ANALYSIS OF THE IMPACT OF DISTRIBUTED GENERATION SOURCES ON THE OPERATIONAL CHARACTERISTICS OF THE DISTRIBUTION SYSTEMS FOR PLANNING STUDIES

Alexandre BARIN
UFSM – Brazil
alexandrebarin@hotmail.com

Luis F. POZZATTI
UFSM – Brazil
fila.rs@gmail.com

Cássio G. CARVALHO
UFSM – Brazil
cassio_giuliani@hotmail.com

Luciane N. CANHA
UFSM - Brazil
lncanha@ufsm.ct.br

Ricardo Q. MACHADO
UFSM – Brazil
ricardombr2002@yahoo.it

Alzenira R. ABAIDE
UFSM – Brazil
alzenira@ct.ufsm.br

Carlos FERNANDES
CEEE-D - Brazil
CarlosMF@ceee.com.br

Felix A. FARRET
UFSM - Brazil
faf@ct.ufsm.br

ABSTRACT

Presence of distributed generation (DG) in electric systems can represent a significant impact on the operational characteristics of distribution networks. Therefore, this paper presents a study aiming at an adequate DG sitting for steady-state operation of distribution systems so as to minimize electrical network losses and to keep the acceptable reliability levels and voltage profile. Moreover, this work intends to develop a multi-objective analysis to define some qualitative and quantitative parameters applicable on fuzzy logic, in order to seek the automatic DG allocation. Besides, this study proposes some basis for the adequate DG sitting in distribution system feeders, as well in any node inside a selected feeder. Considerations and results described in this paper are part of the Research & Development Program developed by the Companhia Estadual de Energia Elétrica (CEEE) and the Federal University of Santa Maria (UFSM), Brazil.

INTRODUCTION

Recent advances in technology for energy generation make DG to become more and more widespread. Therefore, general procedure of DG allocation becomes necessary in order to insure positive its effects on distribution systems. The proposed methodology presented in this work is based on a formerly proposed list of viable places for installation. To support the choice of the main candidates, it is used a power flow method developed in DigSilent® to obtain the calculation results of losses and voltage profile [1]. As regards the multi-objective analysis, this study intends to define some criteria for DG allocation, classifying them in quantitative and qualitative ways. As a quantitative way, it may be analyzed the voltage levels violation, wires loading, power losses, number of customers, costs, for example. As a qualitative way, it is possible to include the access means (to DG unit), security, physical space, ancillary services, etc. Thus, the goal of the methodology proposed in this work is to attribute a fuzzy objective function to each criterion, in order to seek the automatic DG sitting. This study may be applied for distribution system feeders, as well for any nodes inside of a selected feeder, so providing the adequate DG sitting.

BASIC CONSIDERANTIONS OF DG UNITS

As regards the advantages of adequate DG sitting [2] it is observed a significant beneficial impact on power loss levels and on improvement of the voltage levels so as to help in “peak load shaving”. The constant technological advances provide new DG supplies as much for some types of DG which integrate storage energy systems, for example flywheels. This system may store energy and produce electricity from the energy stored, providing great improvement on electrical energy utilization. As regards the environment, renewable DGs may eliminate or reduce the output process of gas emission.

On the other hand, it is important to recognize that the power injected by DG units at inappropriate places, or an excess of power generation without voltage regulation through tap changing, may result in increased system losses and undesired voltage levels outside the allowed electricity company limits. As an undesired outcome of that comes increased network costs which may even imply in fines against the energy supplying companies.

DISTRIBUTION SYSTEM MODEL AND INITIAL CONSIDERATIONS

Before explaining the main developed methodologies applied in this work for DG sitting, it has to be described the distribution system models used in this study. The first model used as an example was created to analyze the impact of DG on power losses and voltage levels. This case is represented by a small feeder of a substation with 22 transformers (loads) connected to the grid (13.8kV/380Y/220Δ). Later on, to complete the proposed study, it was developed a DG penetration model for the 13.8kV system, considering several feeders. As shown in Figure 1, a small generator unit was connected at node G, distant 105.4 km from substation (SS) to supply a specific power generation to some customers, representing about 15% of the whole electrical load at the peak hour, considered just in between the 18h and 21h. Moreover, the storage energy systems (SE) were respectively connected at nodes SE1, distant 3.2 km from SS, and SE2 distant 89.3

km from SS, operating just in between the 1h and 5h.

