Optimum Interconnected Islanded Microgrids Operation with High Levels of Renewable Energy

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ABSTRACT

This paper aims to study the optimal probabilistic energy efficiency horizon of active distribution networks with high penetration of wind power generation considering a variety of possible islanded microgrid (IMG) zones. The penetration of renewable power sources such as wind turbines (WTs) and the load variations can create challenges in the active distribution system that will significantly affect system modeling, power flow algorithm, voltage stability index and system planning. In this regard, an appropriate model for IMGs is suggested, which aims to estimate the voltage stability margin of a two-bus system based on both saddle-node and limited induced bifurcations. Furthermore, a new concept, named reduced IMG network (RIN), is well explored to generalize the proposed index to n-bus islanded MGs using a developed power flow algorithm. The simulated frame work indicates a two-stage probabilistic planning algorithm that considers the variability in load and generation. The proposed algorithm improve voltage stability index and minimize the IMG customers’ interruption. This improvement allow for a time delay in renewing MGs. The performance and effectiveness of the proposed method are tested and verified through the IEEE 33-bus test system across different case studies.

1. Introduction

Distribution grids are one of the critical parts of the power system infrastructure which is becoming more and more complicated due to the interaction of a variety of decentralized power network delivery system components. Recently, with the growing use of Distributed Generators (DGs), the distribution networks are being migrated from the passive distribution system to the active one. Active distribution system operation includes real-time monitoring,
control, and operational planning; ancillary services for active and reactive power support; islanding, black start capabilities, and microgrids (MGs) [1]. A MG can be recognized as a system whose traditional generating units are replaced by a large amount of renewable energy, which can operate at the point of common coupling (PCC) in both grid-connected and islanded operation modes [2]. Therefore, the entire distribution system is decomposed into subsystems named MG based on the connectivity of area by using the island isolation device (IID). Active distribution systems with MGs need a new management approach for optimum operational planning horizon in an islanded mode taking into consideration the use of renewable energy resources such as a wind turbine (WT) generator. This optimum planning is done by islanded microgrid reconfiguration (IMGR) in the absence of the microgrid control center (MGCC).

One significant component of MGs is distributed generation unit (DG) which is categorized into controllable and non-controllable DG (with stochastic generation). The controllable DGs commonly use droop control for the power balance in power system [3]. Moreover, in the islanded mode of operation, the DG units are responsible for maintaining the system frequency control. Several strategies have been applied to use controllable DGs in IMGs. In the droop-control method, the parallel synchronous generators are utilized for power sharing in the system. To obtain the desired static droop gains, the voltage and frequency of the DG units are maintained by adjusting the reactive and active power, respectively [4].

Voltage collapse is still the most significant threat to the power system transmission and distribution system which keeps the operators’ eyes awake all the time. Voltage collapse, a form of voltage instability, commonly occurs as a result of reactive power deficiency. Due to DGs’ operational limit and isolated area constraints, IMG is more vulnerable than MG to experience the voltage collapse. Although voltage stability might be a technical concern in power system, it might affect the economic aspect of MGs as well and needed to be well studied especially in MG implementation.

The voltage instability is not a new concept for power system researchers, but it is not well explored especially in IMG domain. The voltage drop in the system restricts the amount of load being served by IMGs. Hence, it is necessary to consider voltage stability constraints on the planning and operation of IMGs. Following are some of the literature focused on the voltage stability of the MGs. Three aspects of voltage stability issue (i.e. small signal, transient and voltage stability) are studied in [5]. A linearized model of micro sources and loads are used to assess the small signal stability of the MG system considering the P-V and Q-V curves. The P-V curve indicates the maximum loadability while Q-V curve shows the necessary amount of reactive power at the load end for desired voltage. In [6], the simulated PMU data is used to determine the voltage indices and measure the stability of the MG. The islanding detection time is an essential factor for the smooth transition to islanding mode. For this purpose, the voltage security indices can be used to promptly send signals to the Microgrid Control Centre for islanding implementation. Reference [7] presents a decentralized robust mixed H₂/H∞ control strategy for autonomous/islanded multi distributed energy resources (multi-DER) voltage-sourced converter based MGs. The power management system specifies the voltage set points for local controllers and the frequency of each DER unit is determined by the hierarchical droop-based control structure.

