ISLANDING INFLUENCE ON MICROGRIDS PROBABILISTIC RELIABILITY EVALUATION

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Abstract – This paper presents a model that incorporates the influence of islanding into the reliability evaluation of microgrids composed of distributed generation based on renewable energy sources. For such, both the effect of the islanding process on the microgrid voltage and frequency and the microgrid reliability indices due to components failures are analyzed. The proposed model is based on a combination of probabilistic reliability assessment with dynamic simulation of the islanding process. The reliability evaluation is based on non-sequential Monte Carlo Simulation and uses nonlinear optimal power flow for adequacy analysis of the system states. The renewable energy sources are represented by multiple state stochastic models. Results are presented for a MV distribution test system where the process of islanding is evaluated and, for the cases in which the microgrid survives the process, its reliability is evaluated considering network failures as well as power availability. At the end, the success of the islanding process may be combined with the reliability indices providing a more realistic reliability evaluation of the microgrid.

Keywords: Probabilistic Reliability Evaluation, Microgrids, Islanding, Renewable Energy, Distributed Generation.

1 INTRODUCTION

The integration of distributed generation (DG), often associated with renewable energy sources of intermittent nature, can cause positive and negative impacts to the utility distribution network. The increase in the size and complexity of distribution systems, together with the necessity of attending the demand in an economic and reliable way, requires the assessment of the random nature of network failures and generation outages, given that such events can lead to interruptions in electricity supply.

In order to reduce the effects of these events, active distribution networks have been proposed aiming to have self-managing distribution systems, where generators of small and medium size are integrated to the distribution control centers, with the goal of providing an efficient, safe and reliable operation of microgrids [1]. Microgrids may be understood as low or medium voltage distribution networks containing distributed generators, storage systems and controllable loads, which can operate interconnected with the main system or in islanded mode fed by its own resources.

In addition to other technical issues involved in deploying microgrids, a key point is the alternation between the connected and the islanded modes of operation [2]. The islanding of part of the distribution network (establishment of the microgrid) and the reconnection with the main system can be regarded as one of the current challenges in microgrid reliability studies. In general, reliability studies address the impact of network components or DG failures on the microgrid operation without exploring the process of islanding and reconnection to the main system. Strictly speaking, the microgrid reliability is directly related to the dynamic characteristics of the system, given that the presence of DG at active distribution networks imposes new constraints on the dynamic processes of islanding and reconnection. For the process of islanding, it is important to study its effect on the stability of both the microgrid and the main system. As for the reconnection process, it is important to analyze the differences in frequency between the main system and the microgrid prior to try to resynchronize them. Therefore, the complexity involved can be compared with the islanding and restoration phenomenon of transmission systems. Moreover, the power availability of distributed generation may not guarantee the attendance of all the loads in the microgrid and load curtailment may be required. However, the degree of complexity and the data requirements needed to incorporate stochastic dynamic analysis in reliability studies are considerable.

In this sense, the aim of this paper is to incorporate the influence of islanding into the reliability evaluation of microgrids composed of distributed generation based on renewable energy sources. For such, both the effect of the islanding process on the microgrid voltage and frequency and the microgrid reliability indices due to components failures are analyzed. The proposed model is based on a combination of probabilistic reliability assessment with dynamic simulation of the islanding process. The reliability evaluation is based on non-sequential Monte Carlo Simulation (MCS) and uses nonlinear optimal power flow for adequacy analysis of the system states. The dynamic simulation aims to evaluate the islanding process, focusing on long-term analysis where the studied phenomena have slow nature, such as the effect of islanding on voltage and frequency variations. The final goal of the proposed model is to identify ways to incorporate the degree of success of islanding into the microgrid reliability indices and also identify if it can survive the process, besides evaluating its influence on the reliability of the rest of the distribution system. Distributed generation units are represented by multiple states Markov models, being treated differently if the energy sources are non-intermittent, such as biomass and conventional thermal, or intermittent, such as small hydro power plants (SHPP) and wind.

Results will be presented for a MV distribution test system [3] where the process of islanding is evaluated by dynamic simulation and, for the cases in which the microgrid survives the process, its reliability is evaluated by non-sequential MCS considering network failures as well as DG units power availability. At the end, the success of the islanding process is considered in the reliability analysis providing more realistic microgrid reliability indices.

