Quantifying price risk of electricity retailer based on CAPM and RAROC methodology

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Abstract

In restructured electricity markets, electricity retailers set up contracts with generation companies (GENCOs) and with end users to meet their load requirements at agreed upon tariff. The retailers invest consumer payments as capital in the volatile competitive market.

In this paper, a model for quantifying price risk of electricity retailer is proposed. An IEEE 30 Bus test system is used to demonstrate the model. The Capital Asset Pricing Model (CAPM) is demonstrated to determine the retail electricity price for the end users. The factor Risk Adjusted Recovery on Capital (RAROC) is used to quantify the price risk involved. The methodology proposed in this paper can be used by retailer while submitting proposal for electricity tariff to the regulatory authority.

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1. Introduction

The restructured power sector has caused electricity to be a market commodity. These markets are classified as physical market or financial market [1]. The retailer enters in contract with GENCOs in this open market. Entering such contract the electricity retailer commits himself to the obligation to purchase and deliver electricity at an agreed upon price. Hence, one must quantify the price risk related to such electricity retailer contracts. Unlike the retailers for the other types of commodities the electricity retailer have very limited role but they are required to provide value added services to the consumers. They are the financial intermediary who acquires the electricity from the GENCOs and resell it to different types of consumers. Providing future load requirements accurately to the suppliers is an integral part of these supply contracts. In [2] the analysis of retailer’s strategies for determining forward loads is demonstrated. A framework for comparing and analyzing price risk for electricity retailers is presented in [3]. Financial institutions use Value at Risk (VaR) analysis for portfolio management. In [4] application of this approach in case of restructured electricity markets of “Tasmania” is demonstrated.

In restructured environment, the open access encourages the private entities to invest in generation. The Schedule Coordinator (SC) coordinates the generation by submitting offer in bilateral transactions with the Grid. In [5] a bidding scheme is proposed based on the actual cost of generation to minimize risk in profit of such generation companies.

The generation companies need to do optimal bidding in day-ahead power markets to maximize their profit. A robust method for self-scheduling of such generation companies based on VaR is discussed in [6]. This methodology is used to reduce the risk resulting from exposure to fluctuating local marginal prices. In [7] the risks of the energy service company (ESCO) are identified and the contract specifications and the VaR are evaluated. In [8] techno-economical model of an electric energy service provider in Spain is proposed.

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If asset returns are positively correlated, portfolio variance increases and if asset returns are negatively correlated then it reduces portfolio risk. The total portfolio risk can be thought of as the sum of systematic and unsystematic risks. A capital asset pricing model (CAPM) is a simple relationship that links the return on particular stock with the return on portfolio made up of the entire market [9]. The CAPM model is widely used as measure of risk in the portfolio investment. The model can be appropriately used for electricity retailers who invest the payment (capital) received from end users in GENCOs in competitive market.

Different portfolio management techniques are used to quantify the risk in case of electricity markets. An application of efficient frontier, one of the portfolio management tools to assess the risk associated in expected payoff of GENCOs is presented in [10,11]. The upcoming challenge for researchers in electricity market is to quantify the risk associated in case of various market participants. The RAROC (Risk Adjusted Return on Capital) methodology, most commonly used financial risk measure is discussed in [12,13]. The use of RAROC methodology to develop Monte Carlo Simulation based model to quantify risks related to electricity contracts of retailers is presented in [14].

In this paper, the Capital Asset Pricing Model (CAPM) is demonstrated to determine the retail electricity price for the end users. The factor Risk Adjusted Recovery on Capital (RAROC) is used to quantify the price risk involved. The IEEE 30 Bus test system is used to demonstrate the results [15]. The rest of the paper is organized as follows: In Section 2 fundamentals of CAPM and RAROC approach are discussed. The formulation and results are given in Section 3. The main conclusions of this work are summarized in Section 4.

2. CAPM and RAROC methodology

2.1. Capital Asset Pricing Model (CAPM)

CAPM model is basically applied to the portfolio investment in security market. In finance, the CAPM model applied with assumption that for a particular capital how and in what proportion the investor should invest in portfolios so that the returns are maximized. In electricity market the retailer purchase electricity in the market and its price risk is influenced by the behaviour of market participant, network constraints and load. The capital of retailer depends on load and consumer price. For maximum returns the consumer price i.e. capital generation of retailer should be adequate and optimum. Hence, while deciding consumer tariff or while giving tariff proposals to regulator, retailer can use CAPM model as a guideline.