One way to mitigate the cascading failures in emergency scenarios or have better control and monitoring the network under normal condition is to apply the network reconfiguration or topology control methods based on the desired target function. The approaches above which increase the system resilience and restoration process can be applied not only in distribution system but also in power system transmission and operations [8–10]. In the distribution system, microgrid reconfiguration (MGR) and radial grid reconfiguration are the two practical approaches aiming to improve the technical operation of MGs under normal or contingency conditions. In [11], the authors suggested an improved version of multi-objective harmony search applied to IMG reconfiguration applied to improve the voltage stability and minimize power losses. An artificial searching vector optimization engine is presented in [12] to assess the system vulnerability in a modified IMG. A stochastic model for day-ahead Micro-Grid management is proposed in [13] which uses probabilistic reconfiguration and unit commitment simultaneously to maximize MG’s efficiency. MGCC is considered as the heart of the active distribution system enabling the communication between the other MGs of the network. In some conditions, emergency scenarios, the unscheduled transition of MGs to the islanded mode of operation might initiate without MGCC communication [11].

Some new recent research in the field of DGs and different fields of MG are given below:

Ref [14]. proposed a two-stage robust DG investment planning model capable of accommodating uncertainty of electric vehicle charging demand and
renewable generations. The DG investment location and size are optimized in the first stage and the distribution network operation feasibility in the worst case scenario is checked in the second stage to avoid constraint violations in this reference. Authors in [15], the Energy Storage System and Diesel Generators are used as a backup power supply to confront the wavering of voltage profile and power flow in MGs. The study of electricity consumption trend in Aligarh Muslim University provides vital information to analyze, design, and implement a suitable solution for the deployment of the MG. In this work, Polygene ration based on various smart MG topologies in both modes of operation (i.e. grid-connected and off-grid mode) is studied. Gazijahani and Samadi propose an innovative Hong’s 2m point estimate method for simultaneously demand response and reconfiguration scheduling with purpose to minimize the operating costs as well as to reinforce the reliability and resiliency of interconnected MGs in confronting with uncertainties [16]. The problem of voltage stability and reactive power balancing in islanded small-scale electrical networks outfitted with DC/AC inverters (‘microgrids’) is considered in [17]. A multi-objective framework is proposed for thermal and electrical energy scheduling of Industrial Microgrids by optimizing operational cost, energy losses, and voltage stability in [18]. Stochastic programming is used to model uncertainties of photovoltaic generators, load profile, and Plug-in Electric Vehicles in this reference.

Therefore, having a proper plan considering all the possible states of load and statistical renewable generation for an efficient control of MGs’ operation is inevitable. Based on this available state, the right states that have supply adequacy and can satisfy loads/losses are recognized. These possible states assure that the network has sufficient energy to supply its loads, but it cannot guarantee the operational constraint especially the voltage regulation constraints. Then, an IMGR is suggested for improving voltage magnitudes of all buses and loadability limit at different acceptable states. The customers’ interruption due to violation of voltage constraints is minimized by IMGR. In the second stage a harmony search algorithm (HSA) is used to form a new harmony vector that is well dedicated to the IMGR problem. This paper suggests a new 2-stage probabilistic algorithm aiming to find the optimal configuration of IMGs that meet the objective function’s security constraints. The proposed algorithm identifies the most appropriate configuration to satisfy the operational voltage regulation constraints and to ensure operation a secure islanded in the distribution network without the availability of MGCC.

2. Img Model

The role of DG units become vital in the distribution system since the network is being migrated from passive to active. IIDs such as circuit breakers are used to implement the IMG. Circuit breaker management is essential to have a more reliable and robust IMG configuration [19,20]. In the proposed model, it is assumed a distribution network with four planned MGs, which can be interconnected at the specific times to fulfil the required power demand in all zones as illustrated in Figure 1.