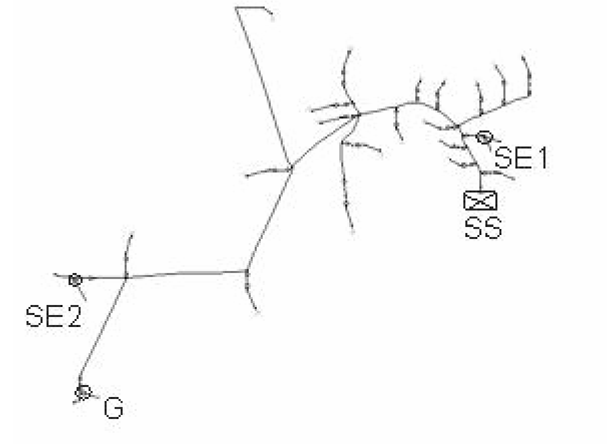


Figure 1. Distribution system model with interconnected DG as simulated by the software DigSilent®.

Below is listed the adequate voltage level ranges (TN) to deliver energy to customers, as established by the Brazilian National Agency of Electric Energy (ANEEL) [3], Resolution number 505, November 26th, 2001.
- Adequate Voltage Levels (V): 201 ≤ TN ≤ 231;
- Precarious Limits (V): 189 ≤ TN <201 or 231 < TN ≤ 233;
- Critical Limits (V): TN < 189 or TN > 233.

By analyzing the system behaviour after the adequate DG sitting, it is observable the positive impact on the operational characteristics on the distribution system, providing loss reduction and voltage levels improvement, as shown in Table 1. During action of the generator supplying 130kVA at node G, it is observed a considerable increase of the voltage profile, emphasizing an elevation of the voltage level at 21h. At this instant, the voltage level reaches 228.5V, closer to the maximum level allowed by the electricity company (231V). Therefore, it is necessary to perceive that although the highest demand (in kW) happened at the 19h, it is always necessary to verify the whole period when DG will operates, avoiding in this way that the voltage profile exceeds the maximum allowed by electricity company limits.

Table I. Voltage levels at node G and overall power losses in the whole grid, in normal regime (without DG) and with DG supplying 130kVA.

	Power Losses-whole grid			Voltage Levels-node G		
Time	Without DG	With DG	With DG	Without DG	With DG	With DG
h	P(kW)	P(KW)	ΔP(%)	V(V)	V(V)	ΔV(%)
18	38.2	18.8	- 50.7	189.9	226.2	+ 13.7
19	53.3	28.0	- 47.5	193.4	222.1	+ 14.8
20	38.5	18.2	- 52.6	197.8	225.5	+ 14.1
21	27.8	12.1	- 56.6	202.2	228.5	+ 13.2

As regards the 260kVA SE operation at nodes SE1 and SE2, just in between the 1h and 5h, it is verified a significant voltage level reductions and power loss increment. An important fact is verified in Table II, during operation of the 260kVA SE at node SE1, where the voltage level reduction remains at about 5.5%, keeping the voltage profile within the ANEEL adequate levels for delivering to customers. As regards the same SE at node SE2, the voltage levels reduction reaches 21.7% (174.3V) causing a voltage profile outside the allowed electricity company limits. This example demonstrates the importance of the correct SE sitting analysis, where the same unit power may cause either a positive or negative effect on the feeder. Regarding power losses during SEs operation, it will depend on distance between SE and SS. This fact is justified by the alterations in power losses happening in all lines just before the node where the storage energy system was operating. Therefore, during the SE operation of node SE1, just a small line was affected (3.2km), whilst in the second case, at node SE2, almost the whole feeder was affected, providing a consequent increase in system power losses.

Table II - Voltage levels in normal regime and with storage energy systems connected to nodes SE1 and SE2.

Voltage levels without and with operational storage energy systems						
	Node SE1 with 260KVA			Node SE2 with 260KVA		
Time	Without DG	With DG	With DG	Without DG	With DG	With DG
(h)	V(V)	V(V)	ΔV(%)	V(V)	V(V)	ΔV(%)
1	227.4	214.9	- 5.5	222.6	174.3	- 21.7
2	227.9	215.1	- 5.6	224.8	176.6	- 21.4
3	228.3	215.3	- 5.7	226.1	178.7	-20.9
4	228.3	215.4	- 5.8	227.3	180.2	-20.7
5	228.4	215.4	- 5.7	226.4	179.3	-20.8

MULTI-OBJECTIVE ANALYSIS

One criteria to find the adequate DG sitting may be minimization of power losses [4]. However, in most cases, this indicator cannot serve as a single criterion for decision-making. Therefore, to reach such objectives satisfactorily, it has to be taken into account several criteria, so much quantitative as qualitative. It is important to observe that the criteria must be chosen according to each electricity company concerns. Besides that, to guarantee the adequate DG sitting in an actual distribution system it is necessary to evaluate the current database, supplied by the electricity company responsible for the distribution system in analysis. Thus, analyzing these criteria through the process of decision-making, added to an approach based on fuzzy logic [5], the methodology developed in this paper intends to seek an adequate DG allocation. Thus, the fuzzy logic presented in this paper will be used to automatically give the priority levels μ(x) searching for a quantitative criterion. With respect to the pertinence fuzzy sets, its curves may alternate according to the parameter behaviour. Consequently, there are several types of pertinence fuzzy sets. In this study it is presented two fuzzy sets.

