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Strategic evaluation of bilateral contract for electricity retailer in restructured power market

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A R T I C L E I N F O

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A B S T R A C T

In a competitive market scenario, consumers make payments for the consumption of electricity to retailers at fixed tariff. The retailers buy power at the Market Clearing Price (MCP) in spot market and/or through bilateral contract at agreed upon price. Due to these different modes at buying and selling ends, the retailers are faced with an involved task of estimating their payoffs along with the risk-quantification. The methodology presented in this paper gives a range of bilateral quantity and associated price for a retailer to ensure risk-constrained payoff. The exercise is carried out with a single retailer in the market as well as for a case of competition amongst two retailers. Risk is quantified using Risk Adjusted Recovery on Capital (RAROC). The problem is evaluated to get a range of bilateral quantity to be quoted for a particular bilateral price at fixed tariff of loyal load and fixed value of switching load. This summary combined with risk-averseness of the retailer leads him to make a judicial choice about bilateral transactions such that it leads to a risk-constrained payoff.

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1. Introduction

A market is classified as physical market or financial market [1]. A retailer enters in contract with GENCOs in this open market. Entering into such contract, the electricity retailer commits himself to the obligation to purchase and deliver electricity at an agreed price. Hence, one must quantify the price risk related to such electricity retailing contracts. Unlike the retailers for the other types of commodities, the electricity retailers have a very limited role but they are required to provide value added services to the consumers. They are the financial intermediaries who buy electricity from GENCOs and sell it to consumers.

A procedure to evaluate electricity supply contracts for retail consumers who have to make a choice of retail supply agency is given in [2]. An evolutionary approach based on the risk management for restructuring an electricity industry to maintain balance between the extremes of vertical integration and direct liberalization of wholesale and retail markets is presented in [3]. In [4], 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 [5]. The generation companies need to do optimal bidding in day-ahead power market to maximise their profits. A robust method for self-scheduling of such generation companies based on Value at Risk (VaR) is discussed in [6]. This methodology is used to reduce risk resulting from exposure to fluctuating local marginal prices. In [7], risks of the energy service company (ESCO) are identified, and the contract specifications and the VaR are evaluated.

Understanding the concepts of risk management in financial markets is now necessary for the ESCOs/retailers and various regulatory bodies. The price volatility is generally high and hence, the risk managers need to implement new methods and instruments to manage energy price risks. While instruments such as forward contracts, swaps, future contracts, and options are designed to reduce price risk, the instruments themselves have associated risks and require their own control mechanisms. While using derivatives, portfolio risk management is of great importance. The role of an ESCO is intermediate financial and servicing entity which does its business by purchasing power from spot market/exchanges, through bilateral contract and/or by way of competitive bidding with other ESCO or consumers, and/or it may have its own generation to supply part of the total load. In [8], optimal bidding strategies with risks for Load Serving Entities (LSEs) to participate in competitive electricity markets are presented. In this approach, stepwise bidding functions and pay-as-bid settlement protocols are utilized. A normal probability distribution function is used to describe the bidding behaviours of competitors and the issue of constructing optimal bidding strategies for LSEs is formulated as a multi-objective stochastic optimization problem.

New techniques have been used by the ESCOs to manage price risk such as Value at Risk (VaR), Risk Adjusted Return on Capital (RAROC), Cash Flow at Risk (CFaR). Many of these tools are based

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on statistical methods of determining the probability of a certain risk event and are meant to assist the risk manager in measuring risk of portfolio and maintain it at certain acceptable levels. RAROC, the most commonly used financial risk measure, is discussed in [9,10]. The use of RAROC methodology, to develop Monte Carlo Simulation based model to quantify risk related to electricity contracts of retailers, is presented in [11]. Recently in [12], a methodology based on the stochastic optimization to evaluate optimal price and quantity for retailer electricity contract is developed. The problem is solved for setting up of contracts on both supplier and end-user sides to maximise profit at acceptable level of settlement risk. In [13], risk-constrained stochastic programming framework is demonstrated to decide the forward contract price, quantity and selling price of the retailer. The Conditional Value at Risk is used to quantify risk. In [14], power portfolio optimization problem with risk management is presented. The optimization problem is solved for retailer for various instruments to maximise profit. In [15], Monte Carlo Simulation based optimal day-ahead scheduling scheme is presented so as to minimise total cost of purchase. In [16], electricity procurement and planning of LSEs is solved based on the modern investment theory. The proposed model optimises purchase cost at minimised risk taking into account volatilities of spot prices. In [17], a model is presented to evaluate an optimal electric power and energy selling price that maximises profit of a service provider. The problem is solved to study impact on the profit due to factors such as price strategy, discount on tariffs, and demand elasticity.

