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# Optimal location of active power flow controller in an intentionally islanded microgrid

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**Abstract -** *The position of the power flow controllers plays a vital role in the overall stability of the interconnected system. The active GUPFC also shows similar effects in the intentionally islanded microgrid. Location optimization becomes further necessary due to the uncertainty of renewable energy sources connected to various feeders in a microgrid. To determine the right position, a new algorithm is proposed in this paper that uses the generation contribution using mathematical theories and is simulated using a suitable tool.*

**Key Words: Distributed generation, GUPFC, Islanding, graph theory.**

## 1. INTRODUCTION

The concept of intentional islanding in a power system refers to the process of supplying electricity to a grid-isolated load using the energy source within the system [4]. The deteriorating stability of the grid system during widespread cascading failure can be mitigated by islanding the healthy part of the system to facilitate restoration. The different approaches and logical methodologies of power system restoration have a common requirement of start-up power or black start power. The idea of intentional islanding is concurrent with all the ways to achieve quick grid restoration [6]. The intentional islanding is a joint venture of sufficient generation, stable load and a strong communications system (power flow transfer entropy index) [11][7]. The generation in the islanded sub-system is mostly unconventional; hence, its modular structure can be located near the load for better performance. This paper discusses a new algorithm and compares it with conventional methodologies for locating a modular source, active GUPFC [3].

## 2. ACTIVE POWER FLOW CONTROLLER

The use of two SSSCs in the Generalised Unified Power Flow Controller (GUPFC) is aimed at controlling active as well as reactive power [2]. In the proposed method, GUPFC is installed for the same purpose by employing an active source, such as a Battery Energy Storage System (BESS) or a fuel cell, on the common DC bus instead of BESS. The system is shown in Fig.1. Where the active source is embedded with GUPFC in a subsystem to ensure an uninterrupted supply under all fault conditions. The heavily loaded feeders experience relaxation due to impedance control and voltage profile improvement after implementing the proposed method. The dependability of generating stations on grid power for supplying auxiliaries will be considerably reduced with improved power quality at the load side, with or without grid connectivity, when fed with an active GUPFC-based sub-system. Fig.1. Shows the general outline of the proposed system.

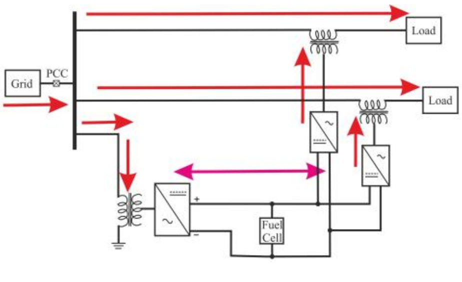


**Fig. 1.**Proposed system with grid connection

In normal working conditions, as sub-system sources float, the main grid supplies power to sub-system loads based on demand. Whenever there is a grid disturbance, and the main grid is unable to supply additional power to the sub-system, it has to separate from the main grid at the point of common coupling (PCC). The sub-system continues supplying power to the auxiliary system of the generating station.Fig.1shows the condition when the sub-system source, i.e. DG embedded GUPFC, fulfils the demand of auxiliaries. The proposed system is an application for generating stations. In this research work, thermal generating stations are considered as it has highest installed capacity in India. Due to the grid disturbance, a generating station usually experiences a shortfall of power for running auxiliaries. This difficulty is overcome by using the power from the sub-system.

However, the stable operation of the subsystem is also an issue of concern when it has a renewable, nature-dependent source. The use of a fuel cell can provide an uninterrupted and stable power supply if installed with proper electronic converters.

## 3. INTENTIONAL ISLANDING USING ACTIVE GUPFC

The active GUPFC-based sub-system is easy to set up. In this research, it is considered a support system of thermal power station auxiliaries, as it has a significant load profile [5]. Hence, it is placed close to the feeders supplying auxiliary power and nearby local loads [8]. A two-step procedure for finding out the active GUPFC system location is stated below:

1. The generating set(s) to be intentionally separated during a fault condition and connected loads are shortlisted according to the network diagram. For the connected loads, the available generator contribution is calculated using graph theory. The load(s) which have maximum contribution from a given generator are lumped together for islanding with that generator [10].
2. From the group of loads connected to the generator, loads satisfying the generation-load balance condition as stated in Eq. 1 are shortlisted for intentional islanding.

