Radial distribution Systems solving in GAMS - Practice Implementation

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Abstract. In the following work, the practical implementation of a radial distribution system will be carried out. This work is done in the GAMS software. In the present work the analysis will be carried out to three radial systems of 10, 33, 69 nodes. In which it is expected to analyze the best location of distributed generation systems (GD) and batteries (B), in order to obtain an objective function (Z) that represent the best performance of each system. The systems have a single source of generation and will be assigned Distributed Generators and Batteries. In the same way taking into account the variation of the systems, it is expected to analyze the active power losses, the reactive power losses, the power of the battery and the charge state of the battery in a period of 24 hours. The analysis was done with the GAMS software.

1. Introduction

Distributed Generation (DG) can be defined as electricity generation by small-scale technologies to produce electricity near the loads fed. Over the last decade, energy and environment have become pivotal concerns to all countries in the world. Most of them have been encouraged through regulations such as the Paris agreement (2016) to face climate change issues \cite{1}. Electricity coming from renewable energy sources accounted for almost 25\% of the world’s capacity in 2018 \cite{2} and it is forecasted to be expanded by 50\% between 2019 and 2024, led by solar photovoltaic (PV) \cite{3}. Widespread penetration of these mature renewable energy and other distributed generation technologies at home and abroad have allowed to incorporate them into the distribution network \cite{4, 5}. As a consequence, there is a global trend of deregulation and decentralization of the electricity market, and subsequently, there is an imminent need for more flexible electric systems. Advances in research have demonstrated that introducing DG in power distribution can bring several benefits including voltage stability, power losses reduction, grid reinforcement, and cost reduction during on-peak periods among others \cite{4, 6}. However, the unappropriated location of DGs can cause adverse effects including increased power losses, as DG can affect power flow distribution in distribution networks. Therefore, it is necessary to find the optimal locations and sizing of DGs to increase their benefits. To date, there have been many approaches reported to solve this problem. These approaches can be grouped into three
categories: Classical optimization \cite{7, 8, 9} Meta-heuristic \cite{10, 11, 12} and analytical approaches \cite{13}.

Classical methods includes linear programming (LP) and optimal power flow (OPF). The first, is probably the easiest to implement, but not all the models allows reducing them into a set of linear equations \cite{14}. The second, can optimize very complex problems with several variables, finding the best operating levels for electric power plants to satisfy demands given while minimizing operating cost \cite{9}.

Regarding analytical approaches, Naik et al. proposed analytical expressions for optimal siting and sizing of DG in radial distributions, based on changes in active and reactive components of branch currents cause by the DG placement \cite{15}. As well, Elsaiah pointed to optimal placement and sizing of distributed generation on power distribution systems for loss reduction by proposing non-iterative and direct equations able to avoid convergence issues \cite{16}.

However, when problems becomes non-linear or solutions gets high dimensions, both above mentioned method may fall (CITE). Meta-heuristic techniques are the most widely used to overcome these problems. These methods are mostly based on nature behavior. Currently, several studies have used metaheuristic methods to address these problems. For instance, in Junjie’s et al. study, authors analyzed the problem of location of Distributed Generation (DG) based on an immune algorithm. They solved the problem of the energy planning of the distribution networks in smart grids and dynamic planning as a final optimal solution considering costs associated to environmental compensation, traditional DG capacity and maintenance costs \cite{17}. Shena and Provas, developed a Krill Herd (KH) based algorithm to solve optimal placement of distributed generator problem; reducing power losses and energy cost in distribution radial networks \cite{18}. Zhiyun et al. proposed a novel methodology to solve the smart distribution network with the goal of minimizing power losses and enhance voltage stability using an algorithm based on the electromagnetism-like mechanism (ELM) \cite{19}. Grisales and Gonzalez solved the problem based on Population-Based Incremental Learning (PBIL) and Particle Swarm Optimization PSO techniques \cite{20}. Likewise, Setyawan and Soeprijanto used a artificial intelligence technique Symbiotic Organism Search (SOS) for sizing distributed generation and Loss Reduction Sensitivity Factor (LRSF) for optimal the placement of DG \cite{21}. Ali et. al use the Ant-Lion (AL) algorithm for optimal location and sizing of renewable DG \cite{22}. Sanjay et al. used the hybrid gray wolf optimizer (HGWO) to solve the allocation of DG \cite{23}.

The main drawback meta-heuristic methods is finding the optimal hyper-parameters. The solution provided by them is near optimal solution for a problem with numerous variables. However, this solution may change when changing algorithm start point or hyper-parameters, as a consequence, the effectiveness could be decreased. In addition, parameters selection task can be more complicated when using ensemble models.

