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Comparative Study of Methods for Estimating Technical Losses in Distribution Systems with Distributed Generation

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Abstract: In this work four methods for estimating annual technical power losses in distribution networks due to the distributed generation (DG) connection are studied. The methods are obtained of professional sources, and are evaluated in a test system. A new method is proposed in this work to be contrasted to previous methods. To find the best method, the power losses of a base case are estimated with simulations every 15 minutes, considering variability of load demand and power generation. Results indicate the effectiveness of the proposed method respect of other analyzed methods. The proposed method can be a useful tool within a Decision Support System for optimizing control, operation and planning of the distribution network.
Keywords: Distribution Network, Distributed Generation, Active Power Losses.

1 Introduction

Nowadays there is a growing concern in using, in the most efficient possible way, the different types of energy available on our country. From this point of view, proposals which foster efficient use of this energy will significantly contribute to solve the possible future problems related to its supply. This can be seen in the continue development and construction of new and more efficient electrical equipment both from the energy consumption point of view as for the benefits they are able to render to an electrical network.

This concern is also shared with the areas involved in the generation, transmission and distribution process where the studies and analysis from the perspective of planning and operation of the network are basic from a technical/economical point of view for an optimum functioning. In this way, electrical distribution systems are of primary importance for the development of research efforts on finding methods and techniques aiming to optimize their design and operation. This is due to the fact that this is the level were a great quantity of customers concentrates entailing the use of lower voltage levels generating greater current flows and finally a less efficient use of energy (increase of energy losses).

1.1 Distributed Generation

Today there exist a global tendency to allow electric energy injection from clients, electrical industries or from third parties on distribution networks which is called Distributed Generation (DG) [1].

These presents two advantages. Firstly, allows an efficient energy use by way of using energy surplus from industries connected to the network fostering also non-conventional energy generation. Secondly, energy injection close to the load allows an improvement on customers quality service due to an efficient energy transport. The above facts are also supported worldwide [2], by facilitating some regulatory aspects associated to the integration of DG to electric networks. In Chile, this can be seen on modifications that laws NÂş 19.940 y 20.018 introduce to D.F.L. 1/82 [3] [4], pointing out incentives and procedures for energy injections on electrical networks. Traditionally, utilities design their networks to receive energy from the transmission system and then deliver it to consumers in the distribution system [8]. For this reason, many radial distribution feeders have a conical configuration, i.e., lines start with larger gauge conductors which are reduced along the feeder. This type of configuration can have drawbacks for DG projects. However, a DG can be favorable to the distribution company, reducing losses in the conductors and energy demand of the substation; therefore, this must be assessed by feasibility studies.

1.2 Losses Estimation

The main difficulty in power loss evaluation is the nonlinear relationship with power injections in the network buses. For this reason, the use of tools such as load flow is required for proper evaluation. This implies necessarily having a lot of information about lines, transformers and equipment, which can be hard to obtain. Furthermore, load variations are a very important factor to evaluate these losses. However, in practice, this variability is not properly registered due primarily to economic factors. This results in application of factors, approximate curves and simplifications, which surely entail a relatively large degree of uncertainty.

Knowing or estimating system losses in real time or in a time window can help operators make better decisions regarding the dispatch of other generation units in real time energy markets [10], or as a way to effectively assess the benefits of DG in distribution networks [11]. For example, the proposed power losses estimation technique can be used as an online, real-time diagnostic device that helps a better and more efficient control of distribution power networks.

1.3 Decision Support System (DSS)

Today technical and social systems are becoming increasingly complex. Their models have a large number of state and control variables, delays and different time constants. Also they show limitations in their information infrastructure and risk sensitivity aspects. Such systems are called large-scale complex systems. Hierarchical approach has been for decades one of the most used methods for controlling these large-scale systems. When human intervention is necessary, Decision Support Systems (DSS) can provide a solution. A DSS is an adaptive and evolving information system intended to implement some of the functions of a human support team that otherwise would be required to assist the decision-maker to overcome the limits and constraints when approaching decision problems [12] [13].

This work allows the development of a useful tool that can be included to a DSS for power distribution networks, as it will provide fast information for decision making. This way, the method will allow optimizing the power distribution system control and operation, especially in presence of DG.

