A PMU-Based Island Detection Technique Validated by a Real-Case Study of a Distribution System in Malaysia

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Abstract

Islanding detection is becoming a vital aspect of the power system as the penetration of distributed generators in the utility power system continues to grow. If the distribution generation (DG) capacity matches the connected feeder load the islanding detection takes longer due to the minimal power imbalance between the DG and the utilities prior to islanding event. This research work proposes a slip and acceleration angle-based islanding detection algorithm using phasor measurement unit (PMU) voltage angle data. Specifically, this research utilizes the grid and DG bus voltage angles in the form of their slip and acceleration angle parameters. This research work presents the performance results of the proposed islanding detection algorithm for the under frequency, over frequency, and match frequency islanding conditions. The proposed algorithm is developed using IEEE 30 bus system and validate with the actual Utility Kerteh system (located in Terengganu, Malaysia) based on simulated PMU voltage angle data for 8 different island and non-island cases. Notably, the proposed algorithm shows that it can detect all islanding conditions of the Utility Kerteh system at 20ms, which means it requires only one cycle duration after island incepts in the network.
20ms, which means it requires only one cycle duration after island incepts in the network. Therefore, the proposed algorithm is able to improve the detection time of the match frequency islanding condition from 500ms, as mentioned in the recent literature survey. Furthermore, the proposed algorithm can distinguish between actual islanding events and non-islanding events.

**Keywords** - Acceleration angle, match frequency, distributed generator, phasor measurement unit (PMU), slip angle

### 1. Introduction

Around the world, the transition from a conventional grid to a microgrid with a combination of distributed generation (DG) units is proceeding at a breakneck speed [1]. The intermittent characteristic of non-dispatchable renewable energy sources causes voltage swings, power fluctuations, and power quality issues [2, 3]. The microgrid’s DG units are still operate in an island state to provide local demand, but the microgrid is electrically separated from the utility grid [4]. As a result, island detection in a microgrid is required for ensuring the reliability. Furthermore, the system's behaviour may be unpredictable in the situation in unscheduled or unintentional islanding [5]. DG should be disconnected within 2 seconds, according to IEEE 1547-2003 and IEEE 1547a-2014 rules [4]. When island happen microgrid get disconnected from the rest of the system [6]. The islanding detection algorithm can work to detect the smallest feasible faulted zone of the microgrid if a fault occurs inside the microgrid and the circuit breaker is opened [7]. Furthermore, the islanding detection algorithm should distinguish between actual islanding and transient events like the onset and clearing of a feeder fault [8]. The literature [9] describes both local and remote islanding detection techniques (IDTs). Based on local measurements, IDTs are divided into two categories: passive and active approaches. Passive techniques fail when the power difference between the DG and the load is minimal or nil [10]. However, the active detection method can minimize the non-detection zone but decreases the power quality [11-18]. Although a blend of active and passive techniques can reduce the NDZ while maintaining the necessary power quality but the algorithms are unable to distinguish between island event and non-island events [7, 19–21]. Most schemes now focus exclusively on grid-side faults [22], but an effective islanding detection algorithm should be able to detect all possible islanding events. In [19], a systemic principle component analysis-based monitoring system is proposed but this method, require longer island detection time. In [23], a multi-functional island detection system based on voltage angle data from PMU with a dynamic monitoring and supervision is proposed. The use of pattern recognition algorithms for island events based on transient signals has been considered [24, 25]. However implementing this system into reality is extremely difficult. The authors of [26, 27] used PMU frequency difference data to detect islanding events. However this method is ineffective for the match frequency condition as match frequency condition has minimal voltage and frequency excursion.

Decision tree (DT) techniques have superior accuracy for recognising islanding events [28, 29]. The supervisory control and data acquisition (SCADA) system is a popular method for detecting islanding events, but it is unable to provide reliable feedback due to the transmission delay and the higher installation cost [30]. In [31], an islanding detection scheme based on the voltage angle difference between two PMUs, where the detection time was improved but the under-frequency and over-frequency islanding condition performance was not included in that algorithm. The paper [32], proposed an island detection technique using voltage angle but transient fault was unconsidered. An islanding detection method based on probabilistic component analysis in [33, 34] but the algorithm fails when phase angle and frequency are properly matched during the island event. These journals [35, 36] proposed a voltage angle and current angle-based islanding detection system that reduced false triggers but did not provide any performance analysis for the match frequency islanding situation. The authors of [37, 38] proposed a voltage magnitude-based islanding detection algorithm but the algorithm unable to detect the match frequency islanding condition. This journal [39] proposed an islanding detection technique using current flow of the circuit breaker but there is a possibility to occur false tripping. A ridgilet probabilistic neural network to detect islanding in [40], and the algorithm is successful in detecting islanding, this algorithm did not include transient faults and match frequency island condition.

