



Applying modern portfolio theory for a dynamic energy portfolio allocation in electricity markets



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ABSTRACT

In deregulated electricity markets, a Generation Company (Genco) has to optimally allocate their energy among different markets including spot, local and bilateral contract markets. Modern portfolio theory (MPT) allows a Genco to achieve their goal by maximizing their profit and decreasing their associated risk. Combining MPT with an adequate tool to forecast energy prices makes it possible for a Genco to vary the optimal allocation of their portfolio even on a daily basis. This paper proposes two MPT models, one applying the Mean Variance Criterion (MVC) and the other one the Conditional Value at Risk (CVaR). The MPT models are combined with a generalized autoregressive conditional heteroskedastic (GARCH) prediction technique for a Genco to optimally diversify their energy portfolio. The two models are applied to a real PJM electricity market showing not only their capabilities but also useful comparisons between them in order to help decision makers to use them as decision-aid tools.

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1. Introduction

New energy markets undergoing deregulation induce participants to face increasing competition and volatility, where the objective of a Generation Company (Genco) is to maximize their profit while minimizing their associated risk. In an electricity market, risk results from uncertainty due to different factors including price volatility, unit outages, transmission congestion and demand changes.

In particular, the risk of price fluctuations can be considered one of the most important risks in spot electricity markets. However, there are other sources of risk such as demand changes and changes in intermittent generation. These other sources of risk could definitely affect the price fluctuations possibly making prices more volatile, and this behavior is captured by the GARCH model applied in this research. In order to deal with price risk, market participants can apply risk management techniques to control risk while maximizing their profits, where diversification is a financial approach to control risk. Diversification in energy trading means that energy

is traded among different markets to minimize the total risk. In this work, the diversification technique applied is called energy portfolio optimization.

Various risk management methodologies have been applied in electricity markets in the past. Previous works have demonstrated that forward contracts provide hedging to minimize risk of spot prices for market participants [1–4]. The usefulness of applying future contracts in electricity markets and the valuation of different contracts have also been considered before [5–11]. Decision analysis and Monte Carlo simulation have been applied to find the optimal contract combination [12–15].

Among the existing models that deal with risk in electricity markets, bidding portfolio optimization of a Genco is one of the most important due to its economic consequences. When bidding, a Genco decides its optimal portfolio to sell its energy, usually including day-ahead market, future market and others. In this regard, there are two techniques that have received a lot of attention: mean-variance models based on the Markowitz portfolio, and CVaR models. The main difference between them is the way in which they define risk. Mean-variance models penalize risk in the objective function, where the measure of risk is the variance of the profit, and CVaR models use their own risk definition based on the probability of reaching a minimum profit. There are other techniques based on the Value at Risk (VaR) that have already been implemented in electricity markets [16–19]. However, they do not enjoy the same

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Notation*Indices*

i	Index of assets/non-local areas
k	Index of trading time periods/scenarios
t	Index of time periods

Parameters

$r_p(t)$	MVC rate of return of the risky portfolio in period t
$r_b(t)$	MVC rate of return of the risk-free asset in period t
r_c	MVC risk of the complete portfolio
A	MVC factor representing the decision maker's preference or aversion to risk
γ	CVaR risk coefficient describing the attitude toward risk in the utility function
l_i	CVaR lower bound applied to each asset of the portfolio
u_i	CVaR upper bound applied to each asset of the portfolio
β	Confidence level of the CVaR
$\lambda_{i,k}^S$	Spot price of non-local area i in the k^{th} trading interval
$\lambda_{i,k}^B$	Contract price signed with customers of area i in the k^{th} trading interval
a, b, c	Fuel consumption coefficients
λ_k^F	k^{th} trading interval's fuel price
p_k	Output power of generators
M	Number of trading intervals
m	Number of scenarios

Variables

$w_i(t)$	MVC weights of the asset returns
$y(t)$	MVC fraction of the complete portfolio allocated to the risky assets
α	VaR for the specified portfolio
CVaR	Conditional Value at Risk
$x(t)$	CVaR portfolio's asset allocation
y_k	CVaR returns of each asset of the portfolio in scenario k
z_k	Auxiliary variable to calculate the CVaR

Functions

$E[r_p(t)]$	MVC expected value of the risky portfolio in period t
$\sigma^2[r_p(t)]$	MVC variance of the risky portfolio in period t
$\sigma_i^2(t)$	MVC variance of the return of asset i in period t
$\sigma_{ij}(t)$	MVC covariances of the returns for assets i and j for period t
$U[y(t)]$	Utility function

uses the third order moment of profit (skewness) to apply it to the PJM market, where the Pareto frontier is also constructed.

