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Peak demand contract for big consumers computed based on the combination of a statistical model and a mixed integer linear programming stochastic optimization model

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ABSTRACT

One of the main objectives of Demand Response Programs is to mitigate the effect of peak electricity demand by inducing consumers to shift or reduce their electricity consumption in peak times. In Brazil, big energy consumers should contract peak demand for the upcoming months with the utility distribution companies under a set of rules defined by the System Regulator. Based on this, the utility will have more information to reinforce the system accordingly. The challenge for consumers is to compute the best value of the peak demand contracted before the peak demand realization. One way to solve this problem is to simulate future scenarios of peak demand and optimize the value of the peak demand contracted in compliance with the current rules. In this paper, a support decision system is proposed to help consumers in this task.

The proposal is divided into two parts, which are a statistical model, for estimating and simulating future scenarios of peak demand, and a stochastic optimization model, to compute the value of the peak demand contracted.

In the first part, a Box & Jenkins model is used to estimate the parameters of the statistical model and to simulate it based on the historical electricity bill data. In the second part, a stochastic optimization model is applied using a convex combination of the Expected Value and Conditional Value-at-Risk, as the risk metrics for the cost uncertainty, in order to obtain the monthly values of peak demand contracted. The results achieved corroborate the importance of using an appropriate mathematical model to address the problem. To illustrate the proposed approach, a real case study for a big consumer in Brazil is presented.

1. Introduction

Peak demand is one of the most important issues for utilities, because it directly affects the investments to reinforce the system. It can be defined as the greatest value of the energy consumed verified over a period within the month.[1] This issue is so important that in Refs. [1] and [2], the authors propose a peak shaving strategy based on a storage system to reduce or postpone new investments on distribution system. In Refs. [3] and [4], the behavior of the consumers was studied in order to implement an effective Demand Response Program (DRP) to create incentives for them to shift or reduce their consumption on peak times. In Refs. [5] and [6], different aspects involving peak demand reduction are studied, however, as mentioned in Ref. [7], to tackle this problem from the consumer viewpoint, a forecast of peak demand is required.

Peak demand may be associated with external variables, such as temperature, humidity, economic variables or even a combination of these. Notwithstanding this correlation, it is important to highlight that the quality of the simulation depends on the forecast of the external variables or of the seasonal variables. The more accurate the forecast is, the better the result of the peak demand simulation will be. On the other hand, due to the nature of the consumer's activity, the seasonal variation can be considered to explain the peak demand behavior.

In order to design the additional capacity of the system to accommodate the peak demand of the consumer, a probabilistic forecast model is presented in Ref. [8] to estimate and to forecast

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[1] For some cases, a maximum 15 min is used and the unit associated to the peak demand is kW 15 min, or, for simplicity, kW.

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Nomenclature

C_t	Cost of peak demand contract in the month t (in R$).
D_t^{max}	Peak demand in the month t (in kW).
D_t^c	Value of the peak demand contracted in the month t (in kW).
$D_t^{AR(1)}$	Peak demand in the month t computed by AR(1) model (in kW).
T_D	Tariff of peak demand (in R$/kW). For this paper, $T_D = \frac{R\$}{kW}18.12$.
T_D^{exc}	Tariff of exceeded peak demand (in R$/kW). For this paper, $T_D^{exc} = 2T_D$.
T	Time horizon of analysis. For this paper, $T = 12$ (months).
AR(p)	Autoregressive model of order "p" (number of time lags).
B	Lag operator.
$\phi(B)$	Non-seasonal autoregressive operator (AR) $(1 - \phi_1 B - \ldots - \phi_p B^p)$.
$\Phi\left(B^S\right)$	Seasonal autoregressive operator (AR) $(1 - \Phi_1 B^P - \ldots - \Phi_P B^{PS})$.
∇^d	Non-seasonal difference operator of degree d.
∇_S^D	Seasonal difference operator of degree D.
Z_t	Time series.
$\theta(B)$	Non-seasonal moving average operator (MA) $(1 - \theta_1 B - \ldots - \theta_q B^q)$.
$\Theta\left(B^S\right)$	Seasonal moving average operator (MA) $(1 - \Theta_1 B^S - \ldots - \Phi_Q B^{QS})$.
a_t	White noise.
C_D	Optimum annual cost of peak demand contract (in R$).
n_S	Number of scenarios.
$\mathcal{S}$	Scenarios set.
$\Delta_{s,t}$	Peak demand tolerance to avoid penalty in the month t and in the scenario s (in kW).
$d_{s,t}^{exc}$	Exceeding demand in the month t and in the scenario s (in kW).
$D_{s,t}^{max}$	Maximum peak demand simulated in month t and scenario s (in kW).
u	Maximum percentage of the peak demand contracted acceptable to avoid penalty due to subcontracting ($u = 5\%$)
x_t	Binary variable that indicates if the peak demand contracted will be violated in the month t.
M	Big M used as an auxiliary parameter.
y_t	Binary variable that indicates if the peak demand contracted will be reduced in the month t.
d_0	Initial value of the peak demand contracted (in kW).
$C_{s,t}$	Cost of the peak demand contract in the month t and scenario s (in R$).
$\delta_{s,t}$	Auxiliary variable that represents the left side of the distribution costs in month t and in the scenario s.
w_t	Auxiliary variable that reaches the value-at-risk (VaR) of the distribution costs in the month t for the period of analysis.
λ	Constant that makes the balance between Expected Value (EV) and the Conditional Value-at-Risk (CVaR).
α	Aversion to risk parameter that defines the confidence level of the CVaR.

