

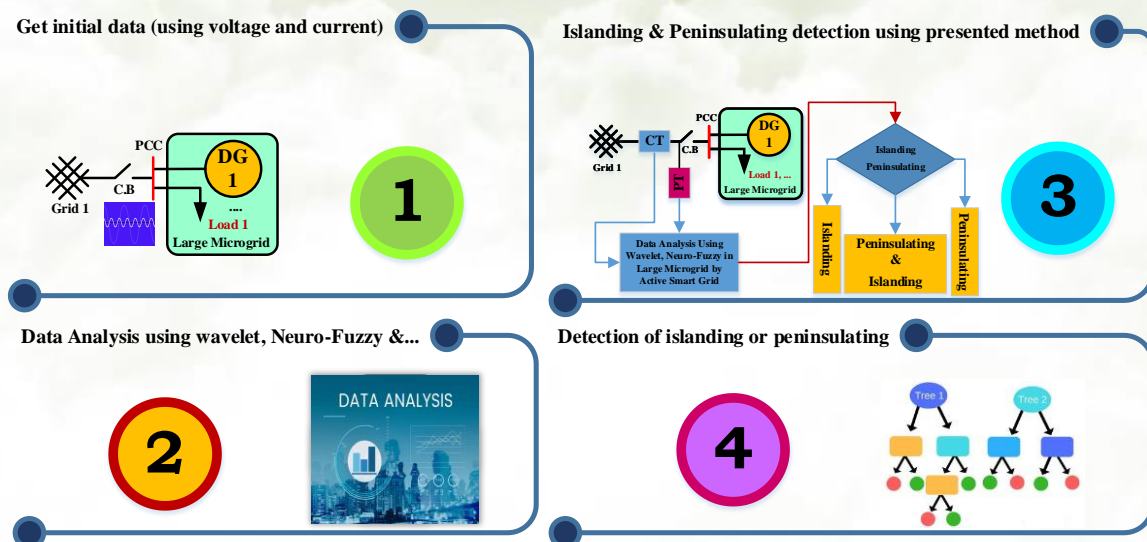
Percentage of Islanding and Peninsulating Detection in Large Microgrids with Renewable Energy Resources with Multiple Connection Points to Different Grids

Saman Darvish Kermani, Mohammad Fayazi, Jamshid Barati, Mahmood Joorabian

Highlight

- ❖ Presenting a new method for islanding and peninsulating detection in large microgrids
- ❖ Presenting of two concepts "percentage of islanding" and "peninsulating" in the study of islanding issues
- ❖ Considering the impact of renewable energy resources in the presented islanding detection method
- ❖ High usability of the proposed method due to the simplicity of its algorithm

Graphical Abstract



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Percentage of Islanding and Peninsulating Detection in Large Microgrids with Renewable Energy Resources with Multiple Connection Points to Different Grids

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ABSTRACT

This paper presents the islanding and peninsulating of distributed generators (DGs), such as wind and solar power plants, that feed microgrid systems. However, the paper does not focus on just an ordinary microgrid but large microgrids that have several sub-microgrids with renewable energy resources and multiple connection points (MCPs) to different grids. When islanding happens, the main microgrid disconnects some connection points from grids whereas some connection points to other grids could be connected and divided into some sub-microgrids for better stability. Two new definitions are proposed for large microgrid islanding: percentage of islanding and peninsulating. The former means how much it is possible that an islanding happens before it happens, and the latter means that: “after separating from some connection points to grids in a large microgrid with MCPs to different grids, remained large microgrid network is an island or a peninsula that is connected in some connection points to other grids? So, peninsulating a large microgrid depends on the number of connection points, at least two points, to different grids. This paper describes these two new definitions. The method involves the measurement of utility currents, voltages, and other signals through a bidirectional communications system in smart grids. These signals are used to calculate the percentage of islanding and decide on microgrid islanding or peninsulating.

1. Introduction

Nowadays, distributed generation (DG), solar, and wind units are growingly used in power networks as a means to satisfy the rising electricity demand and encourage the use of renewable energy sources. The higher penetration of DG amplifies the complexity of the distribution system and gives rise to multiple challenges. Presently, load demand has increased the number and variety of microgrids, resulting in the development of larger regroup systems. Large microgrids, which have several sub-microgrids with multiple connection points (MCPs) to different grids, are one of the system complexities. Islanding

is one of the most significant challenges in these systems. It refers to a situation where a section of the distribution system consists of DG and local loads. During islanding, these loads stay powered even though they are mistakenly disconnected from the rest of the system. The isolation may be attributed to a fault event on the primary distribution feeder. The re-closer will, in this situation, restore the connection to the isolated section of the system after a specific period, as determined by the system operator. This phenomenon is undesirable as it can be harmful to the distribution system. Therefore, the identification of islanding (also known as anti-islanding) has become a crucial necessity for protecting DG systems.

