Detection of Islanding Event in Distribution System in the Presence of PV System

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Abstract— This paper presents an islanding detection method in the distribution system in the presence of solar energy using an algorithm based on the Stockwell Transform. The study has been performed in MATLAB/Simulink environment using an IEEE-13 bus test system. A solar PV system of capacity 1MW is integrated to the IEEE-13 bus test system. The islanding event is simulated by disconnecting the test system from the utility grid network and voltage is captured on the bus where the solar PV system is connected. The voltage signals are decomposed using the Stockwell Transform and S-matrix is obtained. An island index is proposed to detect islanding event which is obtained by summing the absolute values of each column of the S-matrix. Second island index is also proposed based on the phase angle of maximum value of the each column of the S-matrix. The frequency variation and rms value of voltage have been analyzed on bus 650 of the test system during the islanding event.

Keywords— Distribution system; distributed generation; islanding; Stockwell transform.

I. INTRODUCTION

The distributed generation (DG) is small-scale generation which is installed near to a load centre with ability to interact with grid. Distributed generation includes wind farms, micro hydro turbines, solar photovoltaics (PV) system and other generators that are supplied with biomass or geothermal energies. Distributed generation has the ability to improve the power system efficiency, reliability, power quality and increases the system flexibility. However, integrating DG sources into utility is a major concern. One problem that should be taken into account is the islanding condition. Islanding is a condition in which a portion of utility system that contains both load and distributed generation remains energized while it is electrically isolated from the rest of the utility system [1]. A novel and a computationally inexpensive passive islanding detection technique for converter based distributed generation systems have been presented in [2]. The proposed technique utilizes the converter-induced ripples in the instantaneous voltage amplitude at the point of common coupling to detect islanding. The proposed technique was modelled in a converter-based DG network with photo-voltaic arrays. In [3], islanding is detected by measuring the electrical parameters of connection point, selecting effective features and data mining methods. In [4], authors have proposed a method in which the q-axis current in the inverter is measured and the current controller is modelled with a continuous periodic Reference power from a small value. The possibility of false detection is eliminated through the affirmation of the occurrence of islanding as soon as it is suspected. The proposed algorithm detects the island grid formation in the stable condition of the system. In [5], a comparative study of different pattern recognition techniques using wavelet based features for islanding detection in distributed generation is presented. Pattern recognition techniques including decision tree (DT), support vector machine (SVM), artificial neural network (ANN), extreme learning machine (ELM) and differential evolution (DE)-c1ustering are applied to segregate the islanding condition from non-islanding events. In [6], a decision-tree (DT)-learning method with hardware-in-the-loop (HIL) simulations is proposed to address the non detection zone (NDZ) issue of islanding detection in hybrid distributed generation systems including both inverter and synchronous-machine-based distributed energy resources. With the proposed method, the laboratory testing results indicate promising islanding detection performance in terms of dependability, security, reduced NDZ area and detection time. In [7], authors presents an islanding detection approach for synchronous type distributed generation using multiple features extracted from network variables and a support vector machine (SVM) classifier. Features are extracted from a sliding temporal window, whose width is selected so as to achieve the highest detection rate at a fixed false alarm rate. The SVM classifier is trained with linear, polynomial and Gaussian radial basis function kernels, and the parameters of the kernels are tuned to improve the classification performance. The application of the proposed method is illustrated for islanding cases associated with different power imbalance conditions, including small power imbalance conditions associated with the non-detection zone of conventional relays. An accurate active islanding detection method for grid-tied inverters in distributed generation using phase disturbance based on grid synchronisation is presented in [8]. To have good performance on both power quality and islanding detection, a third-harmonic injection is generated by a new kind of phase disturbance and the scope of phase disturbance coefficient is precisely defined, besides, for extracting the third-harmonic component at the point of common coupling accurately, a selective harmonic extraction based on multiple second-order generalised integrators is also provided. In [9], authors presented an islanding detection methodology (IDM) for grid-connected inverter-based DGs. The proposed method is a combination of passive and active islanding detection techniques for aggregation of their advantages and elimination/minimisation of the drawbacks. The main aim of study presented in paper [10] is to analyze recent detection methodologies of unintentional islanding in distributed generators of electric energy. This research focus the use of Unsupervised Learning Techniques and demonstrates that the use of these methodologies can achieve a performance superior to the conventional passive method of islanding detection due to non-detection relays zones. A theoretical approach is taken on the international and national standards that prohibit the islanding occurrence, and the risk and damages caused by it. A phase angle-based principal component (PC) technique for islanding detection of distributed generations (DGs) is proposed in [11]. The phase angle between the positive-sequence components of voltage and current is derived at the DG terminal and used as an input feature vector for the PC technique to identify the islanding situation (IS). The change in phase angle is prominent for both ISs and non-ISs (NISs). By exploiting this change in phase angle, PCs are computed to discriminate between ISs and NISs. The proposed technique is evaluated using data simulated with a real-time digital simulator for IEEE-13 bus microgrids.