![Figure 1. The active distribution scheme with microgrids.](image)
In case of an upstream fault, one IMG will be originated from all downstream MGs. A DG can belong to different MG depending on the fault location. For example, the loads and DGs in MG#5 can belong to MG#1, 2 or 4. Therefore, assessing the features of the IMG such as the operation modes of DGs in an IMG is of great importance. The frequency of the whole network is determined by the primary grid in the grid-connected mode while in the islanded mode, the frequency is obtained through the sharing power between DGs by the droop control strategy. A concise view of IMG components is given in the following section to clarify the problem formulation further. The branches, DGs and load models are based on the models defined by the authors of this paper in [19].

3. Proposed Formulation

The main idea, in this optimization planning process, is to obtain the best configuration that minimizes customers’ interruption improvement voltage magnitudes of all buses and maximize the loadability limit in all applicable states with sufficient energy generation. Since islanded network accosts variety and uncertainty in the system loads and renewable generation, first it is necessary to find the patterns with supply adequacy. These patterns can satisfy the total demand of IMG/IMGs, but they cannot guarantee any interruption in customers’ load demand due to operational constraints. A heuristic algorithm is used to find the optimum reconfiguration for minimization the customers’ interruption by satisfying voltage profile constraints and improve static security as the second stage. In other words, the selection of optimum configuration cannot prevent any reduction in IMG customers’ interruption due to leakage of the generated energy to load energy mismatch, but it can minimize the customers’ interruption by improving the voltage profile.

There are two possible approaches for improving the operation of the islanded network without MGCC. The first one requires additional investment for an enhanced operation of IMGS through upgrading the aged infrastructure, while the second approach aims to incorporate smart technologies to find innovative solutions for modification of IMG. To take benefit of the second approach with minimum additional cost, a powerful toolbox integrated with the IMG modeling and security constraints (e.g. reactive generation limit and frequency deviation) is developed which enable us to access the voltage stability index and the power flow computations. These toolboxes can be utilized in IMGR, as a unique tool, for efficient planning of IMG, as a short-term solution to bypass the time-consuming MG’s infrastructures upgrading.

The stochastic nature of both generation and the loads should take into consideration for the accurate optimum planning of IMGs. An analytical approach given in [21] is used to consider all possible probabilistic generation-load states. It is proven that there are no significant differences between the results obtained by the analytic approach and Monte Carlo Simulation (MCS). The annual loads are categorized into 10 levels in Table 1; each level shows the set of load as a percentage of peak load with their probabilities. The wind speed with their probabilities is also shown in Table 2.

It is assumed that the generation state probabilities of generation states \( \rho_{st}^{G} \{ N_{st}^{G} \} \) are independent of the probabilities of load states \( \rho_{st}^{L} \{ N_{st}^{L} \} \). Based on this reference, the probabilities of all possible states of IMG \( \rho_{st} \{ N_{st} \} \) are obtained by a possible combination of the probabilities of generation states and load states based on below equation:

\[
\rho_{st} \{ N_{st} \} = \rho_{st}^{G} \{ N_{st}^{G} \} \times \rho_{st}^{L} \{ N_{st}^{L} \}
\]

where \( \{ N_{st}^{G} \} \) and \( \{ N_{st}^{L} \} \) are the sets of all possible IMG states, generation, and load states, respectively. An IMG usually has more than one DG in its electrical zone, for example, \( n \) DGs; therefore, it is apparent important to consider \( \rho_{st}^{G} \{ N_{st}^{G} \} \) as a function of the probability of each DG as follows:

\[
\rho_{st}^{G} \{ N_{st}^{G} \} = \rho_{st}^{G1} \{ N_{st}^{G1} \} \times \rho_{st}^{G2} \{ N_{st}^{G2} \} \times \ldots \times \rho_{st}^{Gn} \{ N_{st}^{Gn} \}
\]

where \( \{ N_{st}^{G} \} \) is the set of all possible generation states for the \( ith \) DG unit.

