Islanding Detection in Photo-Voltaic Systems Based on Instantaneous Power Measurements

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Abstract- Today, renewable and clean energy sources are being used to generate electric power and to reduce dependency on conventional fossil fuels, which are limited in supply and cause immense pollution. Renewable energy is also a sustainable type of energy. Although it may not be a cost-effective type of energy in the short term, it can contribute to reducing greenhouse gas emissions. Safety operations and measures are of great concern, and the prevention of islanding phenomena plays an important role for are liable energy system. Therefore, anti-islanding protection is a requirement for connecting to the utility grid. Here, we propose a different and fast method for islanding detection in photo-voltaic (PV) systems. The suggested method is based on instantaneous power calculation at the point of common coupling and is able to detect islanding conditions within a few sampling intervals. No further calculations are needed to detect islanding problems for grid-connected PV systems.

Keywords Power differential method, solar power, PV modules, islanding detection.

1. Introduction

The fossil energy sources are petroleum, coal, natural gas, bitumens, oil shales, and tar sands; the renewable energy sources are biomass, solar, wind, geothermal, and hydropower; and the fissile energy sources are uranium and thorium. The dwindling supplies of fossil fuel resources and the rising communal responsiveness to calls for environmental protection have required an urgent search for alternative energy sources. Therefore, sustainable and clean energy generation is extensively investigated all over the world. Oil, gas, and coal drilling and mining create high levels of pollution that are pumped into local environments and the wider atmosphere. The benefits of renewable energy sources, of course, include low carbon emissions and fewer polluting agents being released into the atmosphere. Not only are the investment and operation costs of renewable systems less than those for fossil fuel systems, they are also regarded as environmentally friendly sources [1]. Solar and wind power generation have experienced especially fast growth among the many types of competitive alternative energy sources [2, 3]. Consequently, power generation from solar and wind sources is swiftly increasing in many areas of the world. Solar energy and PVs, in particular, have very high potential. PV systems simply consist of either a DC/DC or DC/AC converter—with or without battery charging capabilities—that makes use of a maximum power point tracker (MPPT).

Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other systems. MPPTs solve the problem of choosing the best load to be presented to the cells in order to get the most usable power out. MPPT algorithms require measurements of the voltage and current as inputs; however, due to transient behavior, these measured values may not be representative of the system's state—and due to energy storage components, values measured at any one point are likely not even on the current-voltage (IV) curve of the PV module [4].

It is vital to investigate the nature of the renewable systems to manage a reliable and optimal integrated energy system. For instance, the physical characteristics of the solar cells and the electrical characteristics of the power converter affect the design, energy extraction, and grid integration of a solar energy system [5].

Grid connection of PV systems has the benefit of more efficient use of generated power. Nevertheless, the technical requirements from both the grid side and the PV system side need to be fulfilled to guarantee the safety of the PV installer and the reliability of the utility grid [6]. These technical problems for grid connection must be resolved to safeguard the sustainable application of PV systems.

Islanding is one of the major hazards for grid connected PV systems and should be detected for a reliable operation. Simply put, islanding is a condition in which a portion of the utility system, usually a distributed generation system, is isolated from the main utility system where voltage/frequency stability is maintained, and continues to operate without safety controls (Fig. 1). Unintentional islanding can be dangerous for a variety of technical reasons, even if it lasts for only a few seconds, so any islands that arise should be disabled as quickly as possible [7]. Power-system faults are the major causes of islanding phenomena, and the isolation point is usually on the low-voltage side when an islanding condition exists. However, islanding can also occur on the high-voltage side, especially when a large number of PV and other sources are connected to the grid. Utility switching of loads and human errors are the other major causes of islanding condition [8].