II. Test System Used for Study

The proposed study of detection of islanding event in the distribution system with solar energy penetration has been carried out using an IEEE-13 bus test system. This system is operated on frequency of 60Hz and rated at 5*MVA*, two voltage levels of 4.16*kV*, 0.48*kV* having balanced and unbalanced loads in the original system. The distributed generators had not been connected to the original test system. This system is modified to incorporate 1MW solar PV plant (DG) on the bus 680 as shown in Fig. 1. Data of the distribution feeders, loading and capacitor data are same as original test system. Three phase underground cables between nodes 692 and 675 as well as single phase underground cable between nodes 684 and 652 are replaced by three phase overhead lines with 601 configurations. The test feeder is integrated to the utility grid network through a substation transformer. The voltage regulator between nodes 650 and 632 in original system is not utilised in the modified system. The switch between nodes 671 and 692 is realised by three phase circuit breaker. The length of feeder lines is taken same as in the original test feeder. The islanding event is simulated by disconnecting the test system from the utility grid using an island interconnection device (IID) switch. This IID switch has been realized using three-phase circuit breaker. The recording of the voltage has been performed on the bus where the DG source is connected. The frequency and rms value of the voltage are recorded on the bus 650 of the test system. The solar PV data as reported in [12] has been utilized in this study.

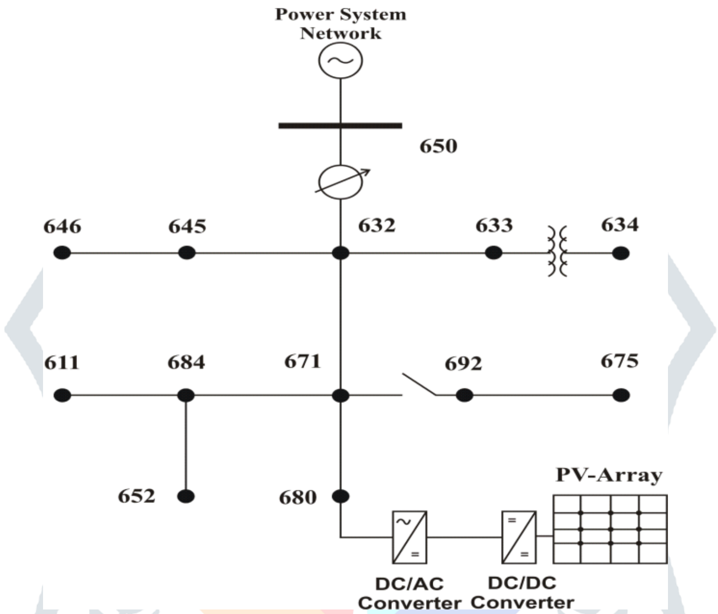

Fig. 1. Single line diagram of the IEEE-13 bus distribution system with solar energy penetration.

The solar PV plant of DG consists of 10 units, each of capacity 100kW connected in parallel. Each solar PV unit of 100kW consists of a solar PV array generating power with dc voltage of 273.5 V. This power is given to the dc-dc boost converter which increases the voltage level to 500 V. These boost converters of each unit feeds power to an inverter which convert dc power to ac power at a voltage level of 260V. A filter with series branch having resistance of 0.5m**Ω** and inductance of 50µH, and shunt capacitor branch of 50kVAr are used at the output terminals of inverter to filter out the harmonic components. The output of this inverter is integrated to the test system.