This paper addresses the problem of technical power losses estimation in radial distribution network when incorporating DG, to estimate energy and power losses in an effective manner, considering all the technical limitations inherent to the lack of data on real systems for developing a quick, precise and reliable tool that can be included to a DSS.

2 Description of methods and loss calculation proposal

This section describes three models used by consulting firms mainly. These methods will be analyzed and compared with a new proposal, explained in the final part of this section.

2.1 Viera-Bonessi Method

Viera-Bonessi method is used for distribution network planning [5]. It is developed for three types of primary sources: wind, biomass and hydropower. In this work, only wind type method is considered.

With the latest available annual active power demand curve, a power duration curve is built. From this curve three scenarios are calculated: maximum (peak) demand, average demand and minimum demand to be used for each simulation. The scenarios are shown in Figure 1. From these scenarios, the time duration of each stage is obtained. In this example, $T1 = 1460$ hours for peak demand, $T2 = 4745$ hours for average demand and $T3 = 2555$ hours for minimum demand.

Then, each demand scenario P_i is defined. These are calculated by (1), where Ai is the area under the power duration curve and T_i is the duration of stage i demand in hours.

Factors to be applied to the peak power load in all nodes are then calculated. This way, the loads to be used for power flows for each demand scenario are obtained. These factors are calculated by (2), where P_i is the demand under the i^{th} scenario and $\widehat{P}$ is the maximum load associated with the zone of influence of the generator. After obtaining the demands and the factors for each scenario, the whole network to be affected by the DG is modeled. Maximum loads must be corrected by the obtained factor f_i, thereby determining loads for different types of scenarios.

$$P_i = \frac{A_i}{T_i} \tag{1}$$

$$f_i = \frac{P_i}{\widehat{P}} \tag{2}$$

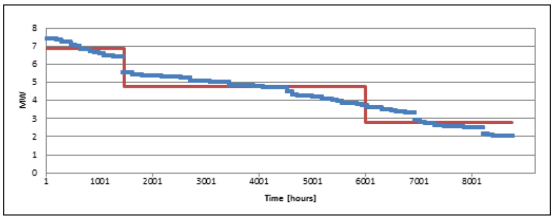

Figure 1: Power duration curve and demand scenarios

Losses without Distributed Generator

Having conducted the above, a power flow is performed and the network losses are calculated for each demand scenario. Then, to get the annual energy losses (3) is used. EPSG are annual energy losses without the generator, in MWh and P_{PSGi} are power losses in the system obtained with the power flow for each demand scenario, without the DG. T_{DI} is the duration of the demand scenario i, in hours.

$$E_{PSG} = \sum_{i=1}^{3} P_{PSGi} \cdot T_{Di} \tag{3}$$

$$E_{PCG} = f_p \sum_{i=1} {}^{3} P_{PCGi} \cdot T_i + (1 - f_c) \cdot E_{PSG} \tag{4}$$

Losses with Distributed Generator

To calculate the annual energy loss with wind based generators (4) is used. The f_p is the annual loss factor, P_{PCGi} are losses in the system connected with the DG at full load obtained from simulations, E_{PSG} is the annual energy loss in MWh without the DG, E_{PCG} is the annual energy loss of the generator in MWh and f_c is the factor of the generator plant. The annual loss factor f_p is calculated with (5), where f_c is the capacity factor, x is a variable whose value depends on the shape of the generating curve, with a typical value of 0.3 [5]. This method does not indicate how to forecast demand feeder for analysis in future years.

$$f_p = x \cdot f_c + (1 - x) \cdot f_c^2 \tag{5}$$

2.2 3G-3D Method

In this method, the maximum, medium and minimum demand scenarios, P_i, f_i values and losses without DG are calculated in the same way as Viera-Bonessi method. This method was developed and is used by a consulting engineering firm in Chile, for hydraulic projects evaluation mainly. The principal difference to the Viera-Bonessi method, is the way of estimating the generation stages, as indicated below.