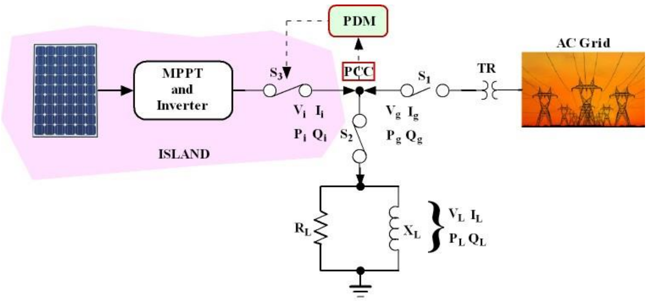

Fig. 1. A simple representation of a PV system and AC grid feeder configuration

Hampering islanding is important with respect to liability and safety, and in order to provide quality energy to paying customers. In a broad sense, anti-islanding should be required for the following reasons:

a) Voltage and frequency stability cannot be guaranteed in the islanded operation. Some devices are more sensitive to voltage fluctuations than others and should always be equipped with surge protectors.

b) The rated values of voltage and frequency may have unacceptable values that cause damage in the utility side.

c) An islanded portion of the power system may create hazardous conditions for working staff and customers.

d) The reconnection of an islanded portion of the system to the grid may cause an undesirable trip in the grid side, leading to another islanding operation.

e) Islanding can interfere with utility equipment, adversely affecting it and causing malfunctions.

Islanding detection techniques may generally be divided into two categories: passive and active islanding detection methods. Passive methods make use of transient signals in the electricity for detecting transient signals in the electric voltage, current, and frequency. The passive methods include techniques such as over/under voltage [9, 10], under/over frequency [11-15], voltage phase jump [16, 17], and detection of voltage and current harmonics [18-22]. Active detection methods, on the other hand, constantly send signals back and forth between the distributed generator and the grid to ensure the status of the electrical supply. The active methods include techniques such as impedance measurement at rated and specific frequencies [23-30], slip-mode frequency shift [31-33], frequency bias [34,35], Sandia frequency shift [36,37], Sandia voltage shift [38,39], frequency jump [40,41], active frequency drift [7], and PLL based [42]. Some of these methods rely on the measurement of system parameters at the distributed generation (DG) side, while others are based on communication between the utility grid and the DG. According to the information gathered during our literature review, it can be concluded that no islanding detection technique is perfect. The advantage of PLL based and active frequency drift methods is the short detection time from the introduction of the signal disturbance [42]. Some drawbacks may include the presence of a non-detected zone (NDZ), which can cause anti-islanding detection failure; degradation of power quality and system stability; false operations in multiple DGs, the requirement of additional circuitry or equipment; high implementation costs[43,44]; and the addition of a second harmonic to the inverter current when islanding causes the system to malfunction [42].

Therefore, the development of an anti-islanding detection algorithm is still necessary to minimize the drawbacks of the supporting techniques. For this purpose, we propose an active islanding detection method based on the power differential method (PDM) at the point of common coupling (PCC). The inflow and outflow of instantaneous power through the PCC is determined by the energy supplied and PV system. The power difference is close to zero under normal operating conditions. The PDM is basically based on average instantaneous power flow into the PCC during one cycle period, T. A simple threshold setting helps to determine whether the calculated power is greater than zero, indicating that the PV system is switched off. Alternatively, if the calculated power is less than zero, it is concluded that an islanding condition has occurred. The suggested algorithm uses a sliding window technique based on the voltage and current samples acquired over a period. Section 2 gives the details of the proposed technique.

2. Power Differential Method

The suggested method is simple, and based on average instantaneous power flow into the PCC: it calculates the apparent power using the products of instantaneous current and voltage samples. A sliding window technique is used for the power calculations, which results in a time delay of only one sampling interval. The average instantaneous power flow into the PCC is calculated in Eq. (1).

$$av_{pcc}(t) = \frac{1}{T}\int_{t-T}^{t}(v_i i_i + v_g i_g + v_L i_L) \qquad (1)$$

Eq. (1) uses instantaneous voltage and current values for PV, grid and load sites. Eq. (1) is generalized in terms of apparent power and represented by Eq. (2).

$$av_{pcc}(t) = \frac{1}{T}\int_{t-T}^{t}(S_i + S_g + S_L) \qquad (2)$$

Eq. (2) can be discretized in Eq. (3) and it is stored in memory for comparison to the threshold value.

$$av_{pcc}(t) = \sum_{k=1}^{N-1} av_{pcc}(k : N + k - 1) \qquad (3)$$

To satisfy Eq. (3) minimum instantaneous load power is assumed to be larger than maximum instantaneous PV power, just as in real life applications. The proposed islanding detection method is similar to the power differential protection method [45-48] that has already been utilized for power transformer protection. The proposed PDM is a robust technique and not affected by power system disturbances. This technique needs only cycle voltage and current samples; for further calculations, a sliding window technique is used. Zero is a suitable threshold value to distinguish between islanding and normal operations. No further complicated techniques (such as frequency dependent techniques) are required to apply Eq. (3).