In [41], island threshold setting methodology has been discussed using PMU voltage angle and an extended
work has been presented in this paper with island detection algorithm to solve the actual island scenarios of the Utility Kerteh system. This research work aim is to develop an island detection algorithm for the different islanding conditions such as under frequency, over frequency, and match frequency of the actual Utility Kerteh system. In addition, the algorithm should not detect transient fault as an island event. There is a substantial challenge in this research work, and this is to prepare a single algorithm that will be applicable for all the islanding conditions which means that we can’t change threshold every time for every island cases. This research work proposes a slip and acceleration angle-based islanding detection algorithm. From this proposed algorithm, detection can take place by a one cycle duration after island incepts in the network. The proposed scheme is different from the other schemes due to the appropriate threshold setting. In other islanding detection schemes, used a much higher threshold, which was not suitable for the match frequency island condition which causes requires a longer detection time. Therefore, the main contribution of this paper are following:

- Designed and developed an actual distribution system with 8 real islanding and non-islanding cases.
- Proposed a new island detection technique using voltage angle of the PMU.
- Proposed algorithm is able to detect island at 20ms which is faster than the existing island detection techniques.
- Proposed algorithm can distinguish between real islanding and non-islanding cases which will lead to avoid false tripping.

The rest of the paper is organized as follows, Section 2, elaborates the proposed algorithm and Utility Kerteh system that is referred as test system, Section 3, presents the results and discussion, and Section 4 describes the conclusion of the paper.

2. Proposed Algorithm and Test System

In our prior work [41] island threshold setting methodology has been described and implemented in the IEEE 30 bus system where the main idea was to find out the critical loads of the system until generator trip due to the over or under frequency protection. This research work presents an extensive work of that prior work for preparing an island detection algorithm for the under frequency, over frequency, and match frequency islanding conditions using that island threshold setting method for the actual Utility Kerteh system. Slip and acceleration angles are following:

\[ \text{Slip Angle} = (1) \]
\[ \text{Acceleration Angle} = (2) \]

Here, is the bus voltage angle difference between the DG and the utility bus. The slip angle and acceleration angle come from the PMU bus voltage angle data.
Fig. 1. Regional layout of the proposed islanding detection algorithm

Fig. 1 illustrates the proposed islanding detection regional layout where horizontal axis presents the slip angle and vertical axis presents the acceleration angle. In the normal condition, the operating spot lies inside the normal operating region. When the operating points pass beyond the threshold line towards the islanding region, then islanding is detected. In the proposed scheme, a transient fault critical clearing time is taken into consideration to avoid the transient fault detected as islanding. As in Fig. 2, for detecting the island firstly, it calculates the angle difference between DG bus and utility grid bus and determine the slip and acceleration angle. In order to obtain the regional layout as shown in Fig. 1, these slip and acceleration angle are converted to their absolute values. In differentiating between actual islanding and transient fault there is a NOT gate operator to nullify the result if it detects any transient fault in the system. Therefore, during the transient fault event this algorithm will not show islanding is detected.

Fig. 2. Implementation of the proposed island detection algorithm

However, proposed algorithm has an AND gate to get the final detection outcome which will ensure the higher reliability since for the island detection both slip and acceleration angle threshold require to meet properly which will also contribute to minimize the false detection alarm. The Utility Kerteh system as shown in Fig. 3 is used to verify the proposed algorithm. Table 1 presents the bus distances of the utility grid system namely, Tenaga Nasional Berhad (TNB).
Fig. 3. Single line diagram of the Utility Kerteh system (located in Kerteh, Terengganu, Malaysia)