Regarding CVaR models, Wang et al. [26] use both VaR and CVaR in a simple example with four markets: spot, day-ahead, monthly and yearly contracts. Sun et al. [27] use a CVaR model to optimize the portfolio of a Genco in the Nordpool. Lorca and Prina [28] produce a more complete portfolio example for the medium term using scenario trees to account for uncertainties in spot prices where the contracts can be either forward or CfD (contract for differences). Other techniques have used robust optimization combined with VaR as a measure of risk [29] for wind farms and storage devices bidding in an electricity market.

Although price variations produce significant changes in the bidding performance of Gencos, none of the MPT models presented, MVC and CVaR, has used a rigorous method to determine the prices based on previous data. To account for this, time series models where price volatility at a certain hour depends on the volatilities of previous hours can be applied. This is achieved by GARCH models, where conditional volatilities can be obtained based on previous values of volatilities. The volatilities conditioned by previous values are the cornerstone of a real dynamic bidding model. To the best of our knowledge, this has not been studied yet.

In view of the above, this paper deals with the trading problem of a Genco that applies an optimal trading approach to maximize its profit taking into account the associated risk factors. We apply MPT approaches [30,31] considering risk aversion of the decision makers and the statistical correlation among different outcomes. Moreover, we apply the GARCH methodology to forecast the day-ahead electricity market prices, enabling a Genco to change its portfolio every day, maximizing profit and decreasing risk. The comparison of two MPT methods, MVC and CVaR, that make use of GARCH to forecast prices, is the main aim of this paper.

The paper is organized as follows. Section 2 describes the two MPT approaches (MVC and CVaR) and the GARCH methodology applied for price forecasting is shown in Section 3. Section 4 presents the overall asset algorithms combining the MPTs and GARCH modeling. Section 5 presents numerical results showing the applicability of the models to the PJM market. Section 6 states the main conclusions.

2. Day-ahead portfolio optimization models

Modern portfolio theory (MPT) includes an analysis and evaluation of rational portfolio choices based on risk-return trade-offs and efficient diversification [30]. MPT measures the risk of an asset, evaluating the trade-off between risk and expected return, forming an optimal asset portfolio.

MPT states that an asset cannot be selected based exclusively on characteristics related to only one security (asset). An investor has then to consider how each security co-moves with all other securities. When co-movements are taken into account, the portfolio can be obtained having the same expected return and less risk than a portfolio obtained when ignoring the interactions among the securities. The formulation of the portfolio optimization problem [20,32] is introduced in the next two subsections.

2.1. Mean Variance Criterion (MVC) model

A portfolio considers a combination of potential assets where n of them represent risky assets and 1 (the $n + 1$ asset) represents a risk-free asset. Given each asset's rate of return, r_i , the return of the risky portfolio, r_p , is the weighted average of the component

properties as CVaR since VaR is not convex and not subadditive, for example.

Previous MVC models based on mean-variance have allocated energy between spot and contract markets in real markets. One example can be found in Liu and Wu [20], where the authors use MPT to allocate energy of risky and non-risky assets in the PJM market. Price forecasts are based on average values and covariances among spot markets are considered. Similar models are explored in Liu and Wu [21] and Mathuria and Bhakar [22]. In Liu and Wu [23] the authors use the VaR in the PJM market. In Gölğöz and Atmaca [24] a similar MVC model is used for the Turkish electricity market with different generation technologies. A related and more sophisticated model, named MVS (mean-variance-skewness) model [25]

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