Synchrophasor Application for Distributed Generation Control

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Abstract— Distributed generation (DG) is gaining popularity across the world. Recently rules encouraging the use of renewable resources is passed. Integrating DG with the utility network poses challenges for anti-islanding schemes. Distributed generation is generating interest due to the desire to increase the use of renewable electrical energy sources. For broader adoption of DG, a reliable way to connect systems to the bulk power grid is needed. So it is necessary to address the challenges associated with the integration of distributed generation (DG). This paper discusses a wide area measurement based islanding detection scheme that uses time synchronized measurements to calculate voltage difference. This paper shows the performance of the IEEE 6 bus system during islanding condition.

Key words: Distributed generation control, Synchrophasor Technology, Islanding Detection, IEEE 6 Bus System, Synchrophasor Application

I. INTRODUCTION

In this modern generation, Renewable energy is very important as renewable energy offers economically viable solutions which does not harm the environment and the social life. Hence we can integrate it with the energy development with proper plan. Currently, innovations in new technologies and power electronics have made DG a significant substitute for extra cogeneration support. The challenges for integrating DG with the service network are enormous. Islanding can be explained as when a unit of the generation system is isolated from the main utility system, the damage to the existing equipment, utility liability concerns, reduction of power reliability and power quality occurs which is undesirable.

A. Events Causing Islanding [1]
- A fault produced in the grid which results in a disconnection that may not be detected by the photovoltaic inverter or the protection equipment.
- An accidental opening of the connection point with the electrical company
- Programmed disconnection
- An intentional opening of the connection point with the electrical company
- Human errors
- Natural causes

B. Anti Islanding System Requirement [1]
- Generally, voltage and frequency anti islanding control systems are not incorporated in the Electrical Grid SCADA systems. During an islanding condition, the voltage and frequency may be within the band defined for nominal values, but the inverter is not capable of regulating these parameters and therefore a hazardous situation may result for the client equipment.

- The electrical companies can be penalized by the users when there are hazards in the PV devices as a result of having the voltage and frequency parameters out of the acceptable ranges.
- The islanding situation can create a hazardous situation for the operators in the electric installations and for the public in general, since circuits which are assumed to be disconnected from their sources, are actually energized.
- The reconnection of the electric system with the islanding can have as a result a new disconnection or a hazard in the equipment if the connection is happens in an out of phase situation, since there is no control of the islanding voltage and frequency.
- The islanding condition can interfere with the manual or automatic service reestablishment process after an important event in the electric system.

II. SYNCHROPHASOR MEASUREMENT CONCEPT

A phasor is a complex number with magnitude and phase angle that is used to represent a sinusoidal signal under a specific frequency (50 Hz or 60 Hz) at a specific point of time. Where, the phase angle is the distance between the sinusoidal peak of the signal and a specified reference point of time (for example time = 0) and is expressed using an angular measure. The phasor magnitude is related to the amplitude of the sinusoidal signal.

When a phasor measurement is time stamped against the UTC time by GPS, it is called a synchrophasor. With the help of synchrophasor, we can have measurements from different sites at a time using time stamped measurement. This synchrophasor measurement will help to have complete view of an entire region or interconnection.

A. Devices and Networks [2]

1) Phasor Measurement Unit (PMU)
A PMU is a standalone device that measures 50/60 Hz AC voltage and/or current signals to provide phasor and frequency measurements. The analog to digital converter is used in each phase to convert the analog AC waveforms into digital AC waveforms. For high-speed-time synchronized sampling, phase-lock oscillator and a GPS reference time source also known as PPS is used. A PMU calculates the current phasors, voltage phasors, line frequency at a high sampling rate. This measured data are sent via a communication channels using GPS time stamp.

2) Phasor Data Concentrator (PDC)
PDCs aligns the data to form a time- synchronized set using a time reference. The data collected at PDC comes from either various PMUs or several PDCs. This information from PDC is forwarded to other information systems. Other functions of the PDC includes the data quality checks and problematic data. It also waits for a set period of
time for all the data to come in before sending the combined dataset. Some PDCs also store data which can use for applications that use data at slower sample rates, such as a SCADA system.

3) Time Synchronization Option
A PMU involves UTC time and high accuracy timing signal to provide synchronized measurements. The existing methods include the direct GPS signal, IRIG-B/PPS and IEEE 1588 PTP.

A direct way for a PMU to refer UTC time is using a GPS signal. Such PMU should be equipped with internal or external GPS receiver, which is specially designed to receive and synchronize a local timing reference to UTC using the GPS signal.