$$1.0 \leq \frac{G}{L} \leq 1.1 \qquad (1)$$

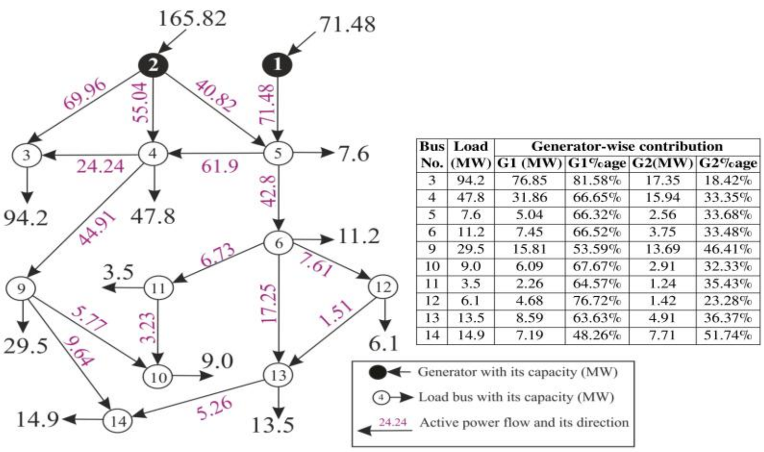
In such islanding pockets, an active GUPFC can be located using the generation load balance condition, and such a subsystem can be intentionally islanded.

## 4. GENERATOR CONTRIBUTION IN LOAD USING GRAPH THEORY

As explained in step 1 above, to find out the generator contribution in a particular load, there are several methods. Out of which graph theory method is considered in this work. The optimal selection of a group of loads near the generator, which makes the maximum contribution, is necessary for a stable islanding and its survival. Two methods are used for load selection. In the first method, load selection is done, which will satisfy Eq. 1, where 'G' is the generator capacity and 'L' is the load value. This method helps to short-list loads from the connected network for a particular generator. The second method is for the selection of load(s) in which a particular generator has maximum contribution. For this method, graph theory is used. The procedure for applying graph theory optimisation is as follows:

1. Run DC Load Flow for the network with the generator and load.
2. Convert the network into a graph: Generator bus will be solid dots, load bus will be hollow dots, transmission line will be branches of the graph and direction of power flow will be indicated by a directional arrow on every branch.
3. The next step is to separate the graph into directed sub-graphs with generation as their roots.
4. Find generator and load combinations which satisfy the ratio of generator power to load power between 1.0 and 1.1, with reference to Eq. 1.
5. Find out the contribution of a particular generator by formula: $C i j$ =Receiving power/Load power for all sub-graphs, where $i$ is the generator and $j$ is the load.
6. Averaging all the sub-graph values, the contribution of all generators in the network for a particular load can be determined.

The IEEE 14 bus test system is converted using the above method. The generator contribution for each load in the IEEE 14 bus system is calculated and summarised in Table 3. From the tabular results, it is clear that for every load in the network, one particular generator has the maximum contribution. The loads with maximum contribution of the generator are paired and such load-generator pairs are considered for sub-system connection and islanding. This method is explained with the help of the IEEE 14 bus system and generator contribution, as shown in fig.2.



| Bus No. | Load (MW) | Generator-wise contribution | | | |
|---|---|---|---|---|---|
| | | G1 (MW) | G1%age | G2(MW) | G2%age |
| 3 | 94.2 | 76.85 | 81.58% | 17.35 | 18.42% |
| 4 | 47.8 | 31.86 | 66.65% | 15.94 | 33.35% |
| 5 | 7.6 | 5.04 | 66.32% | 2.56 | 33.68% |
| 6 | 11.2 | 7.45 | 66.52% | 3.75 | 33.48% |
| 9 | 29.5 | 15.81 | 53.59% | 13.69 | 46.41% |
| 10 | 9.0 | 6.09 | 67.67% | 2.91 | 32.33% |
| 11 | 3.5 | 2.26 | 64.57% | 1.24 | 35.43% |
| 12 | 6.1 | 4.68 | 76.72% | 1.42 | 23.28% |
| 13 | 13.5 | 8.59 | 63.63% | 4.91 | 36.37% |
| 14 | 14.9 | 7.19 | 48.26% | 7.71 | 51.74% |

