A Probabilistic Approach for Maximizing the Islanding Success of Microgrids

Reham A. Osama, Almoataz Y. Abdelaziz,
Rania Swief and Mohamed Ezzat
Electric Power and Machines Department
Faculty of Engineering, Ain Shams University
Cairo, Egypt
reham.osama@eng.asu.edu.eg

Ahmed F. Zobaa
College of Engineering, Design and Physical Sciences
Brunel University
London, Uxbridge, United Kingdom

***Abstract*— With Increasing electricity demand, microgrids nowadays play an important role in smart grids which demand a systematic approach for its optimal design and performance enhancement. Microgrids development is propitious for the electric energy industry from several aspects including environmental aspects, improvement of system operation and power quality, cost saving and other market related issues. In the IEEE Standard 1547.4, splitting large distribution networks into a number of smaller networks can provide enhanced operation and control. In this paper, a distribution test system is considered for optimum design of microgrids. The design considers maximizing the success indicant of the constructed microgrids. The islanded operation of microgrids requires serving important loads when the main supply fails. Thus, the success of the islanding process can be a challenging issue for planners to enhance the distribution system reliability. The indicant formulated in this paper incorporates the crucial conditions for successful operation of microgrids such as power imbalance and voltage constraints. A radial distribution system of 69 buses is chosen for this research. The selected system has a typical fuel mix of distributed generators such as biomass generators, photovoltaic units and wind turbines. The design problem is solved using the recently developed back tracking search optimization algorithm. The intermittent nature of distributed generators is taken into consideration through a probabilistic approach.**

***Index Terms*—Back tracking optimization, microgrids, power distribution, power system planning.**

I. INTRODUCTION

A microgrid is a small network with clear electrical boundaries that includes a group of loads supplied by a group of distributed energy resources (DER). A microgrid is normally connected to the main grid during the normal operation. However, under certain circumstances; a microgrid can function independently [1]. The ability of microgrids to self-supply and operate as an island makes microgrids clearly different from backup generation. Back up generation provide temporary electric supply to associated loads in case of failure of utility main supply. However, microgrids offer wide range of benefits to utility, customers and distributed generators (DG) owners and are more flexible than backup generation. Among these benefits are enhanced grid reliability and resiliency by introducing self-healing in distribution level; economic operation and reduction of emissions through a diversity of less costly renewable energy sources; improved power quality by handling loads as well as responding to market requirements which offers energy efficiency. These significant benefits have encouraged utility planners to exert efforts to increase microgrids penetration in electric power systems. That’s why recent microgrids research activities focus on tackling the challenges associated with the design, operation and control of microgrids.

In [2], the authors present a comprehensive study on DER and the recent practices in microgrids. In [3], the authors explain the concept of a microgrid, technical characteristics, operational constraints and management issues, economic viability and challenges in deregulated market. The study in [4] considers reliability assessment of microgrids during islanding mode of operation with intermittent DGs. In [5], the authors propose a resiliency-oriented microgrid scheduling taking into consideration several factors such as; the uncertain nature of generation and load as well as the interruption time and duration of the utility supply. The economic benefits of microgrids are demonstrated in [6].

The paper intends to elucidate an approach for designing of microgrids. A given distribution system is partitioned into a predefined number of microgrids. The design objective is to maximize the proposed indicant for the successful operation of microgrids if islanding operation is to happen due to grid supply failure. In case of emergencies, it is required to minimize the load interruption within the islanded microgrids in order to decrease the cost of power interruptions for the customers and the utility and to enhance the distribution system security and adequacy. The microgrid success indicant accounts for the main requirements for a successful islanding of microgrids which ensures sufficient amount of power and acceptable voltage limits.

The rest of the paper is structured as follows; section II demonstrates the design concept; section III presents the probabilistic combined generation load model used in this study. The objective function and the constraints that must be satisfied during simulation are formulated in section IV. Section V explains the optimization algorithm used to solve the design problem; section VI presents the clustering results; and finally, section VII provides the conclusions and recommendations.

II. THE DESIGN CONCEPT

Microgrids are small networks that comprise a number of loads, DGs and storage units and are able to detach from the main grid i.e. Islanding. According to the IEEE Standard [7], microgrids can enhance the reliability and security of active distribution networks and can provide easier control and operation that customers, utility and DG owners can benefit from [8]. Among the distinctive features of microgrids are: clearly defined electrical and geographical boundaries; a main controller; and enough installed generation to be able to serve the expected critical load in case the microgrid is disconnected from the utility grid. This paper aims to optimally divide a given distribution system including several distributed generation units into a number of microgrids to maximize the chance of successful islanded operation of microgrids. Under the loss of supply condition, it is required to minimize the load interruption within the islanded microgrids to cut down the power interruptions` cost to customers and to enhance the distribution system reliability.