Energy Losses with Distributed Generator

At this stage, the method proposes performing the analysis with 3 generation scenarios. For this, the maximum, medium and minimum generation scenarios are obtained: Maximum generation (TG1): 1825 hours/year, mean (TG2): 4380 hours/year and minimum (TG3): 2555 hours/year. The following defines the power generation P_{GJ}, corresponding to each generation stage. These are is calculated by (6), where A_{Gj} is the area under the curve generation duration during the active power generation stage j, for T_{GJ} time, which is the duration of the stage of generation j, in hours. A_{Gj} is obtained from the annual expected generation curve of available active power, in hourly basis. The sum of the first 1825 values is AG1, the sum of next 4380 values is AG2 and the sum of the other 2555 values is AG3. This yields the 3 stages of generation for the simulations.

$$P_{Gj} = \frac{A_{Gj}}{T_{Gj}} \tag{6}$$

$$E_{PCG} = \frac{1}{9760} \cdot \sum_{\substack{i=1:3 \\ j=1:3}} P_{CGD} \cdot T_{Di} \cdot T_{Gj} \tag{7}$$

Generation scenarios are shown in Figure 2, where the blue curve is the expected annual generation duration curve of the generation group and in red the generation scenarios indicated by the method. With each generation stage, a power flow is performed for the three demand scenarios (high, medium and low). This way, power losses are obtained for the 9 cases. Then, with the times of occurrence of each scenario, the energy losses of the feeder are obtained using (7), where P_{PCGij} are the system losses with i^{th}-demand scenario and the jth-generator stage, in MW. T_{Di} is the duration of the demand scenario i, in hours, T_{Gj} are the duration of the generation stage j in hours. E_{PCG} is the annual energy loss with the generator, in MWh.

Regarding to feeder demand forecasting, this method proposes to use the country's GDP as growth rate.

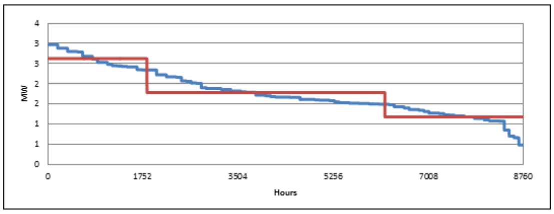

Figure 2: Generation Duration Curve and Generation Scenarios

2.3 Monthly Blocks Method

This method take into account relevant aspects of the above two methods. With the active and reactive power hourly demand curve at the feeder head, a monthly demand curve is created, which is sorted in decreasing active power, maintaining the respective reactive power. With each monthly demand curve, two blocks, B1 and B2 Block are calculated. B1: High power block and B2: Low power block. This totalizes 24 blocks; these blocks will be defined in the same way as does the Chilean National Energy Commission [6]. Table 1 shows the distribution of records (hours) per month of each block used for example.

To calculate demand for each block P_B and Q_B, the procedure is: for January block B1, active power is defined by the average of the first 240 records of the data, assorted from highest to lowest value for the month; i.e., P_B of B1 is determined by the average of the 240 highest active power records in January. The reactive power of B1 (Q_B), is determined by the arithmetic mean of reactive power of the same 240 records considered in the PB calculation of B1 block.

For the January block B2, the procedure is the same, but taking the remaining records of that month (504 records). B1 and B2 blocks for other months are determined in the same way, but considering the distribution of Table 1.

Table 1: Monthly blocks header demands

Month	B1 (Records)	B2 (Records)	NÂ° Records
January	240	504	744
February	86	586	672
Mars	69	675	744
April	288	432	720
May	298	446	744
June	312	408	720
July	340	404	744
August	296	448	744
September	258	462	720
October	42	702	744
November	44	676	720
December	46	698	744
		Total	8760

The demands of each block should be apportioned in proportion to the capacity of distribution transformers (DT) plus lines losses; that is, when making the load flow, power demand in the header must match the demand of the block, considering a degree of tolerance. This assessment can be made proportionally distributing the capacity of transformers. Similarly, the reactive power is calculated.

With the demand for DT obtained through apportionments described above, the functions

"$P_{Total\ TDs}$ Estimate" and "Estimating $Q_{Total\ TDs}$" are defined. These functions relate block demand (demand in the header) with the demand of the DT (8). The coefficients A, B, C, D, E, F, G, H, I and J are constants that can be estimated by a regression.

$$\begin{bmatrix} P_{TotalDTS} \\ Q_{TotalDTS} \end{bmatrix} = \begin{bmatrix} A & B \\ F & G \end{bmatrix} \cdot \begin{bmatrix} P_B \\ Q_B \end{bmatrix} \cdot \begin{bmatrix} C & D \\ H & I \end{bmatrix} \cdot \begin{bmatrix} P_B^2 \\ Q_B^2 \end{bmatrix} + \begin{bmatrix} E \\ J \end{bmatrix} \tag{8}$$

Functions "$P_{Total\ TDs}$ Estimate" and "$Q_{Total\ TDs}$ Estimate" are evaluated with data from more recent feeder hourly demand, which gives the DT demand curve; this curve is called "TD demand curve".

