Electrical Power and Energy Systems 78 (2016) 745–754

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Feasible method for making controlled intentional islanding of microgrids based on the modified shuffled frog leap algorithm

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ARTICLE INFO

Article history:
Received 28 May 2014
Received in revised form 29 November 2015
Accepted 4 December 2015
Available online 30 December 2015

Keywords:
Distributed generation (DG)
Intentional islanding
Reliability
Tree knapsack problem (TKP)
Modified shuffled frog leap algorithm (SFLA)

ABSTRACT

Intentional islanding is a feasible solution to improve the reliability of the smart distribution system with distributed generations (DGs) when the electrical connections between the smart distribution system and upstream network are lost. In this paper, a heuristic method is proposed for the intentional islanding of microgrids. In this method, some practical and important factors such as reduction of problem solution space; load controllability; load priority; bus voltage; line capacity constraints; and the ability to construct larger islands by the combination of islands are taken into account. The proposed method is a two-stage method. In the first stage, the intentional islanding problem is relaxed and in the second stage, the feasibility of the solution is verified. In the first stage, the intentional islanding problem is assumed as a series of tree knapsack problems (TKPs) and solved by the modified shuffled frog leap algorithm (SFLA). In the second stage, the power flow calculation is carried out to check the feasibility of the islands and essential modifications are provided. The proposed method is applied to IEEE 69-bus test system with 6 DGs. The results are compared with other methods and the effects of different methods on the system reliability indices are discussed. These comparisons indicate that the proposed method is feasible and valid.

Introduction

Traditional electric power distribution systems have been designed on the assumption that the main and the only source of power and short-circuit capacity is the primary substation. This assumption is invalidated by the entrance of distributed generations (DGs) [1]. With regard to DGs, the concept of microgrid is proposed as an opportunity to solve the distribution system problems. Microgrid can operate in both island and grid connected modes [2]. Reliability, efficiency and environment improvements, ancillary service market and voltage regulation are some aspects of the smart distribution systems [3]. The intentional islanding is an operation mode that important loads are supplied in the microgrid by DGs, whenever the electrical connections between the microgrid and the upstream network interrupted. This interruption is a scheduled maintenance plan or may occur when protection system trips. Intentional islanding is allowed if the fault is classified as an external fault and the total loads of microgrid are greater than the total maximum generation power of DGs [4]. The benefits of islanding operation are the reliability improvement, reduce the outage cost and mitigate the outage frequency [3–10]. In a feasible intentional islanding procedure, important factors such as power balance, bus voltage, line capacity restriction, load priority and load controllability should be taken into account [11,12]. In [6], the effects of the intentional islanding process on electricity market prices studied and discussed that for power imbalance condition, some loads could be considered as controllable loads. In [15] a heuristic method is proposed by searching the power circles with DGs in the center to obtain the maximum power restoration, but in the case of multiple DGs, this method is challenged because of potential overlaps among different power circles. In [11] an innovated method is proposed in a way that one uniform island is made. In this method, when DGs are far from each other it may be possible that some important loads cannot be restored. A two-stage method for optimal island partition is proposed in [12], where the islands are obtained by branch and bound algorithm. A graph model is presented in [16] and Depth First Search (DFS) method is applied as an approach, but the optimal locations of DGs are not considered and DGs are at the end of the branches. In [17] an Islanding Security Region (ISR) concept to provide security assessment of island operation is proposed. Moreover, evolutionary techniques are also used for islanding issues. In [4], Comprehensive Learning Particle Swarm optimization (CLPSO) is used to optimally partition the distribution system. In [13], the

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http://dx.doi.org/10.1016/j.ijepes.2015.12.012
0142-0615/

feeder addition problem solved by genetic algorithm (GA) is proposed for reliability improvement of islanded smart distribution systems in power balance condition. In [14], based on the graph model, DG nodes are indicated as the roots of a tree graph and GA is used for obtaining the suitable islands. However, the load priority and controllability are not taken into account.

In this paper, a heuristic method is proposed for the intentional islanding procedure in microgrids. In the proposed method, some practical and important factors such as reduction of problem solution space; load controllability; load priority; bus voltage; line capacity constraint; and the ability to construct larger islands by the combination of islands are considered. In the proposed method, the intentional islanding problem is assumed as a series of tree knapsack problems (TKPs) solved by a meta-heuristic optimization method called the modified shuffled frog leap algorithm (SFLA). Then, the power flow calculation is carried out to check the feasibility of the islands and essential modifications are performed. The proposed method is applied to IEEE 69-bus test system with 6 DGs and the results are compared with other methods. In order to evaluate the capability and feasibility of the modified SFLA, Particle Swarm Optimization (PSO) also used to solve TKPs and the results compared. All these comparisons indicate that the proposed method is suitable.

