Risk-Averse Contracting Strategy for the Transmission System Usage

Érica Telles, Raphael Saavedra, Guilherme Bodin, Thuener Silva, André Milhorance, Cristiano Fernandes, Alexandre Street, Armando Leite
Pontifícia Universidade Católica do Rio de Janeiro
Rua Marquês de São Vicente, 225 – Edifício Cardeal Leme, Sala L435
ericaetc@ele.puc-rio.br

RESUMO

As distribuidoras brasileiras contratam um montante de uso da transmissão, i.e., a máxima demanda para um determinado horizonte de tempo, por barra de conexão com o sistema de transmissão. Este contrato sinaliza, através de uma previsão de demanda baseada em uma estrutura de mercado descentralizado, os reforços na expansão da transmissão necessários para atender a demanda futura. Para a distribuidora, a definição do contrato ótimo envolve incertezas como a entrada de novos clientes, contingências e variáveis climáticas que afetam a demanda e a geração renovável interna. Este artigo propõe um modelo de programação linear estocástica que otimiza o montante de uso da transmissão a ser contratado a partir de cenários e probabilidades que caracterizam as incertezas do problema. O Conditional Value at Risk (medida de risco coerente) representa a aversão à risco da distribuidora através de restrições de risco parametrizadas e uma função objetivo ajustável a um perfil de risco.

PALAVRAS CHAVE. Decisão sob incerteza. Companhia de distribuição de energia. Contrato de uso do sistema de transmissão.

ABSTRACT

Brazilian distribution companies (DISCOs) need to contract the amount of transmission usage,i.e., maximum demand within a given horizon, at each connecting bus within the transmission system. This contracting scheme signalizes the future demand needs for the system planner through a decentralized market-based demand forecast. From the DISCO's part, the definition of the optimal contract amount involves a set of uncertainties such as the entrance of new clients, network contingencies, and climatic variables affecting both the demand and renewable generation within the DISCO network. This paper proposes a stochastic linear programming model to optimize the contract amount of the transmission usage for a given set of scenarios and probabilities that depicts the uncertainties of the problem. The Conditional Value at Risk (coherent risk measure) is used to represent the DISCO risk aversion through parameterized risk constraints and a risk-adjusted objective function.

KEYWORDS. Decision under uncertainty. Distribution company. Transmission usage contract.

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Nomenclature
Parameters

λ $CVaR$ weight in the optimization objective function

μ Fixed cost percentage that limits the $CVaR$ of the penalty costs

b_ω Probability of the scenario $\omega \in \Omega$

$T_{j,a}$ Transmission usage tariff (TUST) at $j \in n$, $a \in \mathcal{A}$

Sets

$\mathcal{A}$ Set of years in the MUST contract horizon $\mathcal{A} = \{1, 2, 3, 4\}$

$\mathcal{M}$ Set of months of the year $\mathcal{M} = \{1, 2, ..., 12\}$

$\mathcal{N}$ Set of low-level distribution buses

$\mathcal{T}$ Set of instants of time (15 minutes)

Ω Set of $\tilde{P}_{j,m,a}$ scenarios

n Set of connection buses between distribution and transmission systems

Variables

$\tilde{c}^{MD}_{j,m,a}$ Stochastic cost for maximum demand at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$

$\tilde{c}^{OC}_{j,a}$ Stochastic cost for overcontracting at $j \in n$, $a \in \mathcal{A}$

$\tilde{c}^{T}_{j,a}$ Stochastic annual total cost for MUST contract at $j \in n$, $a \in \mathcal{A}$

$\tilde{c}^{UC}_{j,m,a}$ Stochastic cost for undercontracting at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$

$\tilde{P}^{MAX}_{j,a}$ Stochastic annual maximum demand at $j \in n$, $a \in \mathcal{A}$

$\tilde{P}_{j,m,a}$ Stochastic monthly maximum demand at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$

$d^{MD}_{m,a,\omega}$ and $d^{UC}_{m,a,\omega}$ Auxiliary variables to represent the max operator of the variable cost in the optimization problem