III. MODELING OF SYSTEM COMPONENTS

This research adopts a probabilistic approach for solving the design problem by developing a probabilistic model. This model takes into consideration the intermittent nature of DGs as well as the load profile. DGs present in this study include biomass generators which are considered as dispatchable DGs, wind generators and solar photovoltaics generators (PV). Both the solar irradiance and wind speed have a probabilistic nature. Thus, probability density functions from literature are used for modeling. The Beta distribution is used to represent the behavior of the solar irradiance [9] and the Rayleigh distribution is used to model the behavior of the wind speed [10] after which the probabilistic output power of DGs can be calculated. Loads are modeled using the IEEE reliability test system model as in [11].

The probabilistic model starts with collecting and processing of historical data for a year interval. The data are sorted based on seasons. Probability density functions for windspeed and solar irradiance are generated for four days representing the intermittent behavior in the four seasons. Afterwards, the probability density functions are split into states. Choosing how many states to divide the density functions into is problem specific and can affect the computational time and complexity. The value of the parameter for each state is the mid value of the interval. In order to obtain the state probability, the area under the curve is evaluated. The probabilistic output power of renewable DGs can be then calculated for each state. Probabilistic power flows can be calculated by running the load flow for each state separately and accumulate the power flows using the probability of each state.

IV. FORMULATION OF OBJECTIVE FUNCTION AND CONSTRAINTS

As mentioned earlier, microgrids are normally connected to the main grid but are able to detach and operate independently. In order to ensure the success of the islanding operation, it is necessary for the microgrid to have enough active and reactive resources to be able to solve critical loads and maintain acceptable voltage limits.

$$P_{Gen} \geq P_{cons} \tag{1}$$

$$Q_{Gen} \geq Q_{cons} \tag{2}$$

where P_{Gen} and Q_{Gen} are the generated powers of the DGs i.e. active and reactive, P_{cons} and Q_{cons} are the consumed load powers. One other necessary condition recommended in [12] that penetration level of dispatchable DGs i.e. biomass, must be more than 60% of the total generation of the microgrid.

$$P_{BIO} \geq 0.6 \times P_{DG} \tag{3}$$

where P_{BIO} is the biomass DGs generated power in the microgrids. P_{DG} is the total power generated by the DGs. These necessary conditions presented in Eq. (1) to Eq. (3) are achieved by gradual shed of loads taking into consideration the reliability requirements until the conditions are satisfied i.e. smaller loads first.

Since this study is based on a probabilistic approach. The proposed microgrid success indicant is calculated for each state as follows;

$$SI_{MG_i} = \begin{cases} 1 & P_{Gen_i} \geq P_{cons_i} \ \& \ Q_{Gen_i} \geq Q_{cons_i} \ \& \\ & V_{\min_i} \leq V_i \leq V_{\max_i} \\ 0 & otherwise \end{cases} \tag{4}$$

where SI_{MGi} is the success indicant of the microgrid in the state i, V_i represents the voltage of each bus during the state i. The success indicant of each microgrid SI_{MG} is calculated as follows;

$$SI_{MG} = \frac{\sum_{i=1}^{N} SI_{MG_i} \times \sigma_i}{\sum_{i=1}^{N} \sigma_i} \tag{5}$$

where σ_i is the state probability; N is the total number of states. For a system with multiple number of microgrids, the microgrids success indicant SI_{sys} is the weighted sum of SI_{MG} as follows;

$$F_1 = SI_{sys} = \frac{\sum_{i=1}^{NoM} SI_{MG_j} \times NoL_j \times (1 - Sf_j)}{\sum_{j=1}^{NoM} NoL_j} \tag{6}$$

where NoL is the number of loads in the microgrid and Sf is the shed factor which is the ratio of the amount of shed loads to the total loads in the microgrid in each state and *NoM* is the total number of microgrids.

It is required to maximize the microgrids success indicant F_1. Therefore, the objective function to be considered for the optimal design problem is F_2 as follows;

$$\min F_2 = 1 - F_1 \tag{7}$$

It should be highlighted that this study is a step in the planning phase so the stability issues are out of the scope this paper.

There are other constraints to be satisfied during the optimal design of microgrids that are related to the system topology. The shortest path algorithm [13] is used in the simulation to ensure that all designed microgrids have radial configuration and that no isolated buses i.e. all buses are included in all microgrids.