2 MICROGRIDS

Governmental incentives, as a consequence of growing socio-environmental concerns, and the increase of energy production based on renewable sources, have contributed to the rise of a new concept in distribution networks. These networks, called microgrids, are defined as the association of Medium Voltage (MV) and/or Low Voltage (LV) distribution system with small and/or medium-sized generators, as well as storage devices, controlled by a management system capable of operating them when connected to the main system or, in the case of main system failure, in the islanded mode.

In the connected mode of operation, a microgrid can import or export power and/or supply ancillary services. In islanded mode, it works independently of the main system, using local resources and varying between a power control state and a frequency control state, and if necessary, shedding loads [3].

Numerous generation technologies are being associated with this type of application, such as wind turbines, biomass, SHPP, solar panels, fuel cells and combined heat/cold power generation.

The possible benefits related to the use of microgrids are: reliability improvement, loss reduction and the supply of ancillary services, such as, voltage control. Furthermore, the expected social benefits include: decreased environmental impact of the generation system, decreased consumer exposure to faults in the system and, depending on the case, decreased energy costs for the consumer [4].

On the other hand, an increase in the number of generator units in distribution networks, mainly during an islanded operation, may cause problems of coordination and control, voltage flicker and even system instability.

An important challenge is to change from one mode of operation to another (from connected to islanded and vice-versa) without causing an impact on voltage support, stability and reliability. This makes the protection and control systems of microgrid very important items for the quality of electric power supply.

2.1 The Effects of Islanding

Within the concept of microgrids, the distribution network can be automatically subdivided, during faults or intentional islanding, in small islands with generators partially or wholly assuming the participating loads. Thus, the problem lies in evaluating if the available resources are capable of producing enough energy while simultaneously maintaining levels of voltage and frequency that are adequate for all microgrid consumers [5].

In this context, microgrid stability is associated to its response to the type of disturbance and to the resources available. Severe disturbances can be responsible for large variations in frequency, voltage and power flow. Depending on the event, uncontrollable cascading outages can be observed, deteriorating the system and leading to a significant load shedding. As such, controlling actions should be directed, to the utmost, towards preserving the system from total collapse [6].

According to [7], the response of the system to an islanding condition is basically related to a frequency transient. Therefore, governor speed and power supply control systems play important roles in determining the dynamic performance of the network. Nonetheless, this situation is also frequently associated with events of voltage variation due to insufficient reactive reserves.

We can thus affirm that after the islanding operation two situations can occur:

- Island with insufficient level of generation;
- Island with generation superior to load.

In the first case, if the generator capacity is inferior to load, frequency will drop. In the case that there is no possibility of increasing the power generation level of the microgrid, frequency could reach unviable levels, leading to generator outage by sub-frequency protection schemes, contributing to a worsening of the problem. In this case, in order to avoid a total collapse of the microgrid, measures for load shedding should be used, in such a way that load and generation levels are compatible, aiming to stabilize the system frequency level.

In the second situation, if there is excess of generation in the microgrid, a frequency increase will be observed, forcing the generator speed regulators to adjust the mechanical power generation. If, even after this measure, it is not possible to control the frequency-load of the microgrid, the solution may be shutting down some generator units, which could lead to load shedding.

Additionally, the performance of the system can be influenced by the availability of reactive power within the microgrid. Thus, variations in generated and absorbed reactive power could result in voltage violations such that over/under excitation controls are activated and, depending on the case, could lead to the outage of generating units.

It is worth noting that during islanding, the main system may also be submitted to these events, although in a lesser proportion, due to its larger size and robustness.

After the end of the islanding process, the microgrid operates under steady state conditions during the time that is necessary to solve the problems of the main system. Then, the re-connection process can be started. This involves adjusting generation and load so that both systems, the microgrid and main system, are re-synchronized, turning-on the eventually disconnected generating units and re-establishing the consumers that were unattended during the disturbance.

3 DYNAMIC SIMULATION OF ISLANDING

As a consequence of the need for solving the problems related to the dynamic response of power systems in face of severe disturbances, the concepts of short, medium and long term stability were introduced [7].