Losses without Distributed Generator

The $P_{Total\ TDS}$ and $Q_{Total\ TDS}$ previously calculated for each block (blocks calculated with the demand curve latest feeder, which demand curve will name as year 0) are projected to the year 1, year 3 and year 5, thereby get DTs demand for each block of the mentioned years. The method intends to make the projection considering a growth rate provided by the distributing company or any reliable study.

Power flows are performed for each block (72 blocks, 24 per year) and losses are recorded. The feeder characteristic loss function without DG, (9), where PL is the losses obtained in the simulations, the coefficients K, L, M, N and O are constant and can be determined analogously to the procedure performed to determine the coefficients in (8).

$$P_L = \begin{bmatrix} K & L \end{bmatrix} \cdot \begin{bmatrix} P_{TotalDTS} \\ Q_{TotalDTS} \end{bmatrix} + \begin{bmatrix} M & N \end{bmatrix} \cdot \begin{bmatrix} P_B^2 \\ Q_B^2 \end{bmatrix} + O \tag{9}$$

The demand curve DTs projected year 0 to year 1 and the feeder characteristic loss function is calculated, this way hourly losses feeder in year 1 are obtained; these are multiplied by an hour (demand time duration) and then energy losses in an hour are obtained. Then adding up all the energy losses of the year, the total energy losses of the year 1 are obtained. The DT demand curve is projected to years 3 and 5, and the procedure is repeated to determine the energy losses of 3 and 5 years. With total energy losses for years 1, 3 and 5, a quadratic trend curve is adjusted, which allows the estimation of total energy losses for the intermediate years.

Losses with Distributed Generator

This model proposes to conduct analyzes with a single generation scenario. The generator is modeled with the power available, whereas it has this power available (or not) throughout the year. To get the power output of the generator, it is necessary to know its rated power and capacity factor. This is obtained according to the available power (10), where P_{nom} is the rated output power and P_{disp} is the available generator power.

$$P_{disp} = P_{nom} \cdot f_c \tag{10}$$

With the 72 DT demand blocks previously calculated, power flows are executed for each block, considering the available power injection of the generator. Then, generator losses estimation is analogous to the case without generator.

2.4 Proposed Method

The proposed approach arises from the combination of 3G-3D and monthly blocks method. From the latest active and reactive power hourly demand curve of the feeder header, a demand duration curve based on the active power is built. From this curve, maximum, medium and minimum demand scenarios to be used for each simulation are calculated. TDi time duration of each stage are the same as regards the Viera-Bonessi method.

Then, each demand scenario P_i and Q_i are defined. The calculation of P_i and Q_i is done with (11), where A_i is the area under the curve of the active power demand duration during the demand scenario i, for the time T_{Di}; B_i is the area under the reactive power demand curve during stage i, for the time T_{Di}, T_{Di} is the duration of stage i demand in hours. To calculate A_i the curve using active power duration (Figure 1) is used.

$$\begin{bmatrix} P_i \\ Q_i \end{bmatrix} = \frac{1}{T_{Di}} \begin{bmatrix} A_i \\ B_i \end{bmatrix} \tag{11}$$

Losses without Distributed Generator

With the demand values of each scenario, the apportionment proposed in monthly blocks method is done. Then, the energy losses without generator are calculated using (3).

Losses with Distributed Generator

The same generation scenarios of 3G-3D method are used, which is calculated from the expected generation curve: Generation maximum T_{G1}: 1,825 hours/year, mean T_{G2}: 4,380 hours/year minimum T_{G3}: 2,555 hours/year. Then, the calculation of the P_{GJ} values is the same as in 3G-3D method (see 2.2.1). To demand forecast of the feeder, a growth rate provided by the utility or by any reliable study can be used; which will be applied to the DT demands.

