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Methodology for the calculation of the factor of priority for smart grid implantation using fuzzy logic

M.N.Q. Macedo [a,*], J.J.M. Galo [b], L.A.L. Almeida [b], A.C.C. Lima [b]

[a] Department of Electrical, Federal Institute of Bahia, Street Emidio dos Santos S/N – Barbalho, Salvador, Bahia 40.301-015, Brazil
[b] Department of Industrial Engineering Postgraduate, Federal University of Bahia, Street Aristides Novis, No. 2, 6th Floor – Federação, Salvador, Bahia 40.210-630, Brazil

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ABSTRACT

The smart grid deployment requires high investments in infrastructure and human resources and can take years or even decades to be fully implemented, particularly in large countries, such as Brazil. A deployment plan that uses well-defined criteria to develop the deployment process is necessary to provide the best cost-benefit ratio for the electrical systems.

This paper proposes a methodology to indicate the order of priority, based on the characteristics of each system where there is the possibility of deployment of the smart grid. The methodology is to assess and quantify relevant criteria (technical, economic and environmental) for this deployment and apply the fuzzy logic to calculate a priority factor. This factor will help in the decision-making process for choosing the order of priority for deployment of smart grid analysed systems. This method was applied in the analysis of six local dealership systems and the results are presented in this paper.

Introduction

The growing complexity of electrical systems associated with the expansion of markets is a worldwide phenomenon and a result of the significant growth of the electric network, which has modified the number of consumer units, and the use of renewable energy sources, which can supplement the supply of energy, thus avoiding issues of energy shortages [1].

The goal of this modernisation process is to provide more dynamism in the networks of electrical systems, making more information available to increase the quality, reliability and efficiency of the system. The deployment of the smart grid will work precisely towards this end [2,3].

To achieve the successful deployment of smart grids in a country, a more complex electrical system will obviously pose greater challenges to all of the components in the system. In many cases, the total deployment time of a network can be several years or even decades.

In several countries, the majority of the electrical companies started smart grid projects with pilot projects or deployment in specific areas. Independent of the deployment strategy, to leverage further results, it is crucial that the benefits of the project are felt by all involved. For this to occur, it is essential to consider all regulatory aspects regarding the integration of generation, transmission, and distribution and the necessary infrastructure for deploying the projects, including human resources and consumer involvement [4–7].

In Brazil, the electric generation and transmission systems employed by electric utilities are already supervised by automated systems that use digital technology to monitor consumption processes in virtually all major centres. But, the reality of the distribution system in Brazil (which features a voltage of less than 34.5 kV) is very different. The measurement of energy consumption is manual in 95% of consumers [8].

The idea is to develop a deployment plan for the smart grid system according to criteria deemed the best, based on a cost-benefit analysis for each system.

This article proposes a system using fuzzy logic to calculate a priority index for each system reviewed, using indicators based on criteria to be used by power utilities. Second section presents the determination of variables that can affect the deployment of the smart grid. Third section presents the most relevant criteria used for deployment of the smart grid. Fourth section presents the fundamentals and basic concepts associated with fuzzy logic. Fifth section presents the application of fuzzy logic for the calculation of the priority factor. Sixth section presents the steps to be followed for the application of the proposed method in the evaluation of electrical systems. Seventh section presents the conclusions.

* Corresponding author.
E-mail address: mnevesmacedo@uol.com.br (M.N.Q. Macedo).

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Table 1
Variables to be evaluated in the smart grid deployment.

Technical features	Importance of the loads supplied by the system The system load factor System power factor System load level Technical losses and level of non-technical losses (commercial) Electric system infrastructure (automation, protection and metering) Telecommunications infrastructure and information Failure or defect rate Technical resources for operation and maintenance Lifetime of the assets (degree of ageing) Potential for the development of energy efficiency programmes Inclusion potential of distributed generation sources (wind, solar and biomass) Critical connection or border (important)
Economic characteristics	Invoicing of the electrical systemDelivery cost (kW)Cost of maintenance and operation
Location of installation	Underground installation Distance from the Centre of operation and research centres Border with other concessionaires Region with growth forecast (demographic, financial investment) Region with government social policies Region with historic towns or tourist cities Region with natural resources (agriculture, water, minerals) Region of interest to large companies Region with harsh weather conditions
Human resources	Availability of skilled professionals in the area Technical staff with potential for training in the area
Environmental conditions	Fossil fuel energy sources (greenhouse gas emissions, carbon footprint) Regional climate conducive to natural disasters for the electric system Environmental incentives program
Possibility of partnerships	Research institution (University, Research Centre) Telecommunications operator Manufacturers of equipment or related area Software developers Electric utilities (national or international with projects developed in the area)
Socioeconomic conditions of consumers	Purchasing power of the community HDI (Human Development Index) of the community History of involvement in community projects Region with social programs in progress Community bonded to the incorporation of new services