The CAPM is one of the models in investment modelling. It addresses to reasonable price for an asset. The investor in such case gets returns (profit) depending upon variation in the asset prices. The risk involved in such investment is quantified in terms of variance and for any such fund (capital) total variance of the return must be minimized. Prices of assets under heavy demand will go up and prices of assets under light demand will go down. The price changes will affect the estimates of asset returns. Therefore, investors will recalculate their optimal portfolios. The process continues until demand matches supply; that is, until there is an equilibrium. If the market portfolio is efficient, then the expected return \( E[r_i] \) of any asset \( i \) satisfies Eq. (1). The \( (E[r_m] - r_f) \) is called the Expected Excess Rate of Return of asset \( i \). It indicates the amount by which the rate of return exceeds the risk-free rate. The \( (E[r_m] - r_f) \) is called the Expected Excess Rate of Return of the market portfolio.

\[
E(r_i) = \beta_i(E(r_m) - r_f) + r_f 
\]

where

\[
\beta_i = \frac{\sigma_{i,m}}{\sigma_m^2} 
\]

\( \beta_i \) is normalised covariance between \( i \)th asset and total portfolio returns.

\( r_f \) is risk free rate of return

\( r_m \) is rate of market return

The CAPM model depicts that the expected excess rate of return of an asset is proportional to the expected excess rate of return of the market portfolio and the constant of proportionality factor is \( \beta \) which is given by \( \beta_i = \sigma_{i,m}/\sigma_m^2 \). The \( \beta_i \) is a normalized version of the co-variance of an asset with respect to the market portfolio. The excess rate of return for an asset is directly proportional to its co-variance with the market.

The aggressive assets/companies or highly leveraged companies have high betas and on the other hand, conservative companies whose performance is unrelated to the general market behaviour are expected to have low betas. If \( \beta = zero \) then the asset is completely uncorrelated with the market. In such case as per the CAPM model, the \( E[r_i] \) will be \( r_f \). Even if the asset is risky, its expected rate of return is the risk-free rate. There is no premium for risk with large covariance. In such case, the risk must be diversified by using proper strategy while investing. If \( \beta < 0 \), then \( E[r_i] < r_f \) and the asset may have very high risk (as measured by its \( \sigma \) and expected rate of return will be even less than the risk-free rate. Such an asset reduces the overall portfolio risk when combined with the market. In such case, the investors are willing to accept the lower expected value for this risk-reducing potential. Such assets provide a form of insurance.

The CAPM model has different concept of quantifying the risk of an asset from \( \sigma \) to \( \beta \). In the proposed methodology, the CAPM model is applied to the electricity market. The electricity retailer gets payments from the consumer, which he invests as a capital in different GENCOs. The capital depends on the market price, load and the consumer per unit price of electricity (all other costs not taken into account). The retailer can quantify the risk in his business by applying CAPM model for the different per unit prices (tariff).
In the proposed work, per unit price is determined based on the CAPM model and risk quantification is done using RAROC factor.

2.2. Risk adjusted recovery of capital (RAROC)

RAROC, a risk quantifying factor, is defined as the ratio of expected return and economic capital (EC). The EC is the amount of money, which is needed to secure the investor’s survival in worst-case scenario. EC captures all types of risk and often calculated as Value at Risk (VaR). The VaR is quantile of the profit and loss (P and L) distribution. It measures the maximum amount of money one can lose at given confidence level in specified period. In case of banking, VaR is widely used to quantify risk. However, in case of electricity markets VaR is not an appropriate measure of risk because when VaR is used, it is implicitly assumed that it is possible to close the risky position at any time in future or forward market. This is not practically possible in case of electricity markets. Hence, better approach to quantify risk is Cash Flow at Risk (CFaR) than VaR. The VaR is based on the future prices and on the other hand, CFaR is based on the spot prices.