Table 1. Bus distances of the TNB system

<table>
<thead>
<tr>
<th>Bus</th>
<th>Distance (Kilometer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CJSS to PAKA</td>
<td>2.5</td>
</tr>
<tr>
<td>KTIH to PAKA</td>
<td>6.5</td>
</tr>
<tr>
<td>KTIH to RPTS</td>
<td>13.26</td>
</tr>
<tr>
<td>CJSS to RPTS</td>
<td>18.05</td>
</tr>
</tbody>
</table>
Fig. 4. Islanding scenario 1 of the Utility Kerteh system

Fig. 4 and 5 show the actual islanding scenarios of the Utility Kerteh system. In this research work, the Utility Kerteh system island formation can be occurred by two scenarios and those are:

Scenario 1: Transmission line between PAKA to KTIH open while the RPTS to KTIH line is on outage (Fig. 4).

Scenario 2: Transmission line between RPTS to KTIH open while PAKA to KTIH transmission line is on outage (Fig. 5).

Fig. 5. Islanding scenario 2 of the Utility Kerteh system

Table 2 shows details of the Utility Kerteh system with critical loads at the KTIH bus that create different islanding conditions. Table 3 presents the threshold settings of the proposed islanding detection algorithm for the Utility Kerteh system. However, using (1) and (2) slip and acceleration angle threshold values are calculated for all the island and transient fault cases. Once all the island and transient fault threshold values are available then figure out the common values as threshold from them which will be applicable for the all island and transient fault cases i.e.; island threshold slip and acceleration angle values comes from case MF2.

Table 2. Cases of the Utility Kerteh system

<table>
<thead>
<tr>
<th>Cases</th>
<th>Scenarios</th>
<th>Critical Loads of KTIH bus (MW)</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>OF1</td>
<td>1</td>
<td>58</td>
<td>Over frequency</td>
</tr>
<tr>
<td>OF2</td>
<td>2</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>UF1</td>
<td>1</td>
<td>16</td>
<td>Under frequency</td>
</tr>
<tr>
<td>UF2</td>
<td>2</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>MF1</td>
<td>1</td>
<td>2.820</td>
<td>Match Frequency</td>
</tr>
<tr>
<td>MF2</td>
<td>2</td>
<td>2.820</td>
<td></td>
</tr>
<tr>
<td>Cases</td>
<td>Scenarios</td>
<td>Critical Loads of KTH bus (MW)</td>
<td>Conditions</td>
</tr>
<tr>
<td>-------</td>
<td>-----------</td>
<td>--------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>F1</td>
<td>N/A</td>
<td>16</td>
<td>SLG Fault</td>
</tr>
<tr>
<td>F2</td>
<td>N/A</td>
<td>16</td>
<td>3PB Fault</td>
</tr>
</tbody>
</table>

Table 3. Threshold setting for the Utility Kerteh system

<table>
<thead>
<tr>
<th>Thresholds</th>
<th>Slip Angle (Deg/s)</th>
<th>Acceleration Angle (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Island</td>
<td>0.8</td>
<td>40</td>
</tr>
<tr>
<td>Three Phase Balance (3PB) fault</td>
<td>295.53</td>
<td>3676.25</td>
</tr>
<tr>
<td>Single Line to Ground (SLG) fault</td>
<td>0.34</td>
<td>4.5</td>
</tr>
</tbody>
</table>

3. Results Analysis and Discussions

3.1. CASE OF1 AND OF2

Case OF1 and OF2 represent the over frequency islanding condition of the Utility Kerteh system. Fig. 6 and 7 show the island detection by the proposed algorithm for the case OF1 and OF2. During the pre-island condition (circled area) slip and acceleration angles for both cases are zero as the system is stable. However, when island incept at 2s in the system and it has been detected at 2.02s since on that time slip and acceleration angle values are 97.27 deg/s and 17402.5 deg for case OF1 and 96.32 deg/s and 17158.7 deg for the case OF2 which means that, the operating point has been passed the island threshold of 0.62 deg/s and 31 deg.

Fig. 6. Island detected for case OF1
Fig. 7. Island detection time for case OF2

Notably, when island incept the value of slip and acceleration angles are higher compare to the threshold but it is unrealistic that the island inception and detection can be happened at a same time. Therefore, island has been detected at 2.02s. Now, island detection time for case OF1 and FF2 is, island incept time - island detected time = 2s - 2.02s = 0.02s or 20ms.