When islanding happens in a large microgrid with some sub-microgrids equipped with MCPs to different grids, the main microgrid separates from some connection points to grids whereas some connection points to other grids could be connected and divided to some sub-microgrids for better stability. This new state is not islanding because the microgrid is connected to other grids, so this new state is named "peninsulating" in this paper. After separating from some connection points to grids in a large microgrid with MCPs to different grids, the remaining large microgrid network constitutes an island or a peninsula connected in some connection points to other grids. So, peninsulating a large microgrid depends on the number of connection points, necessarily at least two points, to different grids. Islanding often occurs when the power generated by the DGs matches the power used by the load, resulting in the load being completely supplied by the DGs. Currently, if there is a disruption or failure in the utility, the fluctuations in voltage and frequency of the DGs cannot be identified according to the standards of UL1741 or IEEE1547 [1, 2]. This paper addresses large microgrids with some sub-microgrids, which are very complicated. In brief, if a microgrid connects to two grids and disconnects from one of them, it will be peninsulating not islanding because the microgrid connects to another grid. If the microgrid connected to two grids disconnects completely from the two grids, islanding may happen. An imminent and significant problem lies in the full assimilation of wind and solar power generation units into electric power systems, particularly within distribution networks operating at medium and low voltage levels. Indeed, such integration would enable optimal utilization of the renewable sources (RS) present in the area, which would otherwise remain untapped. This necessitates a comprehensive reconsideration of the administration and regulation of energy networks, transitioning from passive systems to innovative and dynamic "smart grids" [3]. The current passive systems are distinguished by one-way energy flows and a restricted range of intelligent and automated functions. In contrast, the concept of the smart grid involves energy flows that move in both directions. To support this, smart metering technologies and capabilities are required, along with a bidirectional communication system and various intelligent field devices. These devices enable monitoring, automation, protection, and control actions [4]. This technology involves the utilization of a bidirectional communication system in smart grids to measure utility currents, voltages, and other signals. These signals are used for islanding or peninsulating. The central microgrid decision system determines the islanding or peninsulating state, as well as other possible

states, by measuring currents, voltages, and other signals at the point before the main circuit breaker instead of the point of common coupling (PCC), as explained in reference [5]. There are abundant renewable energy resources (RESs) available on islands, such as wind, sun, biomass, ocean current energy, wave energy, tidal energy, ocean thermal energy, ocean salinity gradient energy, and geothermal energy. These resources have the potential to greatly contribute to developing electricity on islands [3]. Nowadays, microgrids are more complicated than before and some of these RESs in a microgrid connected to some grids can create a large microgrid. Nevertheless, the output power of these DGs can vary significantly and prove challenging to regulate due to factors such as weather conditions, geographical location, and other variables, which contribute to their intermittent and unpredictable nature. In recent years, microgrid technology has emerged as a promising solution for addressing the intermittent issues associated with the integration of distributed generators [6, 7]. This technology offers decentralization and localization, allowing for the maximum utilization of distributed energy resources to enhance system stability and reliability, improve power quality, reduce transmission losses, and enable intelligent and flexible control. A large microgrid with MCPs to different grids can be very complicated. Besides all these points, such microgrids need to be subjected to further research. The literature offers several ways for the detection of islanding, which can be categorized into passive, active, and communications-based techniques [4-21]. Ref. [22] presented a real-time analysis of an islanding detection scheme for AC microgrids, and Ref. [23] presented a communication-less islanding detection scheme for hybrid distributed generation systems using recurrent neural networks. Ref. [15] presented another classification for island detection methods, which includes local and remote methods. Active and passive methods are subsets of local methods. Ref. [19] proposed a passive islanding detection scheme using a phase angle of positive sequence voltage. Communications-based solutions encompass a wide range of communication technologies that can be utilized to establish smart grid infrastructures. Each technology possesses its distinct advantages and disadvantages [2, 15, 17, 18, 20, 24]. Hybrid techniques have a small Non-Detection Zone (NDZ) and perturbation is introduced only when islanding is suspected [19]. Large microgrids have complicated and hybrid techniques in which small NDZ should be used. This paper suggests hybrid techniques for the detection of not only islanding but also peninsulating. In addition to the tiny NDZ, the detection time is crucial. Therefore, this paper employs the percentage of islanding and/or peninsulating, as well as a modification in the measurement point of signals from the PCC in conventional approaches, to occur before the primary circuit breaker.