The electricity retailers buy electricity in the spot market from GENCOs for which they invest return (capital) generated out of consumer payment. The traditional performance measures to evaluate the performance of an investment company are mainly RoI – Return on Investment and RoE – Return on Equity. RoI compares the return to the amount of invested money; on the other hand, RoE considers only the invested equity capital.

\[
\text{RoI} = \frac{\text{Return}}{\text{Invested capital}} \quad (2)
\]

\[
\text{RoE} = \frac{\text{Return}}{\text{Invested equity capital}}
\]

The shortcomings of these concepts are (1) they are accounting-based and do not reflect the real performance (2) neither do they consider risk nor is it possible to determine the denominator for single business units from the firm’s balance sheet. The RoI, RoE and similar measures do not consider risk. Suppose there are two investments, both have the same rate of return but one of them can be much riskier. Therefore, the return has to be compared to the risk undertaken. Otherwise, it will be impossible to compare the performances of two different investments or business units. There is a need of an efficient risk management and the ability to compare different business unit’s Risk. The Risk Adjusted Performance Measures (RAPMs) are being used in the banking business.

The Economic Capital ensures enough capital for the survival in worst case. As explained previously CFaR rather than VaR should be used to determine the Economic Capital. The relative CFaR is defined as the difference between the mean and the \( \alpha \)-quantile of the profit and loss distribution. Thus, the RAROC for an electricity retailer becomes

\[
\text{RAROC} = \frac{\text{Expected profit}}{\text{CFaR}}
\]

\[
\text{RAROC} = \frac{\text{E}[\text{profit}]}{\text{E}[\text{profit}] - q_\alpha[\text{profit}]}
\]

The \( \alpha \)-quantile is the loss that will occur at given probability level (Fig.1). For to calculate \( \alpha \)-quantile normal distribution of profit and loss vector is plotted as shown in Fig. 1. Once we get the value of loss from the normal distribution, we can calculate value of the loss using the average and standard deviation of profit/loss vector.

Let the consumer’s fixed retail price be \( k \), the deterministic load at hour \( h \) is \( P_{dh} \), total generation is \( P_{gh} \) and the stochastic spot price of 1 MW h at hour \( h \) be Market Clearing Price MCP\(_h\). Then the profit for each hour is the difference between the retail and the spot price per MW h times the amount of energy. Let the cash flow in hour \( h \) be \( P_{rh} \) and since \( MCP_h \) is stochastic, \( P_{rh} \) is stochastic.

\[
E[P_{rh}] = E[kP_{dh} - MCP_hP_{gh}]
\]

To get the entire profit, calculate a sum over all hours from the starting hour \( \tau \) of the contract until the end hour \( T \) and discount the cash flows to the actual point in time i.e. hour, denoted as hour \( h_0 \). For simplicity, if we take constant risk free interest rate \( r \) with continuous compounding then the profit function of retailer is given by;

\[
E[\text{profit}] = E \left[ \sum_{h=1}^{T} e^{-r(h-\tau)}P_{rh} \right]
\]

\[
= E \left[ \sum_{h=1}^{T} e^{-r(h-h_0)}E[((k)(P_{dh})) - ((MCP_h)(P_{gh}))] \right]
\]

Using Eq. (6) one can calculate the profit i.e. the sum of all cash flows at every hour. The risk factor RAROC is determined to quantify risk in rate of return.

3. Formulation and results

Even though the prices in the competitive market are volatile, most of the times the retailer charges to end user at fixed rates. The normal trend is to charge consumer at
average price but it does not mean for this price the retailer’s business is optimum and at minimum price risk. Hence, there is need of proper methodology based on which the retailer company can estimate non-discriminative fixed price. The assumption made while developing model is flat rate tariff for consumer and the distribution charges, taxes, ancillary service charges and other charges are not taken into consideration.

3.1. Test system

IEEE 30 bus test system is used and MATPOWER™ is used to get OPF solution for given load, generator data, and other network constraints [15]. The cost curve constants of six generators are given in Table 1.

The load at different buses is varying hour to hour. The total average load assumed on the 30 Bus systems is 181.31 MW, the maximum is 217 MW and the minimum is 127.04 MW. Fig. 2 gives the total load variation for the 334 h (2 weeks).

For different per hour load condition the OPF is run. Table 2 summarizes the marginal generation costs of six generators and the highest marginal generation cost is MCP. The average MCP is $153.68, the maximum is $262.5 and the minimum is $82.68.