Although the high efficiency of DG to supply energy sources, there are still challenges to face abrupt increases in electricity demand. The incorporation of energy storage (ES) devices represents a potential solution not only to satisfy the 100% of electricity demand \cite{24}, but also for use the stored energy to be supplied during on-peak periods for cost-reductions \cite{25}. Lithium-based batteries the most used in the industry today, are experiencing its lowest cost in history, more than 85% cheaper than in 2010, bringing electricity cost from this source down to almost four-fifths during the period 2010-2019 and is forecasted that by 2023, battery average prices will fall up to 90% compared with 2010 prices \cite{26, 27, 28}. These reductions are thanks to increasing order size and market uptake in battery electric vehicles sales. However, unappropriated placement and sizing of ES devices and DG altogether may implies technical (transient stability) and economical (cost) impacts \cite{29}. Currently, several approaches have pointed to include ES and DG altogether to maximize benefits on the grid side. For instance, Erdinc et al. addressed the sizing of distributed generation and energy storage for smart households under a demand response strategy over a long-term analysis period \cite{30}. Conducted an approach pointing to
coordinated operation of a neighborhood of smart households considering the vehicle to grid (V2G) concepts, as well as other ES units and DG [31]. In Cao’s et al. study, authors propose a dynamic coordination optimization for active distribution network considering ES devices [32] on a 33-node test feeder.

In this paper, we addressed the problem by using the General Algebraic Modelling System (GAMS) to determine the optimal location and sizing of DG and ES units in radial distribution systems by considering active and reactive power losses, and battery operational parameters such as state of charge during a 24-hours period. Early stages of this approach are presented in [33], were a MATLAB-based GUI was developed to perform analysis of power losses in radial distribution networks considering DG units. In this work, GAMS was selected as nonlinear optimizing package to solve this problem using the large-scale nonlinear optimization CONOPT solver. Finally, we conducted three test systems with 10, 33 and 69 nodes respectively, used for simulation purposes in order to confirm both the effectiveness and robustness of the nonlinear model, and the proposed GAMS solution methodology.

2. Objective function
The objective function, represented by Equation (1), targets the minimization of the operative cost of each of the systems.

$$z = \min \left( \sum_{i=1}^{g} \sum_{t=1}^{24} C(i,t) P_{\text{Gconv}}(i,t) \Delta t \right)$$

Where \( C(i,t) \) is the purchase cost of energy, \( P_{\text{Gconv}} \) is the Power Generation of a Conventional Generator connected to node \( i \) for each period \( t \), \( \Delta t \) is delta of the time period. \( P_{\text{Gdistrib}} \) is the Power Generation of a Distributed Generator. \( P_{\text{Gbat}} \) is the Power Generation of the Batteries. Finally, \( P_{\text{Disp}} \) in the Dispatched Power.

2.0.1. Constraints
Eq. (2) represents the active power balance at each node in the network.

$$P_{\text{Gconv}}(i,t) + P_{\text{Gdistrib}}(i,t) + P_{\text{Gbat}}(i,t) - P_{\text{Disp}}(i,t) = V(i,t) \sum_{j=1}^{n} Y(i,j) V(i,j) \cos(\theta(i,t) - \theta(i,t) - \delta(i,j)) \{\forall i \in \Omega_N\}$$

Eq. (3) represents the reactive power balance at each node in the network.

$$Q_{\text{Gconv}}(i,t) + Q_{\text{Gdistrib}}(i,t) + Q_{\text{Gbat}}(i,t) - Q_{\text{Disp}}(i,t) = V(i,t) \sum_{j=1}^{n} Y(i,j) V(i,j) \sin(\theta(i,t) - \theta(i,t) - \delta(i,j)) \{\forall i \in \Omega_N\}$$

Eq. (4) represent capacity limits of voltage at each node of the network.

$$V_{\text{min}} \leq V(i,t) \leq V_{\text{max}} \forall i \in \Omega_N$$
Eq. 5 represents the capacity limits for Active power coming from CG.

$$P_{min}^{G_{conv}} \leq P_{G_{conv}}(i, t) \leq P_{max}^{G_{conv}} \forall i \in \Omega_{G_{conv}}$$  (5)

Eq. 6 represents the capacity limits for active power coming from DG.

$$P_{min}^{G_{distrib}} \leq P_{G_{distrib}}(i, t) \leq P_{max}^{G_{distrib}} \forall i \in \Omega_{G_{distrib}}$$  (6)

Eq. 7 represents the capacity limits for reactive power coming from CG.