$M_{j,a}$ Transmission usage amount (MUST) at $j \in n$, $a \in \mathcal{A}$

$p_{i,t}$ Demand at instant $t \in \mathcal{T}$ at $i \in \mathcal{B}$

$P_{j,m,a,\omega}$ Monthly maximum demand at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$,$\omega \in \Omega$

$P_{j,t}$ Demand at instant $t \in \mathcal{T}$ at $j \in n$

$z^{UC}_{m,a}$ and $\sigma^{UC}_{m,a}$ Auxiliary variables to represent the $CVaR$ operator in the μ parameter constraints

z_a and $\sigma_{a,s}$ Auxiliary variables to represent the $CVaR$ operator in the objective function

$c^{F}_{j,m,a}$ Fixed cost of MUST contract at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$

$c^{MD}_{j,m,a,\omega}$ Cost for maximum demand at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$,$\omega \in \Omega$

$c^{T}_{j,a,\omega}$ Annual total cost for MUST contract at $j \in n$, $a \in \mathcal{A}$, $\omega \in \Omega$

$c^{UC}_{j,m,a,\omega}$ Cost for undercontracting at $j \in n$, $m \in \mathcal{M}$, $a \in \mathcal{A}$,$\omega \in \Omega$

1. Introduction

In Brazil, the operational and maintenance costs of the transmission system is divided between its users, basically generators and distribution companies (DISCOs). Each connection bus between the transmission and a DISCO/generator has a transmission usage tariff (TUS [2011] – TUST, from *Tarifa de Uso do Sistema de Transmissão* in Portuguese) which is applied to a contract of demand import. In this contract, the users determine a transmission usage amount (MUST, from *Montante de Uso do Sistema de Transmissão* in Portuguese) that is based on a forecast of the annual maximum demand that will be imported, at a specific connection bus, in a four year horizon.

The MUST plays an important role in the transmission expansion planning, since it is used to identify the need for investments and reinforcements to meet the total demand and to guarantee system reliability of the system. For that reason, transmission users must come to a MUST value as adherent as possible to the future maximum demand. If the actual observed demand exceeds the contracted amount, i.e., if the DISCO undercontract the MUST, it pays for the exceeding amount in addition to being penalized for exposing the system to a supply risk. On the other hand, if the DISCO overestimates the maximum demand within the contract horizon, overcontracting penalties may apply to induce better estimates and avoid over investment. Considering the relation between the MUST and the transmission planning, the system regulator establishes rules to foster the efficiency of MUST contracts (REN [2015]). There are differences between the rules for generators and DISCOs. In this paper, the focus will be on MUST contracts for DISCOs, thus generators' rules will not be discussed.

To determine the efficiency of a MUST contract, the difference between the maximum demand observed and the MUST is evaluated considering a given tolerance. Monthly, if the maximum demand during the corresponding period is greater than 110% of the MUST, the overcontracting occurs. Annually, if the maximum demand of the period is less than 90% of the MUST, the undercontracting takes place. In both cases, the penalty costs must be solely payed by the DISCO and cannot be passed on to the final consumer. This affects the DISCOs' cash flow, reducing its investments capacity and the segment attractiveness. Considering the arguments presented, DISCOs need an effective strategy to define the optimal MUST taking into account the trade-off between penalty risks and contract costs.

The strategy to define the MUST should include, besides the regulatory rules, the uncertainties that affect the demand at the DISCO's connection buses. Regarding the DISCO system, two important sources of uncertainty should be mentioned: the demand variability and the renewable injection within the DISCO' network. Concerning the renewable injection within the network, there are two types of generation, namely, run-of-river small hydros and distributed generation (DG) such as photo-voltaic small plants. For the sake of simplicity, all renewable and intermittent injection within the distribution network will be hereinafter referred to as internal renewable generation (IRG).