The paper is composed of the following sections. Section 2 presents the proposed islanding and/or peninsulating detection method. Sections 3 and 4 discuss the islanding detection methods and the percentage of islanding, respectively. The concept of peninsulating is presented in Section 5. Sections 6 and 7 describe large microgrids' formulation and an example of a large microgrid, respectively. The paper comes to an end with some concluding points in Section 8.

2. The Proposed Islanding and/or Peninsulating Detection Method

When a defect occurs in a power network, it is necessary to promptly identify and isolate the fault location in the power system using a circuit breaker. The duration required for fault clearing is equal to the combined time taken for the relay to operate and for the circuit breaker to interrupt the fault current. Even in the immediate operating mode of a relay, it takes around 0.5 to 1 cycle to transmit the open signal to the circuit breaker. The operational duration of a circuit breaker is determined by the number of times it has been activated and its specific kind, typically falling within a range of 3 to 5 cycles. This study focuses on measuring the utility current, voltage, and other signals on the side of the utility circuit breaker connected to DGs. Hence, the detection time for islanding is unaffected by the duration of the circuit breaker operation. By eliminating the circuit breaker operation time, the detection of the islanding state is expedited compared to local approaches. Figure 1 displays the suggested location for the measuring point.

The identification of islanding situations in the local technique commences upon the disconnection or opening of the circuit breaker. The local approach is used to measure system parameters, such as voltage, current, and frequency. The occurrence of islanding is recognized by sensing these variations after it occurs. Islanding situations can be detected by relocating the measuring point from the PCC to a position after the utility circuit breaker, prior to its opening. The suggested method utilizes wavelet transform in a neuro-fuzzy network to detect islanding and/or peninsulating. The suggested approach successfully reduces the islanding detection time. The basic model of the hybrid islanding and/or peninsulating detection method proposed in this paper is illustrated in Figure 1. The transient waveforms of currents, voltages, and other signals in a power network include distinct characteristics that can be used to identify the underlying source of the transient occurrence. The proposed method for detecting islanding and/or peninsulating occurrences is based on the assumption that the transients produced during these events possess a distinct characteristic. By developing a classifier, it is possible to differentiate islanding and/or peninsulating events from other disruptions.

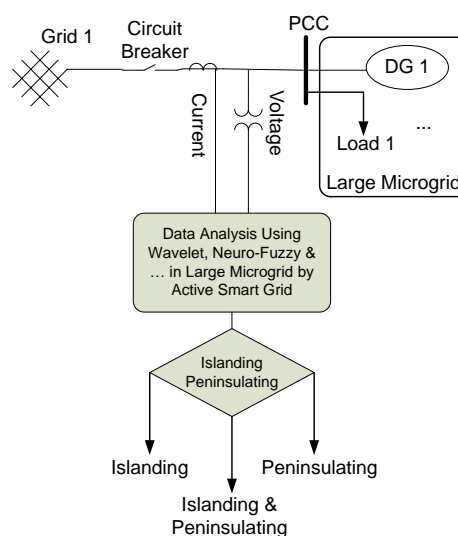


Figure 1. The location of current and voltage measuring point in the proposed model using the transient-based islanding detection method.

In this paper, NDZ is eliminated by identifying the conditions that lead to islanding and/or peninsulating through wavelet transform analysis before the circuit breaker opens. NDZ is created as a result of the disparity between active and reactive power during the occurrence of islanding and/or peninsulating in the local method. The proposed method does not experience any power quality issues as there is no insertion of disturbances. Thus, this strategy is devoid of the issues present in both passive and active procedures. So, a hybrid method is suggested which can detect disturbances and decide on an islanding and/or peninsulating state.

3. Islanding Detection Methods

Several methodologies have been devised to identify the occurrence of islanding. The strategies can be categorized into central (remote), local, and hybrid techniques, as depicted in Figure 2. The boxes in Figure 2 show some methods. These methods are used not only for islanding detection but also for peninsulating detection in this paper. Peninsulating is a decision made by a central smart microgrid unit. So, various combinations of remote and local (passive and active) methods are used for this decision in different microgrids based on their conditions.