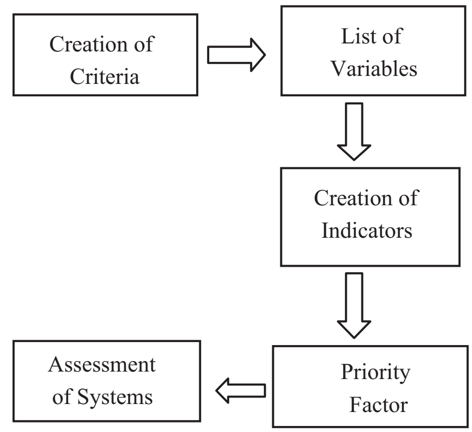

Fig. 1. Steps to evaluate systems for smart grid deployment.

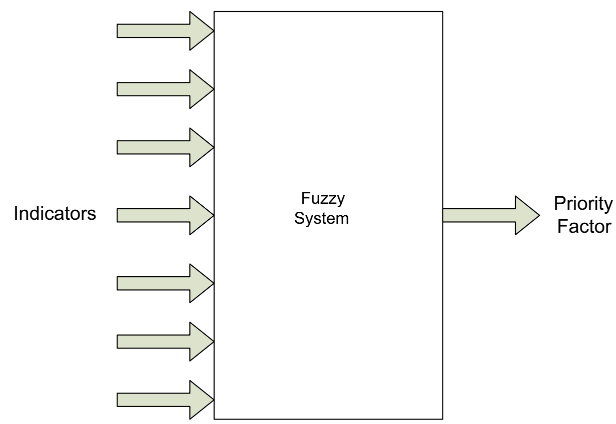

Fig. 2. Diagram of the calculation of the priority factor using a fuzzy system.

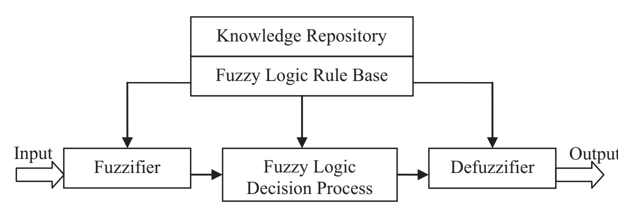

Fig. 3. Block diagram of a fuzzy system.

Table 2
List of fuzzy system input variables.

	Indicators	Acronym in the system fuzzy
1	Importance of system (load)	IpC
2	Level of system losses	NiP
3	Electrical system infrastructure	IfE
4	Telecommunications infrastructure	IfT
5	Ageing system assets	EnA
6	Energy efficiency potential	PEf
7	Potential of distributed generation	PGd
8	Community participation in the development of projects or with high HDI	Pco

Variables that can affect the deployment of smart grid

The practices adopted for smart grid deployment involve high investment in several areas. The results must be of strategic interest to all, including the electric power utilities, consumers, public authorities, suppliers, regulators, the research institutions, funders and development agents. For this reason, the smart grid deployment must be conducted primarily in locations that can add value to the electrical system through gains in productivity gains and improved energy efficiency [9–14].

One of the main gains must be in the area of operational efficiency, which includes: better control of asset life, ease of locating of defects, avoidance of unnecessary offsets, gains in quality of planning, and lower system loading, among other aspects. In the area of energy efficiency, the reduction of both technical losses and non-technical losses should enable a more effective distribution of energy, from the generation until the final consumer [14–18].