### Table 1. Load states profile.

| Percentage of peak load (%) | Probability | Percentage of peak load (%) | Probability |
|-----------------------------|-------------|-----------------------------|-------------|
| 100                         | 0.001       | 58.5                        | 0.163       |
| 85.3                        | 0.056       | 51                          | 0.163       |
| 77.4                        | 0.1057      | 45.1                        | 0.092       |
| 71.3                        | 0.1654      | 40.6                        | 0.0473      |
| 65                          | 0.1654      | 35.1                        | 0.033       |

### Table 2. Wind state profile.

| Wind speed limits (m/s) | Probability | Wind speed limits (m/s) | Probability |
|-------------------------|-------------|-------------------------|-------------|
| 0–4                     | 0.073       | 9–10                    | 0.089       |
| 4–5                     | 0.024       | 10–11                   | 0.109       |
| 5–6                     | 0.032       | 11–12                   | 0.101       |
| 6–7                     | 0.044       | 12–13                   | 0.109       |
| 7–8                     | 0.046       | 13–14                   | 0.062       |
| 8–9                     | 0.075       | 14–15                   | 0.236       |
Based on the above discussion, the flow chart for the proposed algorithm is described in Figure 2. As it can be observed, the flowchart of the main algorithm is divided into two stages; the supply adequacy evaluation as the first and reconfiguration as the second one. These stages are explained with more detailed in the following section.

Figure 2. The flowchart of the proposed algorithm.
### 3.1. Stage 1: Supply Adequacy Evaluation

An IMG requires a sufficient energy generation to meet the total energy demand, regardless of checking operational conditions. This condition assures that an island microgrid has adequacy to supply its load or not. The supply adequacy equation for an IMG which operates at a given state \( st \) is presented as follows:

\[
\sum_{i \in B^{(n)}} S_{G_{i, \text{max}}}^{(i, st)} \geq \sqrt{\left( \sum_{i \in B^{(n)}} P_{i, \text{Loss}}^{(i, st)} \right)^2 + \left( \sum_{i \in B^{(n)}} Q_{i, \text{Loss}}^{(i, st)} \right)^2} + \left( S_{\text{Loss}}^{(i, st)} + S_{\text{Spare}}^{(i, st)} \right)
\]

(3)

\[
S_{\text{Spare}}^{(i, st)} = \left( \frac{5}{100} \right) \times S_{\text{Load}}^{(i, st)}
\]

(4)

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\[
\sum_{i \in B^{(n)}} S_{G_{i, \text{max}}}^{(i, st)} \geq \sqrt{\left( \sum_{i \in B^{(n)}} P_{i, \text{Loss}}^{(i, st)} \right)^2 + \left( \sum_{i \in B^{(n)}} Q_{i, \text{Loss}}^{(i, st)} \right)^2} + \left( S_{\text{Loss}}^{(i, st)} + S_{\text{Spare}}^{(i, st)} \right)
\]

(3)

\[
S_{\text{Spare}}^{(i, st)} = \left( \frac{5}{100} \right) \times S_{\text{Load}}^{(i, st)}
\]

(4)

where \( B^{(n)} \) is the set of all buses in the IMG \((#is)\), \( S_{G_{i, \text{max}}}^{(i, st)} \) is the maximum apparent power generation capacity, \( P_{i, \text{Loss}}^{(i, st)} \) and \( Q_{i, \text{Loss}}^{(i, st)} \) are the active (reactive) nominal load power at bus \( i \) in IMG \((#is)\) at state \( st \); \( S_{\text{Loss}}^{(i, st)} \) and \( S_{\text{Spare}}^{(i, st)} \) are apparent power losses, and the apparent spare capacity requirement at IMG is at state \( st \). The spare capacity is considered as the available capacity to respond to an unexpected increase in its local power demand [16]. Among different approaches that can be used for calculating the spare capacity, \( S_{\text{Spare}}^{(i, st)} \) was defined as 5% total demand by an arbitrary \( S_{\text{Loss}}^{(i, st)} \) power loss in IMGs [22].

