Electrical Power and Energy Systems 77 (2016) 1–8

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Prioritization for allocation of voltage regulators in electricity distribution systems by using a multicriteria approach based on additive-veto model

Marcelo Artur Xavier de Lima [a], Thárcylla Rebecca Negreiros Clemente [b], Adiel Teixeira de Almeida [b,*]

[a] Companhia Energética de Pernambuco – CELPE, Av. João de Barros 111, Boa Vista, Recife-PE 50.050-902, Brazil
[b] Universidade Federal de Pernambuco, Cx. Postal 7462, Recife-PE 50.630-970, Brazil

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form 24 May 2015
Accepted 10 November 2015
Available online 28 November 2015

Keywords:
Electric power distribution
Voltage regulators
Ranking problem
Multicriteria decision problem
Additive-veto Model

ABSTRACT

The responsibility of Brazilian companies which produce and distribute electricity is to comply with standards and requirements about the level and quality of voltage that meet consumer demand. One of the strategies adopted to maintain control over the operations of the electricity supply is that of installing voltage regulators throughout the distribution network. However, this activity requires the management of available resources in terms of investing in equipment installations, and this is a major challenge for companies in the electricity sector. From this perspective, this article proposes a multicriteria model for prioritizing locations for installing voltage regulators in an electricity distribution network, which takes into consideration technical, regulatory, economic and social criteria to evaluate the consequences of installing voltage regulators and their operational performance. Thus, this paper presents an application of the Additive-veto Model for ranking multicriteria decision problems so as to relate the performance assessed by the decision-maker for allocating equipment to the set of available locations.

Introduction

Companies which produce and supply electricity in Brazil must comply with standards and requirements set by the Brazilian Electricity Regulatory Agency (ANEEL), with regard to acquiring equipment and maintaining it so that they meet the quality criteria for the service offered. ANEEL lays down rules and goals of operational performance, as well as indices and market rates of energy trading [1]. Thus, companies must comply with technical procedures to ensure satisfactory levels of quality of service. As a regulator, ANEEL imposes penalties and fines when non-compliance with the established requirements occurs, and this can damage the image and adversely affect the financial investments of companies in the electricity sector [2].

ANEEL presents two performance indicators used to assess the levels of quality of service [3]. The first indicator is DEC (equivalent duration of interruption per consumer unit), a parameter that indicates the average length of time that the power supply to a consumer unit is interrupted in a certain observation period. The second indicator is FEC (equivalent frequency of interruption per consumer unit), a parameter that indicates the frequency of occurrence of interruptions in the supply of energy to consumer units. With these indicators, it is possible to calculate the average time that service delivery is not available and the frequency with which this occurs, thereby allowing the adoption of new technologies for automating service capacity [4].

To determine the rules and operational standards for the electricity sector, ANEEL publishes PRODIST – Procedures for Electricity Distribution in the National Electricity System – [3], a document that presents the requirements for attaining levels of compliance with maintaining the electricity supply and its quality. The requirements listed in this document are related to the maintenance and provision of efficient, regular and reliable energy to consumer units, which is a major challenge for companies in the electricity distribution sector, mainly due to the increase in the number of consumer units and the limits of territorial expansion served by electric power equipment [5].

One of the Brazilian companies that is active in the electricity sector is responsible for supplying electricity to more than 185 cities in the state of Pernambuco, Brazil [6]. This company covers a concession area of 98,546.7 km^2 in which it has over 3.2 million customers who consume 12,266,246 MW h on average per year. These indices favor the characterization of the company at three levels of supply of energy tension throughout the territory of its

* Corresponding author.
E-mail addresses: marceloxlima@yahoo.com.br (M.A.X. de Lima), thnegreiros@ymail.com (T.R.N. Clemente), almeidaatd@gmail.com (A.T. de Almeida).

http://dx.doi.org/10.1016/j.ijepes.2015.11.006
0142-0615/

activities. For the average level of energy voltage of 13.8 kV, there are 73,228 km of transmission lines which have 631 feeders supplied by 135 substations.

The dimension of the distribution network is the main factor that shows the potential difficulty in maintaining quality in the process of offering service to the consumer units. From this perspective, the appeal of investing in voltage regulators throughout the distribution network is desirable to ensure that the company can control that it provides acceptable standards of voltage. Dimmers are used to maintain, on a scale of ±15%, the level of electricity voltage feeders. Thus, installing regulators is recommended when the limits of the permissible power fluctuations fall outside the standards set by standards for the electrical sector in a particular region.

However, investment in voltage regulators requires decisions on the strategic location for installing such equipment in order to serve the largest number of consumer units. From this perspective, it is important to consider technical, regulatory, economic and social parameters, and the extent of investment in equipment, as evaluation criteria, in the process of prioritizing such locations. Therefore this article puts forward a multicriteria model to assist in the process of prioritizing locations for installing voltage regulators in the power distribution network of 15 kV.