### Table 1
Generator cost curve constants

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Bus no.</th>
<th>$pa^2 + (bp)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0.0175</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>0.025</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>0.0625</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>0.025</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>0.0834</td>
</tr>
</tbody>
</table>

3.2. Algorithm

The algorithm used for the solution is as follows

- Using load and system data run OPF and get set of generation schedule for six generators and marginal prices of generators.
- Set the maximum marginal price as MCP for that hour.
- Repeat the above procedure for all 334 h. (Assumed time horizon in present case)
- Determine the non-discriminative consumer price using CAPM and quantify price risk using risk factor RAROC.

3.3. CAPM model

3.3.1. Model description

The quantification of business of the Retailer Company and determination of consumer price is done using CAPM model. The capital of retailer is consumer payment which is dependent on load and consumer price. The consumer price can be the average price in given time horizon. But it cannot be very high in regulated market as consumer welfare is a main concern of market regulator. The expected rate of return of retailer from one generator is determined using CAPM model is as follows

$$E(r_g) = \beta (E(r_m) - r_f) + r_f$$

where

- $E(r_g)$ = expected rate of return from generator
- $r_f$ = risk free rate of return
- $E(r_m)$ = expected rate of market return of each portfolio i.e. each generator and is a ratio of generator mean profit and mean of total profit.
- $\beta$ = normalized co-variance between profit form generator and total profit of retailer.

3.3.2. Results

For different per unit prices (150–168 $/MW h), rate of return for each generator, $\beta$ and average rate of return from generators are determined. From (7), the generator rate of return is dependent on the $\beta$, $r_m$ and on assumed risk free rate of return. In present case, risk free rate of return is assumed 4%, 6% and 8% (refer Table 3–5).

The average rate of return compared to risk free rate must be independent of the risk free rate assumed. From the results tabulated it is implicated that for the price of 161.225/MW h the average rate of return is maximum and is independent of risk free rate of return. For the retailer price of 161.225/MW h the rate of return from GENCOs is maximum. Thus, for the price 161.225/MW h, CAPM model gives best rate of asset returns for the portfolio (GENCOs) in which the retailer company invests its payment (capital) received form consumer. Tables 3–5 give the expected rate of return and $\beta$ for different prices.
To get the entire profit earned in the 334 h we just have to sum over all hours from the starting hour \( h_0 \) until the 334th hour. Discount the cash flows to the actual point of time, which is hour one. In the present case, we have assumed constant risk free interest rate \( r_f \) (4%, 6%, and 8%) with continuous compounding. The \( \beta \)-quantile is determined using standard MATLAB\textsuperscript{TM} function. For all 334 hours different consumer price is assumed, say $150, $152 and so on. The prices assumed are relative to the average price of $153.68 for assumed data and time horizon. For very low prices compared to average price, the

3.4. RAROC factor

3.4.1. Methodology to determine RAROC factor

The retailer’s capital is the payment he receives from load at fixed retailer price. He invests this capital in the generation companies. In the present model, he invests in six-generation companies. The generation companies are paid at MCP, which is volatile spot price. Thus, the retailer’s profit (expected return) is stochastic. Fig. 3 gives the variation of MCP compared to the average MCP of $153.68.
Table 5
\( \beta \) of different generators and price and expected return of retailer from each generator (\( r_t = 8\% \))

