Electrical Power and Energy Systems 33 (2011) 1262–1271

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Application of neural networks to the management of voltage constraints in the Spanish market

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ARTICLE INFO

Article history:
Received 11 August 2006
Received in revised form 28 April 2011
Accepted 9 May 2011
Available online 8 June 2011

Keywords:
Neural networks
Power system dispatch
Security assessment
Congestion management
Decision trees
Clustering

ABSTRACT

The security criteria of a power system require that branch power flows and bus voltages are within their limits, not only in normal operating conditions but also when any credible contingency occurs. In the Spanish electricity market, voltage constraints are solved by connecting a set of off-line generators located in the areas where they occur. Thus, for a market participant it is necessary to predict approximately when its generating units are connected in order to prepare the annual budget and/or decide the time and location of new plants. The authors have presented in a former paper a methodology based on decision trees to estimate the daily load pattern of units, which have not been cleared in the daily energy market and can be connected to alleviate voltage constraints. In this paper, considering a set of potential explanatory variables, a different methodology based on neural networks is proposed to forecast if a non-connected unit will be committed by the System Operator to remove voltage violations. The performance of neural networks is illustrated with a study case. In addition, a thorough comparison with the methodology based on decision trees is carried out.

1. Introduction

The solution of power system constraints is an important issue to be addressed in deregulated power markets. The Spanish electricity market [1], as it started on January 1st, 1998, is organized and operated by two separate entities: the Market Operator and the System Operator. The Market Operator receives the offers of generation and demand for each hour of the following day and clears the market according to economic criteria. The System Operator is responsible for the secure operation of the power system and owns the transmission system [2]. One of the main tasks of the System Operator consists of solving the power system constraints that arise after the daily energy market has been cleared.

Power system constraints are addressed in Spain by increasing and decreasing the generation of connected units, and by connecting off-line ones. Both generation re-dispatch and adjustment of the demand–generation imbalance is computed according to the generation offers submitted by the agents into the market [3].

Power system constraints are classified in the Spanish system in [4–7]: (a) branch overloads and (b) bus voltage violations.

Branch overloads occur occasionally in the Spanish power system. They are solved by increasing and decreasing power in connected units and in some cases, connecting off-line ones. The Spanish transmission system is a highly meshed one. Under the transmission planning criteria applied when the Spanish transmission power system was developed, most of the lines carry less than 50% of their thermal rate under normal operating condition, and therefore, overloads are not frequent.

However, voltage violations are more frequent than overloads in the Spanish system, due to the lack of reactive power in the areas where they occur and the existence of a big generation imbalance between exporting and importing areas. The generation demand imbalance of an electrical area is computed subtracting from the total area demand the total area generation, and thus, it indicates the magnitude of the energy transport entering the area from the rest of the system. Voltage constraints are solved by connecting a set of off-line generators, and reducing an equal amount of power in the most expensive connected ones. The new connected generators provide reactive support in the importing areas and also inject active power in the system, thus reducing the power transfers between exporting and importing areas (the effect of injecting active power to increase the voltage profile is significant when a power system is close to the critical loading condition of the nose curve [8,9]). This type of constraints has a local effect: they can only be solved by the connection of generators located in the importing areas where they occur. Fig. 1 shows a map of the Spanish power system and the locations where voltage constraints may occur.

Spanish regulation imposes that generators that increase their output in the congestion management procedure are paid at their offer price. In this context, the annual income that a unit located in

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doi:10.1016/j.ijepes.2011.05.002

Fig. 1. Locations of voltage constraints in the Spanish power system.

an area where voltage constraints are frequent, is highly dependent on the solution of power system constraints by the System Operator. Thus, for a market participant it is necessary to predict when its generating units are connected, in order to prepare the annual budget and/or decide the time and location of new plant investments. In [10] the Spanish regulation concerning the remuneration of new connected units in the congestion management procedure is summarized, justifying the importance of load pattern estimation in the internal budget of a generating utility.