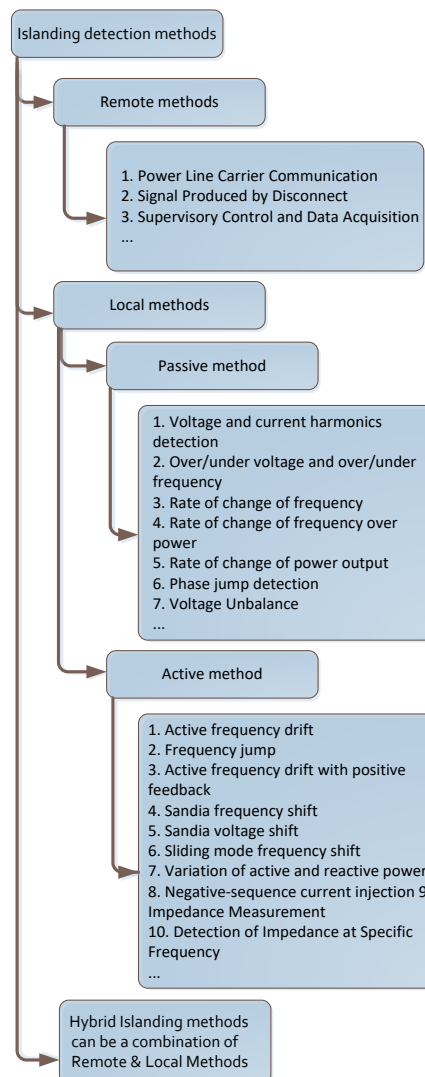


Figure 2. The classification of islanding detection methods.

4. Percentage of Islanding

This paper uses “percentage of islanding” in a new definition. It is the answer to this question, “Before islanding, how much is it possible for islanding to happen?”

For example, a failed network happens and some voltages and current characteristics are changed such that calculation in the central smart microgrid unit shows that this state will probably be islanding, so the active detection method starts to work with amplitude current proportion to probably calculation (for example in increasing current amplitude active method). Beforehand, the active detection method did not work, and this method can be useful for power quality in microgrids. If the calculation in the central smart microgrid unit shows that the probability of islanding is increased, the current amplitude will increase. This method influences power quality in a short time and if islanding does not happen in a definite time, the current amplitude will gently decrease to zero and only other detection methods like passive and remote detection methods will work in the microgrid. In brief, the percentage of islanding is a method for conditionally using active methods combined with passive and remote methods. The percentage of islanding is used for peninsulating, too. The central smart microgrid unit decides that a large microgrid should separate from some connection points to grids and the remaining large microgrid network is an island or a peninsula. So, the percentage of islanding is a general concept for explaining the probability of the shift from normal to island and/or peninsula state in a large microgrid.

5. Peninsulating

An island refers to a landmass that is smaller than a continent and is surrounded by water. A peninsula is a landmass that is surrounded by water on three sides and is attached to a larger landmass. A microgrid without any connection to other grids is an island, but a microgrid that is connected to other grids can be named a peninsula. This paper uses “peninsulating” in a new definition. In a large microgrid with MCPs to different grids, if a failure happens after separating from some connection points, the remaining large microgrid network will be an island or a peninsula connected in some connection points to other grids. Peninsulating a large microgrid depends on the number of connection points to different grids, which should be at least two connection points. A microgrid in normal condition with a connection point to a grid is a peninsula itself.

5.1. Concept of Islanding and Peninsulating in Large Microgrids

The concept of islanding in large microgrids with MCPs to different grids differs from islanding in microgrids. A large microgrid can be a microgrid that is connected to different grids. [Figure 3](#) displays a power island after islanding. In this figure, breaker B1 separates the microgrid from the main grid, so this state is islanding. A large microgrid is illustrated in [Figure 4](#) with two connection points to different grids via two main breakers (B1 and B3). When these two breakers (B1 and B3) separate a large microgrid from these two grids (grid 1 and grid 2), islanding happens again, but all main grids should separate from a large microgrid which can be an islanding state.

Figure 5 depicts a large microgrid with two connection points to different grids via two main breakers (B1 and B3). When breaker B1 separates main grid 1 from a large microgrid, peninsulating happens. If grid 1 and grid 2 connect via breakers B1 and B3 shown in Figure 6, peninsulating will occur again. So, a normal state in a large microgrid with different points to grids can be a peninsula.

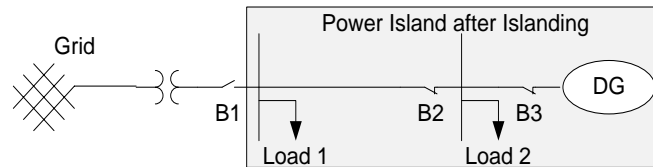


Figure 3. Islanding a microgrid with a main breaker (B1).

