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A long-term risk management tool for electricity markets using swarm intelligence

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ABSTRACT

This paper addresses the optimal involvement in derivatives electricity markets of a power producer to hedge against the pool price volatility. To achieve this aim, a swarm intelligence meta-heuristic optimization technique for long-term risk management tool is proposed. This tool investigates the long-term opportunities for risk hedging available for electric power producers through the use of contracts with physical (spot and forward contracts) and financial (options contracts) settlement. The producer risk preference is formulated as a utility function (U) expressing the trade-off between the expectation and the variance of the return. Variance of return and the expectation are based on a forecasted scenario interval determined by a long-term price range forecasting model. This model also makes use of particle swarm optimization (PSO) to find the best parameters allow to achieve better forecasting results. On the other hand, the price estimation depends on load forecasting. This work also presents a regressive long-term load forecast model that make use of PSO to find the best parameters as well as in price estimation. The PSO technique performance has been evaluated by comparison with a Genetic Algorithm (GA) based approach. A case study is presented and the results are discussed taking into account the real price and load historical data from mainland Spanish electricity market demonstrating the effectiveness of the methodology handling this type of problems. Finally, conclusions are dully drawn.

1. Introduction

Long-term contractual decisions are the basis of an efficient risk management. On a vertical integrated electricity market, price variations were often minimal and heavily controlled by regulators. In this structure, electricity price evolution is directly dependent on the government's social and industrial policy. The price forecasting was mainly focused on the underlying costs (namely, fuel prices and technological innovation among others). Any price forecasting made on this basis was tended to be over the long-term. With electricity markets re-regulation process, aforementioned features have been changed dramatically. Thus, ownership on this activity sector becomes private rather than public or a mixture of both. Moreover, pools or power exchanges have been introduced for wholesale trading.

Price forecast on re-regulated electricity markets is a hard task due to the high pool price volatility. Charge characteristics (seasonality, mean-reversion and load stochastic growth) and producer's characteristics (technology, generation availability, fuel prices, technical restrictions, import/export, etc.) are at the origin of high price volatility in electricity markets. Several techniques have been used for short-term price forecast in electricity markets. In [1], artificial intelligent tools were proposed to forecast spot prices, namely, a combination of neural networks and fuzzy logic. Indeed, neural networks have now an extensive use in load and in price forecast [2–6]. Fuzzy techniques mixed with neural networks are used to predict possible prices range [7,8]. Stochastic processes are also used to analyze time series as ARIMA processes [9]; a class of stochastic processes was used to predict next-day electricity prices in mainland Spanish and in California markets. In [10], two forecasting tools based on dynamic regression and transfer function models are presented.

However, for the market agents who want to maximize their profits and simultaneously to practice the hedge against the market price volatility, the use of forward, futures and options contracts become a constant in developed electricity markets. Those types of contracts have a maturity that goes from 1 year to several years in the future, turning more difficult the decision process related to contracts establishment if they are not supported with a robust price forecast methodology.

Due to long delivery periods of the contracts described above that make more sense to forecast the market price mean value

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for each month. Moreover, contractual positions should be continuously review (say once a month) or each time the agent needs to consider the ones already locked. After review references, we assure that this problem has not been treated deeply in the scientific literature. It is not a good practice in risk management to take contractual decisions based exclusively on a single forecasted value. In Section 3 is presented a different approach for long-term price forecast. The proposed methodology, based on regression model, aims to find a maximum and a minimum monthly Market Clearing Price (MCP) average for a programming period, with a desired confidence level α. This method makes use of statistical information extracted from mainland Spanish market historical data. Due to the complexity of the problem, the parameters are obtained using the meta-heuristic PSO [11–14]. This model could also be applied to forecast electricity market price for more than 1 year.

The long-term price forecast makes use of the monthly load average forecast for the same period. For this reason, the authors have also developed a long-term monthly load forecast using PSO.

For both models, long-term price and load forecast, PSO performance has been evaluated by comparing it with a GA.