Climatic variables such as temperature and rainfall indexes generally explain demand peaks and IRG profiles. Whenever the IRG is relevant compared to the total DISCO's demand, it reduces the demand verified at the connection buses. In some cases, the IRG reaches over than 50% of the DISCO's demand. This represents a benefit to the transmission system expansion, since less investments are needed to guarantee the DISCOs' demand supply. To capture this effect, the presence of the IRG must be considered in the decision of the MUST. The current regulatory rules advise the DISCO to ignore any generation; however, this guideline wastes the IRG advantage, and can also induce cases of severe overcontracting. This aspect becomes more important once it has been seen an accentuated growth in distributed generation expansion, mainly in renewable sources (small hydros, photo-voltaic generators, among others). As an example, within a ten-year horizon, the production of photo-voltaic distributed generators is expected to grow exponentially (PDE [2017]).

Additionally, contingencies, whose occurrence is also random, can disturb the regular power flow distribution, affecting the import at connection buses. Given these aspects, the DISCO decision should consider the trade-off between the minimum MUST that avoids excessive investments in the transmission system and the MUST that minimizes the penalty costs of the contract, which represent direct costs for the DISCOs' stakeholders. A stochastic approach allows for both the financial risk aversion profile of the DISCO and the aforementioned random variables. Commonly, the DISCOs' approach to contract the MUST involves deterministic strategies, which motivates researches in this area.

Prior works have visited this subject. In Leite da Silva et al. [2006] the authors propose optimizing the MUST trough a probabilistic power flow. Probability distribution functions (PDF) are used to represent the maximum demand at a connection bus by a non-sequential Monte Carlo simulation or by historical data of maximum demand. The expected value of costs' PDF is then minimized and the optimal MUST is obtained. However, the dynamic temporal profile of the demand is not explicitly considered. Also, it is assumed the approach assumes that DISCOs are risk neutral, which is not always truth. In Lima et al. [2006], a multi-period stochastic mixed integer optimization is applied to optimize the MUST value. The DISCO's total cost is minimized considering scenarios of the maximum demand at the connection buses. As in Leite da Silva et al. [2006] the DISCO is considered risk neutral. The paper presented in Lima and et al [2011] takes into account uncertainties of the hydrological dispatch, of the transmission system, of the IRG, and of the DISCO's demand and contingencies. The optimal MUST results from a multi-period stochastic optimization problem that minimizes the $\alpha\%$ Conditional Value at Risk ($CVaR$) of cost scenarios. Here, the α parameter represents the risk aversion profile of the DISCO. By considering the complete transmission system, solving the problem requires a large computational effort. To minimize this issue, in Carvalho et al. [2014] an equivalent system is used to represent the transmission effect on the DISCO's maximum demand import. Also, the sensitivity of the power flow optimal solution is considered. All the aforementioned papers consider the randomness of the DISCO's maximum demand by including different uncertainty aspects. However, none of them considers parameters capable of introducing MUST contract policies into the risk analysis, which would offer performance and risk indicators to support the DISCO's decision under uncertainty. We define as contract policy the set of constraints, established by the company, that guides the MUST contract. For instance, such a policy could consider how the worst scenarios guide the MUST decision, how the company deals with penalty exposure, and so forth.

This paper proposes a support decision strategy that is able to incorporate uncertainties that affect the MUST decision and to consider the contract policies and risk aversion profile of the DISCO. Given a set of maximum demand scenarios at a connection bus, a risk analysis of the respective cost scenarios measures the cost-benefit trade-off of each possible decision. In a multi-period stochastic optimization model this measures are optimized according to the parameters that reflect the company's contract policies and risk aversion profile.

The paper is organized as follows: Section 2 describes the problem and defines its notation. Section 3 defines the cost function to be considered on the MUST contract. In Section 4, the risk analysis is presented and parameters that support the decision under uncertainty are defined. The methodology proposed by this paper is presented in Section 5. A case study with real data from a Brazilian DISCO is presented in Section 6. Finally, section 7 presents the authors conclusions and future work perspectives.