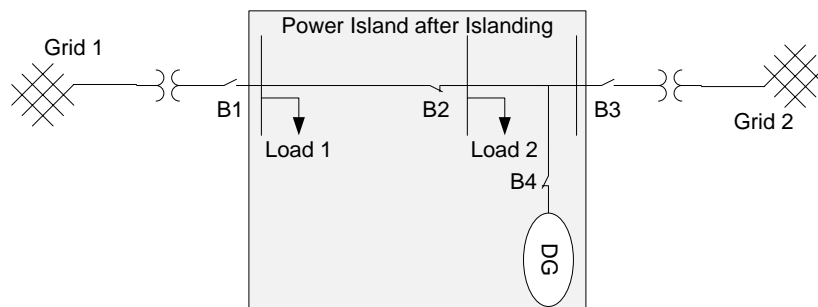


Figure 4. Islanding a large microgrid with two connections points to different grids via two main breakers (B1 and B3).

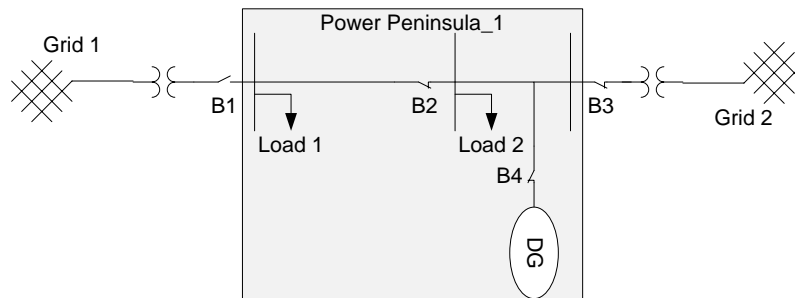


Figure 5. Peninsulating a large microgrid with two connections points to different grids via two main breakers (B1 and B3). Breaker B1 separates main grid 1 but, grid 2 is connected via Breaker B3.

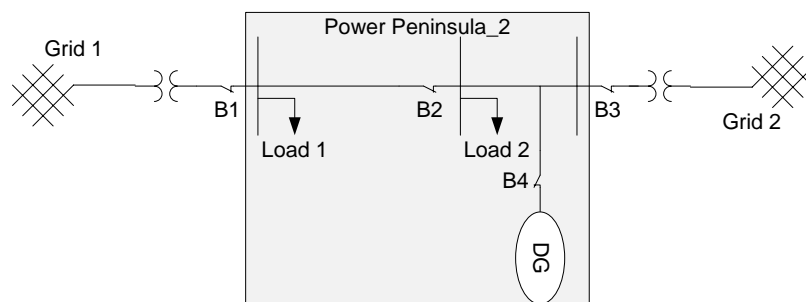


Figure 6. Peninsulating a large microgrid with two connections points to different grids via two main breakers (B1 and B3). Grid 1 and grid 2 are connected via breakers (B1 & B3).

5.2. Power Island and Peninsula in Large Microgrids

A power peninsula is illustrated in Figure 7 with two connection points to different grids via two main breakers (B1 and B3). When breaker B2 separates two DGs from each other, as shown in Figure 8, a large microgrid changes to two power peninsulas because one of them is connected to grid 1 via breaker B1 and the other is connected to grid 2 via breaker B3 and these are not power islands. Another state is illustrated in Figure 9. Grid 1 is connected via breaker B1, and grid 2 is separated via breaker B3. So, one of them is a power peninsula and the other one is a power island. Another state is illustrated in Figure 10. Grid 1 and grid 2 are separated via breakers B1 and B3 from a large microgrid. So, this is a power island. If breaker B2 separates two power islands, they will be two separate power islands as shown in Figure 11.

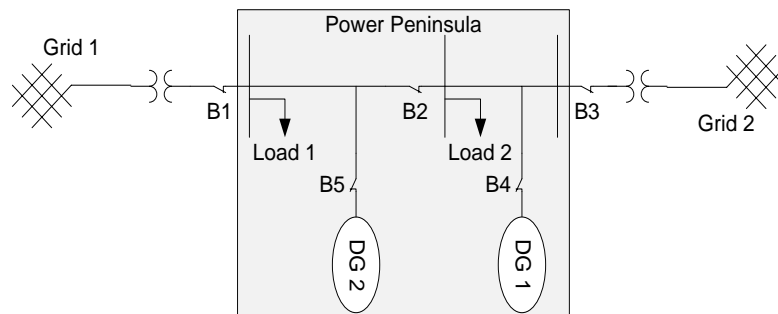


Figure 7. A power peninsula with two connections points to different grids via two main breakers (B1 and B3). Grid 1 and grid 2 are connected via breakers (B1 & B3).