$$Q_{min}^{G_{conv}} \leq Q_{G_{conv}}(i, t) \leq Q_{max}^{G_{conv}} \forall i \in \Omega_{G_{conv}}$$  (7)

Eq. 8 represents the capacity limits for reactive power coming from DG.

$$Q_{min}^{G_{distrib}} \leq Q_{G_{distrib}}(i, t) \leq Q_{max}^{G_{distrib}} \forall i \in \Omega_{G_{distrib}}$$  (8)

ES units were constrained specifically on the State-of-the-charge (SoC). Eqs 11 and 10 models the charge and discharge processes. Eqs 13 and 12 bound the time of charge. Finally, Eq. 13 bounds the SoC.

$$SoC_{bat}(i, t) = SoC_{bat}(i, t-1) + \gamma_{bat}P_{G_{bat}}(i, t)$$  (9)

$$SoC_{bat}(i, t) = SoC_{bat}(i, t-1) - \gamma_{bat}P_{G_{bat}}(i, t)$$  (10)

$$SoC_{bat}(i, t = 1) = SoC_{initial}(i, t)$$  (11)

$$SoC_{bat}(i, t = 24) = SoC_{final}(i, t)$$  (12)

$$0 \leq SoC(i, t) \leq 1, \forall i \in \Omega_N$$  (13)

Where $\gamma_{bat}$, is the charging efficiency of the batteries, $SoC_{initial}$ is the initial state of charge of the batteries. $SoC_{final}$ is the final state of charge of the batteries.

3. General modeling system: GAMS implementation

4. Test systems and simulation cases

This section introduces the electrical configuration and the test system information, for the radial distribution systems used in this work for validating the proposed formulation in the GAMS package. Three test system were used: a 10-node and a 33-node test systems, and a 69-node test feeder. Detailed information of these test systems is presented below.

5. Optimal flow cases

In this section we will be giving the specifications of each of the radial systems, radial systems of 10 nodes, radial system of 33 nodes and radial system of 69 nodes. In each one of them will be given the index of generators, the index of nodes, the index of times, the index of distributed generators, the index of batteries to be used, the association of generators and nodes; by means of which the point where the main generator will be established, the association of distributed generators and nodes; through which it will be established which is the best place to locate the system of distributed generators and the association of batteries and nodes; By means of the latter it is expected to improve the performance of the system, improving the losses and obtain a better performance of the system, since there is no interruption with the main generation of the system. This process will be presented step by step explaining the process mounted GAMS software screen to screen.
5.1. Optimal flow cases tf 10 nodes

In this introductory part of the GAMS code, the respective variations will be made in order to establish the best location of the two systems of Distributed Generation and the best location of the storage system. The radial system to take into account to perform the analysis is a radial system of 10 nodes and nine lines, See Figure. 16. The YBUS information is in the Table 1.

| Node | Node | R [Ω] | X [Ω] | P [kW] | Q [kVAR] | V [p.u.] |
|------|------|-------|-------|--------|----------|---------|
| 1    | 2    | 0.1233| 0.4127| 1840   | 460      | 0.9929  |
| 2    | 3    | 0.2467| 0.6051| 980    | 340      | 0.9823  |
| 3    | 4    | 0.7469| 12.050| 1790   | 446      | 0.9581  |
| 4    | 5    | 0.6984| 0.6084| 1598   | 1840     | 0.9427  |
| 5    | 6    | 19.837| 17.276| 1610   | 600      | 0.9116  |
| 6    | 7    | 0.9057| 0.7886| 780    | 110      | 0.9015  |
| 7    | 8    | 47.953| 27.160| 980    | 130      | 0.8527  |
| 8    | 9    | 53.434| 30.264| 1640   | 200      | 0.8313  |

To establish the analysis, the variation of the Distributed Generators will be presented as follows:

Index of Distributed Generators and Nodes
To complement the analysis, the Association of the Battery and Nodes will be presented as follows:

Association Index of Battery and Node

\[(1)\] \( B_{1}.N_{10} \)

\[(1)\] \( GD_{1}.N_{4},GD_{2}.N_{10} \) \( GD_{1}.N_{5},GD_{2}.N_{10} \) \( GD_{1}.N_{6},GD_{2}.N_{10} \) \( GD_{1}.N_{7},GD_{2}.N_{10} \) \( GD_{1}.N_{8},GD_{2}.N_{10} \) \( GD_{1}.N_{9},GD_{2}.N_{10} \)

Figure 4. Line Input data

Figure 5. Input data YBUS
5.2. Optimal flow cases of 33 nodes

To present the analysis process done in GAMS software as the first instance, it will be presented the respective variations will be made in order to establish the best location of the two systems of Distributed Generation and the best location of the storage system. The radial system to
Figure 9. Input scalar

```
152 SCALAR
153 PI /3.1416/;
---
```