3. Simulation and Test Studies

The PDM is implemented through the configuration shown in Fig. 2.

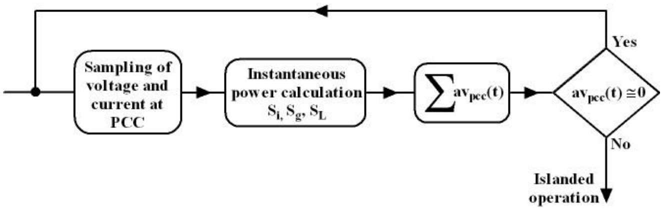

Fig. 2. Proposed islanding detection technique

To test the proposed algorithm, a case study is performed on a model system including PV generation, AC power grid, and load (Fig. 3). The grid system is represented by an equivalent source behind the system impedance. The model has 6 IGBTs and the IGBT output is connected to the grid using an11/0.23 kV step-up transformer. A smoothing inductor is used for harmonic filter and no other device is required. The MPPT system controls the PV output voltage around 1.5kV and a DC/DC converter is used for maximum power point tracing [49-51].

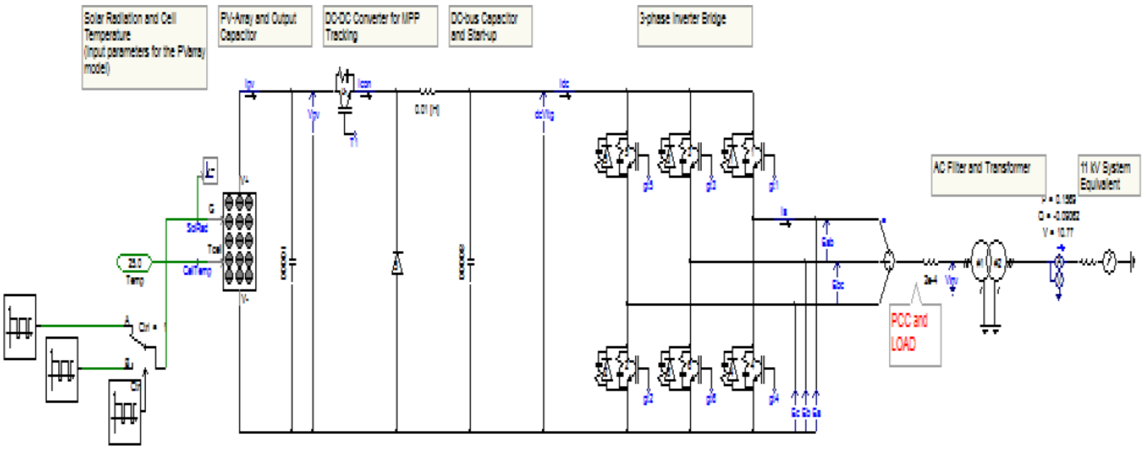

Fig. 3. Grid-connected PV system simulation

The I-V curve of the PV array is obtained at a constant temperature (25°C) and variable solar radiation (Fig. 4). Eq. (4) is used to simulate the solar radiation logic. Of course, different radiation logic combinations can be tested to assess the efficiency of the model.

$$\left\{\begin{array}{cc} time(\text{sec}) & radiation \\ 0-1 & 200 \\ 1-3 & 400 \\ 3-5 & 600 \\ 5-8 & 800 \\ 8-10 & 1000 \end{array}\right\} \qquad (4)$$

