES General Meeting*, Montreal, Canada, Jun. 2006, pp. 1–8.

[2] L. A. C. Lopes and H. Sum, "Performance assessment of active frequency drifting islanding detection methods," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 171–180, Mar. 2006.

[3] M. E. Ropp, M. Begovic, and A. Rohatgi, "Analysis and performance assessment of active frequency drift method of islanding prevention," *IEEE Trans. Energy Convers.*, vol. 14, no. 3, pp. 810–816, Sep. 1999.

[4] Y. Jung, J. Choi, B. Yu, G. Yu, and J. So, "A novel active frequency drift method of islanding prevention for grid-connected photovoltaic inverter," in *Proc. IEEE PESC Conf.*, Brazil, Jun. 2005, pp. 1915–1921.

[5] S. J. Huang and F. S. Pai, "A new approach to islanding detection of dispersed generators with self-commuted static power converters," *IEEE Trans. Power Del.*, vol. 15, no. 2, pp. 500–507, Apr. 2000.