2. Problem Description

In this section we describe the problem motivated in Section 1 and its base nomenclature. Figure 1 shows the power system under analysis at an instant t. The demand $P_{j,t} \forall j \in n, t \in \mathcal{T}$ at the connection bus j is a consequence of the transmission system and the operation point defined by $p_{i,t} \forall i \in \mathcal{N}, t \in \mathcal{T}$. Monthly, the MUST efficiency is evaluated over the maximum verified for $P_{j,t}$.

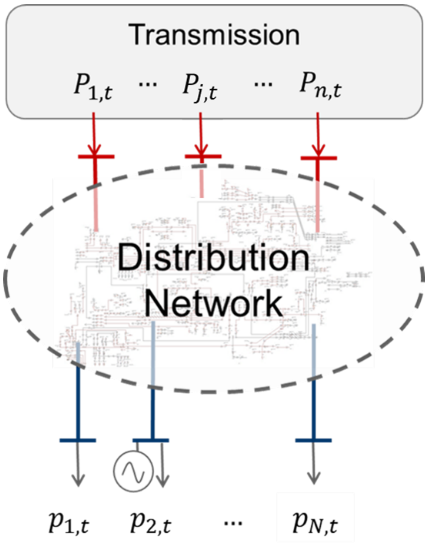

Figure 1: Power system.

The demand and IRG uncertainties mentioned in Section 1 produce a variability in $p_{i,t} \forall i \in \mathcal{N}, t \in \mathcal{T}$, whose variables are treated as random. To carry out this approach, a set of demand scenarios should be defined for each $i \in \mathcal{N}$ and $t \in \mathcal{T}$. In this case, statistical methods can simulate a scenario set regarding the history demand and climatic variables. Then, a power flow study considering the occurrence of contingencies can provide scenarios for $P_{j,t}$. The challenge of this process is to simulate the demand in a high frequency t for a four-year period (the MUST contract horizon). A proposal to tackle this issue is presented in Saavedra et al. [2018] and Bodin et al. [2018].

Given the scenarios for $P_{j,t}$, the monthly maximum demand at each connection bus can be characterized. The $\tilde{P}_{j,m,a} \forall m \in \mathcal{M}, a \in \mathcal{A}$ represents the set Ω of scenarios for the monthly maximum demand at a connection bus j. In the next sections, we assume that $\tilde{P}_{j,m,a}$ is known for a given j and incorporates the uncertainties sources.

3. Cost Function for the MUST Contract

As said in Section 1, there are regulatory rules for the MUST contract, which defines the cost to be paid by the DISCOs. Considering a connection bus j, the total cost can be divided into two components: the fixed cost and the variable cost. The fixed cost $c^F_{j,m,a}$ is deterministic and a function of the MUST $M_{j,a}$ and the TUST $T_{j,a}$, as in (1).

$$c^F_{j,m,a} = M_{j,a} T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A} \tag{1}$$

The components of the variable cost are a function of $\tilde{P}_{j,m,a}$, thus, they are stochastic as well. Defining those components requires subtracting $M_{j,a}$ from the maximum demand. In (2)-(4) the cost components for maximum demand $\tilde{c}^{MD}_{j,m,a}$, for undercontracting $\tilde{c}^{UC}_{j,m,a}$, and for overcontracting $\tilde{c}^{OC}_{j,a}$ are defined, respectively.

The $\tilde{c}^{MD}_{j,m,a}$ in (2) represents the rule that establishes that, besides penalties, the monthly cost is defined considering the maximum between $M_{j,a}$ and $\tilde{P}_{j,m,a}$. If $\tilde{P}_{j,m,a} \leq M_{j,a}$ only the fixed cost $c^F_{j,m,a}$ is paid. Otherwise, when $\tilde{P}_{j,m,a} > M_{j,a}$, the additional variable cost $\tilde{c}^{MD}_{j,m,a}$ is applied to consider the amount $\tilde{P}_{j,m,a} - M_{j,a}$ through the tariff $T_{j,a}$. The monthly penalty $\tilde{c}^{UC}_{j,m,a}$ stands for the undercontracting rules. If $\tilde{P}_{j,m,a}$ is grater than 110% of $M_{j,a}$, then $\tilde{c}^{UC}_{j,m,a} > 0$, otherwise it equals zero. The cost accounting referent to the amount $\tilde{P}_{j,m,a} - 1.1 M_{j,a}$ is done through three times the regular tariff $T_{j,a}$, characterizing the financial penalty. Analogously, the annual penalty