Figure 10. Optimization Variables declared

```
156 ** The optimization variables are declared **
157
158 VARIABLES
159 z    value of the objective function
160 p(G,T) active power generated by the generator G
161 pgd(GD,T) power generated by GD
162 q(G,T) Reactive power generated by the generator G
163 v(N,T) modulus of tension in node N
164 d(N,T) angle of tension in node N
165 pb(B,T) Battery power B
166 SoC(B,T) Battery state of Charge B
167 Ploss(T) Losses of active power
168 Qloss(T) Losses of reactive power:
---
```

Figure 11. Assignment of limits of the variables

```
170 ** Assignment of limits of the variables **
171 **p. lo(G)=GDATA(G,'PMIN'); p. up(G)=GDATA(G,'PMAX');
172 **q. lo(G)=GDATA(G,'QMIN'); q. up(G)=GDATA(G,'QMAX');
173 v. lo(N,T)=BUS(N,'VMIN'); v. up(N,T)=BUS(N,'VMAX');
174 d. lo(N,T)=-PI; d. up(N,T)=PI;
175 pgd. lo(GD,T) =0; pgd. up(GD,T) =GDS(T,GD);
176 pb. lo(B,T) =BAITS(B,'pbmin'); pb. up(B,T) =BAITS(B,'pbmax');
177 SoC. lo(B,T) =BAITS(B,'SoCmin'); SoC. up(B,T) =BAITS(B,'SoCmax');
178 ** El nudo 3 se toma como nudo de referencia, por
179 ** eso se fija su angulo a cero.
180 d. fx('N1',T)=0;
181 v. fx('N1',T)=1;
```

Figure 12. input data variables

```
188 ALIAS (N,NP);
189 ** Las matrices de datos y PHI se definen simetricas mediante
190 ** la condicion $\odot (\text{ORD}(N) \text{ GT } \text{ORD}(NP))$ sobre los conjuntos N y NP.
191 *LINE(N,NP,'Y')$\odot (\text{ORD}(N) \text{ GT } \text{ORD}(NP))=$LINE(NP,N,'Y');
192 *LINE(N,NP,'PHI')$\odot (\text{ORD}(N) \text{ GT } \text{ORD}(NP))=$LINE(NP,N,'PHI');
193 ** Se declaran las restricciones.
---
```

take into account to perform the analysis is a radial system of 33 nodes and 32 lines, See Figure. 17 The YBUS information is in the Table 2

To establish the analysis, the variation of the Distributed Generators will be presented as follows:

Index of Distributed Generators and Nodes

\[ \{(1)\} GD1.N7, GD2.N20, GD1.N8, GD2.N21, GD1.N9, GD2.N22, GD1.N10, GD2.N23, GD1.N11, GD2.N24, GD1.N12, GD2.N25 \]
To complement the analysis, the Association of the Battery and Nodes will be presented as follows:
Figure 17. Radial system 33 nodes