V. BACK TRACKING SEARCH OPTIMIZATION

The BTS is an iterative optimization algorithm [14] based on population search. The BTS main stages are as follows;

A. Initialization

BTS starts with initializing a population matrix of control variables *P*.

$$P_{i,j} \leftarrow U(low_j, up_j) \quad \begin{matrix} i = \{1,2,3,....Npop\} \\ j = \{1,2,3,....Dim\} \end{matrix} \tag{8}$$

where *U* is the uniform distribution, *low* and *up* are the lower and upper boundaries of control variables respectively. N_{pop} is the size of each population and *Dim* is the problem dimension.

B. First Selection

Another population matrix of control variables is randomly generated called the historical population matrix *oldP*.

$$oldP_{i,j} \leftarrow U(low_j, up_j) \tag{9}$$

The *oldP* matrix is permuted randomly at the beginning of each iteration to shuffle the order of individuals.

$$oldP \leftarrow permute(oldP) \tag{10}$$

C. Crossover and Mutation

The trial population *T* is generated using the experience from the preceding generations.

$$T = (F \times map \times (oldP - P)) + P \tag{11}$$

The parameter F controls the amplitude of the matrix *(oldP-P)*, *map* is binary integer matrix calculated from the crossover step. The size of *map* is *(Npop* Dim)*. This matrix determines the elements of the trial population *T* to be manipulated.

D. Second Selection:

The global minimum is determined according to the least corresponding value of the fitness function.

VI. TEST SYSTEM AND RESULTS

Fig. 1 shows the distribution system chosen for the implementation of the solution algorithm.

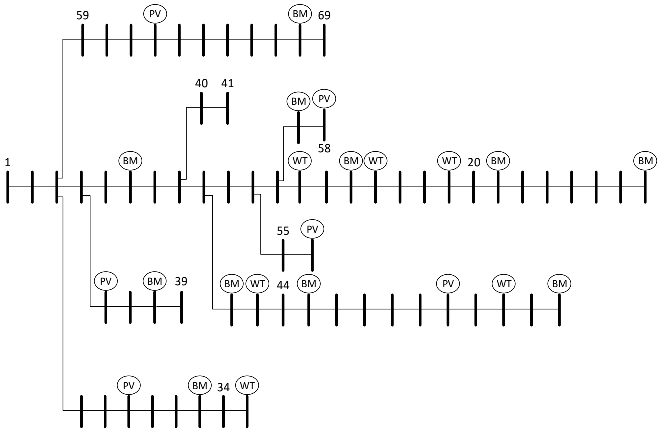

Figure 1. Test system under study

The system has a typical combination of DGs. The capacities and locations of the DG units are listed in Table I. The system active and reactive loads are shown in Fig.2.

TABLE I. SYSTEM DG MIX LOCATIONS AND CAPACITIES

DG Type	**Bus**	**Capacity (kW)**
Wind Turbine	16-35-43-52-13-19	25-50-50-50-50-25
PV Modules	30-36-50-56-58-62	25-25-25-25-25-25
Biomass DG	6-15-21-27-33-38-42-45-54-57-68	25-50-25-50-75-50-50-50-75-75-75

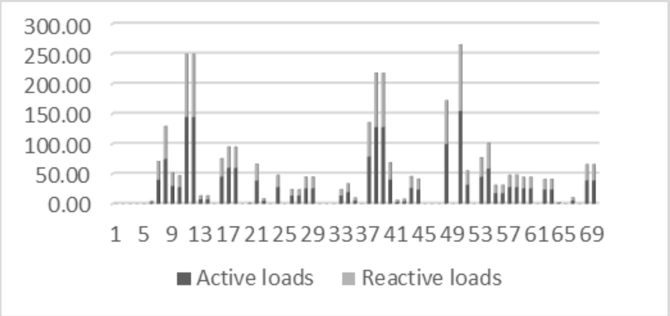

Figure 2. System active and reactive loads

The BTS optimization algorithm is applied to optimally cluster the test system into number of microgrids to maximize the microgrids success indicant. Fig. 3 shows a flowchart for the main design steps.