To find best portfolio for a market agent and particularly for producers, which allow to hedge against market price volatility and simultaneously increasing their profits. Ref. [15] proposes solutions for electricity producers in the financial risk management field for electric energy contract evaluation using efficient frontier as a tool to identify the preferred contract portfolio. In [16] a decision-support system based on stochastic simulation, optimization and multi-criteria analysis, is applied to electricity retailer. A statistical study of direct and cross hedging strategies using futures contracts in an electricity market is presented in [17,18]. A framework to obtain the optimal bidding strategy of a thermal price-taker producer on a pool-based electric energy market is presented in [19]. The optimal involvement in a futures electricity market of a power producer to hedge against the risk of pool price volatility using conditional Value-at-Risk as risk measure is presented in [20]. A risk-constrained stochastic programming framework to decide which forward contracts the retailer should sign and at price it must sell electricity and its expected profit is maximized at a given risk level has been proposed in [21]. A technique based on stochastic programming to optimally solve the electricity procurement problem faced by large consumer is presented in [22]. Ref. [23] analyzes the impact of the degree of unavailability of the generating unit on its forward contracting decisions.

In this work, long-term risk management tool makes use of a long-term price range forecast has been developed and discussed. The proposed long-term risk management tool aims to find the best portfolio in function of the risk aversion factor (λ) of the producer, which maximizes the expected return and, simultaneously, allows hedging against market price volatility. To achieve this, the decision-support system maximizes a mean-variance utility function (U) of the total return (π).

In this methodology, a portfolio model based on utility functions instead of option pricing models [24,25] has been used, because the financial markets on electricity markets are incomplete (hedging instruments unavailable). Uncertainties associated to generators availability, fuel prices, technical restrictions and weather conditions, turn difficult, if not impossible, to find a replicating portfolio, which perfectly matches the future spot market payoffs. The power market exercise by some agents is also a source of uncertainty. Moreover, several markets around the world are still on their recent stage, with a small number of financial tools for an efficient risk management. Another issue in power markets is that electricity cannot be stored for later use. Consequently, the strategy of buying the asset today to offset part of future losses does not apply. The closest strategy is to buy a forward or futures contracts. Therefore, the delivery price of these mentioned contracts should be equal to the expected spot market price for the delivery period, which not always happens. Consequently, the electricity markets are not "complete" (i.e., any desired financial hedges are not available at a price), so risk attitudes and mean-variance frontiers are still relevant.

PSO and GA algorithm performance are evaluated to show PSO is a very successful meta-heuristic technique for solving this problem in particular.

The paper is organized as follows: Section 2 presents a long-term load forecasting model, followed by a case study applying aforementioned model. Section 3 presents a long-term price forecasting method, followed by the application of this method to a case study. Section 4 shows the problem formulation of the risk management. Finally, Section 5 draws the relevant conclusions.

2. Long-term load forecast

The proposed method is based on regression models. The main goal of this methodology is to find the regression parameters that minimize the absolute error to considered load historical data for monthly time interval for 1-year period.

Load pattern is not complex as the revealed by the market price. To find the best regression parameters, load historical data of the previous 2 years has been used.

2.1. General description

The optimization problem that allows to find the best regression parameters for the monthly load average is given by (1) and (2):

$$\begin{aligned} &\text{Min} \sum_{i=1}^{12} |C_{i,j} - \hat{C}_{i,j}| \\ &\text{Subjected to :} \\ &\hat{C}_{i,j} \geq 0 \end{aligned} \tag{1}$$

with

$$\hat{C}_{i,j} = \omega_{1,i} \cdot C_{i-1,j} + \omega_{2,i} \cdot C_{i,j-1} + \omega_{3,i} \cdot C_{i,j-2} \tag{2}$$

2.2. Penalty function

To solve the optimization problem, PSO has been used to find the best solution.

To satisfy constraint (2) for each period i, the penalization function (3) has been added to the optimization problem:

$$p_f = \begin{cases} 0 & \text{if } \hat{C}_{i,j} \geq 0 \\ e^{100 \times a^2} - 1 & \text{otherwise} \end{cases} \tag{3}$$

where

$$a = |\hat{C}_{i,j}| \tag{4}$$

2.3. PSO and GA parameters

Tables 1 and 2 present the parameters of PSO and GA algorithm, respectively. Besides the optimum parameters of PSO method, being also dependent on the fitness function. Experimentations show that the number of evaluations used cannot compromise the results and allow to achieve the best solution.

2.4. Case study

This test case uses a real load historical data (2001–2006) that has been extracted from the mainland Spanish market has been used to forecast the monthly load average for the year 2007. Fig. 1