### 3.2. Stage 2: Reconfiguration

A necessary condition for IMG operation is checked by the step \#1 of the proposed algorithm. This step constructs all acceptable states of each possible IMG. These applicable states guarantee the sufficient energy to supply the load, but it cannot guarantee the customers’ interruption followed by the violation of operational constraints especially voltage constraints. Selection of a good configuration for IMGs minimizes the customers’ interruption due to the construction process. Therefore, it uses a HSA as a heuristic algorithm for reconfiguration of IMGs to minimize customers’ interruption and maximize loadability index by considering the states of the first stage. The process of HSA and reconfiguration are explained in the following section.

### 4. Proposed Methodology

#### 4.1. Islanding Microgrid Reconfiguration

Recently, due to an increase of non-renewable energy cost and load demands, exploiting the renewable energy resources in MGs such as WTs are trending higher and higher, and the concerns related to maintaining the security of the system have been growing increasingly regarding the customers’ interruption. Maintaining the active and reactive power generation in the presence of WTs with leading power factor in the islanded operation mode of MGs is more challenging since the main grid is excluded in the IMG distribution network. To evaluate the voltage of IMG, a new static bidirectional power flow algorithm is suggested by the authors of the paper in [19]. Moreover, a voltage stability index is proposed for a typical 2-bus system which will be expanded to a more complicated n-bus power system.

The voltage stability index and power flow algorithm are separately described as follows:

- **Voltage Stability Index (VSI):**

The voltage stability index based on saddle Node Bifurcation (SNB) and Limited Induced Bifurcation (LIB) are introduced in (5):

\[
cat_{VSI} = \left( P_n R_m + Q_n X_m - 0.5 |V_m|^2 \right)^2 - Z_m^2 (P_n^2 + Q_n^2)
\]

(5)

where, \( P_n \) and \( Q_n \) are the sum of the active and reactive loads of all the buses beyond bus \( n \), (the active and reactive power load of bus \( n \) itself, and the sum of the active and reactive power losses of all the branches beyond node \( n \)). Since an IMG may consist of more than one RIN, the \( cat_{VSI} \) is calculated through Equation (6).

\[
cat_{VSI} = \min\{ cat_{VSI_{RIN_1}}, cat_{VSI_{RIN_2}}, \ldots, cat_{VSI_{RIN_N}} \}
\]

(6)

where, \( N \), is the number of RINs, which exist in the IMG. The ‘\( cat_{VSI_{RIN_i}} \)’ denotes as the voltage stability of the \( i \)th RIN. It is noteworthy to mention that a region with the minimum \( cat_{VSI} \) determines the critical RIN and the bus with the lower stability index in the critical RIN is considered as the most sensitive bus to the voltage collapse which is identified as the critical bus that must be carefully tracked.

- **Constraints**

Following are the operational security constraint considered in this study:

1. Generation limit: usually, there is a limitation on the active and reactive power of DGs in an
Table 3. The location and technical information of DGs in the 33-bus test system.

| DG # | Bus # | Ș<sub>max</sub> p.u. | Ș<sub>max</sub> p.u. | m<sub>p</sub> p.u. | n<sub>q</sub> p.u. | w<sup>*</sup> p.u. | v<sup>*</sup> p.u. |
|------|-------|----------------------|----------------------|------------------|------------------|-----------------|------------------|
| 1    | 4     | 1.8                  | 0.750e-3             | 0.0166 p.u.      | 1                | 1.01            |
| 2    | 18    | 0.5                  | –                    | –                | –                | –               |
| 3    | 22    | 1.5                  | 1.501e-3             | 0.0333 p.u.      | 1                | 1.01            |
| 5    | 25    | 1                    | 0.6                  | 2.252e-3 p.u.    | 0.050            | 1.01            |
| 6    | 33    | 1                    | 0.6                  | 2.252e-3 p.u.    | 0.050            | 1.01            |

4.2. Harmony Search Algorithm

The HSA \[24,25\] is used to optimize the solution of IMG reconfiguration. This heuristic algorithm is incorporated in stage #2 shown in Figure 2. The best configuration of the islanded network can be obtained by solving the objective function presented in Equations (8) and (9).