the peak demand over the year using temperature, wind speed and luminosity as external variables.

In Ref. [9], peak demand was analyzed under a perspective of density of scenarios using a stochastic approach. The authors stated that utilities should assess the risk considering the density of scenarios produced by the statistical model because it is suitable for long-term applications. In Ref. [10], the authors proposed a method based on a multi-model partitioning technique and compared it with traditional well-known statistic methods.

Other applications, apart from system planning were proposed using peak demand forecast, as in Ref. [11], where the authors evaluated the optimal integration of renewable energy produced in the system considering future scenarios of peak demand.

One way to implement a DRP is to create a mechanism to encourage consumers to reduce their peak demand. A peak demand contract between consumers and utility can be used for this objective. In this way, from the consumers' viewpoint, the challenge is to compute the value of the peak demand contracted before the peak demand realization. After the application of the statistical model to simulate scenarios of peak demand, a stochastic optimization model can be applied to compute the peak demand contracted.

There are not many projects dedicated to optimizing peak demand contracted in literature, thus, the model proposed in this paper was inspired in the optimization energy contract for consumers from other papers. In Ref. [12], a stochastic programming model is presented to solve the electricity procurement problem for big consumers, accounting self-production, pool market and bilateral contracts as well. Recently, in a pilot project in Canada [13], the authors highlighted the importance of taking into account the peak demand in the optimization of the daily load profile of an industrial consumer. The corresponding reductions in this study, by re-scheduling the industrial process and, consequently, changing the load daily profile, in peak demand and energy consumption were 32.82% and 11.95% respectively. Similar idea had been applied in Ref. [14] for reducing costs of energy and/or peak demand of another industrial consumer. In this case, the mathematical model took into account some constraints such as the industrial process, storage units, distribution system components and operator's requirements.

A risk aversion profile is implemented using the Conditional Value-at-Risk (CVaR) as a risk measurement. In Refs. [15] and [16], a preliminary version of the combination between the statistical model and the optimization model were formulated to contract energy and peak demand.

In this paper, both models were improved in order to achieve the best value of the peak demand contracted. Here, a Box & Jenkins model [17] was used to estimate and simulate future scenarios of peak demand for a specific consumer. Moreover, an optimization model was developed, considering the rules applied in Brazil for the contract between the utility and the consumer, and a convex combination of Expected Value (EV) and CVaR was used to optimize the cost by using the peak demand contracted. As will be seen in Section 4, due to the nature of the problem, the optimization model was adapted to consider integer variables and the scenarios simulated. Therefore, the proposed problem is a Mixed Integer Linear Programming.

Based on the aforementioned, the main contributions of the paper are:

- To propose a new approach from the consumer's viewpoint to address the DRP used in Brazil to encourage them to reduce their peak demand;
- To propose a statistical model to estimate and simulate future scenarios of peak demand for big consumers using historical electricity bill data;