There is a need to ensure proper design and functioning of the markets. Recently, researchers have made significant contributions towards changes in the market design in view of restructuring of power sector. The important research areas related to the energy market design are surveyed in [18]. A price-taker seller purchases power via bilateral contract in auction. In [19], a mathematical model for allocation of the seller's offers into the auctioned products with maximising financial benefit is developed. The generation scheduling in restructured market is based on the offers and bids to buy and sell energy. Generally, generating unit's reliability in not taken in to account while scheduling. In [20], scheduling problem is demonstrated to obtain the equilibrium between reliability and price bidding strategy of generating units.

This paper presents risk-constrained methodology for evaluation of the bilateral contract of retailer. The risk-constrained analysis gives framework to decide as to which bilateral contract retailer should opt. The risk is quantified using RAROC. The exercise is carried out for two *cases*, viz, single retailer in the market and competing retailers. The rest of the paper is organized as follows: Section 2 gives an overview of market model that is used to demonstrate the results. The fundamentals of RAROC are given in Section 3. Section 4 gives the problem formulation. Section 5 gives results for no-competition case and Section 6 gives results for the competition case. The main conclusions are summarized in Section 7.

2. Overview of market model

Fig. 1 shows one retailer case where it purchases power from the spot market and sells to consumers at a fixed tariff. The power hub/spot market is a day-ahead one and the retailer purchases power at volatile MCP. The risk in payoff is characterised by the volatile MCP [21]. In order to hedge against the volatile prices the retailer may enter into bilateral contract as shown in Fig. 2. In this model, the retailer caters the load assigned to it by virtue of purchase of electric power from spot market at volatile MCP and through bilateral contract. The bilateral contract of retailer can be hourly basis or fixed for short duration of couple of days.

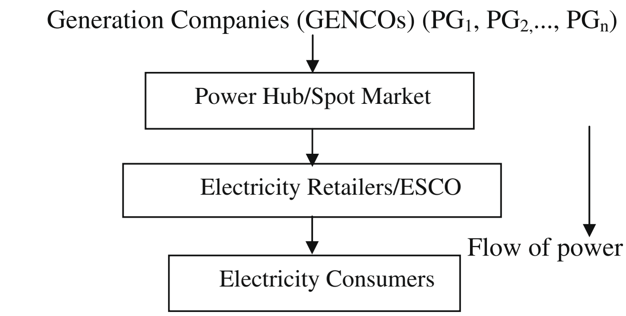

Fig. 1. Model for electricity retailing without competition.

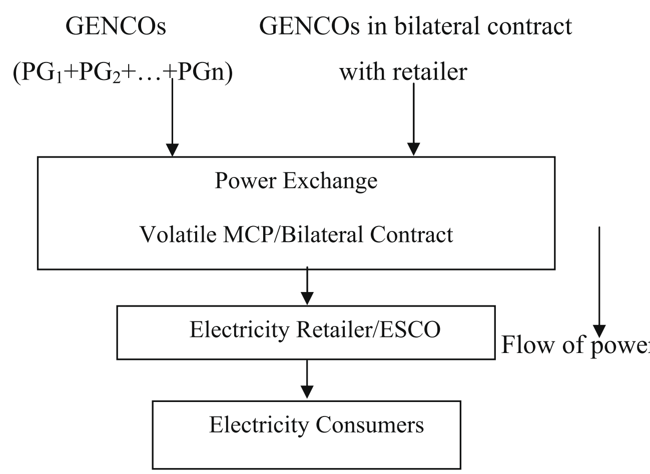

Fig. 2. Modified model for electricity retailing without competition.

Once the bilateral quantity and price are fixed the retailer has an obligation to execute the contract.

Fig. 3 shows model for competition case involving two retailers. The loads are categorised into loyal and switching type. Out of the total hourly load, part of load is assumed as switcher, i.e. the one who shifts from one retailer to another depending upon quoted prices. This is only for financial settlement for a predefined contract period. The rest of the load is assumed to be loyal to each individual retailer. The loyal load pays at fixed tariff which is set by the regulator for a longer period of year or so. The switching load is in contract for fixed period in the range of weeks or couple of months. The contract of the switching load is again revised at the expiry of the period. Thus, the switching load bid submitted by the retailers has a validity period during which switching loads will be in contract. Once the retailer wins switching load bid, the switcher load has an obligation to pay at that bid. The range of bilateral contract for which the payoff is risk constrained can be used by the retailer in order to enter into bilateral contract on hourly basis or for longer duration. The model shown in Fig. 3 is used in this paper to present a methodology for evaluating range of bilateral quantity and associated price from retailers' perspective for no-competition and competition cases.