The authors have proposed in a former paper a methodology based on decision trees to estimate the daily load pattern of non-connected units that result in the Spanish congestion management procedure [10]. The main advantage of decision trees is the easy interpretability of the results and the supply of probability values without assuming normal distributions.

In this paper, the application of neural networks to the problem under consideration is explored, and a thorough comparison with the results obtained with decision trees is performed. Neural networks are widely used in the literature to forecast when the problem of interest presents a high non-linear characteristic [11,12]. The main quality of a neural network is typically the high accuracy of its results. However, neural networks act as a black box: given a set of input variables, it is not easy to interpret their output. In the methodology based on neural networks proposed in this paper, decision trees are also a key tool employed in the process of removing non-significant explanatory variables.

The paper has been organized as follows. In Section 2 a search of potential explanatory variables of the problem of interest is carried out. Section 3 contains an overview of the neural networks based methodology developed to predict whether a non-connected unit will be committed by the System Operator to remove voltage violations. The following sections deal with the details of each step of the methodology: clustering in Section 4, data processing in Section 5, division of the total data set in Section 6, removal of explanatory variables in Section 7 and Bayesian probability with neural networks in Section 8. Section 9 is dedicated to the results obtained using the neural network methodology and the comparison with the results obtained using decision trees. Finally, conclusions are established in Section 10.

2. Identification of potential explanatory variables

Within an area, the main technical factors that affect the solution of voltage constraints are the imbalance between the exporting and importing energy in the area, the position of the voltage control resources (capacitors, reactors, transformer taps and generator voltages) and the status of transmission lines that feed the electrical area under consideration. On one hand, the demand–generation imbalance is considered as an important explanatory variable. In other words, the higher the energy import of the area is, the higher is the probability of being connected in the congestion management procedure to remove voltage problems within the area. However, usually the voltage control resources are positioned according to the load and generation level, and hence they are not considered as independent explanatory variables. On the other hand, the transmission lines are essential for the energy supply and so their status is considered as explanatory variable.

The electrical nodes, generators and lines that must be included in the electrical area of the generator under study are decided according to the knowledge and experience of the power system operation. For instance, for a generator located in the southern part of Spain, all the equipment within the circled electrical area depicted in Fig. 1 should be selected. This equipment includes the 400 kV transmission lines that feed the area (see Fig. 1), the 400 kV ac interconnection submarine line between Morocco and Spain, and all generators exceeding 50 MW. The experience yields that for the southern zone, the 220 kV lines do not play a significant role in voltage constraint alleviation.

It should be noted that the start up cost of the new generators to be connected couples the daily solution along the 24 hourly periods [6]. This means that the value of explanatory variables for 1 h does not explain the power connected in the congestion management procedure for the hour. Instead, 24 hourly values of explanatory variables are needed to predict the whole daily load pattern.

In addition to the aforementioned explanatory variables (also used in the decision trees methodology presented in [10]), other variables have shown to improve the accuracy of the forecasting process. Therefore, in this research the following potential explanatory variables have been initially considered to explain if a non-connected unit will be committed by the System Operator to remove voltage violations:

(a) Daily demand curve: 24 hourly demand values of the electrical area of the generator, which can be easily predicted using the temperature of the zone.
(b) Peak demand of the day corresponding to the maximum value of the daily demand curve.
(c) Daily generation curve: 24 hourly generation values of the electrical area of the generator. These values are more difficult to predict. In the short term they can be tracked with the daily operation of the market and the available failure information of the units within the area. In the long term, it can be simulated with long-term optimization models [13].
(d) Status of the transmission lines that feed the electrical area of the non-connected units in each hourly period. Most of the lines that are off for more than a few instants are due to planned maintenance working. Maintenance working is planned by the System Operator, and its scheduling is facilitated to the market agents.
(e) Type of day: this explanatory variable represents the day of the week (from Sunday to Saturday). The days with similar characteristics can be grouped (for instance, in working days and holidays).
(f) Daily load pattern of the unit in the previous day. In a number of cases, if a unit is committed to solve voltage constraints 1 day, the following day it is also committed.
(g) Daily load pattern of the unit for the same type of day of the previous week.