A. Solar Photovoltaic Cell

The basic working principle of photovoltaic is same as that of simple diode. The constructional model of PV diode is shown in Fig. 2. As light waves incident on junction, energy photon are absorbed immediately by the junction and the energy of photon is transmitted to the lepton system of the fabric leading to the creation of charge carriers that area unit separated at the junction. In case of electrolytic PV cells, the charge carriers may be electron ion pairs and in case of semiconductor solid cells charge carriers are electron-hole pairs. A voltage gradient is developed by charge carriers separation within the junction region, as a result electrical field so developed cause the charge carriers to get accelerated across the junction and current through an external circuit. The energy of photon thus gets converted to electrical energy in external circuit. A part of energy generates thermal heat in the PV diode which elevates the temperature of the cell. The reason of the electrical phenomenon potential is that the distinction within the chemical potential, known as the Fermi level, of the electrons within the 2 isolated materials. When the two type of semiconductor material are joined, an equilibrium condition is reached at the junction and negative and positive charge separation causes a potential gradient across depletion layer. When the Fermi level on two sides of depletion becomes equal then equilibrium is achieved. This happens by electrons flow from n-type material to p-type material across junction till a voltage distinction is established across junction that has the potential simply capable the initial distinction of the Fermi level. This potential drives the photocurrent [13].

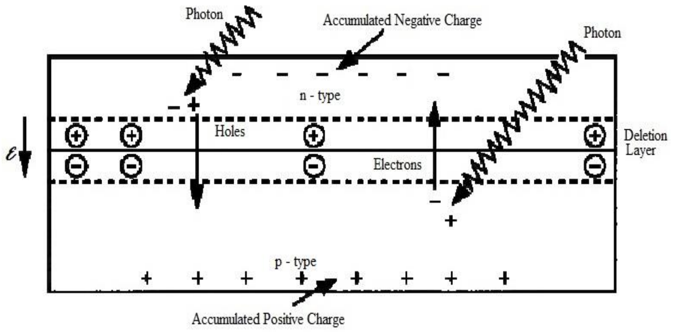

Fig. 2. P-N junction of PV cell showing hole-electron pair created by photons.

III. PROPOSED METHODOLOGY

The proposed algorithm for the detection of Islanding event in distribution system with solar energy penetration has been implemented with the following steps:

- Islanding event in the presence of solar energy has been simulated in MATLAB using the test system shown in Fig. 1.
- The rms value of voltage and frequency are recorded on the bus-650 of the test system and plotted directly to investigate the behavior of the test system during the event of Islanding.
- Islanding event are performed at 30 cycles from start of simulation by opening the IID switch and voltage is recorded on the bus of the solar source for a period of 60 cycles.
- Voltage is decomposed using the Stockwell Transform and S-matrix is obtained which is further used for the analysis.
- The proposed island index based on summing the absolute values is obtained from S-matrix using the following relation and plotted.

$$IIS=sum(abs(ans))$$

- The proposed island index based on phase angle is obtained from S-matrix using the following relation and plotted.

$$IIP=abs(angle(max(ans)))$$

IV. SIMULATION RESULTS AND DISCUSSION

This section presents the simulation results related to Islanding detection in distribution system with solar energy penetration using the Stockwell Transform (S-transform). The results related to the island index based on summing of absolute values and island index based on phase angle have been analyzed on the bus of solar PV system for the detection of islanding event. The frequency variation and rms value of voltage have been analyzed on the bus 650 of the test system during the islanding event.

The solar PV energy source is connected on the bus 680 of the test system. Islanding event is performed by opening the IID switch at 30 cycles from start of the simulation. The voltage is captured on the bus 680 and decomposed using the S-transform to obtain the S-matrix. The proposed island index based on the summing of the absolute values of each column of the S-matrix is obtained and provided in Fig. 3. It is observed that a high magnitude peak is obtained at the time of islanding event. This first peak observed in the islanding index curve can be utilized for the detection of the islanding event in the presence of the solar energy. The disturbances obtained after the first peak are due to the unbalanced system as the solar energy is not able to supply the power to the load during the islanding condition.

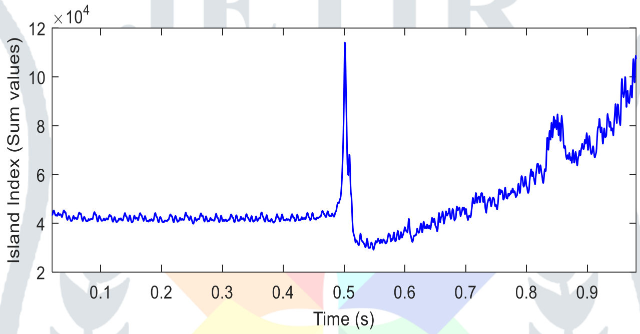

Fig. 3. Island Index based on summing of absolute values on bus of source DG during islanding event.

The island index based on phase angle is obtained by first calculating the maximum values of each column of the S-matrix and then calculating the phase angle of these values and provided in the Fig. 4. It is observed that a sharp magnitude peak is observed just after the Islanding event. This will give the command to the relay for tripping of the circuit breaker of the solar energy. The subsequent peaks will not be utilized. However, if the breaker does not trip on the first peak due to some technical reason then second peak may be utilized.