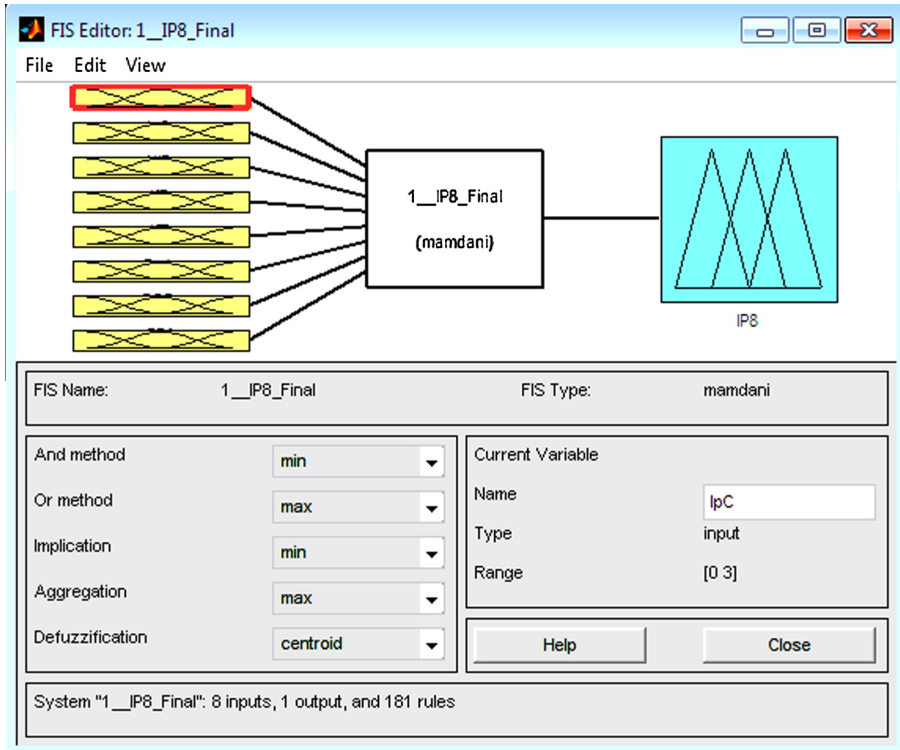

Fig. 4. Input variables (indicators) and the output variable (priority factor).

Determining which variables are relevant in smart grid deployment involves conducting an assessment of the conditions of the electrical systems where the smart grid environment must be deployed. These conditions include economic and technical characteristics, installation location, available human resources, environmental conditions, and socio-economic conditions of consumers, as listed in Table 1.

Criteria for the selection of the relevant variables and the representation as indicators

Due to the high investment, long deployment time, and rapid technological developments required, the smart grid deployment must be performed in well-planned steps. The study and evaluation of the electrical systems should be performed in their current conditions of operation to select the best deployment sequence, based on the verification that the system must require high benefit-cost ratio (see Fig. 1).

This article proposes a method for planning the deployment of electrical systems with a lower cost per benefit expected, based on the calculation of an index that will determine the priority order of smart grid deployment in the analysed systems. Fig. 2 shows the various steps that must be followed in the deployment process. The first step is to prepare guidelines and criteria to be followed because the deployment process is usually long and, thus, must be constantly re-evaluated and updated.

The order of the smart grid deployment in electrical systems can make a significant difference in the final outcome of the deployment.

The purpose of this article is to create an index based on criteria to be selected by each energy company that will determine the priority of each system to be analysed for smart grid deployment. Fig. 2 shows the various steps that must be followed in the process of evaluating a system to determine the order of deployment.

The first step is the preparation of guidelines or criteria to be followed because the deployment process is usually long and must also be constantly re-evaluated because some updates will be required at the previous steps. The selection of the most relevant variables should be made from the variables shown in Table 1, and a procedure for reducing the number of relevant variables must be applied, thereby selecting the most significant variables for the deployment process and noting their correlation with other similar variables.

The next step is the representation of variables as indicators, which can establish a method of quantification (attribution of comparative values for a selection).

An indicator provides significant information about a particular area of interest and corresponds to a representation of a situation. An indicator corresponds to the selected variable used to convey information and has as a main characteristic the ability to synthesise a complex set of information, retaining only the essential meaning of the aspects analysed [19].

The selected indicators are quite diverse so as to provide a wide scope in the evaluation of systems because the implementation relies on strengths (such as electrical system infrastructure) as well as points that will be able to be improved with the implementation of the smart grid (level of losses).

The priority factor proposed in this article will be calculated from the use of indicators at the entrance of a fuzzy system, as shown in Fig. 2.

Fuzzy system

Fuzzy systems are based on the creation of a knowledge base, in the form of a bank of rules created by an expert to assist in the decision-making process [20–22].

The conventional logic admits only two possibilities (T or F, 0 or 1). A fuzzy system is based on the extension of the conventional logic because it admits intermediate values in the range [0–1].