**Fig.2**. IEEE 14 Bus System

## 5. PROPOSED NEW ALGORITHM

The proposed algorithm is divided into two parts. In the first part, the contribution of the source is calculated for each node and based on that, the node ranking is done. In this ranking, the node with the maximum contribution of the source is given first rank and given the first preference for intentional islanding. The second part of the algorithm is executed after obtaining the real-time node and source weight. With the help of a computer program, nodes are short-listed from the node ranking. The node ranking is based on the ratio of source weight to node weight, which lies between 1.0 and 1.1. The ranking total of the short-listed nodes decides the boundary of the intentional landing scheme.

### 5.1 Steps:

1. Read the network as an undirected graph model
2. Read source and node weight
3. Consider one source at a time, and its weight is named as ‘a.’

   **Part - I**
4. Run the DC load flow for the given network
5. Redraw the directional rooted graph model with ‘a’
6. Draw a sub-graph by considering a permutation-combination of graph branches, connection with the node
7. Calculate the ratio of the average incoming weight to each node’s weight in each sub-graph
8. Calculate the average ratio for each node
9. The average ratio of each node is the source ‘a’ contribution in each node
10. End

    **Part - II**
11. Read the source contribution in each node
12. Assign a rank to each node based on the source contribution.
13. Allot the first rank to the node with the maximum source contribution and subsequently allot ranking to the other nodes.
14. Calculate the ratio in the limit condition as $\left[1.0 \le \frac{Source\ weight}{node\ weight} \le 1.1\right]$ make a group of such nodes
15. Choose the highest-ranking group of nodes for intentional landing
16. End

## 6. DEMONSTRATION OF THE NEW ALGORITHM

### 6.1. With a hypothetical system

Fig. 3 represents a hypothetical system for understanding the algorithm. In the network generator, it is connected with seven different loads ($L1$ to$L7$). One generator is considered at a time for this algorithm. The figure also shows the load contribution of a generator in each load. The load ranking is assigned based on contribution. Rank 1 is given to the load which has the maximum generator contribution. In the same way, all loads connected in the network are given a ranking. Fig.4 shows the generator and load combinations which satisfy the G/L ratio as mentioned above. The rank total (RT) is calculated based on Ranking. The generator-load combination with the lowest RT is selected for intentional islanding and active GUPFC installation, as it has the load with maximum generator contribution. In this way, the location of active GUPFC is decided. After considering the proposed algorithm, the following sample systems are considered for evaluation of the proposed method.

(a) Generator and load connection

(b) Generator and load pair ranking

**Fig. 3.** Generator and load pairing

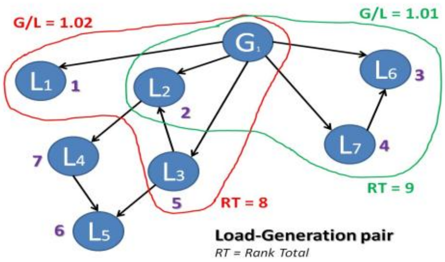


**Fig. 4.** Generator and load pair with Rank Total

### 6.2. IEEE14 bus system

The above approach is applied to the IEEE 14 bus system shown in fig. 2. Initially, in case I, only one generator G1 is considered with the load connected as shown in Table 1.

**Table 1.** IEEE 14 bus system case-I

| Generators : a | Load : 10 | |
|---|---|---|
| G[1] : 165.8 | L[1] : 94.199997 | L[6] : 9.0 |
| | L[2] : 47.8 | L[7] : 3.5 |
| | L[3] : 7.6 | L[8] : 6.1 |
| | L[4] : 11.2 | L[9] : 13.5 |
| | L[5] : 29.5 | L[10] : 14.9 |

Using a computer program using Python, a combination of loads with a generator is obtained which satisfies Eq.1. The load combinations having G/L ratios near to 1.0 and near to 1.1 are tabulated in Table 4.

Similarly, considering generator G2 as case-II, for finding out the load connected as shown in Table 2.