3.2. CASE UF1 AND UF2

Case UF1 and UF2 represent the under frequency islanding condition of the Utility Kerteh system. Fig. 8 and 9 show the island detection by the proposed algorithm for the case UF1 and UF2. During the pre-island stage slip and acceleration angles are zero as the system is stable. However, when island incept at 2s in the system it has been detected at 2.02s since on that time slip and acceleration angle values are 21.545 deg/s and 3568.25 deg for case UF1 and 21.5432 deg/s and 3556.5 deg for the case UF2 which means that, the operating point has been passes the island threshold of 0.62 deg/s and 31 deg.
Therefore, island detection for case UF1 and UF2 is, island incept time - island detected time = 2s - 2.02s = 0.02s or 20ms. Which means that, the proposed algorithm is required 20ms for detecting the island after incept island in the system.

3.3. CASE MF1 AND MF2

Case MF1 and MF2 represent the match frequency islanding condition of the Utility Kerteh system. Fig. 10 and 11 show the island detection by the proposed algorithm for the case MF1 and MF2. During the pre-island stage slip and acceleration angles are zero as the system is stable. However, when island incept at 2s in the system it has been detected at 2.02s for both MF1 and MF2 cases since on that time slip and acceleration angle values are 0.8 deg/s and 40 deg for case MF1 and 0.81 deg/s and 40.5 deg for the case MF2 which means that, the operating point has been passes the island threshold of 0.62 deg/s and 31 deg. However, the slip and acceleration angle values of case MF1 and MF2 are very small compare to other island cases due to minimal power imbalance between the DG and utility bus.
Now to find out the island detection time, island incept time - island detected time = 2s - 2.02s = 0.02s or 20ms. Which means that, the proposed algorithm is required 20ms for detecting the island after incept island in the system.

3.4. CASE F1 AND F2

Case F1 and F2 represent the 3PB and SLG fault conditions of the Utility Kerteh system. Fig. 12 show that the transient fault threshold detected (a) 3PB fault and (b) SLG fault. This result will be nullified or become zero since there is a NOT gate with the fault thresholds in the algorithm, and this converted result moves towards to the logical block (AND gate). When the logical block gets a zero as an input, it will make the overall detection result zero. Fig. 12 (c) shows flat line which means no islanding detection occurred by the proposed algorithm for the case F1 and F2.

3.5. Results Summary

Table 4 shows the proposed islanding detection algorithm performance for the actual Utility Kerteh system. The proposed algorithm can detect the islanding of the Utility Kerteh system at 20ms for all the islanding conditions. In addition, the proposed algorithm does not detect transient fault as an islanding event.

Table 4. Cases of the Utility Kerteh system
### Cases Status Detection Time Pass/Fail

<table>
<thead>
<tr>
<th>Cases</th>
<th>Status</th>
<th>Detection Time</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>OF1</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>OF2</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>UF1</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>UF2</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>MF1</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>MF2</td>
<td>Island Detected</td>
<td>20ms</td>
<td>Pass</td>
</tr>
<tr>
<td>F1</td>
<td>No Island Detection</td>
<td>NA</td>
<td>Pass</td>
</tr>
<tr>
<td>F2</td>
<td>No Island Detection</td>
<td>NA</td>
<td>Pass</td>
</tr>
</tbody>
</table>

### 3.6. Result Comparison

Table 5 shows a comparative analysis of the proposed algorithm with other methods. In [42-47], there are different island detection time but those methods did not consider the transient fault blocking method in their algorithm so there is a higher possibility that those algorithms might consider transient fault as an islanding event.