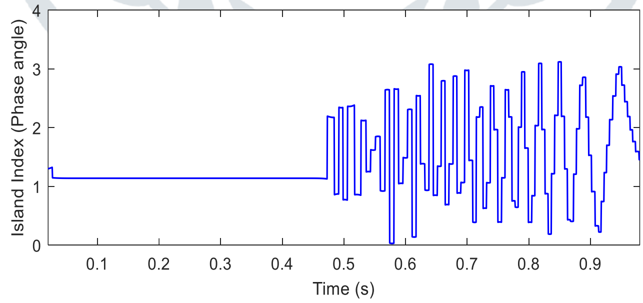

Fig. 4. Island Index based on phase angle of S-matrix on bus of source DG during islanding event.

The frequency is recorded on the bus 650 of the test system and provided in Fig. 5. It is observed that the frequency is constant at a value of 60 Hz before the islanding event as expected. It increases after the islanding event as the system has become unstable due to difference in the demand and supply. Further, since only the solar PV generator of capacity 1MW is connected, it will not be possible to supply active and reactive powers demanded by the system.

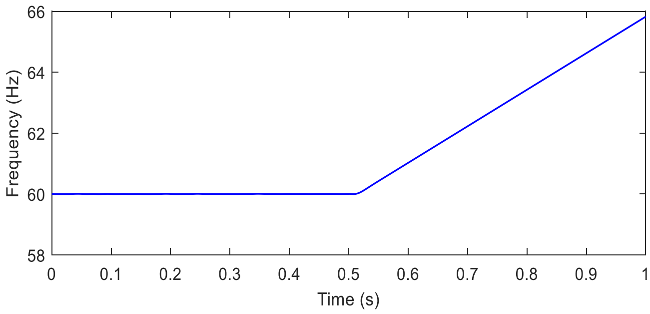

Fig. 5. Frequency variations on bus-650 during islanding event in the presence of source DG.

The root mean square (RMS) value of the voltage captured on the bus 650 of the test system is shown in Fig. 6. It is observed that voltage decreases just after the islanding event indicating that the system collapses after the event of the islanding due to the gap between the demand and supply in the power. An irregular trend in the magnitude of the voltage is observed after the islanding event.

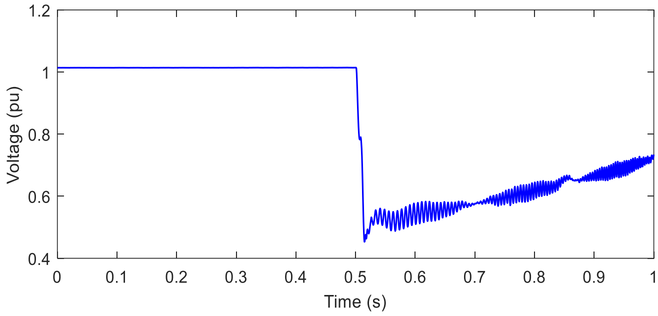

Fig. 6. Root mean square value of the voltage on bus-650 during islanding event in the presence of source DG.

V. CONCLUSIONS

The research work carried out in the due course of this paper is focused to develop a passive islanding detection method which can be implemented to detect the islanding event in the distribution system in the presence of solar energy. This method is based on the Stockwell Transform based Island Index. The study has been performed using an IEEE-13 bus test system on which solar source is connected. A solar PV system of capacity 1MW is integrated to the IEEE-13 bus test system. This complete test system is integrated to the utility grid using an island interconnection device (IID) switch simulated by a three phase circuit breaker. The islanding event is simulated by opening the IID switch. The rms value of the voltage and frequency is recorded on bus 650 of the test system. The voltage is captured on bus of solar energy. These voltage signals are decomposed using the Stockwell transform and S-matrix is obtained. Two island indexes are proposed to detect islanding event. First island index is obtained by summing the absolute values of each column of the S-matrix. Second island index is also proposed based on the phase angle of maximum value of the each column of the S-matrix. The proposed study has been carried out in the MATLAB/Simulink environment. It is concluded from the proposed study that both the proposed Island Indexes are effective in the detection of the Islanding event in the distribution system in the presence of solar energy based on the threshold values selected for these indexes. The values of these indexes above the threshold indicate the presence of the islanding event and below the threshold values indicates that the islanding event is not present. The variations in the frequency are also observed after the islanding event. The rms values of the voltages also fluctuate after the islanding event in the system.

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