In the study of short-term stability, the analysis considers the dynamic equations of equipment and controls with extremely rapid characteristics, to capture information that occur during the period immediately after a disturbance in the system.

In the long-term analysis, on the other hand, it is considered that the synchronization oscillations between machines have been reached, implying a uniform frequency. In this case, the point of interest lies in the long-lasting phenomena that accompany severe disturbances and in the variations between generation and consumption of active and reactive power.

In an intermediate interval, in turn, the medium-term evaluation is associated with events that occur between the transient period and the long-term analysis. Thus, the focus is, besides the question of machine synchronization, on the effects of slow phenomena and, also, on those that result in large variations of voltage and frequency.

In both the medium and long-term analyses, the rapid dynamics are not significant. Actually, there is not a well-defined difference between these time intervals. This varies according to modeling needs, such that model choice is conditioned to the evaluated phenomena.

In the case of evaluating the effect of islanding distribution systems with microgrids, an interval of interest that extends beyond the transient period is used for analysis in this paper. Thus, for the evaluation of islanding, the objective is to analyze disturbances in the system that results in cascading faults and, consequently, in island formation. These faults can be related to problems in the responses of the machine control systems and/or resulting from insufficient active and reactive power reserves. The point of relevance for this paper is that the islanding process can result in the non-survival of the microgrid due to the large voltage and frequency variations in response to the problem, what will influence in the microgrid reliability.

To evaluate stability, a complete simulation through time is the one most-frequently used and the most precise, as it supplies the dynamic response closest to the real condition before and after the disturbance. Therefore, a complete dynamic simulation of the islanding process for the creation of the microgrid is used in this paper, although focusing on long-term analysis. In other words, the objective is to identify if the microgrid frequency and voltage attain acceptable levels to operate in islanding mode after the transient period. However, this simulation may require an elevated computational effort due to data volume.

4 RELIABILITY EVALUATION

Until recently, distribution systems had received less attention than generation and transmission in reliability evaluations. This is primarily due to the high costs involved in the latter and in the huge proportion of the consequences resulting from generation and transmission faults. Besides, traditional distribution systems are relatively cheap and their faults have a local effect. On the other hand, statistical analysis demonstrates that most consumer interruptions are due to faults in the distribution system. Thus, the need for quantitative evaluation of these systems has been recognized worldwide.

The methodology necessary to evaluate distribution systems basically depends on the type of network analyzed and the depth of the study to be undertaken. The evolution of distribution systems, linked to the integration of distributed generation on the network, led to the proposal of active distribution networks, which include the possibility of the islanding operation, in the form of microgrids. The study of microgrids has demanded the search for new methods to quantify their impact on the networks.

This need has become even more important with the reorganization of electric sectors in numerous countries, where the establishment of competition in activities of generation and commercialization for free consumers, combined with free access to utility network, ended up enhancing the figure of the independent energy producer and encouraging increased generation near the load centers.

In this new scenario, the evaluation of microgrid impact on load point and system reliability indices is an important task for the development of specific and adequate regulations for integration and implementation of microgrids. Another important point is the identification of the costs associated to microgrid implementation in counterpart to the reduction of costs associated to the penalties for violations of continuity standards, applied by the regulator agencies in numerous countries.

The uncertainties involved in the planning and the operation of microgrid based distribution systems have become greater than in the past, principally in relation to the survival capacity of the islanded system when faced with a problem on the main grid and, also, due to the use of generator units based on energy sources of an intermittent nature.

Therefore, to evaluate the reliability of distribution systems with microgrids it is necessary that the analyses take into consideration the probabilistic character of power systems, the influence of the intermittent nature of some renewable energy sources and the medium and long-term dynamics associated with the formation of islands in the distribution system.