$\tilde{c}^{OC}_{j,a}$ contains the overcontracting rules. If the annual maximum $\tilde{P}^{MAX}_{j,a}$ is less than 90% of $M_{j,a}$, then $\tilde{c}^{UC}_{j,a} > 0$, otherwise it equals zero. The cost of the amount $0.9M_{j,a} - \tilde{P}^{MAX}_{j,a}$ is calculated using 12 times the regular tariff $T_{j,a}$, which generates the penalty.

$$\tilde{c}^{MD}_{j,m,a} = \max[0, \tilde{P}_{j,m,a} - M_{j,a}]T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A} \tag{2}$$

$$\tilde{c}^{UC}_{j,m,a} = \max[0, \tilde{P}_{j,m,a} - 1.1M_{j,a}]3T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A} \tag{3}$$

$$\tilde{c}^{OC}_{j,a} = \max[0, 0.9M_{j,a} - \tilde{P}^{MAX}_{j,a}]12T_{j,a}, \forall a \in \mathcal{A} \tag{4}$$

The total annual cost $\tilde{c}^{T}_{j,a}$ for the MUST contract is defined in (5).

$$\tilde{c}^{T}_{j,a} = \tilde{c}^{OC}_{j,a} + \sum_{m=1}^{12} (c^{F}_{j,m,a} + \tilde{c}^{MD}_{j,m,a} + \tilde{c}^{UC}_{j,m,a}), \forall a \in \mathcal{A} \tag{5}$$

4. Risk Analysis

Given the cost functions defined in Section 3, in this section the risk analysis that will lead the decision under uncertainty is presented. We define risk as the probability of a given cost to be greater than the expected. The more conservative the decision strategy is, the lower this probability and the higher the fixed costs. In this paper, the conditional value at risk (CVaR) Street [2010] and Artzner et al. [1999] will be used as a metric to measure the risk associated with a MUST decision. For a set of cost scenarios with the same probability, the $CVaR_\alpha$ can be defined as the average between the $\alpha\%$ worst (higher) scenarios. For this paper it will be used $\alpha = 95\%$.

In order to obtain the optimal $M_{j,a}$, for a connection bus j and a given year a, a convex combination of $CVaR_\alpha(.)$ and expected value $E(.)$ of the cost $\tilde{c}^{T}_{j,a}$ will be minimized. The parameter $\lambda \in [0, 1]$ is a choice of the decision maker (DISCO) and should reflect the desired risk aversion. The higher the λ, the more conservative is the risk profile.

$$\lambda CVaR_\alpha(\tilde{c}^{T}_{j,a}) + (1 - \lambda)E(\tilde{c}^{T}_{j,a}) \tag{6}$$

Additionally, we propose another risk parameter to reflect the contract policy of the DISCO related to penalty exposure. As said above, the MUST optimization will minimize the risk measure of the costs scenarios. As consequence, $M_{j,a}$ will be also minimized for a given optimization feasible set. This feature naturally avoids overcontracting situations. Thus, only the undercontracting penalty will be considered. The idea is to provide the DISCO the possibility to limit the $CVaR_\alpha$ of the undercontracting costs $\tilde{c}^{UC}_{j,m,a}$ as presented in (7). In other words, the DISCO will be able to define, in average, the maximum to be paid monthly for the worst penalty scenarios. To make this limit intuitive and easier to define, it is parametrized in the fixed cost $c^{F}_{j,m,a}$, and the coefficient μ is the risk parameter to be chosen.

$$CVaR_\alpha(\tilde{c}^{UC}_{j,m,a}) \leq \mu c^{F}_{j,m,a} \tag{7}$$

5. MUST Decision Under Uncertainty

This section presents the optimization model that includes all the aspects discussed in the previous sections. The proposed model (8)-(22) is a multi-period stochastic linear programming that decides the MUST $M_{j,a}$ for the contract horizon $\mathcal{A}$ and the connection bus j.