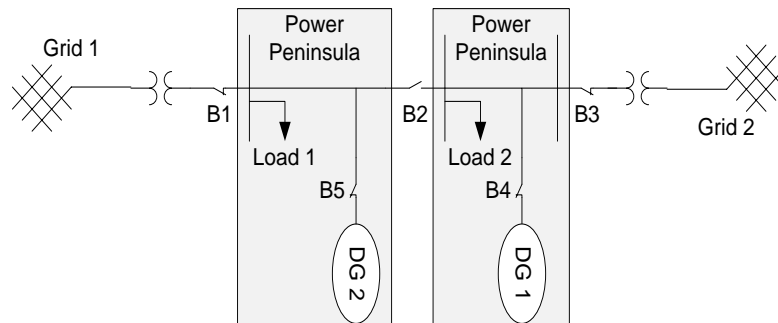


Figure 8. Grid 1 is connected via breaker B1 and grid 2 is connected via breaker B3 to two separate microgrids. These are power peninsulas.

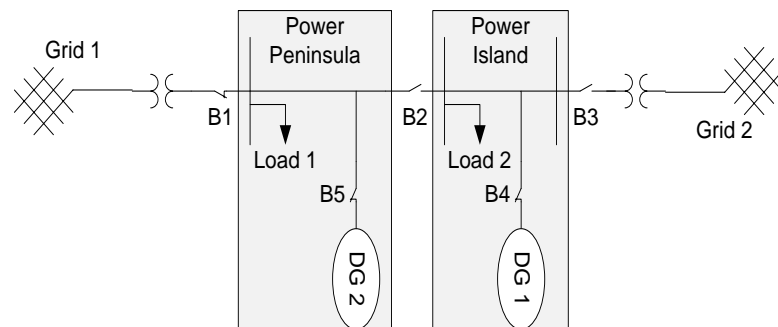


Figure 9. Grid 1 is connected via breaker B1 and grid 2 is separated via breaker B3. So, one of them is a power peninsula and the other one is a power island.

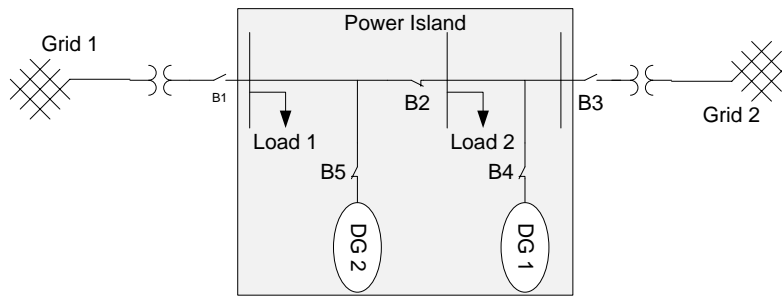


Figure 10. Grid 1 and grid 2 are separated via breakers B1 and B3 from a large microgrid. So, this is a power island.

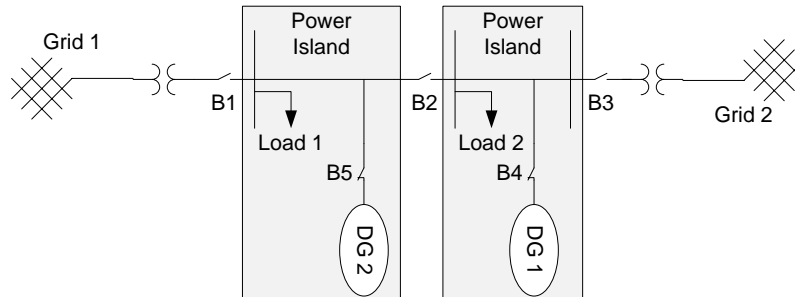


Figure 11. Grid 1 and grid 2 are separated via breakers B1 and B3 from a large microgrid and breaker B2 separates two power islands.

5.3. Changing Power Island to Power Peninsula and Vice Versa

A power peninsula and a power island are illustrated in Figure 12. The power peninsula is connected to grid 1 via breaker B1, but the power island is created by breakers B2, B3, and B7 that separate DG 1 and DG 3 from other networks.

In Figure 13, another peninsula and island create different situations. In this figure, the power peninsula contains DG 2 and DG 3. Power island only contains one DG (DG 1), but it is not important how many DGs there are in sub-microgrids. What is important is the stability of sub-microgrids and situations that will happen in microgrids, grids, and the connection between them.