**Table 2.** IEEE 14 bus system case-II

| Generators : b | Load : 10 | |
|---|---|---|
| G[2] : 71.480003 | L[1] : 94.199997 | L[6] : 9.000000 |
| | L[2] : 47.799999 | L[7] : 3.500000 |
| | L[3] : 7.600000 | L[8] : 6.100000 |
| | L[4] : 11.200000 | L[9] : 13.500000 |
| | L[5] : 29.500000 | L[10] : 14.900000 |

The load combinations having G/L ratios near to 1.0 and near to 1.1 are shown in Table5.

**Table 3.** Generator contribution for IEEE 14 bus system

| **Load No.** | **Load (MW)** | **Generator-wise contribution and** | | | |
|---|---|---|---|---|---|
| | | **G1%ag** | **G1 Rank** | **G2%ag** | **G2 Rank** |
| L[1] | 94.2 | 81.58% | 1 | 18.42% | 10 |
| L[2] | 47.8 | 66.65% | 4 | 33.35% | 7 |
| L[3] | 7.6 | 66.32% | 6 | 33.68% | 5 |
| L[4] | 11.2 | 66.52% | 5 | 33.48% | 6 |
| L[5] | 29.5 | 53.59% | 9 | 46.41% | 2 |
| L[6] | 9 | 67.67% | 3 | 32.33% | 8 |
| L[7] | 3.5 | 64.57% | 7 | 35.43% | 4 |
| L[8] | 6.1 | 76.72% | 2 | 23.28% | 9 |
| L[9] | 13.5 | 63.63% | 8 | 36.37% | 3 |
| L[10] | 14.9 | 48.26% | 10 | 51.74% | 1 |

**Table 4.** IEEE 14 bus G/L ratio case-I and RT

| **Sr. No** | **G/L ratio** | **Generator (s)** | **Load (s)** | **Rank Total** |
|---|---|---|---|---|
| 1 | 1.099185 | G1 | L1 + L3 + L5 + L8 + L9 | **26** |
| 2 | 1.0007 | | L1 + L3 + L5 + L8 + L9 + L10 | 36 |

**Table 5.** IEEE 14 bus G/L ratio case-II and RT

| **Sr. No** | **G/L ratio** | **Generator (s)** | **Load (s)** | **Rank Total** |
|---|---|---|---|---|
| 1 | 1.099185 | G2 | L2 + L3 + L7 + L8 | **24** |
| 2 | 1.0007 | | L3 + L4 + L5 + L7 + L8 + L9 | 29 |

The load generation pair obtained for case-I and case-II with the G/L ratio approach is shown in Fig.5.

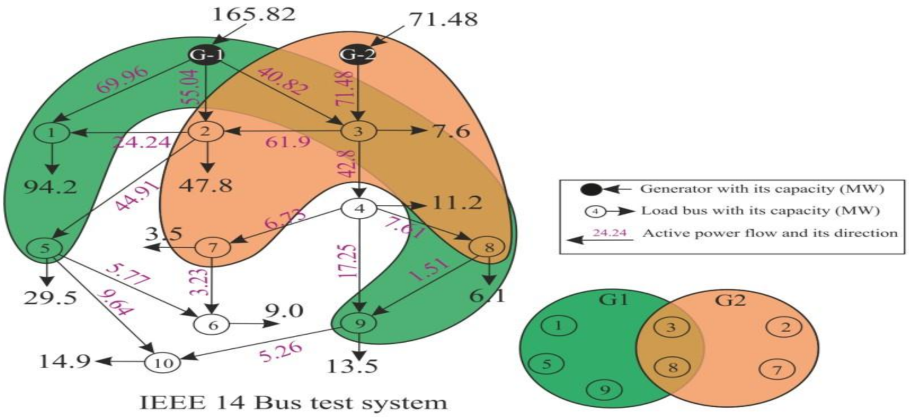
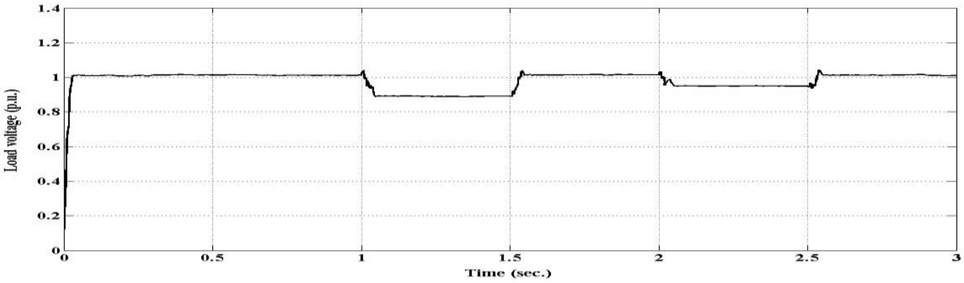