3 Estimation of real losses

To know which method obtains the best results, the simulation of a system with different kinds of loads and known daily power variations, as well as the behavior of the DG. This will get different levels of demand and losses for different hours. This system is called the "Base Case" and will be the benchmark to compare the methods.

3.1 Distributed Generator

This study uses a wind park with a nominal power of 2 MW [7]. The daily generation curve of the park, for the winter, summer and fall are shown in Figure 3, discretized every 15 minutes. The analysis considers that spring and autumn curves are the same. According to the same study, the capacity factor of the park is 0.445 and considers that each turbine has a capacitor bank that allows only active power injected to the grid. The DG wind park is simulated as a PQ bar where only the active power injected into the network.

3.2 Test Network

The analysis is done on a test system consisting of 17 bars and 16 lines, with loads connected in all buses. Figure 4 shows the network topology.

Grid parameters can be found in [8]. These values are in per unit, with base values of 23 [kV] and 100 [MVA]. The total active power is 13.88 MW and reactive power is 5.96 MVAr.

Selection of connection points of the DG for evaluating the methods was made considering the power injection at nodes located at the end of feeder, i.e. the node 11 and 17, where a greater impact on loss is expected. Also two other feeder midpoints were considered in nodes 6 and 12.

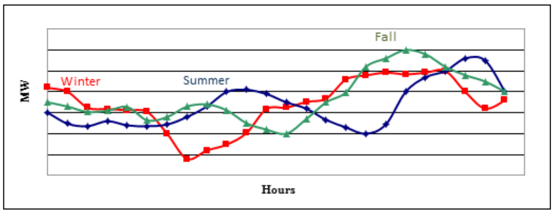

Figure 3: Supply of power to the grid by the wind farm

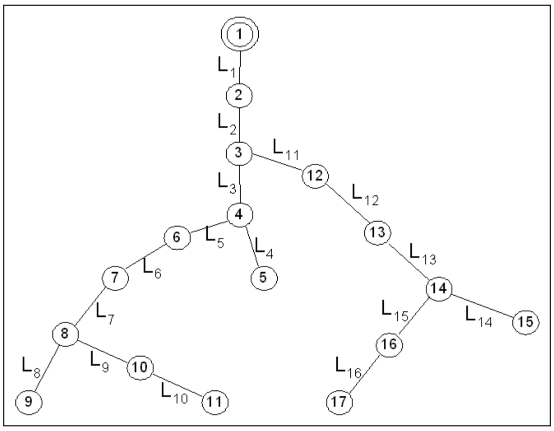

Figure 4: Test System

3.3 Base Case Details

The base case is intended to represent the behavior of a real system. For this reason, hourly variations are considered for the various loads connected to the network distributed along the feeder and with different power levels.

Hourly behavior curves of the considered loads are shown in Figures 5 and 6 [8]. Besides differentiate types of loads, the seasonal variability of demand is taken into account. Demand curves for seasons were obtained from [9] and are shown in Figure 7. Autumn and spring demands are considered equal. The duration of each station are 94 days Summer, Fall 93, Winter 89 and Spring 89. The data from these load curves are discretized every 15 minutes.

4 Results and Comparison of Methods

To apply the methods presented in the test system, the hourly demand curve at the top of the feeder in year cero, without DG, obtained from the base case analysis is used. Each method is evaluated considering a five years horizon, where the DG is connected in year 1. Losses estimated by each method will be compared to the base case. The rate of growth in demand to be used is 4.5% per year, the same as used in the base case.

From the hourly demand curve at the head of the feeder in year 0 without GD, maximum demand is 7.156 MW; minimum demand is 1,966 MW. Power factor varies between 0.90 and 0.92, whereby, in evaluating the methods, this range is considered.

