Available online at www.sciencedirect.com
SCIENCE DIRECT®

Electric Power Systems Research 73 (2005) 61–66

ELECTRIC POWER SYSTEMS RESEARCH

www.elsevier.com/locate/epsr

Application of an experimental design methodology for economic parameter analysis in an open market environment

D. Moitre*, F. Magnago, J. Martinez, M. Galetto

National University of Rio Cuarto, University Campus, Ruta 36, Km 601, Rio Cuarto, Cordoba 5800, Argentina

Received 1 October 2003; accepted 6 May 2004
Available online 21 September 2004

Abstract

Statistical data analysis, through the utilization of experimental design, is a powerful tool commonly used in different areas where uncertainty is a problem, and a great amount of data is available for the analysis. After 10 years of open market experience, the data recorded during the last decade from the electric markets suggest that experimental design can be useful for electrical market data analysis. In this paper, the impact of different factors on the determination of economic parameters such as the spot price in an electric market is analyzed. The analysis is based on the experimental design methodology. The implementation of the proposed methodology is illustrated using simple examples from the Argentinien electric market.

Keywords: Experimental design; Electric energy market; ANOVA methodology; Spot price estimation

1. Introduction

During the last decade, several electric market structures have changed all over the world from a vertical integrated monopoly to a vertical and horizontal segmented market. This process has been observed in countries such as Chile (1982), the United Kingdom (1989), Argentina (1992), Norway (1992), Central American countries (1997), and the United States (1998) [1]. As a result, two important issues can be highlighted taking into account over 10 years of open market experience in the countries that led themselves to those changes and from the available data. The first item to be considered is uncertainty with an open market; uncertainty increases with regards to power system structure, development, and price determination. The second one is the great amount of data available in databases. These two issues make the statistical data analysis, through the utilization of experimental design, a powerful tool for electrical market data analysis that can serve as a base for a second generation of reforms in the electric market sector. Experimental design is a set of tests carried out on process or systems where inputs are changed in order to observe the output response and their relation with inputs. The main objective of the experimental design is to determine which variables are most influential on the output response, that is, to determine the parameters which lead to the best possible output response [2,3]. Initial experimental designs were applied in the area of agronomy and chemistry for the selection of the most efficient factor combination as described in [4–6], respectively. Later, the electronic industry used this methodology for the development of products and process [7]. Thus, experimental design becomes one of the most important tools in the statistical analysis of data in several areas, allowing companies to improve within an aggressive competitive environment. Recently, the idea of implementing experimental design in the power system area has been suggested. In [8], authors present a technique based on the analysis of the variance to calculate the contribution of generators to an electric market. Another implementation of the analysis of the variance method to detect the most influential factors on the level of line congestion is shown in [9,10]. The aim of this paper is to analyze the impact of different

* Corresponding author. Tel.: +54 358 4676 495; fax: +54 358 4676 495.
E-mail address: dmoitre@ing.unrc.edu.ar (D. Moitre).

0378-7796/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2004.05.005

factors on the determination of economic parameters such as the spot price in an electric market based on the experimental design methodology. First, the mathematical formulation of factorial experiments is revised; then, the implementation of this technique on the spot price determination is shown, and finally to illustrate the proposed method, a study case is presented.

2. Factorial experiments

Factorial experiments are widely used within the area of experimental design when experiments involve several factors and the study of their joint effect on a response is necessary [11]; the simplest type includes two factors: factor A with a levels and factor B with b levels.

The hypotheses under which results are analyzed are the following:

- fixed factors;
- full randomized design;
- normality assumptions are satisfied.

The observations can be described by the following statistical lineal model:

$$y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

where μ is the total media, α_i denotes the effect of the i-level of the first factor, β_j the effect of the j-level of the second factor, $(\alpha\beta)_{ij}$ the interaction effect between the i-level of the first factor,and the j-level of the second factor, and ε_{ijk} the experimental error. Repeating the experiment n times, there will be nab observations, which are assumed normally distributed, media μ_{ij} and variance σ^2. The objective of the factorial design is to determine the effect of the first and second factor for which the following tests of hypothesis are performed:

$$\begin{aligned} &H_0' : \alpha_1 = \alpha_2 = \cdots = \alpha_a = 0 \\ &H_1' : \text{at least one } \alpha_i \neq 0 \end{aligned} \quad (2)$$

$$\begin{aligned} &H_0'' : \beta_1 = \beta_2 = \cdots = \beta_b = 0 \\ &H_1'' : \text{at least one } \beta_j \neq 0 \end{aligned} \quad (3)$$

Furthermore, it is very important to determine the interaction between both factors; therefore, the following test of hypothesis is formulated:

$$\begin{aligned} &H_0''' : (\alpha\beta)_{11} = (\alpha\beta)_2 = \cdots = (\alpha\beta)_{ab} = 0 \\ &H_1''' : \text{at least one } (\alpha\beta)_{ij} \neq 0 \end{aligned} \quad (4)$$

For a given data set, the total sum of squares SS_T is defined as follows:

$$SS_T = SS_A + SS_B + SS_{AB} + SS_E \quad (5)$$

where SS_A is the sum of squares for the main effect A, SS_B is the sum of squares for the main effect B, SS_{AB} is the sum of squares of the interactions between factors, and SS_E is the sum of squares of the error. Then, the tests described by Eqs. (2) and (3) are based on a comparison between the independent estimates of σ^2 provided by the division of each term of SS_T by their degree of freedom, known as mean square:

$$\begin{aligned} MS_A &= \frac{SS_A}{a-1} \\ MS_B &= \frac{SS_B}{b-1} \\ MS_{AB} &= \frac{SS_{AB}}{(a-1)(b-1)} \\ MS_E &= \frac{SS_E}{ab(n-1)} \end{aligned} \quad (6)$$

The effect of a factor is defined by the variations in the factor's level. This is called main effect because it refers to the primary factors in the study. In some experiments, the factors may have different level response, when this occurs, and there is a considerable interaction between factors, the corresponding main effects will have no meaning since a significant interaction can masks main effects. Assuming fixed factors A and B, the mean square expected values are:

$$\begin{aligned} E(MS_A) &= \sigma^2 + \frac{bn\sum_{i=1}^{a}\alpha_i^2}{a-1} \\ E(MS_B) &= \sigma^2 + \frac{an\sum_{j=1}^{b}\beta_j^2}{b-1} \\ E(MS_{AB}) &= \sigma^2 + \frac{n\sum_{i=1}^{a}\sum_{j=1}^{b}(\alpha\beta)_{ij}^2}{(a-1)(b-1)} \\ E(MS_E) &= \sigma^2 \end{aligned}$$

In order to perform the test described by Eqs. (2)–(4), mean square values are divided by the mean square error:

$$\begin{aligned} F_A &= \frac{MS_A}{MS_E} \\ F_B &= \frac{MS_B}{MS_E} \\ F_{AB} &= \frac{MS_{AB}}{MS_E} \end{aligned} \quad (7)$$

These ratios follow an F distribution with two degree of freedoms; one degree of freedom corresponds to the numerator term and the other corresponds to the denominator, in this case, $ab(n-1)$. The critical region is located in the upper tail of the distribution, as shown in Fig. 1.

The test procedure is arranged in an analysis of variance (ANOVA) table, shown in Table 1.

Rejecting the null hypothesis H_0' and H_0'' implies that there are differences between the means, although the exact nature of the differences is not specified. In this situation, further comparisons between groups through the implementation of multiple comparison techniques may be useful. This