**Fig. 5.** IEEE 14 bus system as per Table: 4 and 5

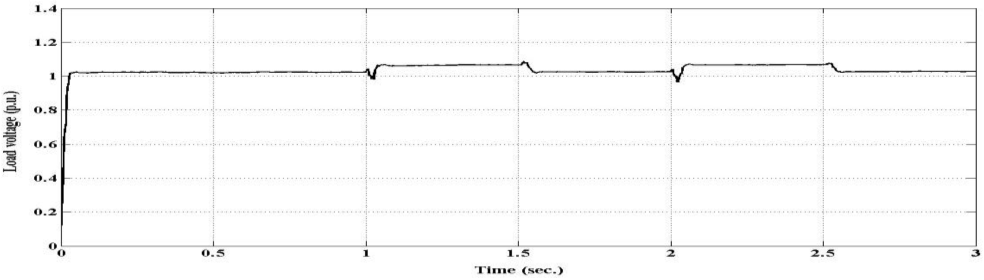
## 7. SIMULATION

An active GUPFC is simulated with the IEEE 14-bus test system. The graph theory model is shown in Fig.2. The proposed approach is applied on a test system using graph theory and RED for finding out the generator contribution in each load bus and location for the active GUPFC-based sub-system. The system was tested for the three different locations. The test conditions are simulated in MATLAB for a single line to ground fault twice in the simulation.

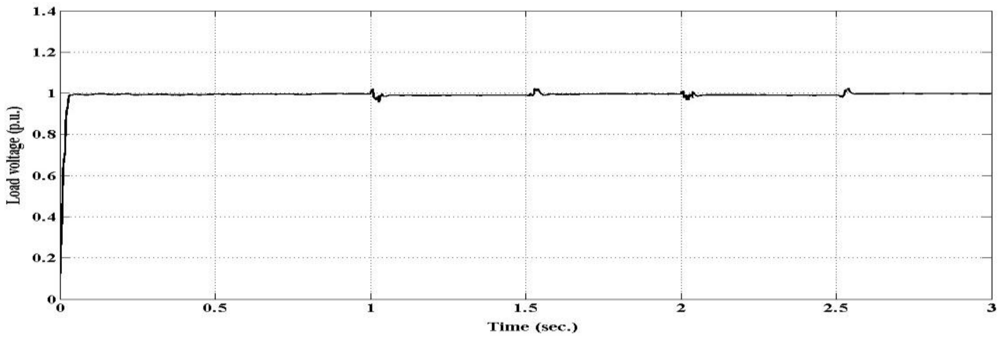
The voltage response at node *g* obtained from three different test conditions is shown in Fig. 6. After locating the sub-system, the test system is simulated using MATLAB simulation.



(a) Load voltage without intential islading



(b) Load voltage with intential islading without active GUPFC



(c) Load voltage with intential islading with active GUPFC at optimal location

**Fig. 6.** Load voltage at node 9 with and without active GUPFC

## 8. SUMMARY

The location of the active source embedded in GUPFC is determined using the proposed algorithm. For stable operation of the subsystem during intentional landing, the active GUPFC is located near the nodes having maximum source contribution, with which it is islanded. Hence, with the help of the proposed algorithm, the shortest path or the minimum Relative Electrical Distance for nodes is calculated. It is observed that, using the Dijkstra algorithm, the time taken to calculate the shortest path is proportional to the number of nodes in the graph, and so the proposed algorithm will take less time for a network with a large number of nodes.

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## BIOGRAPHIE

Jayesh Joglekar received a Doctoral Degree from the University of Pune, India, in 2016. He is working with the School of Engineering and Technology at HSNC University, Mumbai, India. His areas of special interest include islanding and grid Restoration.