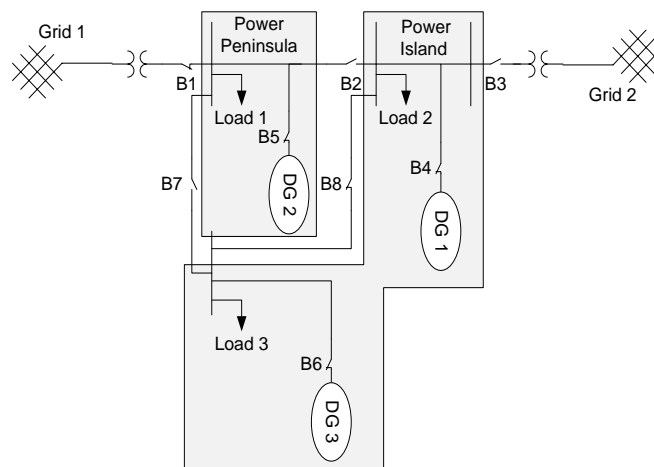


Figure 12. A power peninsula and a power island. The power peninsula is connected to grid 1 via breaker B1.

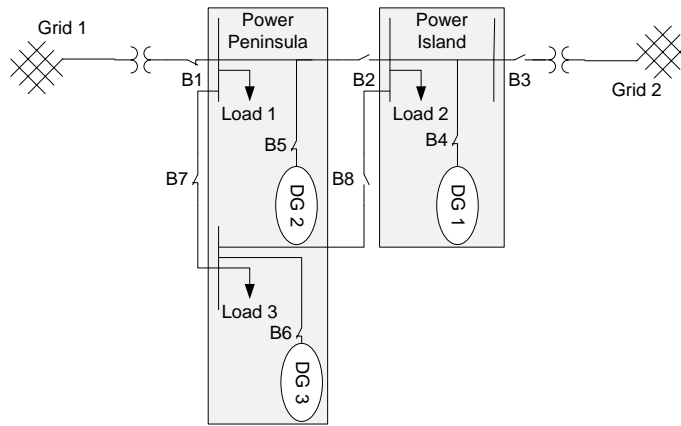


Figure 13. A power peninsula and a power island. The power peninsula is connected to grid 1 via breaker B1, but it contains DG 2 and DG 3.

6. Large microgrids' Formulation

Some possible formations of large microgrids which are shown in previous figures confirm that there are so many states of islanding and peninsulating in large microgrids. So, there should be a method that mathematically formulates connections between large microgrids, grids, sub-microgrids, loads, and other network components.

In a large microgrid, m_D is a matrix that shows the connection between DGs and loads, and m'_D is a matrix of microgrid design that describes the connection between DGs and loads in normal utilization of it. In matrix m_D , value 1 shows that a DG is connected to a load or other DGs and 0 shows that it is not connected. As with matrix m_D , M_D is a matrix that shows the connection between grids, DGs, and loads. M'_D is a matrix of the main grid design that describes the connection between grids and DGs and also grids and loads in the normal utilization of it. In matrix M_D , 1 shows that a grid is connected to a DG or load and 0 shows that it is not connected.

Another matrix $Grid_D$ is a matrix that shows the connection between grids themselves. $Grid'_D$ is a matrix of grid design that describes the connection between main grids in the normal utilization of it. In matrix $Grid_D$, 1 shows that a grid is connected to another grid, and 0 shows that it is not connected.

Finally, matrix Mm_D is a matrix of the main grid and microgrid design that describes all connections in the network in normal utilization.

$$Mm_D = \begin{bmatrix} [m_D]_{i \times i} & [M_D]_{i \times j} \\ [M'_D]_{j \times i} & [Grid_D]_{j \times j} \end{bmatrix}_{(i+j) \times (i+j)} \tag{1}$$

in which i is the number of DGs + loads and j is the number of main grids. This matrix completely describes the connection between grids, DGs, and loads in the network and the large microgrid.

7. A Large Microgrid Example

A large microgrid is illustrated in Figure 14 with four DGs that are connected to three grids and two loads.

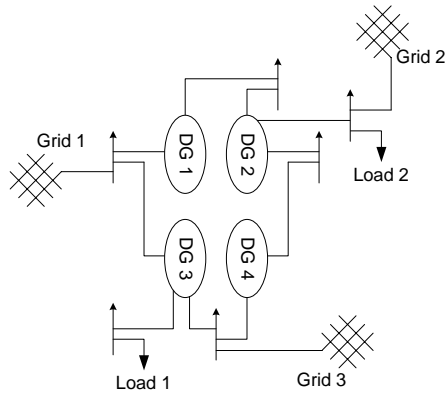


Figure 14. A large microgrid with four DGs that are connected to three grids.