4.1 Integrated System Monte Carlo Simulation

The probabilistic reliability evaluation of the distribution system can be obtained using the Non-Sequential Monte Carlo simulation, combined with a model of minimum load shedding. The algorithm used in this paper, for evaluating system reliability before islanding as well as for the islanded operation, is composed of the following steps:

1. *A stochastic model of multiple load levels is obtained from the curve of the system hourly workload, for the period of one year, using a data clustering technique.*
2. *The system states for each load level are sampled using MCS. The generating units are represented by multiple state stochastic models, while the network components are represented by two state stochastic models.*
3. *The load shedding minimization model is solved for each system state sampled, aiming to identify if the system is capable of supplying the load without violation in the operating constraints.*
4. *Steps 2 and 3 are repeated until all the load levels are evaluated.*
5. *The results for all the load levels are analyzed regarding their probability of occurrence aiming to calculate annual reliability indices.*

The model of load shedding minimization is used to analyze the adequacy of the system state sampled. This model can be characterized as a Non-Linear Optimum Power Flow problem, solved using the following equations:

$$Min \sum_{i \in ND} W_i \cdot C_i$$

Sujeito a:

$$PG_i + C_i - P_{Li} - V_i \sum_{j \in \Omega_i} V_j \cdot [G_{ij} \cdot \cos(\delta_i - \delta_j) + B_{ij} \cdot sen(\delta_i - \delta_j)] = 0$$

$$Q_{Gi} + C_{Qi} - Q_{Li} - V_i \sum_{j \in \Omega_i} V_j \cdot [G_{ij} \cdot \mathrm{sen}(\delta_i - \delta_j) - B_{ij} \cdot cos(\delta_i - \delta_j)] = 0$$

$$\sum_{i \in NG} PG_i + \sum_{i \in ND} C_i = \sum_{i \in ND} PD_i$$

$$V_i^{min} \le V_i \le V_i^{max}$$

$$PG_i^{min} \le PG_i \le PG_i^{max}, (i \in NG)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$$

$$0 \le C_i \le PD_i, (i \in ND)$$

where PG_i is the active power generated in the i-th bus [MW], Q_{Gi} is the reactive power generated in the i-th bus [Mvar], P_{Li} is the active power load in the i-th bus [MW], Q_{Li} is the reactive power load in the i-th bus [Mvar], C_i is the active load shedding in the i-th bus [MW], C_{Qi} is the reactive load shedding in the i-th bus [Mvar], V_i is the voltage in the i-th bus [V], δ_i is the voltage phase angle in the i-th bus [rad], $G_{ij} + jB_{ij}$ are elements of the nodal admittance matrix, W_i is the cost of interruption in the i-th load bus [R$/MWh], ND is the number of load buses, NG is the number of generation buses and Ω_i is the group of buses directly linked to bus i, including it.

The reliability indices calculated to capture severity and importance of the distribution system faults are:

1. System Average Interruption Frequency index

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i}$$

where λ_i is the failure rate and N_i is the number of consumers connected to load point *i*.

2. System Average Interruption Duration Index

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i}$$

where U_i is the annual mean repair time of load point *i*.

3. Average Service Unavailability Index

$$ASUI = \frac{\sum U_i N_i}{\sum N_i \cdot 8760}$$

where *8760* is the number of hours of an year.

4. Average Service Availability Index

$$ASAI = 1 - ASUI$$

5. Energy Not Supplied

$$ENS = \sum L_i U_i$$

where L_i is the medium load of load point *i*.

6. Average Energy Not Supplied

$$AENS = \frac{ENS}{\sum N_i}$$

4.2 Islanding Simulation

As previously-mentioned, to evaluate the reliability of distribution networks with microgrids, it is important to evaluate, besides the associated risk level, the dynamics of the system when faced with faults in the network. In other words, before assessing the reliability of the main system and the microgrid, it is necessary to evaluate if these networks are capable of surviving determinate disturbances.

With this in mind, models of synchronous machines combined with thermal and hydraulic turbines and their respective voltage/speed regulators are used for distributed generation. The objective is to try to capture the medium and long-term dynamics for each type of generating unit related to the islanding process of the microgrid, registering information about voltage variations in the buses and system frequency.

4.3 Main System and Microgrid Monte Carlo Simulation

After evaluating the dynamics of the islanding process, in the case where microgrid and main system voltage and frequency stay within operating limits, the reliability evaluation can then be realized, separately for each system, bearing in mind that they are subject to disturbance during the islanded operation. Thus, the reliability indices are calculated to quantify microgrid and main system level of risk, when operating in islanded mode. The objective is to evaluate these indices to quantify the benefits of using microgrids in comparison with traditional distribution networks and evaluate the degree of risk for consumers under microgrid islanded operation.