$$\min_{M_{j,a \in \mathcal{A}}} \sum_{a \in \mathcal{A}} \left[\lambda \left(z_a + \frac{1}{1-\alpha} \sum_{\omega \in \Omega} b_\omega \sigma_{a,\omega} \right) + (1 - \lambda) \sum_{\omega \in \Omega} b_\omega c^{T}_{j,a,\omega} \right] \tag{8}$$

subjected to:
CVaR constraints for the objective function

$$\sigma_{a,\omega} \geq c^T_{j,a,\omega} - z_a, \forall a \in \mathcal{A}, \omega \in \Omega \tag{9}$$

$$\sigma_{a,\omega} \geq 0, \forall a \in \mathcal{A}, \omega \in \Omega \tag{10}$$

Cost definition constraints

$$c^T_{j,a,\omega} = \sum_{m \in \mathcal{M}} c^F_{j,m,a} + c^{MD}_{j,m,a,\omega} + c^{UC}_{j,m,a,\omega}, \forall a \in \mathcal{A}, \omega \in \Omega \tag{11}$$

$$c^F_{j,m,a} = M_{j,a} T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A} \tag{12}$$

$$c^{MD}_{j,m,a,\omega} = d^{MD}_{m,a,\omega} T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{13}$$

$$c^{UC}_{j,m,a,\omega} = d^{UC}_{m,a,\omega} 3T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{14}$$

Maximum demand rule constraints

$$d^{MD}_{m,a,\omega} \geq P_{j,m,a,\omega} - M_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{15}$$

$$d^{MD}_{m,a,\omega} \geq 0, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{16}$$

$$M_{j,a} \geq 0, \forall a \in \mathcal{A} \tag{17}$$

Undercontracting rule constraints

$$d^{UC}_{m,a,\omega} \geq P_{j,m,a,\omega} - 1.1 M_a, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{18}$$

$$d^{UC}_{m,a,\omega} \geq 0, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{19}$$

μ parameter constraints

$$z^{UC}_{m,a} + \frac{1}{1-\alpha} \sum_{\omega \in \Omega} b_\omega \sigma^{UC}_{m,a,\omega} \leq \mu M_{j,a} T_{j,a}, \forall m \in \mathcal{M}, a \in \mathcal{A} \tag{20}$$

$$\sigma^{UC}_{m,a,\omega} \geq (d^{UC}_{m,a,\omega} 3T_{j,a}) - z^{UC}_{m,a}, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{21}$$

$$\sigma^{UC}_{m,a,\omega} \geq 0, \forall m \in \mathcal{M}, a \in \mathcal{A}, \omega \in \Omega \tag{22}$$

In (8), the risk measure defined in (6) is minimized, having $M_{j,a}$ as the decision variable. The $CVaR$ formulation for minimization problems used in (8)-(10) and (20)-(22) can be found in Street [2010]. The constraints (11)-(14) include the cost definitions presented in Section 3. The constraints (15)-(19) reproduce the max operator used in (2)-(3). Finally, constraints (20)-(22) include the risk parameter μ that limits the CVaR of penalty cost scenarios.

6. Case Study

This section presents a case study using the methodology proposed in the Section 5. The data and results presented in this section are from a real Brazilian DISCO[1]. Figure 2 exhibits a simulation (four years ahead) of 200 scenarios of $\tilde{P}_{j,m,a}$ at a connection bus j. This simulation was performed using a statistical model that considers historical data and climatic variables. All the scenarios have the same probability of occurrence. These set Ω of scenarios was used to obtain the results below.

The first test evaluates the effects of the risk parameter μ on the optimal M^*_a. The Figure 3 presents three risk aversion profiles: risk neutral ($\mu = 1$), intermediary ($\mu = 0.1$), and conservative

[1]The vision, results and conclusions presented in this article do not represent the perspective of the mentioned DISCO, being the sole and exclusive responsibility of its authors.