In this example, matrix m_D is:

$$m_D = \begin{matrix} & \begin{matrix} DG1 & DG2 & DG3 & DG4 & Load1 & Load2 \end{matrix} \\ \begin{matrix} DG1 \\ DG2 \\ DG3 \\ DG4 \\ Load1 \\ Load2 \end{matrix} & \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \end{matrix} \quad (2)$$

and matrix M_D is:

$$M_D = \begin{matrix} & \begin{matrix} Grid1 & Grid2 & Grid3 \end{matrix} \\ \begin{matrix} DG1 \\ DG2 \\ DG3 \\ DG4 \\ Load1 \\ Load2 \end{matrix} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}_{6 \times 3} \end{matrix} \quad (3)$$

and matrix $Grid_D$ is:

$$Grid_D = \begin{matrix} \begin{matrix} Grid1 \\ Grid2 \\ Grid3 \end{matrix} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}_{3 \times 3} \end{matrix} \quad (4)$$

So, matrix Mm_D can be written from Equation (1):

$$Mm_D = \begin{bmatrix} [m_D]_{6 \times 6} & [M_D]_{6 \times 3} \\ [M'_D]_{3 \times 6} & [Grid_D]_{3 \times 3} \end{bmatrix}_{9 \times 9} \quad (5)$$

In detail, matrix Mm_D is:

$$Mm_D = \begin{matrix} DG1 \\ DG2 \\ DG3 \\ DG4 \\ Load1 \\ Load2 \\ Grid1 \\ Grid2 \\ Grid3 \end{matrix} \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{9 \times 9} \quad (6)$$

In this example, matrix Mm_D is used to describe large microgrid states. Islanding and peninsulating can be shown by changing connection states. In this example, if a failure happens in the connection of grid 1, and grid 1 is separated from the large microgrid, all connection numbers in matrix Mm_D will change from 1 to 0 (in this example, the connection state between grid 1 to DG 1 and DG 2 will change from 1 to 0).

Using this method, all the states that happen unintentionally or are decided for better performance can be controlled by central microgrid decisions. A large smart microgrid is a system that should control stability, power quality, and other network parameters. The central microgrid decision system controls all islanding and peninsulating states for enhancing the process of the large microgrid and/or sub-microgrids created.

8. Conclusions

This paper presents the detection of islanding and peninsulating in large microgrids which constitute some sub-microgrids with MCPs to different grids. Two new definitions are proposed for large microgrids: "percentage of islanding" and "peninsulating". These new definitions necessitate a comprehensive reconsideration of the administration and regulation of energy networks, transitioning them from passive systems to innovative and dynamic "smart grids". In the proposed method, the measured utility current and voltage signals and other signals received through a bidirectional communication system in smart grids are used to determine the islanding percentage and decide whether to island or peninsula the microgrid. The shift in the location of measuring currents, voltages, and other signals from the PCC to before the main circuit breaker has resulted in the central microgrid decision system determining whether to isolate, create a peninsula, or enter into other potential states. Peninsulating is a decision made by a central smart microgrid unit, and all unwanted states or decisions for better working can be controlled by central microgrid decisions. So, various hybrid methods are used for this decision in different microgrids based on their conditions. Some possible formations of large microgrids confirm that there are many states of islanding and peninsulating in large microgrids. Therefore, a mathematical formulation is needed to explain the connection between large microgrids, grids, sub-microgrids, loads, and other network components. These new definitions and formulations are used for control stability, power quality, and other network parameters in large smart microgrids. Central microgrid decision system controls all islanding and peninsulating states and creates sub-microgrids, power islands, and power peninsulas for better usage of networks.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

Credit Authorship Contribution Statement

Saman Darvish Kermani: Conceptualization, Data curation, Formal analysis, Methodology, Resources, Software, Validation, Roles/Writing - original draft. **Mohammad Fayazi:** Conceptualization, Resources, Software, Validation, Visualization, Roles/Writing - original draft, Writing-review & editing. **Jamshid Barati:** Methodology, Project administration, Resources, Validation, Visualization, Roles/Writing - original draft. **Mahmood Joorabian:** Conceptualization, Project administration, Supervision, Validation, Visualization, Roles/Writing - original draft.

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