IRIG-B is commonly used by PMUs for synchronizing to UTC time. It may be provided in a level shift, a 1 kHz amplitude modulated signal, or in the bi-phase Manchester modulated format. A PPS in timing systems is a pulse train of positive pulses at a rate of 1 Hz. The rising edge of the pulses coincides with the seconds change in the clock and provides a very precise time reference.

IEEE 1588 PTP is a protocol used to synchronize distributed clocks with an accuracy of less than 1 microsecond via Ethernet networks.

B. Different Synchrophasor Application in Distribution

Different problems identified in distribution system which can be solved by synchrophasor application are [3]:

- Islanding detection
  - Phase identification
  - Load Characterization
  - System Monitoring

III. ISLANDING DETECTION METHOD

The idea behind the islanding detection is to observe the output and the system parameters of distributed generation and from that we can decide if the islanding situation will occur or not.

A. Traditional Islanding Detection Method

1) Passive Detection Schemes

Passive detection schemes uses voltage and current signals. Based on the measurements the islanding condition can be detected.

a) Voltage Based Detection

The undervoltage and overvoltage occurs due to the reactive power mismatch. This measurement of undervoltage and overvoltage can help to detect if any islanding condition would occur or not. A voltage relay is used to measure such mismatch. Voltage-based detection balances frequency-based detection. Also, voltage-based detection gives faster response than frequency-based detection because generally the voltage changes occur faster than frequency changes.

b) Frequency Based Detection

When there is a difference between the generation and the load, the frequency is changed. If the generation exceeds the load, the frequency increases, whereas if the load exceeds the generation, frequency decreases. Hence islanding condition can be easily detected by frequency changes. The allowable frequency changes are 60 Hz ± 20 mHz or 50 Hz ± 20 mHz.

2) Active Detection Schemes

In the active detection methods, an low-frequency interharmonic current is injected at the generator terminals. The impedance from voltages and currents is calculated which is measured at the generator terminals. The impedance of the DG is very small during normal conditions of the system. During the islanding condition, the impedance of the DG increases. Hence in this method, the change in impedance is to used detect islanding conditions. This method does not depend on the power divergence.

3) Communication Based Detection Schemes

In communication based detection, the status of the circuit breaker is used to detect the islanding condition. Based on the already known logic, a central processor is used to observe the status of the circuit breaker. Based on the status of the CB, the islanding condition can be detected. These method can be easily applied.

B. Islanding Detection Using Synchrophasor [1]

The PMUs are implemented to identify the separation of one part of the Electrical System (Island) where the island contains one photovoltaic source and several loads of different characteristics. For that purpose two Phasor Measurement Units (PMU) were installed: one inside the island and other one in the main grid, connected to a Phasor Data Concentrator (PDC), which will time align the data received from PMU’s and forwarding it to a PC running a soft PLC.

1) Angle Difference

Angle difference method indicated an islanding condition if the difference of angles of respective voltage signals received from two points of the system exceeds a programmable threshold. The angles of the positive sequence voltage and the voltage calculated from the Clarke transformation were both tested and compared.

\[ \delta_{\text{Diff}}(t) = \delta v_1(t) - \delta v_2(t) \]

2) Voltage Difference

The voltage difference method operates similarly to the angle difference method. It compares the magnitudes of the voltage phasors obtained from Clarke transformation.

\[ V_{\text{Diff}}(t) = V_1(t) - V_2(t) \]

3) ROCPAD (Rate Of Change Of Phase Angle Difference)

a) Single Ended

This method calculates the rate of change of the angle difference between respective voltage and current signals. It is using measurements only from one PMU attached to the island area.

\[ R(t) = \frac{\Delta (\delta v(t) - \delta i(t))}{\Delta t} \]

The islanding condition is detected whenever the value of ROCPAD exceeds a settable threshold.

b) Double Ended

The double ended ROCPAD uses values from both sides of the system and operates whenever the result of differences exceeds a programmable threshold. Alternatively, ROCPAD can also be calculated using rate of change of angle differences at two end synchrophasor voltages.

\[ \text{ROCPADDiff}(t) = \text{ROCPAD2}(t) - \text{ROCPAD1}(t) \]
4) **THD Difference**

This novel method calculates the sum of Total Harmonic Distortion (THD) of the voltages from each PMU and compares the difference of the sums of THD.

\[
\text{THDDiff}(t) = \left[\text{THDVa}_1(t) + \text{THDVb}_1(t) + \text{THDVc}_1(t)\right] - \left[\text{THDVa}_2(t) + \text{THDVb}_2(t) + \text{THDVc}_2(t)\right]
\]