#### Table 5. Comparison with other islanding detection methods

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Island detection Methods</th>
<th>Transient Faults</th>
<th>Detection Time</th>
<th>Implementation Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>[42]</td>
<td>WSE</td>
<td>Not Considered</td>
<td>&lt;10ms</td>
<td>High</td>
</tr>
<tr>
<td>[43]</td>
<td>ST</td>
<td>Not Considered</td>
<td>26ms</td>
<td>Moderate</td>
</tr>
<tr>
<td>[44]</td>
<td>EMD</td>
<td>Not Considered</td>
<td>&lt;35ms</td>
<td>High</td>
</tr>
<tr>
<td>[45]</td>
<td>TMF</td>
<td>Not Considered</td>
<td>55ms</td>
<td>Moderate</td>
</tr>
<tr>
<td>[45]</td>
<td>Over/Under Voltage</td>
<td>Not Considered</td>
<td>796ms</td>
<td>Low</td>
</tr>
<tr>
<td>[46]</td>
<td>ROCOF</td>
<td>Not Considered</td>
<td>337ms</td>
<td>Low</td>
</tr>
<tr>
<td>[47]</td>
<td>VMD</td>
<td>Not Considered</td>
<td>10ms</td>
<td>Moderate</td>
</tr>
<tr>
<td>[48]</td>
<td>ANN</td>
<td>Considered</td>
<td>0.5s</td>
<td>High</td>
</tr>
<tr>
<td>[49]</td>
<td>SVM</td>
<td>Considered</td>
<td>50ms</td>
<td>Moderate</td>
</tr>
<tr>
<td>[50]</td>
<td>HoGF+SVM</td>
<td>Considered</td>
<td>218ms</td>
<td>High</td>
</tr>
<tr>
<td>[51]</td>
<td>ELM</td>
<td>Considered</td>
<td>NA</td>
<td>Moderate</td>
</tr>
<tr>
<td>[52]</td>
<td>Ensemble Tree</td>
<td>Considered</td>
<td>NA</td>
<td>Moderate</td>
</tr>
<tr>
<td>[53]</td>
<td>RF</td>
<td>Considered</td>
<td>NA</td>
<td>Moderate</td>
</tr>
<tr>
<td>[54]</td>
<td>MIMF</td>
<td>Considered</td>
<td>70ms</td>
<td>High</td>
</tr>
<tr>
<td>[20]</td>
<td>FL</td>
<td>Considered</td>
<td>229ms</td>
<td>High</td>
</tr>
<tr>
<td>[55]</td>
<td>Slip frequency and acceleration</td>
<td>Considered</td>
<td>500ms</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Proposed algorithm</strong></td>
<td>Considered</td>
<td><strong>20ms</strong></td>
<td><strong>Low</strong></td>
<td></td>
</tr>
</tbody>
</table>

However, [20, 48-55] consider the transient fault blocking approach but discovered a longer detection time to detect islanding and the longest time has been found in [55]. On the other hand, the proposed algorithm can detect the islanding event of the Utility Kerteh network by 20ms with a low implementation complexity.

### 4. Conclusion

This research work proposes a new slip and acceleration angle-based islanding detection using voltage angle data of the PMU. The proposed algorithm can improve the island detection time of the match frequency islanding condition as well as distinguishing between actual islanding events and non-islanding events. The main contribution of this research work are:
As existing algorithm has limitations in terms of long detection time to detect islanding and this research work demonstrate the steps of developing an improved island detection algorithm which is very important to protect electrical grid from the hazardous situation.

The proposed algorithm is able to solve the actual islanding issue of the Utility Kerteh system. In addition, proposed algorithm can distinguish between actual islanding and non-islanding events which were confirmed through detailed analysis.

In future, proposed algorithm can be integrated with adaptive load shedding technique since consumers always prefer power continuity even under island conditions. It is also typical to keep power systems running while islanded. Therefore, if the proposed algorithm can be integrated with an adaptive load shedding scheme, the power delivery during the islanding condition can be maximized by tripping only required load to keep the system stable.

**Abbreviation**

- PMU Phasor Measurement Unit
- UF Under Frequency
- OF Over Frequency
- MF Match Frequency
- DG Distribution Generation
- TNB Tenga Nasional Berhad
- SLG Single Line to Ground
- 3PB Three Phase Balance
- WSE Wavelet Singular Entropy
- ST S-Transform
- EMD Empirical Mode Decomposition
- TMF Transient Monitoring Function
- VMD Variational Mode Decomposition
- ANN Artificial Neural Networking
- HoGF Histogram of Oriented Gradient Features
- ELM Extreme Learning Machine
- RF Radio Frequency
- MIMF Modified Intrinsic Mode Function
- SVM Support Vector Machine
- FL Fuzzy Logic

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