Electrical Power and Energy Systems 97 (2018) 155–164

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Optimal island partitioning of smart distribution systems to improve system restoration under emergency conditions

Vahid Hosseinnezhad[a], Mansour Rafiee[a], Mohammad Ahmadian[a], Pierluigi Siano[b,*]

[a] Faculty of Electrical and Computer Engineering, Shahid Beheshti University, A.C., Tehran, Iran
[b] Department of Industrial Engineering, University of Salerno, Fisciano, Italy

ARTICLE INFO

Keywords:
DG
Emergency operation
Restoration
Island partitioning scheme
Optimal load control
Optimal power flow

ABSTRACT

In the case of emergency operation, intentional islanding of distributed generations is an interesting solution to maintain the reliable power supply in the smart distribution grid. This paper deals with an optimal systematic strategy to restore the post-contingency distribution grid after the occurrence of severe disturbances causing an outage. Hence, a two-stage solution procedure is developed in this paper. In the first step, the optimal partitioning scheme is addressed through a number of graph-theory related algorithms. By applying these algorithms, the loads are optimally assigned to the distributed generations and optimal load shedding programs are determined and performed if there is a shortage of generation. The second step deals with the adjustments issues. In fact, the preliminarily partitions achieved from the first stage should be checked for feasibility. Also, these partitions should be adjusted if it is necessary in order to satisfy the system related constraints. To this purpose OPF calculation is incorporated and optimal load management measures are taken to mitigate violations considering the voltage constraints, line capacities and controllable loads. Since the proposed method considers the key factors of load priorities, load controllability, power balance, voltage and line capacity constraints, it covers the requirements of practical applications. Numerical results from the PG&E-69 test system are used to verify the effectiveness of the proposed method. The comparison with previous methods demonstrates that the proposed method outperforms other techniques.

1. Introduction

Maintaining system sustainability has become one of the main necessities in modern societies with the impending energy crisis and environmental deteriorations [1]. In order to comply these requirements, the application of distributed generation (DG) is considerably increased and it is expected to be higher in the near future. This tendency has led to a demand for a new electricity distribution paradigm in the framework of smart grids [2]. One of the most promising concepts, which is gaining importance in parallel to the rapid evolution of smart-grid-based solutions, is the microgrid. A microgrid is a cluster of both DGs and loads which act to cooperate with the main grid or autonomously from it [3]. The main feature of a microgrid is its ability to seamlessly separate itself from the main grid during the occurrence of an upstream network disturbance and operate as a self-controlled entity with high efficiency [1]. Inspired by this feature, a new strategy, so-called island partitioning, has been introduced as an interesting solution to help the affected customers to survive in the case of severe disturbance occurring. In this paper, the island partitioning means making, inside the distribution system, self-sufficient areas with minimized generation-load imbalance. When an outage occurs in a distribution grid, the islanding operation of DGs could rapidly restore the energy supply of important loads, and reduce the outage time. Accordingly, implementing this concept brings out reliability improvement, reduces the outage cost and mitigates the outage frequency [4–7]. In a feasible partitioning solution, key requirements such as power balance, bus voltage, line capacity restriction, load priority and load controllability should be considered [8,9].

The intentional partitioning procedure in power systems has been studied by several researchers as a restoration procedure able to defend against the catastrophe of system-wide blackout [10–13]. Recently, considering the advantages of the mentioned procedure, this subject also gained growing interest from distribution system researchers. These advantages include easier control strategy, distributed control among partitions, load routing and transfer among partitions, enhanced reliability, promoting the level of DG utilization efficiency and sustainability in response to cascading disturbances [9–13].

In [7], an adaptive intentional islanding operation system

* Corresponding author.
E-mail address: psiano@unisa.it (P. Siano).

https://doi.org/10.1016/j.ijepes.2017.11.003
Received 7 November 2016; Received in revised form 15 April 2017; Accepted 4 November 2017

Nomenclature

A. Indices

b	index for branches of system
i	index for loads
j	index for distributed generations (DGs)
k,e	index for buses
max,min	superscript for maximum and minimum values of variables, respectively
ul,cl	superscript to represent uncontrollable and controllable loads, respectively
α	index for controllable loads
μ	index for uncontrollable loads