Table 2. YBUS Data System TF33

| Node | Node | R [ ] | X [ ] | P[kW] | Q[kVAr] | V[p.u] |
|------|------|-------|-------|-------|--------|--------|
| 1    | 2    | 0.0922| 0.0477| 100   | 60     | 0.9970 |
| 2    | 3    | 0.4930| 0.2511| 90    | 40     | 0.9929 |
| 3    | 4    | 0.3600| 0.1864| 120   | 80     | 0.9754 |
| 4    | 5    | 0.3841| 0.1941| 60    | 30     | 0.9679 |
| 5    | 6    | 0.8190| 0.7070| 60    | 20     | 0.9495 |
| 6    | 7    | 0.4372| 0.2185| 200   | 100    | 0.9459 |
| 7    | 8    | 1.7114| 1.2351| 90    | 40     | 0.9323 |
| 8    | 9    | 1.0400| 0.7400| 60    | 20     | 0.9260 |
| 9    | 10   | 1.0400| 0.7400| 60    | 20     | 0.9260 |
| 10   | 11   | 0.1966| 0.0650| 45    | 30     | 0.9192 |
| 11   | 12   | 0.3744| 0.1238| 60    | 35     | 0.9177 |
| 12   | 13   | 1.4600| 1.1550| 60    | 35     | 0.9115 |
| 13   | 14   | 0.5416| 0.7129| 120   | 80     | 0.9092 |
| 14   | 15   | 0.5910| 0.5260| 60    | 10     | 0.9078 |
| 15   | 16   | 0.7463| 0.5459| 60    | 20     | 0.9064 |
| 16   | 17   | 1.2890| 1.7210| 60    | 20     | 0.9044 |
| 17   | 18   | 0.7320| 0.5740| 90    | 40     | 0.9038 |
| 18   | 19   | 0.1600| 0.1506| 90    | 40     | 0.9065 |
| 19   | 20   | 1.5042| 1.3554| 90    | 40     | 0.9029 |
| 20   | 21   | 0.4995| 0.4784| 90    | 40     | 0.9022 |
| 21   | 22   | 0.7089| 0.9373| 90    | 40     | 0.9016 |
| 22   | 23   | 0.4512| 0.3083| 90    | 50     | 0.9793 |
| 23   | 24   | 0.8980| 0.7091| 420   | 200    | 0.9726 |
| 24   | 25   | 0.8960| 0.7011| 420   | 200    | 0.9693 |
| 25   | 26   | 0.2030| 0.1034| 60    | 25     | 0.9475 |
| 26   | 27   | 0.2842| 0.1447| 60    | 25     | 0.9450 |
| 27   | 28   | 1.0590| 0.9337| 60    | 20     | 0.9335 |
| 28   | 29   | 0.8042| 0.7906| 120   | 70     | 0.9253 |
| 29   | 30   | 0.5075| 0.2585| 200   | 600    | 0.9218 |
| 30   | 31   | 0.9744| 0.9630| 150   | 70     | 0.9176 |
| 31   | 32   | 0.3105| 0.3619| 210   | 100    | 0.9167 |
| 32   | 33   | 0.3410| 0.5302| 60    | 40     | 0.9164 |

Association Index of Battery and Node

5.3. Optimal flow cases tf 69 nodes

To present the analysis process done in GAMS software as the first instance, it will be presented the respective variations will be made in order to establish the best location of the two systems of Distributed Generation and the best location of the storage system. The radial system to
take into account to perform the analysis is a radial system of 69 nodes and 68 lines, See Figure. The YBUS information is in the Table 3.

Figure 18. Radial system 69 nodes

To establish the analysis, the variation of the Distributed Generators will be presented as follows:

Index of Distributed Generators and Nodes

\[ \{(1)\} GD_1.N_{17},GD_2.N_{49} \quad GD_1.N_{88},GD_2.N_{59} \quad GD_1.N_{19},GD_2.N_{51} \quad GD_1.N_{20},GD_2.N_{52} \quad GD_1.N_{21},GD_2.N_{53} \quad GD_1.N_{22},GD_2.N_{54} \]

To complement the analysis, the Association of the Battery and Nodes will be presented as follows:

Association Index of Battery and Node

\[ \{(1)\} B_1.N_{68} \]

6. Results

6.1. Analysis Result GAMS tf10 nodes

Taking into account the variations with the Distributed Generator G1, the Distributed Generator G2, and the storage system connected to the node N10. The following objective function is obtained. See Table 4.

In the first test configuration it can be seen that the objective function \( z \) reaches up to 4.04893, in the second configuration it can be seen that the value increases to 4.28028, in the third configuration it shows a significant decrease with respect to the previous two with a value of \( z \) equal 3.62215, in the fourth configuration it is observed that the value decreases and the objective function \( z \) shows a value of 3.5376, in the fifth configuration when the GD 1 is connected to node 8 the function decreases further showing a \( z \) equal to 3.46973. Taking into account this progress it was to be expected that when testing with the GD1 configuration connected to node
### Table 3. Radial system 69 nodes