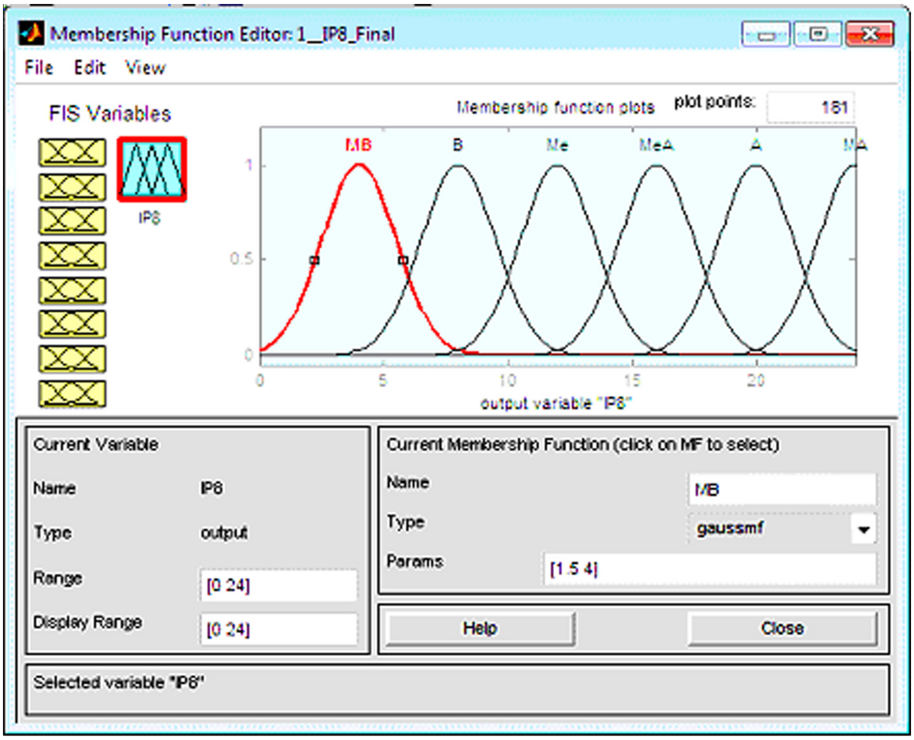

Fig. 5. Output variable, Gaussian function and Mamdani method.

Table 3
weights of rules used in the fuzzy system.

Indicator score	Weight rule
8	8/8 = 1
7	7/8 = 0.875
6	6/8 = 0.750
5	5/8 = 0.625
4	4/8 = 0.500
3	3/8 = 0.375
2	2/8 = 0.250
1	1/8 = 0.125
0	1

Fuzzy logic is applied by implementing its architecture based on the variables, function of relevance and rule base.

Fuzzy variables are variables that have their value expressed by a linguistic term that provides a variable concept, which is quantified by a function of relevance. A linguistic variable has values that are not numbers but rather words or sentences in natural language, which allows the language of fuzzy modelling to express the semantics used by specialists. The main function of linguistic variables is to provide a systematic method to approximate the characterisation of complex or poorly defined phenomena [23–25].

A membership function represents the behaviour of the fuzzy variables throughout the domain. A fuzzy set is characterised by a membership function that takes on values within the range [26].

A block diagram of a fuzzy system is presented in Fig. 3, which indicates the methodology for the construction of a system based on fuzzy logic [25–27].

The fuzzifier transforms the input variables of the problem in fuzzy values; this step mathematically models the information of the input variables by means of fuzzy sets This module demonstrates the great importance of the specialist who will parse the process: every input variable must be assigned linguistic terms that represent the states of this variable and every linguistic term must be associated with a fuzzy set by a membership function [28].

Table 4
Evaluation of six electrical systems to eight indicators (fuzzy system).