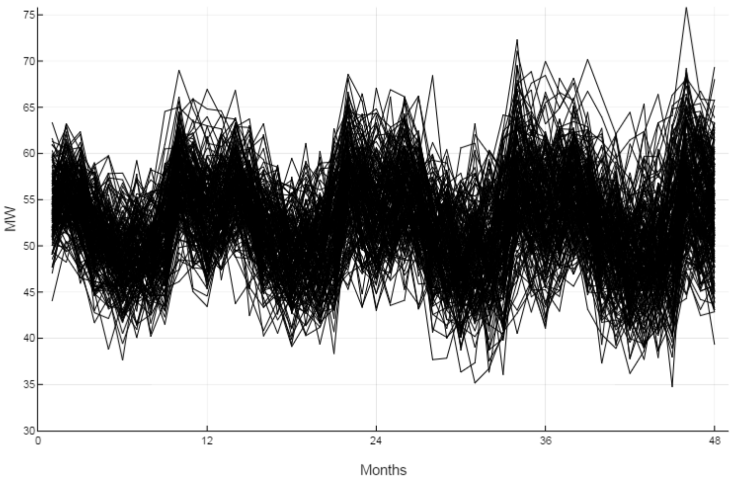

Figure 2: Set of 200 scenarios (four years ahead) of $\tilde{P}_{j,m,a}$.

($\mu = 0$). The scenarios are represented, month by month, by its maximum, minimum, and 5%, 50% and 95% quantiles. For all M_a^* results, the parameter λ is fixed on 0.5. Firstly, observe that the M_a^* for $\mu = 0$, which implies in no penalty cost scenarios, is not above the scenarios' maximum because of the 10% tolerance defined in 3. This tolerance is used by the optimization problem to reduce the total costs.

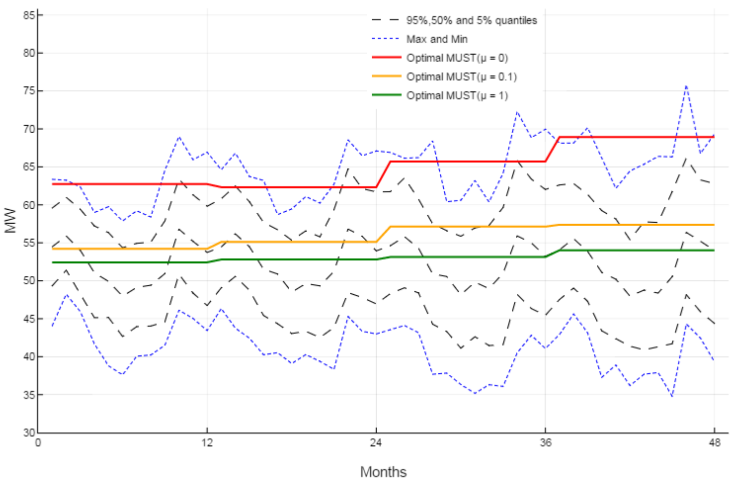

Figure 3: Optimal MUST for different μ choices.

The results show that a more conservative approach leads to a higher M_a^* and, as consequence, a higher fixed cost $c_{j,m,a}^{F*}, \forall m \in \mathcal{M}, a \in \mathcal{A}$. This can be seen as an insurance payment. The higher the fixed cost (i.e., the higher M_a^*), the smaller the exposure to penalty scenarios. This relation can be verified in Figure 4, which presents a risk analysis for several parameter μ values for the first year of the contract horizon. If $\mu = 0$, there is no penalty and the higher fixed cost occurs. As μ grows, and the penalty occurrence is allowed, an increase of the $CVaR$, the average of the penalty cost scenarios ($\tilde{c}^{UC}$), and the penalty probability is verified. On the other hand, the fixed cost decreases. This tendency continues until $\mu \cong 0.15$, in which all the curves in Figure 4 stabilize.