3. Fundamentals of RAROC

Economic Capital is the amount of money which is needed to secure the investor's survival. EC captures all types of risks and is often calculated using Value at Risk (VaR). The VaR is α quantile of the profit and loss (P&L) distribution. Risk Adjusted Recovery on Capital (RAROC), a risk quantifying factor, is defined as the ratio

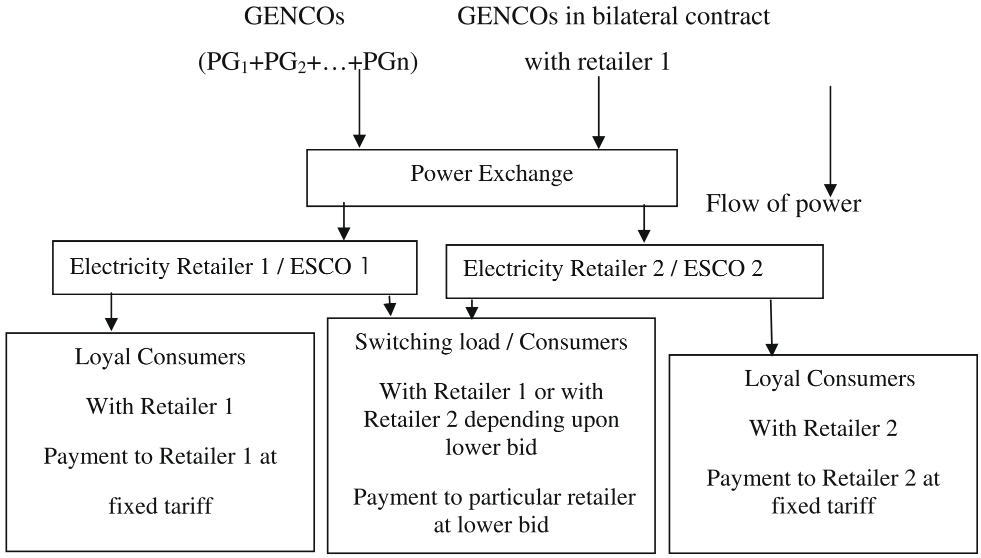

Fig. 3. Modified model for electricity retailing with competition.

of expected return and Economic Capital (EC). It gives comparison between the expected return and economic capital and hence, if it is higher, it means that the expected returns are enough to cover the EC which is the capital that must be available in case of all types of risks. Thus, if retailer takes decision based on RAROC about bilateral quantity and associated price then its payoffs are risk constrained. RAROC can be expressed in terms of different variables as follows:

$$\mathrm{RAROC} = \frac{\text{Expected Return}}{\text{Economic Capital}} = \frac{\mathrm{E(Payoff)}}{\mathrm{E(Payoff)} + (\mathrm{VaR})} \tag{1}$$

$$\mathrm{RAROC} = \frac{\mathrm{Mean(Payoff)}}{\mathrm{Mean(Payoff)} + (\alpha\,\text{Quantile of Payoff Distribution})} \tag{2}$$

$$\mathrm{RAROC} = \frac{\mathrm{Mean(Payoff)}}{\mathrm{Mean(Payoff)} - 1.65(\text{Standard Deviation of Payoff})} \tag{3}$$

A risk-averse investor will go for maximised RAROC factor as risk in business is minimised, and a retailer, who is ready to take risk will go for RAROC equal to unity, i.e., it is prepared to take risk against high value of payoff. If RAROC is less than unity then it means net payoff is negative, and the negative payoff means loss. It will be just higher than unity when payoff is very high. In such a case the business is very much in profit (high mean payoff) and α quantile value is far less compared to mean (average) payoff. The economic capital and mean payoff are comparable. This is a high profit high risk situation.

Energy trading companies/retailers are intermediate agencies between consumers, GENCOs and power market. They are responsible of capturing and evaluating the risks occurring when electricity is traded in spot and future markets. The electricity consumers do not buy electricity at an exchange and rather they make direct contracts with electricity retailers at a fixed per-unit price. Entering in such a contract, the electricity retailers commit themselves to the obligation of delivering electricity for a fixed price. This means that they have to bear several kinds of risks. Thus, the business of retailers is like capital investment in electricity purchase via different contracts in the exchange and they also provide other services to consumers. The capital generated is at a fixed consumer tariff, and the returns are risky due to volatility in market prices. Hence, RAROC is an appropriate risk measure for the retailer to quantify risk before taking any decision on contractual obligation in the market.

Significance of RAROC

RAROC < 1.0 and positive: The average payoff is negative i.e. loss.
RAROC < 1.0 and negative: Average payoff is less than α quantile.
RAROC $\gg$ 1.0: High risk coverage and payoff is risk-constrained.
RAROC just greater than 1.0: High profit and high risk condition.