Where, \(n_{\text{MG}}\) and \(n_{(a)}\) are the number of possible IMG and the number of islanded states in the network under study. \(B^{(a)}\) is the set of all buses in IMG; \(x_{(a),st}\) is a binary variable that identifying the voltage deviation status of load point \(i\) in IMG is at state \(st\); \(\Delta v_{(a),st}\) is equal to one when the voltage regulation is in acceptable region and otherwise it is zero; \(\lambda_{(a),st,m}\) and \(\lambda_{(a),st}\) are the loading factor of IMG is at state \(st\) for loading point, \(m\) and the upper bound of the loading factor of IMG is at state \(st\); and finally \(\lambda_{(a),st}\) is the calculated by the following equation.

5. Case Study: IEEE 33-Bus Test System

The proposed method is tested through an IEEE 33-bus test case shown in Figure 3 is used. The optimization problem and simulation were run with MATLAB on a computer with a Pentium IV, core 7i, 3.2 GHz, 16 GB RAM. For the implementation of the HSA, the harmony memory size (HMS) and harmony memory considering rate (HMCR) are set to be 100 and 0.9, respectively. The phase angle regulator (PAR) increases linearly from 0.44 to 0.99. To find the optimal solution, the heuristic algorithm is run for a total of 50 iterations. Following are the 33-bus case study specifications:

This system is composed of three MGs which IID#2 is an interconnection between MG#2 and #3 and IID#1 can isolate MG#1 from the main grid. The island isolation switch is used to initiate the isolating process. The details of the location and operation mode of DGs are tabulated in Tables 3 and 4. The load and feeder data profile used in the test system (at the nominal frequency) are given in \[26\]. Therefore, Tables 1 and 2 are suggested to consider annual load and wind speed in 10 and 12 states as it explained. In this table, annual loads and wind speed are categorized into 10 levels and 12 levels with its respective probabilistic. In this case study, all coefficients in load model are assumed to be one. For evaluation of the proposed algorithm, two case
studies are suggested. For the first one the operation of the base case without considering the proposed algorithm is studied, in the second case, the proposed algorithm is applied to the base case.

5.1. Scenario I: Base Case

In the base case study, the power flow algorithm given in Section 4 is used for all applicable IMG states. The minimum and maximum magnitude of voltage profiles that can occur for all possible IMGs are shown in Figure 4. This figure shows that the base case has nine buses with under voltage at buses from bus number 10 to 18.

Unfortunately, there is customers’ interruption due to a violation of voltage constraints. Therefore, the proposed algorithm is used as an optimization tool for minimization customers’ interruption and maximization voltage stability in the next case study.

5.2. Scenario II: Optimal Reconfiguration of IMGs

In the second case study, the best configuration of IMGs is found based on minimization of voltage profile violation from its constraints and maximization of voltage stability by using the proposed algorithm as shown in Figure 2. The best configuration and its voltage profiles are illustrated in Figures 5 and 6, respectively. Figure 6 shows that the voltage profile is in its acceptable range, and the minimum and maximum voltage magnitudes do not exceed the allowable deviation tolerance. Figure 7 illustrates the box-plot for the system frequency for the all-possible MG states in MG#2 and MG#3.

According to the definition of the frequency regions, the frequency deviation is in the strict region. Figure 8 represents the maximum system loadability at different wind power ratios (WPR) in MG #2 and #3. The WPR is calculated in (7):

\[
WPR = \frac{P_{w,a}}{P_{w,r}}
\]

Where, \(P_{w,a}\) and \(P_{w,r}\) are the available wind power capacity and the rated wind power capacity, respectively.