| Node i | Node j | R [Ω] | X [Ω] | P [kW] | Q [kVAR] |
|--------|--------|-------|-------|--------|----------|
| 1      | 2      | 0.0005 | 0.0012 | 0      | 0        |
| 2      | 3      | 0.0005 | 0.0012 | 0      | 0        |
| 3      | 4      | 0.0015 | 0.0036 | 0      | 0        |
| 4      | 5      | 0.0251 | 0.0294 | 0      | 0        |
| 5      | 6      | 0.366  | 0.1864 | 0      | 0        |
| 6      | 7      | 0.3811 | 0.1941 | 0.0251 | 0.0294   |
| 7      | 8      | 0.0922 | 0.047  | 0      | 0        |
| 8      | 9      | 0.0493 | 0.0325 | 0.0251 | 0.0294   |
| 9      | 10     | 0.8190 | 0.2707 | 0.0640 | 0.1565   |
| 10     | 11     | 0.2999 | 0.0912 | 0      | 0        |
| 11     | 12     | 0.2300 | 0.0704 | 0      | 0        |
| 12     | 13     | 0.2900 | 0.0874 | 0      | 0        |
| 13     | 14     | 0.2600 | 0.0784 | 0      | 0        |
| 14     | 15     | 0.1840 | 0.0305 | 0      | 0        |
| 15     | 16     | 0.0176 | 0.0035 | 0      | 0        |
| 16     | 17     | 0.0166 | 0.0034 | 0      | 0        |
| 17     | 18     | 0.0166 | 0.0034 | 0      | 0        |
| 18     | 19     | 0.0166 | 0.0034 | 0      | 0        |
| 19     | 20     | 0.0166 | 0.0034 | 0      | 0        |
| 20     | 21     | 0.0166 | 0.0034 | 0      | 0        |
| 21     | 22     | 0.0166 | 0.0034 | 0      | 0        |
| 22     | 23     | 0.0166 | 0.0034 | 0      | 0        |
| 23     | 24     | 0.0166 | 0.0034 | 0      | 0        |
| 24     | 25     | 0.0166 | 0.0034 | 0      | 0        |
| 25     | 26     | 0.0166 | 0.0034 | 0      | 0        |
| 26     | 27     | 0.0166 | 0.0034 | 0      | 0        |
| 27     | 28     | 0.0166 | 0.0034 | 0      | 0        |
| 28     | 29     | 0.0166 | 0.0034 | 0      | 0        |
| 29     | 30     | 0.0166 | 0.0034 | 0      | 0        |
| 30     | 31     | 0.0166 | 0.0034 | 0      | 0        |
| 31     | 32     | 0.0166 | 0.0034 | 0      | 0        |
| 32     | 33     | 0.0166 | 0.0034 | 0      | 0        |
| 33     | 34     | 0.0166 | 0.0034 | 0      | 0        |
| 34     | 35     | 0.0166 | 0.0034 | 0      | 0        |

9. GD2 connected to node 10 and Battery connected to node 10; but the response of the system shows a high z of 3.68020. A similar behavior is observed in the following combination when GD1 is connected to node 10, GD2 to node 10 and Battery to node 10. In this case z showed a value of 4.10496. With which it can be concluded that in this radial system of 10 nodes to move away from the main conventional generation can be observed better efficiencies of the system but only to a certain extent.

Taking into account the best performance of the system tf10 nodes locating the distributed generators in nodes 8, 10 and the storage system in node 10. It is presented in Table 4. The active power losses. It is presented in Table 5. Losses of reactive power. It is presented in Table 6. The state of charge of the SoC battery.

### Table 4. Objective Function Analysis tf10 nodes

| GD | N | GD | N | B | N | z   |
|----|---|----|---|---|---|-----|
| 1  | 5 | 2  | 10| 1 | 10| 4.04893 |
| 2  | 4 | 2  | 10| 1 | 10| 4.28028 |
| 3  | 6 | 2  | 10| 1 | 10| 3.62215 |
| 4  | 7 | 2  | 10| 1 | 10| 3.51376 |
| 5  | 8 | 2  | 10| 1 | 10| 4.10496 |
| 6  | 9 | 2  | 10| 1 | 10| 3.46973 |
| 7  | 10| 2  | 10| 1 | 10| 3.68020 |

6.2. Analysis Result GAMS tf33 nodes

Taking into account the variations with the Distributed Generator G1, the Distributed Generator G2, and the storage system connected to the different nodes. The following objective function
Table 6. Losses of reactive power \( t_{f10} \) nodes

|       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |
|-------|------|------------------|-------|------|------------------|-------|------|------------------|-------|------|------------------|
| \( T_0 \) | 0.14762 | T1    | 0.12230 | T2    | 0.05977 | T3    | 0.08465 |
| \( T_5 \) | 0.23812 | T6    | 0.25220 | T7    | 0.27562 | T8    | 0.16886 | T9    | 0.15460 |
| \( T_{10} \) | 0.16594 | T11   | 0.10102 | T12   | 0.16263 | T13   | 0.10118 | T14   | 0.09263 |
| \( T_{15} \) | 0.09423 | T16   | 0.09916 | T17   | 0.15701 | T18   | 0.37527 | T19   | 0.45129 |
| \( T_{20} \) | 0.42553 | T21   | 0.45262 | T22   | 0.28967 | T23   | 0.11690 |