The remaining of the paper is organized as follows: the microgrid graph model and the mathematics of the intentional islanding problem are presented in 'Graph model and mathematics of intentional islanding problem'. The modified SFLA and reliability indices are discussed in 'Modified shuffled frog leap algorithm and reliability indices' and the proposed method to select the feasible islands is explained in 'The proposed method to obtain the intentional islands'. The validation of the method along with the results is represented in 'Results', finally conclusions are provided in the last section.

Graph model and mathematics of intentional islanding problem

Microgrid graph model

A practical microgrid usually encompasses numerous pieces of equipment that bring about complexity in the microgrid model. To solve the intentional islanding problem, an undirected and node-weighted tree graph for microgrid is presented. To reduce the scale and the topology simplification, the following assumptions are taken into account:

1. DG nodes considered as the roots of the tree graph, and the generation of DGs considered negative and at the maximum output power.
2. If there are no controllable switches such as circuit breakers or isolating switches between the nodes, these nodes are merged and considered as a new node. The new load is the load of the merged nodes.
3. For any node n except DG node, the active power P_n is positive and divided into two parts as below:

$$P_{cn} + P_{un} = P_n \tag{1}$$

where P_{un} is presumed as the uncontrollable part of the load and P_{cn} is $b \times P_L$ presumed as the controllable part of the load.

Mathematics of intentional islanding problem

The intentional islanding problem could be formulated as a constrained nonlinear integer programming problem, which can be represented as follows:

$$P_n \times w_n = C_n \tag{2}$$

where P_n and w_n are the active power and per unit weight of node n respectively and C_n is the weight of node n which is considered as load priority in this paper. The objective function is to maximize the load priority of the selected nodes for each DG as (3), thus the problem can be expressed as follows:

$$\text{Max}\sum_{n=1}^{N} C_n X_n \tag{3}$$

Subject to :

$$\sum P_n + P_{loss} \leqslant |P_{gen}| \tag{4}$$

$$V_n^{\min} \leqslant V_n \leqslant V_n^{\max} \tag{5}$$

$$P_{line(n-1,n)} \leqslant P_{line(n-1,n)}^{\max} \tag{6}$$

$$X_n = \begin{cases} 1 & \text{if } n = 0 \\ 0 \text{ or } 1 & \text{if } n = 1, 2, \ldots \end{cases} \tag{7}$$

$$X_n \leqslant X_{sn} \tag{8}$$

In (4), the power balance constraint is indicated, where P_{gen} is the DG power generation, P_n is the load of the selected node n, and P_{loss} is the network loss. The bus voltage and the line capacity constraints are expressed in (5) and (6), respectively. Eq. (7) states that DG is the rooted node and represented as X_0 and the state variable of node n is considered as X_n; if node n is selected as an optimal node, then X_n = 1, otherwise X_n = 0. It is expressed in (8) that if node n is selected, all the nodes between this node and DG are also selected.

Tree knapsack problem

Although obtaining an exact solution is always desirable, most of the times it is either not possible to obtain or it is time-consuming. Thus, a high-speed approximate solution can be a feasible solution. If (5) and (6) are removed and the network loss is temporarily ignored in (4), the intentional islanding problem is simplified as follows:

$$\text{Max}\sum_{n=1}^{N} C_n X_n \tag{9}$$

Subject to :

$$\sum P_n \leqslant |P_{gen}|$$

$$X_n = \begin{cases} 1 & \text{if } n = 0 \\ 0 \text{ or } 1 & \text{if } n = 1, 2, \ldots \end{cases}$$

$$X_n \leqslant X_{sn}$$

Eq. (9) is a linear integer programming and a non-deterministic polynomial (NP) complete problem. The objective function is that the selected nodes have the maximum load priority in the condition that the simplified constraints are satisfied. A problem as (9) is a tree knapsack problem (TKP) [18]. In this paper, instead of solving a constrained nonlinear integer programming problem as (2)–(8), a two-stage method is proposed. In the first stage, the problem is simplified as (9) and in the next stage, the power flow calculation is carried out; then (5) and (6) along with the power loss are checked and essential modifications are made.

Modified shuffled frog leap algorithm and reliability indices

Modified shuffled frog leap algorithm

Shuffled Frog Leaping Algorithm (SFLA) is a meta-heuristic optimization method based on the evolution of the memes carried by interactive individuals and on a global exchange of information