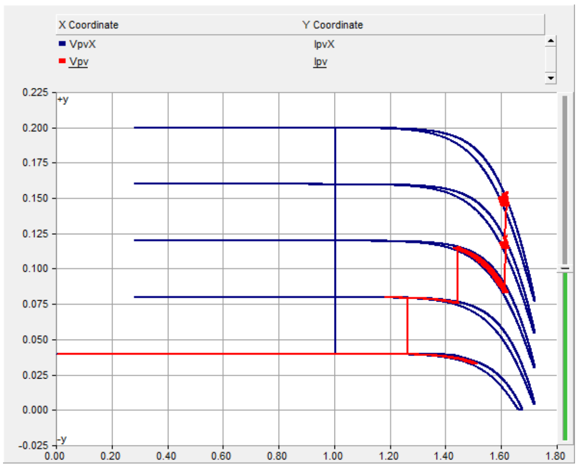

Fig. 4. MPPT under variable solar radiation and constant temperature

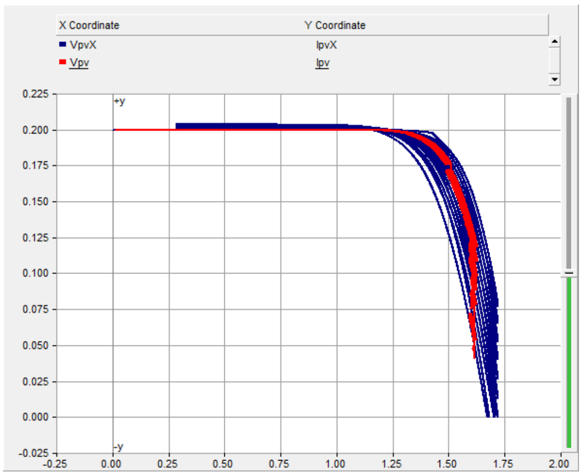

Fig. 5. MPPT under constant solar radiation (1000 W/m^2) and variable temperature (25°C – 70 °C)

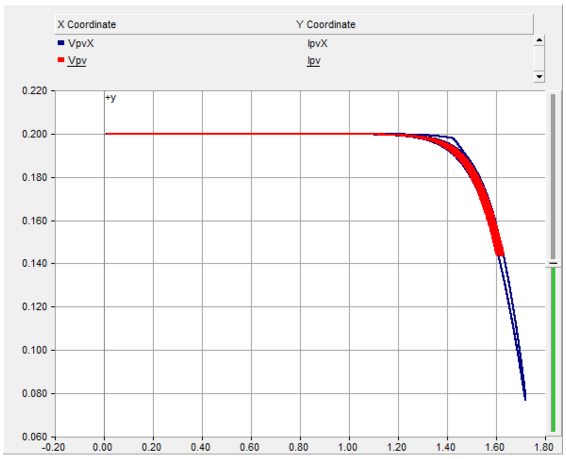

Fig. 6. MPPT under constant solar radiation (1000 W/m^2) and temperature (25°C)

The thick red line superimposed on the I-V curves demonstrates the variation of the operating point of the PV array when MPPT is active (Fig.4 – Fig. 6). Due to the tracking of the algorithm, the operating point of the system can oscillate. The blue I-V curves are obtained by simulating a second PV array with the same inputs but without the MPPT. It is obvious that the MPPT controller tracks the knee point fairly and truly. In the simulations, a popular MPPT algorithm based on the incremental conductance method is implemented [52]. In these scenarios, the sampling time step is set to 300us. Three phase current and voltage samples are obtained to calculate PCC, then Eq. (5) is used to detect potential islanding conditions.

$$-set \le av_{pcc}(t) \le set \qquad (5)$$

In Eq. (5), the *set* value can easily be chosen as 0.1 to compensate for power system disturbances and sampling errors.

4. Results and Discussions

Primary and secondary currents are obtained through CTs both in computer simulations (Fig. 3) and real-time experiments. A non-linear model based on Jiles-Atherton modeling is used to model the CTs under several working conditions. The proposed system is tested under various operating conditions with low and high power angles. These are summarized below:

a) Normal operating conditions: (MW) is chosen as 0.1, 0.5, 1, 1.5, 2, 3, 10, 50 while (MVAr) is chosen as 0.001.

b) Normal operating conditions with high power angle: (MW) is chosen as 0.1, 0.1, 0.5, 1, 1, 2, 2, 3, 3 while (MVAr) is chosen as 0.1, 0.5, 0.5, 0.5, 1, 1, 2, 2, 3.

c) PV system is intentionally switched on-off while feeding the load with a low power angle.

d) PV system is intentionally switched on-off while feeding the load with a high power angle.

e) Load with a low power angle is intentionally switched on-off.

f) Load with a high power angle is intentionally switched on-off.

g) Grid while feeding a load with a low power angle is intentionally switched on-off.

h) Grid while feeding a load with a high power angle is intentionally switched on-off.