5 RESULTS

5.1 Test System

The proposed model is applied to the RBTS-Bus2 [5] system, presented in Figure 1.

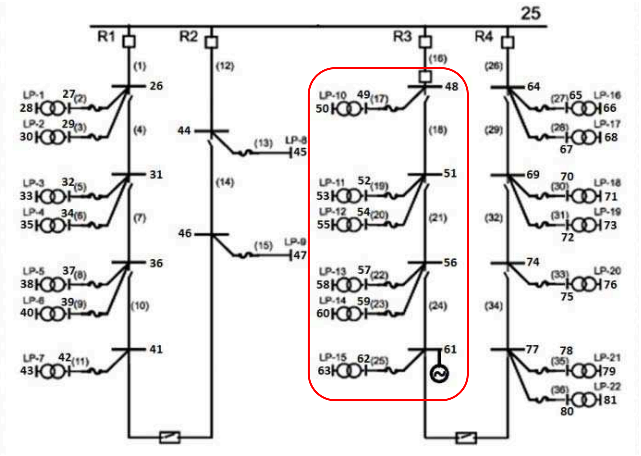

Figure 1: RBTS-Bus2.

RBTS-Bus2 is a distribution system composed of four radial feeders with a total load of 20 MW. Feeder 3, with a load of 5MW, is also evaluated when operating as a microgrid, with the distributed generating unit connected at Bus 61.

In relation to DG, two types of renewable sources are considered: Small Hydro Power Plant and Biomass Thermal Plant. The SHPP model used, developed in [8], combines the river inflow model with the generator model, so as to incorporate the effects of inflow variation, which directly affects the generation of energy. The SHPP is represented by a Markovian model of individualized multiple states, as shown in Figure 2, with their respective transition rates. The different inflow values are represented by 1 to N states and the λ_{ij} rate indicates the transition from the i^{th} inflow state to the j^{th} inflow state. The transitions between generator operation and repair states are represented by λ and μ.

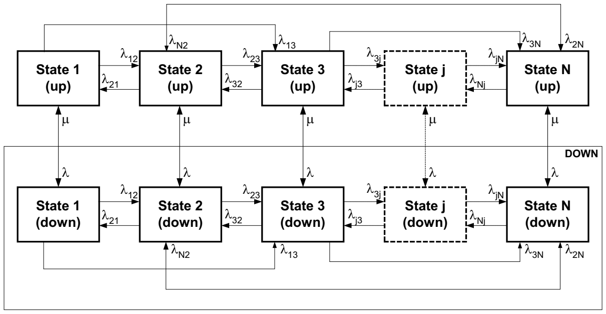

Figure 2: SHPP Model.

The biomass thermal units are represented by the three state models shown in Figure 3. In this model, the faults of certain components do not result in unit outage, but rather imply an operating condition with reduced power.

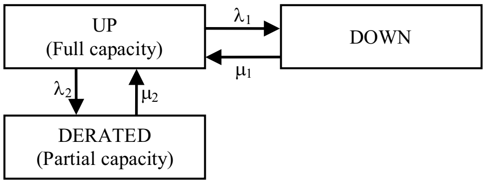

Figure 3: Biomass Model.

5.2 Islanding Dynamics

To evaluate the dynamic performance of the islanding process, a three-phased short-circuit occurrence in line 16 of the RBTS-Bus2 system was considered, followed by the opening of the respective switches, forming the microgrid. The simulation was performed considering the use of DG units of 5.5 MW and 9 MW. The models of synchronous machines, voltage and speed regulator are included in the generator models.

5.2.1 Distributed Generation of 5.5 MW

The voltage and frequency variations at the generation buses of the two formed islands (bus 61 in the microgrid and bus 25 in the main system, since it is the connection point to the transmission system) are shown in figures 4 to 7 for a DG of 5.5 MW.

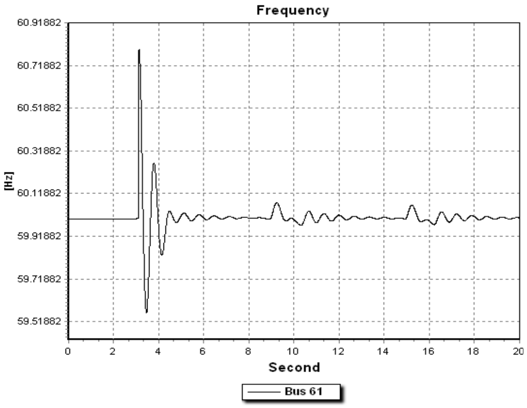

Figure 4: Microgrid Frequency (DG 5.5MW).