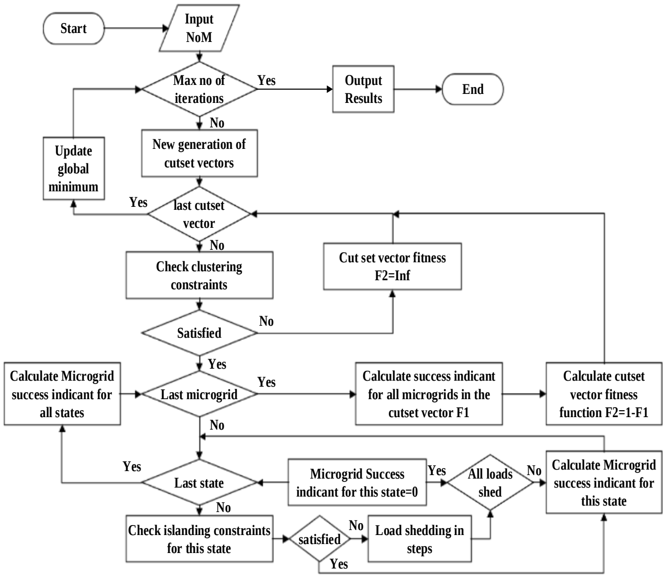

Figure 3. Main design steps flowchart

Table II shows the optimum switch locations obtained as well as the corresponding fitness values and success indicants. The cut set line *x* is the line whose end is the bus *x*+1 i.e the cut set line 8 is the line whose end nose is bus 9.

NoM	**Cut set lines/ Switch locations**	**F2 (pu)**	**Microgrids Success Indicant (%)**
2	8	0.633	36.7
3	5-10	0.726	27.4
4	3-13-41	0.784	21.6
5	4-15-41-58	0.823	17.7
6	4-10-15-44-58	0.853	14.7
7	3-6-10-15-47-58	0.882	11.8

TABLE II. OPTIMUM DESIGNED MICROGRIDS

In Table II, the resultant cut sets are different for each case such that if the system is partitioned into 3 microgrids, the cut set lines are [5-10] and the success indicant is 27.4% while if the system is partitioned into 6 microgrids, the cut set lines are [4-10-15-44-58] and the corresponding success indicant is 14.7%. The electrical boundaries of the optimum constructed microgrids are shown in Fig.4 to Fig.9.