B. Sets:

B	set of buses
Br	set of branches
D	set of loads
G	controllable DGs
Y	admittance matrix
Δ_{cl}	set of controllable loads
Δ_{ul}	set of uncontrollable loads

C. Parameters:

R	resistance of each branch
v	per unit value of each load
value	total value of each load
w^{br}	weight of each branch

D. Variables

c_{ij}	cost per unit of transferring the power from source j to load i
d	active power demand
d^q	reactive power demand
H	knapsack capacity
p	DG active power output
P_{loss_b}	power loss of branch b
q	DG reactive power output
S_l	capacity of lines
u	load commitment state
V	magnitude of bus voltage
x^{kp}	binary vector which is define the commitment of uncontrollable loads
x_{ij}	power amount transferred from source j to load i
δ	angle of bus voltage
θ	angle of admittance

E. Functions

C	cost function of DGs
f_{crd}	DGs redispatching objective function
f_{ad}	adjustment objective function
f_{kp}	knapsack problem objective function
f_T	transportation problem objective function
ε	demand-generation balance objective function

configuration is provided. In [14], a procedure based on the strategy of extended sequential sampling is presented to provide the islanding operation mode of the system. However, in both [7] and [14], the optimality of islanded network partitions has not been discussed. An island partitioning plan based on exploring the power circles with DG in the center is utilized by [15] to determine the maximum restored load; however, it is difficult to find the optimal scheme in presence of multiple DGs. Besides, the procedure of [15] only considers uncontrollable loads. A graph-based procedure is introduced in [8] to execute island partitioning, however, since only one island can be planned, it may not restore a significant area in the case of the existence of DGs which are far away from each other. In [16,17], the authors introduced innovative smart grid design solutions providing virtual autonomous microgrids in a distribution system to improve power sustainability with the focus on self-healing capability. However, due to the computational complexity and uncertainties, these solutions are suitable only for planning tasks rather than to provide the optimal performance during the operation.

In [18], a procedure is presented to provide and coordinate the autonomous partitions of a microgrid in the case of disconnection from the main grid. However, in this study an optimal island network adjustment procedure to make the feasible autonomous partitions is not discussed. In [9], a strategy based on the island partitioning is proposed to operate the distribution system with DGs in the case of emergency. This strategy is executed in the form of the two-stage method by using the branch and bound algorithm. The authors of [4] followed the similar approach of [9] but used a modified shuffled frog leap algorithm to address the strategy. However, both [4] and [9] acknowledged that their methods could not guarantee the optimality of the solution, since a simple sensitivity analysis is used to manage the loads instead of an optimal power flow (OPF) to get the final solution. Moreover, the procedures described in these studies could not handle the cases in which there is over generation, because they did not consider the DG adjustment possibility in their proposed models. Besides, those procedures require applying multiple complementary rules to check and obtain the partitions boundaries.

The review of the previous studies confirmed the intuition that the power supply reliability and DG power utilization in the post-contingency situation of a smart distribution grid can be significantly promoted by appropriately island partitioning strategies. However, previous results also reveal the need for a general, systematic and optimized approach to address the islanding strategy. This algorithmic approach should be able to tackle the above-mentioned deficiencies of previous studies, as well as to provide the maximum equivalent restored load. Besides, the presented solution must be reliable from the point of optimality.

This paper proposes a systematic procedure for optimal island partitioning of smart distribution grids in the emergency operation. The procedure is a two-stage algorithmic solution. The first step utilizes the graph-theory related algorithms which consider the network as a weighted network matrix based on the power losses. Considering this matrix, the optimal partitioning scheme is determined through the modeling of the problem by using the transportation theory. Also, in order to manage the shortage of generation a knapsack problem is solved by the recently introduced species-based quantum particle swarm optimization (SQPSO) [19]. Then, in the second stage, an OPF calculation is carried out to check the feasibility of the formed partitions. In order to keep the practical perspective on the proposed method, it is developed such that the key factors of load priorities, load controllability, power balance, voltage, and line capacity constraints can be applied. Simulation results from the PG&E-69 test system and provided comparisons with previous works are used to verify the effectiveness of the proposed method. The key innovative contributions proposed in this paper can be summarized as follows:

- Proposing a systematic and flexible procedure in order to solve the island partitioning problem which provides the possibilities of