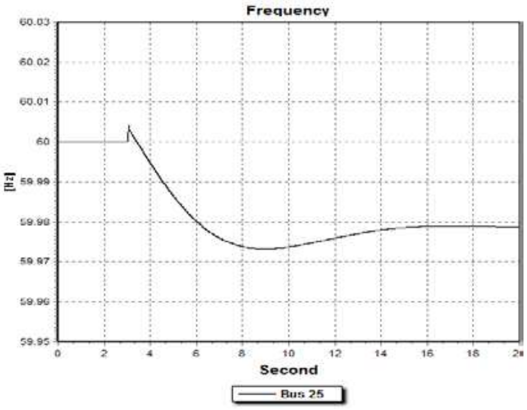

Figure 5: Main System Frequency.

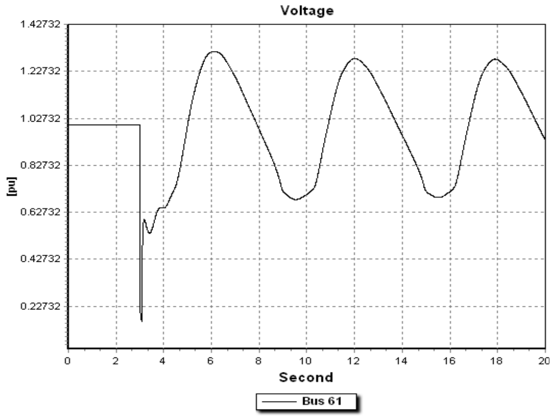

Figure 6: Microgrid Voltage (Bus 61) (DG 5.5MW).

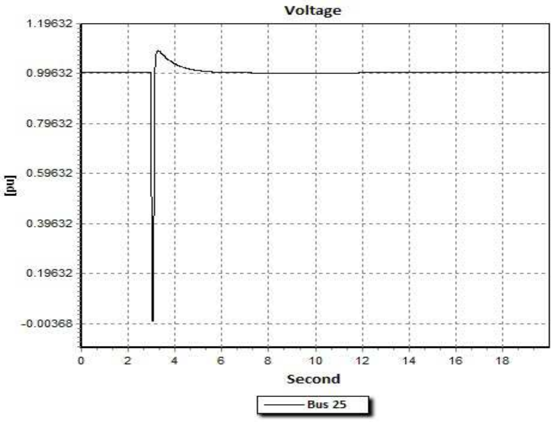

Figure 7: Main System Voltage (Bus 25).

We can note that the microgrid does not survive the islanding process resulting from the considered event, since the overvoltage at bus 61 reaches more than 1.3 pu and the regulator is not able to damp the voltage oscillation within the simulation period. This response would result in the DG disconnection via protection schemes. However, in terms of frequency variation, the microgrid would return to acceptable limits in less than 3 sec after the event.

On the other hand, the main system is capable of surviving the event, remaining stable. The system frequency varies within an interval of 59.97 Hz to 60.00 Hz, remaining within the usually acceptable range. In steady state, in turn, the main system frequency changed from 60 Hz to 59.98 Hz, as a consequence of the action of the speed regulator. In terms of voltage variation, a very large variation in voltage is observed during the short-circuit event but after the transient period, the voltage stabilizes at a value adequate for steady state operation.

This result shows how important is to consider the islanding process dynamics on reliability evaluations. It is usual to consider in reliability studies that if the DG capacity is higher than the load, then there is no load shedding. In more detailed studies, a load flow analysis is performed in order to include losses, voltage and power flow limits. Based on these criteria, however, the result would be that there is no load shedding for a DG of 5.5MW. However, the dynamic simulation shows that the microgrid does not survive the islanding process and, therefore, its entire load would be shed.

5.2.2 Distributed Generation of 9 MW

Other simulations considering a larger DG unit of 9 MW are performed in order to verify the possibility of operating feeder 3 as a microgrid. Figures 8, 9 and 10 show the frequency, voltage and active power variation in the generation bus of the microgrid, respectively.