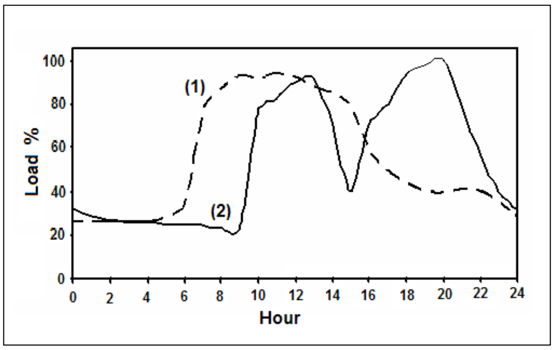

Figure 5: Commercial (1) and industrial (2) type load curve

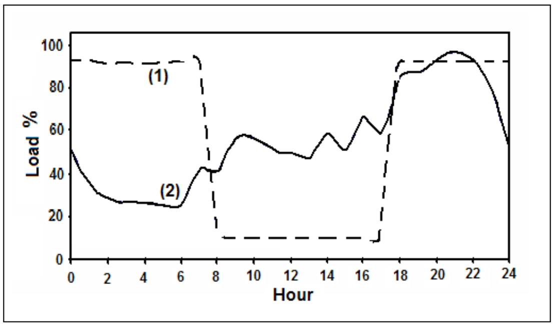

Figure 6: Commercial (1) and industrial (2) type load curve

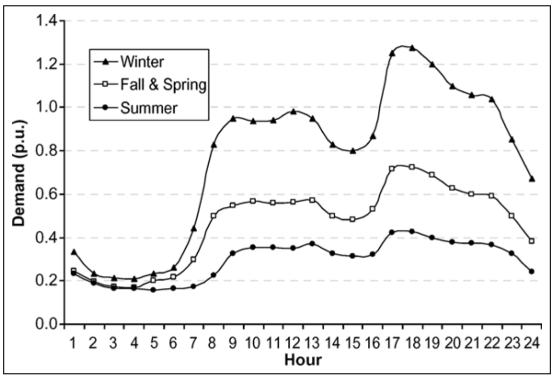

Figure 7: Commercial (1) and industrial (2) type load curve

4.1 Viera-Bonessi Method

The generator power injection is 4 MW, the capacity factor, annual loss factor and the variable x values are: fc = 0.445, fp = 0.272 and x = 0.3 respectively. Demand scenarios are shown in Table 2. According to the results in Table 3, the method has low error in estimating losses without DG. However, the result shown in tables 4 and 5 shows an abnormal operation of Viera-Bonessi method, in the estimation of losses with DG and savings in energy losses.

4.2 3G-3D method

Demand scenarios are the same as in Viera-Bonessi method (Table 2). The power losses estimation without GD is also equal, thus the results are the same (Table 3). This method proposes to perform the analysis with three stages of generation these are shown in Table 6.

Nine power flows resulting from considering each generation scenario with three demand scenarios are carried out. Results are shown in Table 7. These results show that the method estimated correctly the losses with DG. The energy savings achieved by the method over 5 years in the analysis and comparison with the calculated base case are shown in Table 8.

Table 2: Demand scenarios. Viera-Bonessi method

Demand	A_i	T_i [h]	P_i [MW]	f_i
Maximal	10065	1460	6,894	0,497
Average	22542	4745	4,75	0,342
Minimal	7081	2555	2,77	0,199

Table 3: Comparison of total losses without DG. Viera-Bonessi method

Losses M1 [GWh]	Losses CB [GWh]	% Error
3,99	3,77	5,77

Table 4: Losses with DG comparison. Viera-Bonessi method

Bus	Losses [GWh]	Base case losses [GWh]	% Error
6	2,74	2,2	24,54
11	3,61	2,4	50,18
12	2,94	2,81	4,77
17	3,26	3	8,51

4.3 Monthly Blocks Method

The active and reactive power hourly demand curve at the head of the feeder in year 0 without DG is brought to a demand curve for each month, which are sorted in descending order of active power demand. This result in demand blocks B1 and B2 of each month taking into account the distribution records of Table 1. Table 9 shows the demand blocks.

Then the apportionment of the extraction points is carried so that the feeder head power is equal to the sum of DT demands plus lines losses. With this apportionment, DT demand for

Table 5: Savings in energy losses. Viera-Bonessi method

Bus	Savings [GWh]	Base case savings [GWh]	% Error
6	1,25	1,57	-20,58
11	0,38	1,37	-71,97
12	1,05	0,97	8,65
17	0,73	0,77	-4,92

Table 6: Generation scenarios. 3G-3D method

Generation	A_i	T_i	P_i
Maximal	4786	1825	2,623
Average	7802	4380	1,781
Minimal	3005	2555	1,176