The same risk parameter evaluation is done to λ. The Figure 5 presents three risk aversion profiles: risk neutral ($\lambda = 0$), intermediary ($\lambda = 0.5$) and conservative ($\lambda = 1$). For all results, the

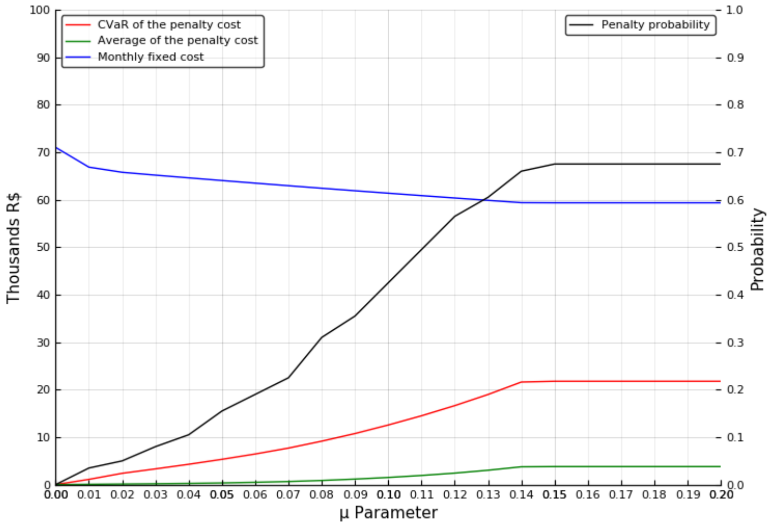

Figure 4: Risk analysis for different μ parameter choices.

parameter $\mu = 10$, so only the λ effect is present. Firstly, comparing the results in Figures 3 and 5, one can see that the risk aversion control through μ is stronger than through λ. However, the M_a^* is sensible to both parameters, which justifies the inclusion of μ and λ in the optimization problem. Observing the M_a^* results, the more conservative approach results in the higher M_a^* and the higher fixed cost $c_{j,m,a}^{F*}, \forall m \in \mathcal{M}, a \in \mathcal{A}$.

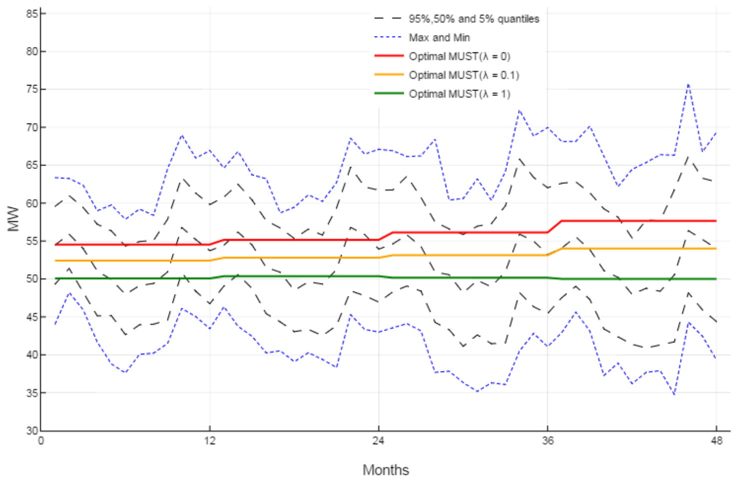

Figure 5: Optimal MUST for different λ choices.

7. Conclusions

This paper presented support decision methodology to define a optimal MUST contract for DISCOs. The methodology takes into account the uncertainties that impact the maximum demand at the connection buses, as the demand behavior and the presence of internal renewable generation (IRG). The proposed framework creates the possibility to establish MUST contract policy, which provides important features to the decision process. First, all the parameters can be DISCO as a company, and not based on the subjective perceptions of one or more employees. Also, the overall decision process can reproduced for auditing purposes or after-contracting analysis. Lastly, the proposed methodology permits to test different kinds of contract strategy, always considering the maximum demand uncertainty at each connection bus. The results presented showed a coherent relation between each a risk profile choice and the optimal MUST contract and respective costs.

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