We can note that the microgrid survive the islanding process in this case. The voltage at bus 61 varies considerably during the transient period but returns to within the acceptable limits of 1.2 - 0.8 pu in less than 3 sec after the event. Its steady state value is 0.99 pu.

In terms of frequency, there is a small variation during the transient period that does not violate the limits. After 10 sec, the frequency stabilizes in 60.03 Hz due to the action of the velocity regulator that is capable to manage the active power generation reduction, as can be seen in Fig. 10. The steady state frequency error at the microgrid is small because the DG governor switches to the island mode operation with a small frequency droop.

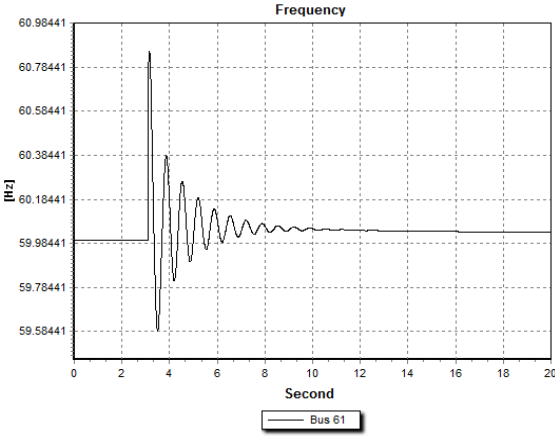

Figure 8: Microgrid Frequency (DG 9 MW).

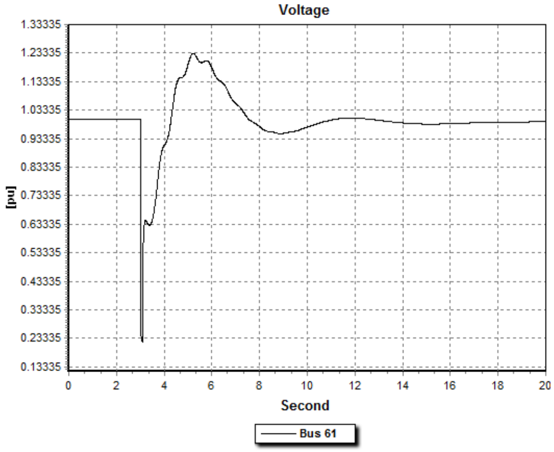

Figure 9: Microgrid Voltage (Bus 61) (DG 9 MW).

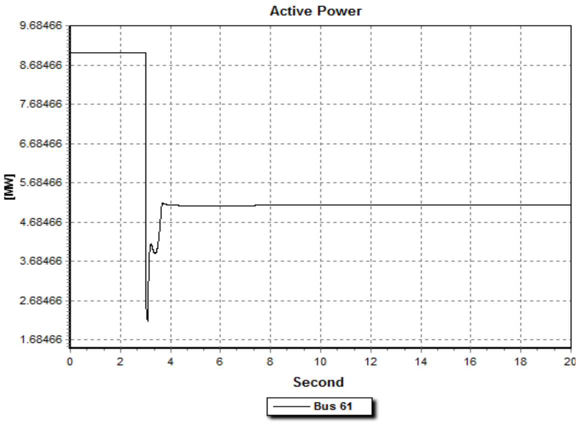

Figure 10: Microgrid Active Power (Bus 61) (DG 9 MW).

5.3 Reliability Indices – DG of 9 MW

After identifying that the microgrid with this DG capacity survived the islanding process, the microgrid reliability indices are calculated.

Tables 1 and 2 show the reliability indices of the entire RBTS-Bus2 system, that is, before the formation of the microgrid, for the entire system and for each feeder 3 load point, respectively.

Indices	System Results	Feeder Results			
		Feeder 1	Feeder 2	Feeder 3	Feeder 4
Ni	1908	652	2	632	622
SAIFI	0.135	0.105	0.125	0.152	0.149
SAIDI	3.587	3.445	0.626	3.707	3.623
ASUI	0.000409	0.000393	0.000072	0.000423	0.000414
ENS	64036.341	21511.6	2220.9	19522.252	20781.572
AENS	33.562	32.993	1110.5	30.9	33.411

Table 1: Reliability Indices of RBTS-Bus2.