Table 7: Losses with DG comparison. 3G-3D method

Bus	Losses [GWh]	Base case losses [GWh]	% Error
6	2,37	2,2	7,54
11	2,26	2,4	-5,67
12	2,95	2,81	5,19
17	3,07	3	2,25

Table 8: Savings in energy losses. 3G-3D method

Bus	Savings [GWh]	Base case savings [GWh]	% Error
6	1,62	1,57	3,28
11	1,73	1,37	25,77
12	1,04	0,97	7,44
17	0,92	0,77	19,42

Table 9: Demand blocks, year 0

Month	Blocks	P_B [MW]	Q_B [MVAr]
January	B1/B2	4,12 / 3.00	1,89 / 1.39
February	B1/B2	3,32 / 3,37	1,53 / 1,55
Mars	B1/B2	3,36 / 3,37	1,55 / 1,55
April	B1/B2	3,92 / 4,20	1,80 / 1,92
May	B1/B2	4,17 /4,22	1,91 / 1,93
June	B1/B2	4,20 / 4,20	1,92 / 1,92
July	B1/B2	5,00 / 5,65	2,28 / 2,56
August	B1/B2	5,58 / 5,66	2,53 / 2,57
September	B1/B2	5,61 / 5,64	2,55 / 2,56
October	B1/B2	5,52 / 4,27	2,53 / 1,95
November	B1/B2	4,17 / 4,21	1,92 / 1,93
December	B1/B2	4,21 / 4,20	1,93 / 1,92

each block is obtained, which is necessary to calculate the functions "$P_{TotalTDs}$ Estimate" and "Estimating $Q_{TotalTDs}$" (8) that relate the block demands to the DT demands.

DT Demand curves are projected years 1, 3 and 5, and then evaluated in the "characteristic feeder losses without DG function", so power losses in every hour for the same years are obtained. Table 10 shows the losses without GD and Figure 8 shows the graph of each year losses and the quadratic trend curve used to calculate losses in years 2 and 4.

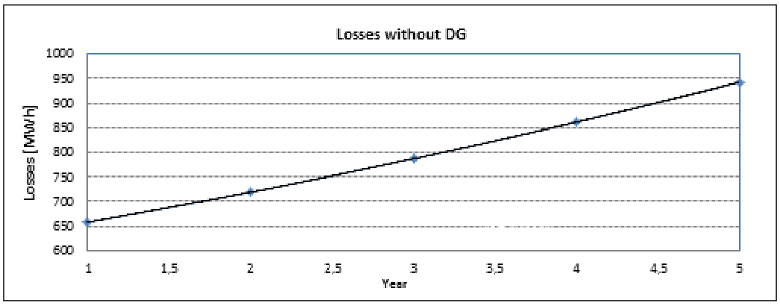

Figure 8: Commercial (1) and industrial (2) type load curve

It is noted that the method estimates with good precision losses in the feeder without DG. For analysis with DG, the method proposes making simulations with the generator injecting its available power, which is calculated by the product of the nominal power factor for the plant, which in this case would $P_{DISP} = 1.78$ MW.

With the blocks 72 previously calculated, power flows are carried with the DG injecting its available power. The procedure is analogous to the case without DG. Losses with and without DG along the 5 years in analysis for each injection point and the comparison with the base case are shown in Tables 11 and 12 respectively. Energy savings achieved over the five years are shown in Table 12.

Table 10: Comparison of total losses without DG. Monthly blocks method

Losses method [GWh]	Base case losses [GWh]	% Error
3,97	3,77	5,18

Table 11: Losses with DG Comparison. Monthly blocks method

Year	Losses method [GWh]	Base case losses [GWh]	% Error
Bus 6	2,33	2,2	5,88
Bus 11	2,15	2,4	-10,55
Bus 12	2,92	2,81	4,09
Bus 17	3,01	3	0,44

4.4 Proposed Method

The active and reactive power hourly demand curves at the head of the feeder in year 0 without DG, are sorted in descending order of active power. Thus demand scenarios are calculated (Table 13). For analysis with DG the same generation scenarios of 3G-3D method are considered (Table 6). The 9 power flows resulting from each stage of generation and the three demand scenarios are then made. The method results for loss estimation without DG are shown

Table 12: Savings in energy losses. Monthly blocks method

Bus	Savings [GWh]	Base case savings [GWh]	% Error
6	1,64	1,57	4,2
11	1,82	1,37	32,7
12	1,05	0,97	8,33
17	0,95	0,77	23,57

in Table 14, which shows that the method is very accurate in the estimation. The results along the 5 years of analysis of the method for estimating losses with DG are shown in Table 15.