Table 7. Battery State of Charge B \( t_{f10} \) nodes

|       | Time | \( SoC_L \) |       | Time | \( SoC_L \) |       | Time | \( SoC_L \) |       | Time | \( SoC_L \) |
|-------|------|------------|-------|------|------------|-------|------|------------|-------|------|------------|
| \( T_0 \) | 0.50000 | T1    | 0.50000 | T2    | 0.50019 | T3    | 0.75018 | T4    | 1.00000 |
| \( T_5 \) | 0.88994 | T6    | 0.71795 | T7    | 0.50000 | T8    | 0.53422 | T9    | 0.65098 |
| \( T_{10} \) | 0.66286 | T11   | 0.86475 | T12   | 0.87232 | T13   | 0.96436 | T14   | 1.00000 |
| \( T_{15} \) | 1.00000 | T16   | 1.00000 | T17   | 1.00000 | T18   | 0.99734 | T19   | 0.77221 |
| \( T_{20} \) | 0.63287 | T21   | 0.50000 | T22   | 0.50000 | T23   | 0.50000 |

is obtained. See Table 8.

In the first test configuration it can be seen that the objective function \( z \) reaches up to 2.07447, in the second configuration it can be seen that the value decreases to 2.06209, in the third configuration it shows a significant increase with respect to the previous two with a value of \( z \) equal 2.075470, in the fourth configuration it is observed that the value decreases and the objective function \( z \) shows a value of 1.754244, in the fifth configuration when the GD 1 is connected to node 11 the \( z \) function increases a little big again with respect to the previous showing a \( z \) equal to 1.849709. Taking into account this progress it was to be expected that when testing with the GD1 configuration connected to node 12, GD2 connected to node 25 and Battery connected to node 20; but the response of the system shows a high \( z \) of 1.899920. With which it can be concluded that in this radial system of 33 nodes for proven cases the best performance of the system \( t_{f33} \) nodes locating the distributed generators GD1 in nodes 10, GD2 in nodes 23 and the storage system in node 18. It is presented in Table 9. The active power losses. It is presented in Table 10. Losses of reactive power. It is presented in Table 11. The state of charge of the SoC battery.

Table 8. Objective Function Analysis \( t_{f33} \) nodes

|       | GD   | N    | GD   | N    | B   | N    | Time | \( z \) |
|-------|------|------|------|------|-----|------|------|-------|
| \( 1 \) | 7    | 2    | 20   | 1    | 15  | 2.07447 |
| \( 1 \) | 8    | 2    | 21   | 1    | 16  | 2.06209 |
| \( 1 \) | 9    | 2    | 22   | 1    | 17  | 2.07547 |
| \( 1 \) | 10   | 2    | 23   | 1    | 18  | 1.754244 |
| \( 1 \) | 11   | 2    | 24   | 1    | 19  | 1.849709 |
| \( 1 \) | 12   | 2    | 25   | 1    | 20  | 1.899920 |

Table 9. Losses of active power \( t_{f33} \) nodes

|       | Time | \( P_{loss_L} \) |       | Time | \( P_{loss_L} \) |       | Time | \( P_{loss_L} \) |       | Time | \( P_{loss_L} \) |
|-------|------|------------------|-------|------|------------------|-------|------|------------------|-------|------|------------------|
| \( T_0 \) | 0.12550 | T1    | 0.17115 | T2    | 0.62783 | T3    | 0.03065 | T4    | 0.04174 |
| \( T_5 \) | 0.08653 | T6    | 0.08921 | T7    | 0.08938 | T8    | 0.07119 | T9    | 0.06984 |
| \( T_{10} \) | 0.07370 | T11   | 0.05055 | T12   | 0.06965 | T13   | 0.05095 | T14   | 0.04743 |
| \( T_{15} \) | 0.04619 | T16   | 0.04629 | T17   | 0.05647 | T18   | 0.09444 | T19   | 0.10916 |
| \( T_{20} \) | 0.09489 | T21   | 0.10369 | T22   | 0.07113 | T23   | 0.04072 |

Table 10. Losses of reactive power \( t_{f33} \) nodes

|       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |       | Time | \( Q_{loss_L} \) |
|-------|------|------------------|-------|------|------------------|-------|------|------------------|-------|------|------------------|
| \( T_0 \) | 0.12550 | T1    | 0.17115 | T2    | 0.62783 | T3    | 0.03065 | T4    | 0.04174 |
| \( T_5 \) | 0.08653 | T6    | 0.08921 | T7    | 0.08938 | T8    | 0.07119 | T9    | 0.06984 |
| \( T_{10} \) | 0.07370 | T11   | 0.05055 | T12   | 0.06965 | T13   | 0.05095 | T14   | 0.04743 |
| \( T_{15} \) | 0.04619 | T16   | 0.04629 | T17   | 0.05647 | T18   | 0.09444 | T19   | 0.10916 |
| \( T_{20} \) | 0.09489 | T21   | 0.10369 | T22   | 0.07113 | T23   | 0.04072 |
6.3. Analysis Result GAMS tf69 nodes

Taking into account the variations with the Distributed Generator G1, the Distributed Generator G2, and the storage system connected to the different nodes. The following objective function is obtained. See Table 12.