In items (c) through (h), and are selected as in the case of (a) and (b).

Real time experiments were performed in the laboratory to demonstrate the strength of the proposed technique. This system is composed of both wind and solar power. The rated power and maximum power are 1.8 kW and 2.4 kW, respectively, with a 2.7% total harmonic distortion. Load power is chosen as 3-5 kW with a power angle of 0.8 (lagging).

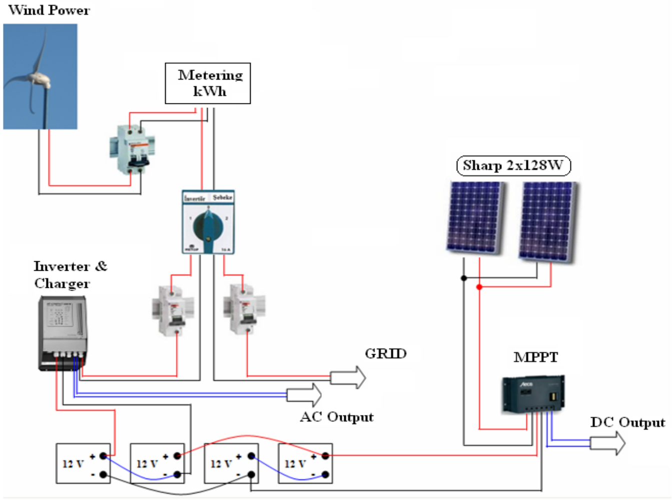

Fig. 7. A laboratory set-up for islanding detection

Three power analyzers are used to calculate instantaneous powers. Calculated instantaneous powers are transferred to a personal computer using an internet connection over RS-485. The personal computer then performs Eq. (3) to identify islanding conditions and sends a trip signal to the PV system. Eq. (3) is able to identify and correct islanding phenomena within 2-3 sampling intervals for computer simulations and within 2-10 sampling intervals for real-time tests. Moreover, it is noted that the maximum detection speed is less than a quarter period for real-time tests even if the load angle is too high.

The suggested islanding detection methodology is applied to an experimental system and the following results are obtained. During the real-time tests, loss of power utility is tested for several load conditions from resistive to high inductance (Table 1). Switching instants are obtained using an NI-DAQ (PCI MIO-16E) board. Matlab^{TM} is used for getting switching instants.

Table 1. Real-time tests and response of the suggested technique

Load (R+jX)	Load Angle (in degrees)	Time (in msec)
4.4+j30.12	78.46	4.85
6.6+j27.85	72.54	4.79
8.8+j25.5	66.42	4.78
11+j23.05	60.00	4.57
13.2+j20.4	53.13	4.00
15.4+j17.49	45.57	3.96
17.6+j14.15	36.86	2.42
19.8+j9.92	25.84	2.10
22+j0	0.0	0.70

5. Conclusion

Among the PV generation systems, the grid-connected system has held the largest percentage of the installations over the past decades. Therefore, preventing islanding in grid-connected solar PV systems is highly important. To reduce non-detection zones of islanding operations for different loading conditions, this paper proposes a simple remote anti-islanding technique based on a power differential method. The time and accuracy of islanding detection have been improved, as presented in the results and discussion section.

The modeling and simulation were based on PSCAD/EMTDC, a widely used power-system simulation tool. This simulation model enables extensive analysis of the control and dynamic performance of a PV system and its interactions with the power system, such as power control dynamics, harmonics, anti-islanding performance, and response to grid faults. Various simulation results were presented to examine and analyze transient behaviors of islanding phenomena. In the practical experiments, a grid-connected 2.4 kW wind and solar PV system was used. The proposed power differential method was validated by reliably detecting the occurrence of islanding operations within 2-3 sampling intervals, which is less than the 0.5 msec required by the IEEE standard.

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