The method results in estimating loss savings over 5 years of analysis for each injection point are shown in Table 16.

Table 13: Demand scenarios proposed method

Demand	A_i	B_i	T_i	P_i	Q_i
Maximal	9631	4348	1460	6,597	2,978
Average	21571	9840	4745	4,546	2,074
Minimal	6776	3173	2555	2,652	1,242

Table 14: Comparison of total losses without DG. Proposed method

Losses M1 [GWh]	Losses CB [GWh]	% Error
3,92	3,77	3.98

4.5 Discussion

Regarding Viera-Bonessi method, it considers that the DG always inject its rated power, so the scenarios proposed for power flows are not representative of what actually take place. Moreover, it shows the condition of flow reversal in the substation; but this condition never happens in the base case, so the results are far from the expected values. Therefore it is considered that the Viera-Bonessi method is not reliable, especially when the rated value of the DG is much higher than its usual power injection. Therefore, for comparison Viera-Bonessi method is discarded and we will proceed to an analysis of the results of the three remaining methods, to determine which is the best.

To determine which method is better, errors in estimating losses without DG, losses with DG and feeder energy losses savings due to DG operation are compared. Table 17 shows errors of each method in estimating losses without DG. It is noted that in estimating losses without DG, the proposed method is winner. The errors in estimating losses with DG are shown in Table 18 for each evaluated method. The proposed method has a clear advantage over the rest in the average values (absolute) and their standard deviations also. Table 19 shows the victorious method for each connection point for the DG, considering the estimated savings in losses. It can be seen that the proposed method obtains fewer errors compared to other evaluated methods, so it can be considered the winner.

Table 15: Losses with DG comparison. Proposed method

Bus	Losses [GWh]	Base case losses [GWh]	% Error
6	2,38	2,2	8,2
11	2,29	2,4	-4,45
12	2,94	2,81	4,67
17	3,05	3	1,74

Table 16: Savings in energy losses. Proposed method

Barra	Savings [GWh]	Base case savings [GWh]	% Error
6	1,53	1,57	-2,37
11	1,62	1,37	18,24
12	0,98	0,97	1,27
17	0,86	0,77	11,8

Table 17: Error of Methods in estimation of losses without GD

Method	Error [%]
3G-3D	5,77
Monthly blocks	5,18
Proposed	3,8

Table 18: Porcentual error of methods in estimation of losses with DG

Method	Bus 6	Bus 11	Bus 12	Bus 17	Average/ Deviation
3G-3D	7,54	-5,67	5,19	2,25	5.16 / 4.79
Monthly blocks	5,88	-10,55	4,09	0,44	5.24 / 4.20
Proposed	8,2	-4,45	4,67	1,74	4.76 / 2.64

Table 19: Error of methods in energy losses savings for each DG connection point

Method	Bus 6	Bus 11	Bus 12	Bus 17
3G-3D	3,28	25,77	7,44	19,42
Monthly blocks	4,2	32,7	8,33	23,57
Proposed	-2,37	18,24	1,27	11,8

5 Conclusion

This study addressed the problem of estimating technical losses of a radial feeder when incorporating a DG. For this a test system was chosen in which 4 connection points were tested, to evaluate different methods of loss assessment.

As for the method validation, is can be concluded that the Viera-Bonessi method is unreliable for plants where rated power is far from the power that usually provide. For the other methods, it is demonstrated first that their error varies according to the point of injection; second, an hypothesis arises: the error in saving energy loss increases as the GD injection point is further away from the feeder head; this due to error values obtained when the generator is connected to the feeder center points (specifically on the buses 6 and 12), are lower than when the DG is connected to the endpoints (buses 11 and 17). The analysis determines that the proposed method provides the best results by combining the best aspects of 3G-3D and monthly blocks method, although it involves more computational effort than the previous methods.

The proposed method is a valuable technique that can be easily programmed for its implementation in a Decision Support System that will assist the decision maker for a fast, accurate and reliable control, operation and planning of the distribution network.

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