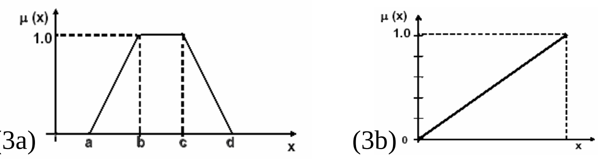
Trapezoidal Function

The trapezoidal function presents its conditions defined by a set of Equations (1), regarding the parameter values "x" and their priority level μ(x). In this study this function will represent power losses and voltage level violation criteria. In a graphic form, this function is represented in Figure 3a.

$$\mu(x)=\begin{cases}0 & if\;\; x\le a\\ 1-\dfrac{(b-x)}{(b-a)} & if\;\; a<x\le b\\ 1 & if\;\; b<x\le c\\ \dfrac{(d-x)}{(d-c)} & if\;\; c<x\le d\\ 0 & if\;\; x>d\end{cases} \qquad (1)$$

Linear Function

The linear crescent function presents a condition directly defined regarding the comparison between the parameter values "x" and their priority level μ(x). In this study this function will represent wires loading criterion. Graphically, this function is characterized in Figure 3b.



(3a) (3b)

Figure 3 (a) Trapezoidal Pertinence Fuzzy Function; Figure 3 (b) Linear Crescent Pertinence Fuzzy Function.

Qualitative Analysis

As regards the qualitative analysis method and specialists estimative, it is necessary to estimate some parameters to take into account the point of view of several specialists. Hereby, it was assumed that several specialists may participate of these analyses and that numerous characteristics define a reasonable parameter. An average estimation is defined by Equation 2.

$$k_1=\frac{\sum_m x_{ij}}{m} \qquad (2)$$

where X_{ij} represents the estimation of parameter j, given by specialist i and "m" is the number of specialists.
In sequence, it is presented Equation 3, as an example of analysis for the pair of parameters O_j and O_i.

$$\begin{aligned}O_i \succ O_j &\rightarrow x_{ij}=1{,}5; x_{ji}=0{,}5\\ O_i \approx O_j &\rightarrow x_{ij}=x_{ji}=1\end{aligned} \qquad (3)$$

Taking into account Equation 3 implying values to each pair of parameter, it is possible to find estimative k_2 calculated by:

$$k_2=2-k_1 \qquad (4)$$

Thus, the specialists must organize the parameters regarding their importance, analyzing them in pairs. The priority coefficient for each parameter is defined by Equation 5.

$$k_p=\frac{\sum_{i=1}^{n}k_i}{n(n-1)} \qquad (5)$$

where "n" is the number of evaluated parameters.

Using the results of k_p, the parameter priority can be defined through the natural numbers 1, 2, 3, ..., n, regarding the reduction of the parameter importance. If values of k_p are equal, they may receive same priority. Analyzing these results, it is possible to classify the parameter priority. To ease this step, it must be built a table (as shown in next section). In this window, results of k_1 must be positioned above the main diagonal (oblique line), and results of k_2 are below the main diagonal. In the next step, it is necessary to estimate the influence level of each parameter, regarding each object, for example, pointing a scale from 0 to 10. Thus the average estimation achieved to each parameter is multiplied by its respective k_p. Later, these results are normalized, summing the parameter values regarding each analyzed object, and dividing them by the maximum value among the added values.
Hence, to obtain a complete outcome regarding the criteria analysis and the specialist estimates, it is used Equations 6 e 7, resulting in a final index Y(x) and final ranking X^0, which shows the adequate DG sitting ranking.

$$Y(x)=\arg m\acute{\imath}n\,\mu(x) \qquad (6)$$

$$X^0=\arg m\acute{a}x\,Y(x) \qquad (7)$$

PRACTICAL EXAMPLE

In order to validate the methodology applied in this work, it was developed a practical example regarding a distribution system model with 23 feeders of 13.8kV. Assuming a previously provided list of candidate places, only 10 feeders will be analyzed, taking into account the probability these will support a DG allocation and the electricity company concerns. As regards the multi-objective analysis, quantitative and qualitative criteria were taken into account. Among several parameters, for quantitative criteria were chosen power losses, voltage level violation (VLV) and wire loading (WL); as qualitative criteria were chosen: access, security, ancillary services and physical space. In sequence, it is related the rated voltage levels (TN) to deliver customers in 13.8kV, as established by ANEEL [3]:

- Adequate Voltage Levels (kV): 12.83 ≤ TN ≤ 14.49;
- Precarious Limits (kV): 12.42 ≤ TN < 12.83;
- Critical Limits (kV): TN < 12.42 or TN > 14.49.