It is observable from Figure 8 that by increasing WPR from 0 to 1, the injection of active and consumption of reactive power is increased due to the lead operation of DFIG turbines. By varying WPR from 0 to 0.75, the MG#2 can supply the consumption of reactive power of its load and its WTs. Therefore, the reason for instability is the active power generation limits in this region. However, unlike this region, the leakage of reactive power is the reason of instability with increasing WPR from 0.75 to 1. Here, the reactive power consumption of WTs is increased so that it can be considered as the reason for instability.

Also, the leakage of reactive power is the reason of the instability in MG#3 by increasing wind power injection due to the fact that WTs consume reactive power.

| DG#1 | DG#2 | DG#3 | DG#4 | DG#5 | DG#6 |
|------|------|------|------|------|------|
| Type | Dispatch | DFIG Wind | Dispatch | DFIG Wind | Dispatch |
| Mode | Droop | PQ (PF = 0.95 Lead) | Droop | PQ (PF = 0.95 Lead) | Droop |

Figure 4. Minimum and maximum voltage magnitude.
Figure 5. The best configuration of the 33-bus test system.

Figure 6. Minimum and maximum voltage magnitude at the best configuration.

Figure 7. Box plot: the system frequency obtained by optimization problem.
6. Results and Discussion

From Section 3 of this paper, it can be observed that different concept of implementation of interconnected IMGs operation with high levels of WTs is define. In this definition, the wind power injection, optimum functions and constraints is clearly explained. From Figure 3, it can be observed that about 27% of buses have under voltage that is reason for customers’ interruption. The proposed two stages algorithm is able to improve voltage deviation as well as maximize loadability. Also, author formulate the nature of wind power generation in term of WPR. The importance of definition WPR in IMG is explained in Figure 8. By increasing active power of WTs in MG, this renewable energy is a reason for improve the voltage stability if MG can satisfy reactive power consumption of WTs. Otherwise MGs’ inability to supply the reactive power of WTs is the reason of happening LIB and instability.

7. Conclusions

In this paper, a new probabilistic algorithm has been proposed for a possible operational energy efficiency horizon of offline islanded active distribution system.
involving MGs. The demand and generation variability due to the changing nature of generation in WTs is considered in security constraint of the algorithm. In this regard, this probabilistic algorithm is contained in two stages to delay the renewing MG’s infrastructures by minimizing the IMG customers’ interruption and improving voltage stability margin. The first step creates the set of acceptable states with a maintained supply and demand ratio. In the second step, IMG reconfiguration is used as an optimization engine to minimize the voltage profile deviation and thus, improve the voltage stability index. The unique IMG features provide an appropriate model for IMG. Since there is no central grid in IMG topology, no slack bus exists, and thus, the frequency is obtained from the sharing power between DGs. Needless to mention that to achieve the best operation configuration of the IMG and generalize the model, the impact of frequency on various parts of the system such as feeders, loads, and branches should be deeply considered. Also, a generalized voltage stability index, called cat_VSI, and an enhanced power flow algorithm have been developed for the proposed IMGs reconfiguration technique.

In this paper show that the voltage stability index varying as a function of WPR, the maximum capacity of DGs and MGs’ configuration. The voltage stability index change between 1.649 and 1.8630 in MG#2 and increase from 1.359 to 1.443 in MG#3. In Scenario 2, the frequency of MG#2 (MG#3) varying from 59.92 (59.93) to 60 (59.98) that are in acceptable region. Also, the minimum value for voltage profile change from 0.948 to 0.965 by using the proposed algorithm. The results verify that the proposed technique is robust and can generate the best optimal configuration solutions that meet the objective function constraints. Finally, the results verify that the proposed algorithm is a powerful and helpful tool for the successful implementation of the IMG concept in the active distribution networks.

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No potential conflict of interest was reported by the author.

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