In the first test configuration it can be seen that the objective function $z$ reaches up to 2.85431, in the second configuration it can be seen that the value is 2.85475, in the third configuration it shows a significant decrease with respect to the previous two with a value of $z$ equal 2.450519, in the fourth configuration it is observed that the value increases and the objective function $z$ shows a value of 2.556052, in the fifth configuration when the GD 1 is connected to node 21; the $z$ function decreases a little big again with respect to the previous showing a $z$ equal to 2.333838. Taking into account this progress it was to be expected that when testing with the GD1 configuration connected to node 22, GD2 connected to node 54 and Battery connected to node 68; we can see the response of the system shows a decrease of the objective function $z$ with a value of 2.267984. With which it can be concluded that in this radial system of 69 nodes for proven cases the best performance of the system tf69 nodes locating the distributed generators GD1 in nodes 22, GD2 in nodes 54 and the storage system in node 68. It is presented in Table 13. The active power losses. It is presented in Table 14. Losses of reactive power. It is presented in Table 15. The state of charge of the SoC battery.

### Table 12. Objective Function Analysis tf69

| GD N | GD N | B N | $z$  |
|------|------|-----|-----|
| 1    | 18   | 2   | 2.85431 |
| 1    | 19   | 2   | 2.450519 |
| 1    | 20   | 2   | 2.556052 |
| 1    | 21   | 2   | 2.333838 |
| 1    | 22   | 2   | 2.267984 |

### Table 13. Losses of active power tf69 nodes

| $z$ Time | Ploss.L |
|----------|---------|
| T0 0.15887 | T1 0.16672 |
| T5 0.09750 | T6 0.10609 |
| T10 0.10617 | T11 0.07101 |
| T15 0.06425 | T16 0.06640 |
| T20 0.13609 | T21 0.13084 |

### Table 14. Losses of reactive power tf69 nodes

| $z$ Time | Qloss.L |
|----------|---------|
| T0 0.05888 | T1 0.05797 |
| T5 0.04230 | T6 0.04666 |
| T10 0.04626 | T11 0.03097 |
| T15 0.02804 | T16 0.02811 |
| T20 0.05555 | T21 0.05699 |

7. Conclusions

Taking into account the best performance of the system tf10 nodes locating the distributed generators in nodes 8, 10 and the storage system in node 10. It is presented in Table 5. The
active power losses. It is presented in Table 6. Losses of reactive power. It is presented in Table 7. The state of charge of the SoC battery.

Taking into account this progress it was to be expected that when testing with the GD1 configuration connected to node 12, GD2 connected to node 25 and Battery connected to node 20; but the response of the system shows a high $z$ of 1.899920. With which it can be concluded that in this radial system of 33 nodes for proven cases the best performance of the system $T_{33}$ nodes locating the distributed generators GD1 in nodes 10, GD2 in nodes 23 and the storage system in node 18. It is presented in Table 9. The active power losses. It is presented in Table 10. Losses of reactive power. It is presented in Table 11. The state of charge of the SoC battery.

With which it can be concluded that in this radial system of 69 nodes for proven cases the best performance of the system $T_{69}$ nodes locating the distributed generators GD1 in nodes 22, GD2 in nodes 54 and the storage system in node 68. It is presented in Table 13. The active power losses. It is presented in Table 14. Losses of reactive power. It is presented in Table 15. The state of charge of the SoC battery.

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Table 15. Losses of reactive power $T_{33}$ nodes

| Time | Soc. L T | Time | Soc. L T | Time | Soc. L T | Time | Soc. L T | Time | Soc. L T |
|------|----------|------|----------|------|----------|------|----------|------|----------|
| T0   | 0.50000  | T1   | 0.50000  | T2   | 0.54192  | T3   | 0.57662  | T4   | 0.5968   |
| T5   | 0.50178  | T6   | 0.50000  | T7   | 0.52197  | T8   | 0.56459  | T9   | 0.60968  |
| T10  | 0.65013  | T11  | 0.71261  | T12  | 0.76409  | T13  | 0.82095  | T14  | 0.89282  |
| T15  | 0.94609  | T16  | 0.95003  | T17  | 1.00000  | T18  | 0.93850  | T19  | 0.84706  |
| T20  | 0.79615  | T21  | 0.50424  | T22  | 0.50000  | T23  | 0.50000  |
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