**IV. CASE STUDY**

![IEEE 6 Bus System](image1)

Above figure shows the IEEE 6 bus system having base MVA = 100 MVA, base kV = 34.5 kV and system frequency = 60 Hz. The other system details are given below:

<table>
<thead>
<tr>
<th>BUS</th>
<th>REAL POWER (P.U)</th>
<th>REACTIVE POWER (P.U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At bus 4</td>
<td>0.90</td>
<td>0.60</td>
</tr>
<tr>
<td>At bus 5</td>
<td>1.00</td>
<td>0.70</td>
</tr>
<tr>
<td>At bus 6</td>
<td>0.90</td>
<td>0.60</td>
</tr>
</tbody>
</table>

**Table 1: LOAD DATA of IEEE 6 Bus system**

<table>
<thead>
<tr>
<th>GEN NO</th>
<th>P + jQ (P.U)</th>
<th>V (P.U.)</th>
<th>MVA</th>
<th>BUS TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>0.9 + j1.5</td>
<td>1.05</td>
<td>100</td>
<td>PV</td>
</tr>
<tr>
<td>G2</td>
<td>1.4 + j1.5</td>
<td>1.05</td>
<td>100</td>
<td>SLACK</td>
</tr>
<tr>
<td>G3</td>
<td>0.6 + j1.5</td>
<td>1.05</td>
<td>100</td>
<td>PV</td>
</tr>
</tbody>
</table>

**Table 2: GENERATOR DATA of IEEE 6 Bus system**

Following Islanded Case is considered of the above IEEE 6 Bus system,

![Islanded case of IEEE 6 Bus System](image2)

**A. MATLAB Model**

The MATLAB model of the above given IEEE 6 Bus system is shown in figure 3.

![MATLAB Model of IEEE 6 Bus System](image3)

The above given MATLAB Model of IEEE 6 bus system is operated using traditional method and synchrophasor method at both normal condition and in the islanded condition. Now according to IEEE 1547 Standard, the permissible voltage difference allowed in the distributed system is 1%. Hence the system can be smoothly operated when the system voltages is between 0.9 > V < 1.1 P.U.

But during the islanding condition, the system voltages will be out of the permissible values. Hence the DG connected at the Bus 1 should be tripped as soon as possible.

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>NORMAL VOLTAGES</th>
<th>ISLANDED VOLTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.07</td>
<td>0.6221</td>
</tr>
<tr>
<td>2</td>
<td>1.048</td>
<td>1.263</td>
</tr>
<tr>
<td>3</td>
<td>1.049</td>
<td>1.241</td>
</tr>
<tr>
<td>4</td>
<td>0.9934</td>
<td>0.5288</td>
</tr>
<tr>
<td>5</td>
<td>0.9763</td>
<td>0.5062</td>
</tr>
<tr>
<td>6</td>
<td>0.9944</td>
<td>1.187</td>
</tr>
</tbody>
</table>

**Table 4: Comparison of Voltages**

We can see that during the islanding condition, the voltages goes out of range. Hence the DG is tripped as shown in figure. 4.

Now the same model is operated by installing the PMU (Phasor Measurement Unit) at both normal operation and islanded operation. During the normal operation there is no change in the voltage magnitudes but during the islanding condition, the voltage changes drastically and the DG is tripped.

![DG tripped](image4)
Comparison of the islanding condition between the traditional method and synchrophasor method will get us to know which method works faster to detect the islanding condition.

Table 5: Comparison of Voltages

<table>
<thead>
<tr>
<th></th>
<th>0.9537</th>
<th>1.263</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.9704</td>
<td>1.241</td>
</tr>
<tr>
<td>4</td>
<td>0.8888</td>
<td>0.3807</td>
</tr>
<tr>
<td>5</td>
<td>0.8812</td>
<td>0.3844</td>
</tr>
<tr>
<td>6</td>
<td>0.9127</td>
<td>1.187</td>
</tr>
</tbody>
</table>

Fig. 5: Comparison of the voltage waveform of traditional method and synchrophasor method when the generator is tripped at bus 1 during islanding condition

From figure 5 we can see that the time required for both the method is different. In case of traditional method the time taken for DG tripping is 0.0224 seconds, whereas in case of synchrophasor method the time taken for DG tripping id 0.0195.

Hence we can say that the synchrophasor technology works faster and gives accurate result faster which will help to control and protect the distribution system in case of any fault.

REFERENCES