	LP10	LP11	LP12	LP13	LP14	LP15
Ni	210	210	200	1	1	10
λ	0.103	0.177	0.174	0.172	0.183	0.224
Ui	3.593	3.772	3.731	3.896	4.034	4.199
ENS	3114.5	3269.6	2720.1	3571.4	3697.6	3149.1
AENS	14.831	15.570	13.600	3571.402	3697.6	314.9

Table 2: Reliability Indices of Load Points of Feeder 3.

The indices calculated for the microgrid, considering biomass or SHPP DG types, are shown in Table 3, for the system, and in Tables 4 and 5, for the load points.

Indices	Biomass 9 MW	SHPP 9 MW
Ni	632	632
SAIFI	0.218	0.257
SAIDI	4.218	4.073
ASUI	0.000481	0.000465
ENS	19270.94	19131.878
AENS	30.491	30.272

Table 3: Reliability Indices of the Microgrid.

	LP10	LP11	LP12	LP13	LP14	LP15
Ni	210	210	200	1	1	10
λ	0.266	0.218	0.177	0.111	0.132	0.073
SAIDI	4.766	3.959	3.959	4.253	3.299	3.373
ASUI	0.000544	0.000452	0.000452	0.000485	0.000377	0.000385
ENS	4131.1	3432.0	2886.8	3898.4	3024.6	2529.6
AENS	19.7	16.3	14.4	3898.4	3024.6	252.9

Table 4: Reliability Indices of Load Points of the Microgrid (Biomass 9 MW).

	LP10	LP11	LP12	LP13	LP14	LP15
Ni	210	210	200	1	1	10
λ	0.296	0.293	0.189	0.090	0.152	0.082
SAIDI	4.555	4.030	3.679	4.380	3.154	2.803
ASUI	0.000520	0.000460	0.000420	0.000500	0.000360	0.000320
ENS	3948.368	3492.787	2682.451	4051.066	2890.847	2102.358
AENS	18.802	16.632	13.412	4015.066	2890.847	210.236

Table 5: Reliability Indices of Load Points of the Microgrid (SHPP 9 MW).

Comparing the indices of Feeder 3 (Table 1) with those of the microgrid (Table 3), it can be observed that, generally, the feeder indices are better when connected to the main system, than in the microgrid operation. The microgrid operation provides improvement only in terms of ENS and AENS, for the SHPP as well as for the Biomass DG types. This is due to the fact that, in the microgrid operation, the loads can be maintained by the DG, implying in the reduction of the non-supplied energy of the system.

Yet, for some load points, the microgrid operation (Tables 4 and 5) implies in improvement of all the reliability indices in relation to the connected operation (Table 2), both for the SHPP and the Biomass DG types. This improvement mainly occurs for the load points closest to the DG, such as LP14 and LP15, because in the connected operation, these points are situated at the end of feeder 3, thereby having worse reliability indices.

The indices obtained with the biomass-type DG are, generally, better than those obtained with SHPP. The reason is because there is lower intermittence in the biomass thermal generation in relation to SHPP, where the availability of energy depends on the river inflow values.

6 CONCLUSIONS

This paper presented a model that incorporates the influence of islanding in the evaluation of distribution systems with microgrids, including the representation of renewable energy sources. The effects of the islanding process on the voltage and frequency of both the main system and the microgrid are presented.

The results show that, in certain cases, the microgrid may not survive the islanding process and, therefore, the reliability assessment alone is not enough for proper evaluation of the microgrid.

Additionally, it is observed that the microgrid loads may be submitted to large variations in frequency and voltage, especially for severe events. Thus, the control and protection schemes of microgrids are really important for ensuring power supply quality.

The use of models that treat adequately the intermittent energy sources within a probabilistic evaluation is important to capture the states of microgrid generation, since these units do not have the same availability of the conventional energy sources.

Although the reliability level of some load points is lower in microgrid operation than in main system connected operation, the possibility of having microgrid operation is a great alternative, since it allows keeping the power supply even in cases of failure of the main system. In addition, the reliability of load points closer to the DG connection point is significantly improved under the microgrid operation mode.

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