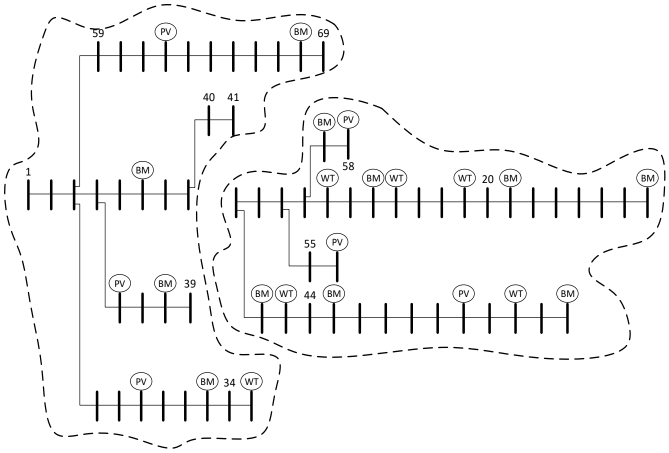

Figure 4. Number of Microgrids = 2

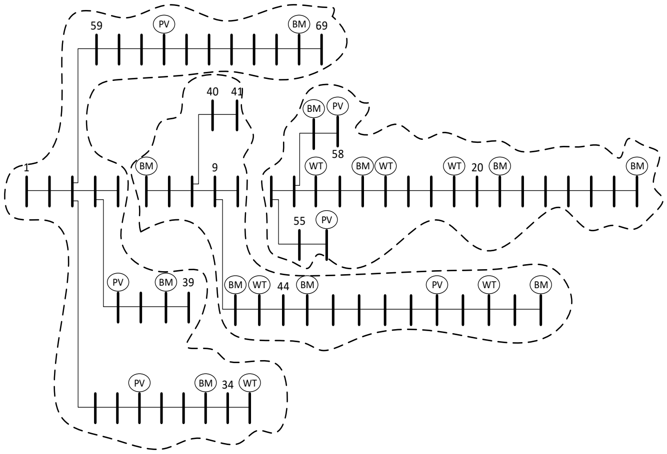

Figure 5. Number of Microgrids = 3

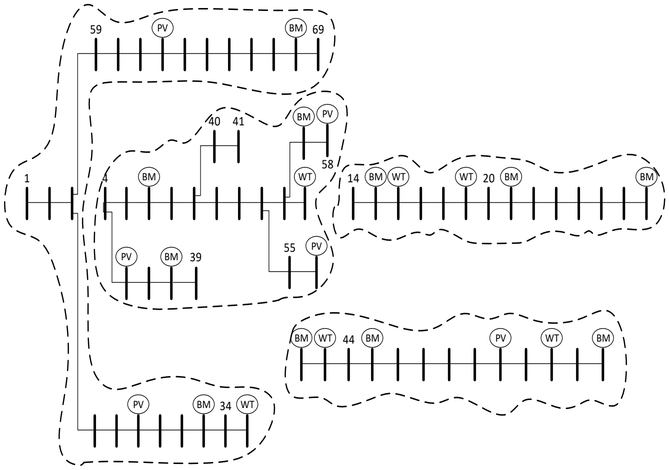

Figure 6. Number of Microgrids = 4

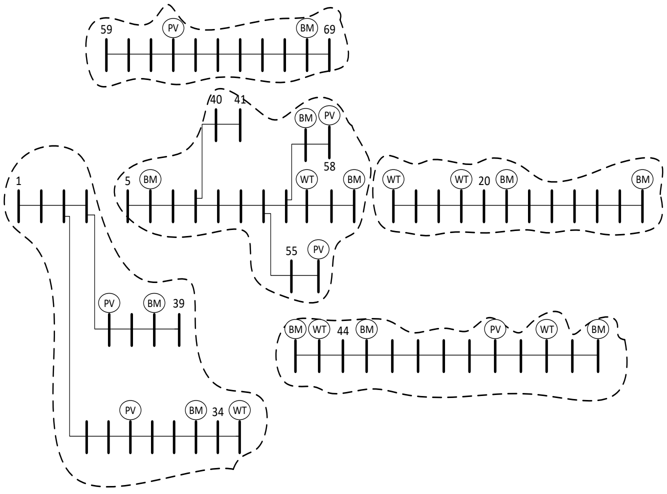

Figure 7. Number of Microgrids = 5

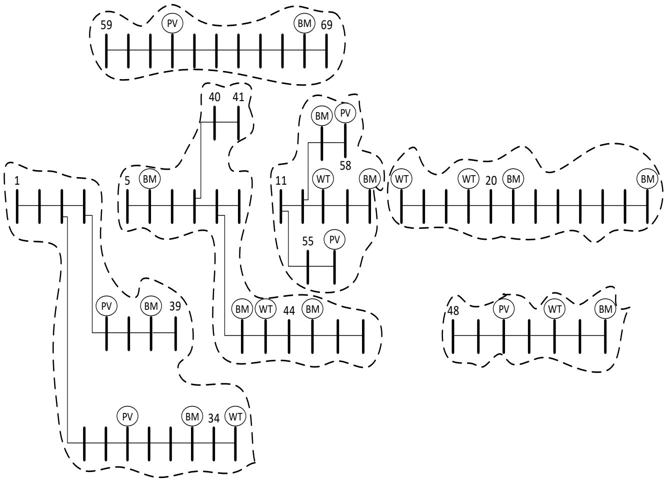

Figure 8. Number of Microgrids = 6

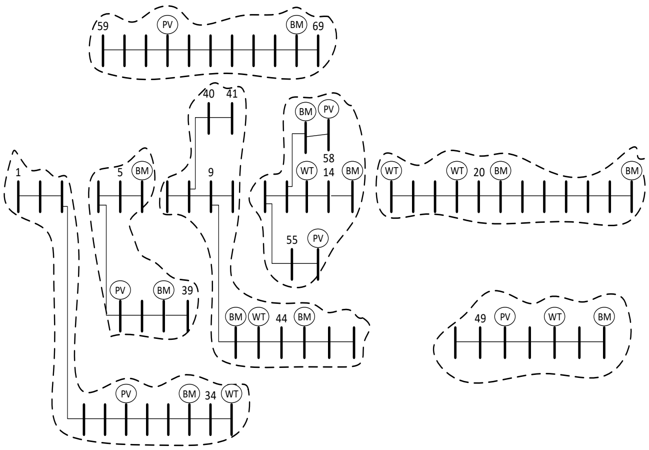

Figure 9. Number of Microgrids = 7

VII. CONCLUSION

In this paper, an indicant is used for assessing the successful operation of islanded microgrids. The proposed indicant accounts for the power adequacy, voltage limits and the amount of load to be shed for the islanding operation to be successful. A distribution system of 69 buses is chosen for partitioning. In each case, the system is split into a predefined number of microgrids with the objective of maximizing the success indicant of microgrids during loss of supply. The electrical boundaries of the optimum microgrids vary according to the chosen number of microgrids for design. Future work may include placement of storage units and/or reactive sources to improve the microgrids success indicant during the planning stage as well as determining the optimum number of microgrids to divide the system into through cost-based studies.

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