<table>
<thead>
<tr>
<th>Price $/MW h</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( \beta_4 )</th>
<th>( E(rg_1) )</th>
<th>( E(rg_2) )</th>
<th>( E(rg_3) )</th>
<th>( E(rg_4) )</th>
<th>Ave.( E(rg) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0.2577</td>
<td>0.2713</td>
<td>0.1465</td>
<td>0.0649</td>
<td>0.1155</td>
<td>0.123</td>
<td>0.060</td>
<td>0.059</td>
<td>0.068</td>
</tr>
<tr>
<td>152</td>
<td>0.2566</td>
<td>0.2701</td>
<td>0.1469</td>
<td>0.0647</td>
<td>0.1167</td>
<td>0.123</td>
<td>0.060</td>
<td>0.059</td>
<td>0.068</td>
</tr>
<tr>
<td>154</td>
<td>0.2526</td>
<td>0.2689</td>
<td>0.1474</td>
<td>0.0645</td>
<td>0.1179</td>
<td>0.123</td>
<td>0.060</td>
<td>0.059</td>
<td>0.068</td>
</tr>
<tr>
<td>156</td>
<td>0.2546</td>
<td>0.2677</td>
<td>0.1479</td>
<td>0.0643</td>
<td>0.1190</td>
<td>0.124</td>
<td>0.060</td>
<td>0.059</td>
<td>0.068</td>
</tr>
<tr>
<td>158</td>
<td>0.2535</td>
<td>0.2664</td>
<td>0.1484</td>
<td>0.0641</td>
<td>0.1202</td>
<td>0.124</td>
<td>0.060</td>
<td>0.059</td>
<td>0.067</td>
</tr>
<tr>
<td>160</td>
<td>0.2525</td>
<td>0.2652</td>
<td>0.1490</td>
<td>0.0639</td>
<td>0.1214</td>
<td>0.125</td>
<td>0.060</td>
<td>0.059</td>
<td>0.066</td>
</tr>
<tr>
<td>160.5</td>
<td>0.2522</td>
<td>0.2649</td>
<td>0.1491</td>
<td>0.0638</td>
<td>0.1217</td>
<td>0.125</td>
<td>0.060</td>
<td>0.059</td>
<td>0.065</td>
</tr>
</tbody>
</table>

\( ^a \) For the price of 161.22$/MW h the average rate of return is maximum.

RAROC is determined using
\[
\text{RAROC} = \frac{E[\text{profit}]}{E[\text{profit} - g]} = \frac{E[\text{profit}]}{E[\text{profit} - q]} \quad (9)
\]

3.4.2. Results

Table 6 gives the profit, Value at Risk (VaR), average profit and RAROC factor for different consumer prices. When the consumer price is $161.22 the risk-adjusted return for retailer is maximum.

The profit, Value at Risk (VaR), average profit and RAROC for different consumer prices and risk free rate are given in Table 6. The risk factor RAROC is optimal when retailer price is 161.22$/MW h.

4. Discussion

There are other financial tools used to quantify the financial performance of the business. Cost-benefit analysis (CBA), traditionally used technique, typically involves the concept of time value of money. This is usually done by converting the future expected costs and benefits to a present value. In order to calculate the present value of money,
The important cost-benefit indicators are (1) Present Value of benefits (PVB), (2) Present value of Cost (PVC), (3) Net Present Value (NPV), which is difference between PVB and PVC, and (4) Benefit to Cost Ratio (BCR). The BCR is also interpreted as the ratio of return on investment (ROI). If there are number of profit making units under one business unit, the CBA does not take into account rate of returns from individual profit making units and rather it takes into account returns of overall business unit. It also does not take into account risk in returns apart from accounting returns based on the risk free rate to calculate present value.

The shortcomings of CBA are (1) they are accounting-based and do not reflect the real performance (2) neither do they consider risk. The RAROC factor, which is also based on the risk free return rate, (defined in Section 2.2) takes into account the Value at Risk i.e. while calculating the returns the worst possible loss in returns is taken into account. In this respect the RAROC is better option from the risk in the returns point of view. In the era of restructuring, the retailers are involved in the financial transactions with multiple GENCOs via bilateral contracts which make it essential to value the business of retailer for returns point of view from each GENCO. The CAPM model (defined in Section 2.1), is also based on the comparing returns with reference to the risk free rate. The CAPM gives rate of returns of retailer from the each individual GENCO which is necessary while going for bilateral contracts.

Finally, the retailer’s business is quantified from both the return on investment point of view and the risk on returns which is one of the unique feature of the methodology proposed in this paper (refer Tables 3–6).

5. Conclusion

In certain market mechanisms, the retailers get fixed rate of return, subject to regulator approval, while they purchase the power at volatile market clearing prices. Work presented in this paper helps the retailers in deciding their quotes for the retail price of the consumers, under this market structure. In this case, the volatile energy prices are not reflected on the consumer side and hence, price risk involved in retail business is high.

Rate of return for the retailer’s business is calculated using CAPM model. The risk on returns is quantified using RAROC factor. The VaR parameter is also monitored for the retailer which is further useful for risk quantification.

Thus, the use of the above tools can provide a guideline for retailers to quote, and regulators to fix the consumer tariff.

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