The impact of this study can be seen from an economic point of view, as well as from the society point of view. The geographical region of this system consists of the whole State of Pernambuco in Brazil, which has an estimated population of 9 million. The 3.2 million consumers includes industry, commerce and residences (49%). The total annual revenue of the company is around US$ 1.3 billion. For the company's 135 substations, the voltage regulation equipment is one of the items of capital investment. The total capital investment in 2013 was US$ 120 million. Therefore, the priority for these investments is an important issue and considers multiple objectives in order to fulfill strategic issues of the company. Thus, this geographical region is analyzed by criteria (which represent organization's objectives), which are: sector's regulations, company image, size of consumer units affected and billing. From the results, it is possible to consider investment priorities such as equipment acquisition and its installation in these regions, while considering the definition and application of the decision model to support strategic and financial planning in the electricity sector.

Context of the problem

In goods production systems, the occurrence of faults and interruptions in the operation of machines can be mitigated by managing strategic production so that the situation is overcome and losses perceived by customers are minimized. However, when failures and interruptions occur in service production systems, it is difficult to hide these from customers, since, in general, services are produced at the same time as they are delivered to customers who are therefore directly affected by them. Thus, assessments must be made of the costs incurred because of such interruptions and of customers' negative perceptions [7,8].

Planning and installing an electrical power and energy system involves using resources to invest in equipment to meet the demands of consumer units. The proposal for such planning is to use the available resources and plant to maintain the level of quality required in service delivery throughout the region of operation of the power supply company, and to obtain the best return for the operational and management functions of the company [9].

Therefore, to maintain standards in the quality of service, the aspects that may affect the company's operations in the energy supply process must be identified. These issues, which can easily be listed as potential causes of failures or interruptions of service, directly affect the companýs performance indicators, namely DEC and FEC. These discontinuities, in general, can cause voltage variations in the grid, which causes loss of control or of evidence about the operating process [10,11].

One of the measures commonly taken to maintain compliance with the standards of service to be offered is to use and install voltage regulators beside power feeder equipment at certain points of the energy supply [12]. To adopt this strategy, the need for installing such equipment must be identified by calculating the probability of technical and regulatory losses on operational performance in a given region. Thus, on observing a set of locations, if a feeder presents a high probability in this regard, it does not serve a region at the standards set for the quality, and thus the greater will be the need to install a voltage regulator in this region.

The set of possible locations for installing voltage regulators can be identified by a computational simulation of the load of the system throughout the distribution network. This system identifies the power feeders that must be attended to. In other words, they are those which are closest to or beyond the limits of voltage levels regulated by ANEEL in the electricity network. The voltage regulator is defined for a distribution networks of 15 kV.

According to the PRODIST instructions, the compliance of electrical voltage refers to the comparison between the voltage value obtained from a measurement process and the voltage specified as appropriate, precarious or critical according to the connection point observed in the consumer unit. Thus, the voltage level is considered adequate when it is between 0.95 and 1.05 of its nominal voltage value when a steady supply of electricity is maintained. Thus, it is possible to set indicators for standards so as to establish quality and this requires appropriate investment by the organization [13]. Thus, it is possible for the company to obtain data which it can use to plan for investments.

By using a simulator system of a power load, the company is able to check which locations need to be assisted by a voltage regulator to enable oscillations of the power voltage to be controlled. However, investment in the installation equipment is restricted by the financial resources that the company can make available. Thus, the problem of installing voltage regulators involves the issue of prioritizing locations selected in accordance with the degree of need for a power feeder controller.

Therefore, what should be done is to plan and prioritize the areas that most need such regulators so as to prevent interruptions to the transmission of power transmission. This can be done by evaluating different factors involved in the acquisition and maintenance of equipment needed to meet standards for the supply of electricity, such as by considering the technical parameters, regulatory issues, and economic and social conditions that must be met by the company so that it can conduct the interactions needed for the decision process. This is an activity that requires more effort by management and operational sectors [10,11,14].

The problem of allocating voltage regulators

Efforts required in the process of allocating voltage regulators in electricity distribution systems, in general, consider strategic aspects of the interaction of the various operational functions of the company. These aspects may be associated with the cost of installation, utilization rate of equipment, service quality and minimizing losses in different dimensions with regard to the control of voltage changes throughout the network [15,16], and they can be treated as evaluation criteria in the selection process for installing such equipment.

When many evaluation criteria are involved, allocating equipment can be understood as a complex decision process. However, there are analytical and strategic tools that assist in managing resources to determine the consequences of the