	Electrical systems	Evaluations of systems with 8 indicators	Priority factor
1	Small, urban, modern system, with good infrastructure and balanced loads	[1 0.5 1.5 1.5 0.5 0.5 0.5 2]	4.52
2	Small, rural, aged system, unbalanced load, with the potential for energy efficiency and distributed generation	[0.5 2 0.4 0.5 2 0.5 2 0.5]	4.97
3	Mid-sized urban area, balanced loads and potential priority of distributed generation	[2 0.5 2 1 0.5 1 1 2]	4.98
4	Medium-sized suburban zone unbalanced load with the potential for energy efficiency and distributed generation	[2 1.5 1 1 1.5 2 1 1.5]	6.03
5	Large urban area, high system electric and telecommunications infrastructure, systems with balanced loads and of high importance, with the potential for energy efficiency and distributed generation	[3 0.5 2.5 2 1 1 1.5 3]	12.1
6	Large suburban area, high failure rate, unbalanced loads and of great importance, with the potential of energy efficiency	[2.5 2 1.5 1.5 2 2 2 2]	12.5

The knowledge base comprises the database, where the fuzzy sets and membership functions are defined, and the rule base, which is the core of the system, where the rules, variables and their linguistic classifications are stored and inference is performed.

The inference unit values of the premises of each rule are computed and applied to generate the conclusion of each rule. A sequence of composition rules is used to generate the defuzzifier entry.

The values of the premises of each rule are computed and applied to generate each unit rule of inference. Again, a sequence of composition rules is used to generate the defuzzifier entry.

Implementation of a fuzzy system for the calculation of the priority factor

The creation of a fuzzy system for the calculation of the priority factor in smart grid deployment involves the following steps:

(a) Definition of the input variables, domains, range of variation and the functions of relevance.
(b) Definition of the output variable, domains, range of variation and the functions of relevance.
(c) Elaboration of the rules, with the respective weights.
(d) Choice of aggregation methods and the defuzzifier.
(e) Calculation of the priority factor using the fuzzy system.
(f) Evaluation of the fuzzy system for improvement.

The software used was the toolbox of Matlab fuzzy [29,30]. The input variables of the fuzzy system were the eight indicators considered to be the most relevant in the deployment of a smart grid, as listed in Table 2.

The choice of the function of relevance was the Gaussian because it most resembled the results of the tests conducted for the system as well as the mass of data collected for the study, which presented its distribution around the centre.

The input variables are 0–3 domain and may take the following attributions:

Low – simple Gaussian function parameters [0, 34, 1].
Medium – simple Gaussian function parameters [0.29, 2].
High – simple Gaussian function parameters [0.3, 3].

Fig. 4 represents the eight input variables and an output variable (IP8), which is the priority factor.

The output variable has a domain of 0–24. The maximum value of each indicator assessment is equal to 3, and there are eight (8) variables. Fig. 5 illustrates the representation of the output variable, the domain and the functions of relevance.

The priority index (IP8), with a value ranging from 0 to 24:

Very low (VL) – simple Gaussian function, parameters: [1.5, 4].
Low (L) – simple Gaussian function, parameters: [1.5, 8].
Medium (Me)-Gaussian function, parameters: [1.512].
Mid-high (MeH) – simple Gaussian function, parameters: [1.5, 16].
Very high (VH) – simple Gaussian function, parameters: [1.5, 24].

The construction of the fuzzy system covered 181 creation rules. Table 3 indicates the values of the weight of these rules.

Such rules were elaborated from the definition of the weight of each rule according to the degree of importance of each of the eight variables. For this analysis, the following weights ranging from 0.125 to 1 were set, based on the number of high ratings.

Application of the proposed method

The proposed method was applied and analysed in the evaluation of six random electrical systems in Brazil, that have had the most relevant characteristics based on Table 2. The systems were then transformed into an array (1×8) of indicators, as shown in Table 4. Subsequently, this matrix of indicators was applied at the entrance of a fuzzy system to calculate the priority index for each system analysed.

It is observed that System 6 presented the highest priority factor because it corresponds to the system that offers the greatest return with the smart grid deployment in addition to being large, with important loads and good infrastructure; problems in the operation of the loads are also involved with the energy efficiency potentials.

Conclusion

The deployment of the smart grid is a global trend, and in the case of complex electrical systems such as in Brazil, attention must be paid to the challenges and opportunities of this deployment. As a result, it is important to have a strategic plan that prioritises systems that can provide the best solutions to the requirements of reliability, continuity and efficiency for deployment of the smart grid.

The method proposed in this work uses fuzzy logic for the calculation of an priority factor, which enables the evaluation of systems to achieve the best cost-benefit analysis in the implementation of the smart grid. This method prioritises the systems that present the greatest vulnerabilities, possess greater potential for distributed generation and energy efficiency, and present higher commercial losses as well as other important factors.

The use of fuzzy logic for creating the index proved to be suitable due to the ability to cope with uncertainties and ambiguities, which is not possible using conventional logic approaches.

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