As regards the qualitative criteria, it is assumed that three specialists give marks to the four chosen criteria (parameters), analysing each feeder (object). Besides, following Equation 3, the importance among the criterion was compared, letting each specialist to expose his opinion. Therefore, it was built Table III, showing the achieved results for Equation 3 and the following Equations 2 and 4.

Table III. Arrangement of Parameters

Pair of parameters i,j	Specialists			Estimative	
	1	2	3	k_1	k_2
x_1,x_2	1.5	1.0	0.5	1.0	1.0
x_1,x_3	1.5	0.5	1.0	1.0	1.0
x_1,x_4	1.5	0.5	1.5	1.16	0.83
x_2,x_3	1.0	0.5	1.5	1.0	1.0
x_2,x_4	1.5	0.5	1.5	1.16	0.83
x_3,x_4	1.5	1.0	1.5	1.33	0.66

Regarding Equation 5, the next step was to calculate the results for k_p for each parameter, as shown in Table IV.

Table IV. Coefficient Parameter Priority

Parameters	x_1	x_2	x_3	x_4	Σ	k_p
x_1	-	1.0	1.0	1.16	3.16	0.26
x_2	1.0	-	1.0	1.16	3.16	0.26
x_3	1.0	0.83	-	1.33	3.16	0.26
x_4	1.0	0.83	0.66	-	2.49	0.21

The average estimation of parameters was obtained from the average marks attributed to the four criteria, multiplied by their respective k_p. By summing these results, it is possible to identify the maximum value. Later, dividing each sum by this maximum value, it is obtained the qualitative analysis index (QAI) for each feeder, representing the final normalized values of the qualitative analysis. In Table V was related the DG sitting ranking, obtained from Equations 6 and 7, for the quantitative and qualitative criteria.

Table V. Final DG Sitting Ranking

Feeder	Losses	WL	VLV	QAI	Y(x)	X^0
1	1.0	0.98	0.13	0.95	0.13	6°
2	0.90	0.97	0.53	0.91	0.53	2°
3	0.17	1.0	0	0.96	0	-
4	0.43	0.97	0.93	0.94	0.43	4°
5	0.67	0.93	1.0	1.0	0.67	1°
6	1.0	1.0	0.07	0.91	0.07	7°
7	0	1.0	0	0.86	0	-
8	0.72	0.94	0.26	0.97	0.26	5°
9	0	0.73	1.0	0.91	0	-
10	0.48	0.85	1.0	0.93	0.48	3°

CONCLUSION

This paper discusses some partial basic considerations of DG penetration in energy systems. Moreover it is analyzed the results of power losses and voltage levels in steady-state operation, obtained from a distribution system model, simulated with software DigSilent®. In addition, this paper concentrates on a general multi-objective fuzzy method. This study applies the algorithm of Bellman-Zadeh to evaluate quantitative and qualitative criteria, in order to search for an adequate DG allocation. Validation of this methodology was verified with a practical example, resulting in a ranking of DG sitting for a distribution system model. Further research work to know the fuzzy logic effects will be explored in a qualitative parameter analysis for the system transient operation. This future paper focuses on how to quantify these qualitative parameters (ancillary services, for example), expanding this method to both steady-state and transient operations (according electrical energy concerns). Finally, to take into account the widespread of DG in electric systems, which represents significant impact on the operational characteristics of distribution networks, it is necessary to recognize that the correct DG allocation is a essential study for modern distribution system planning.

REFERENCES

[1] C.L.T. Borges, D.M. Falcão, Z.S. Machado, A. Manzoni, 2003, “Análise do Impacto da Localização e Dimensão da Geração Distribuída na Confiabilidade, Perdas Elétricas e Perfil de Tensão de Redes de Distribuição”, Proceedings of II Citenel 2003. EE - COPPE/UFRJ.

[2] W. El-Khattam, M.M.A. Salama, 2004, “Distributed generation technologies, definitions and benefits”, Department of Electrical and Computer Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ont., Canada.

[3] National Agency of Electrical Energy – ANEEL, Resolution 505, November 26th, 2001, Brazil.

[4] T. Griffin, K. Tomsovic, D. Secrest, and A. Law, 2000, “Placement of dispersed generation systems for reduced losses, *Proceedings 33rd Annu. Hawaii Int. Conf. Systems Sciences.*

[5] J. Ramírez-Rosado, J. A. Domínguez-Navarro, 2004, “Possibilistic model based on fuzzy sets for the multiobjective optimal planning of electric power distribution networks”, IEEE Trans. Power Syst., vol. 19, no. 4, pp. 1801–1810.

Acknowledgments

The authors would like to thank CEEE for their financial support given for this project.