4. Problem formulation

The model used is as shown in Fig. 3. The retailer is having fixed share of loyal load. In case of one retailer case (no-competition), the retailer gets payment from loyal load at fixed tariff. The retailer purchases power from spot market at volatile MCP and through bilateral contract. The problem is formulated to evaluate the bilateral quantity and associated price such that the payoff is risk-constrained. The risk in payoff is quantified using RAROC. The load, MCP, and fixed tariff are the prerequisite data. In case of competition, the loyal load with the retailer remains loyal and the switching load is assumed to be with a particular retailer for fixed duration of week or so. The retailer, who bids lower, wins the switching load. Each retailer has its own estimation about the probable switching load bid of other retailers. The problem is formulated to evaluate range of bilateral quantity and associated price, with prerequisite data of load, MCP, loyal load tariff, switching load, and the probable switching load bid.

5. Evaluation of bilateral contract for electricity retailer in case of no-competition

Even though the prices in the competitive market are volatile, retailer charges to end user at fixed rate. The tariff is regulated by regulator and it is fixed for a comparatively longer duration. The spot prices are volatile and the retailer can maximise risk-constrained payoff through bilateral contract. Thus, the retailer needs a guideline for the range of bilateral contract to hedge against volatile MCP. The retailer may execute bilateral contract on hourly basis or for particular fixed duration. The problem presented in this paper is based on the historical price and load data of 2 weeks. The formulation to evaluate range of bilateral contract is presented based on the risk-constrained payoff determined using RAROC.

5.1. Sample calculation of RAROC

The fundamentals of RAROC are discussed in Section 3. In [11,18], RAROC is used to quantify risk of retailer in an electricity market. The model shown in Fig. 2 is used to demonstrate sample calculation of RAROC. A case of no-competition is considered. The bilateral price is deterministic variable and is evaluated at fixed tariff and bilateral quantity. For different values of bilateral prices, RAROC is estimated and a plot of variation of RAROC against bilateral price is obtained. For each case, payoff of retailer is evaluated. The range of bilateral price within which retailer should bid to ensure risk-constrained payoff is decided on the basis of RAROC. The maximised RAROC gives retailer risk-constrained payoff, and if RAROC is positive and just greater than unity then it ensures maximum payoff. Values less than one are ignored as in such cases the payoff is negative (loss). For a negative RAROC value, α quantile of payoff is more than mean payoff, i.e. economic capital is negative (hence ignored). This sample calculation presents typical variation of RAROC as a function of bilateral price. The analysis carried out shows similar variation for fixed price and variable bilateral quantity.

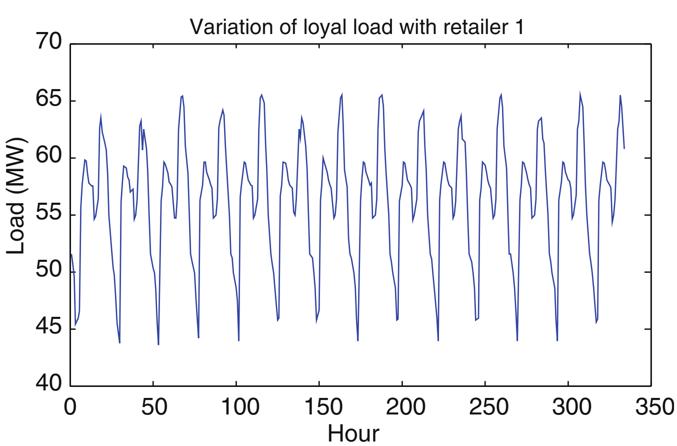

Fig. 4. Variation of loyal load with retailer.

Fig. 4 gives the loyal load variation for 336 h (2 weeks) of retailer. The maximum load is 103.52 MW, minimum is 66.58 MW and average load is 88.76 MW. Fig. 5 gives the variation of MCP with an average value of \$49.86. The maximum MCP is \$62.24 and the minimum is \$36.36.

Let the consumer's fixed retail price be P, and P_{dh}, P_{gh}, and MCP_h be the load, total generation and MCP at hour h, respectively. The bilateral contract for 'BG_h' generation at 'BP_h' price and hour h may be fixed for a day or may be varied on hourly basis depending upon the contractual conditions. The per hour cash flow (payoff) P_{rh} is given by the difference between payment received and payment done (4).

$$E[P_{rh}] = E[P(P_{dh}) - MCP_h(P_{gh} - BG_h) - BG_h \times BP_h] \tag{4}$$

To get the entire payoff, calculate sum over all hours from the starting hour τ of the contract until the end hour T and discount the cash flow to the starting hour. For simplicity, if we take constant risk free interest rate r with continuous compounding then the payoff of retailer is given by,

$$E[\text{Payoff}] = E\left[\sum_{h=\tau}^{T} e^{-r(h-\tau)} P_{rh}\right] \tag{5}$$

If the time horizon is short the discounting is not taken into account. The time horizon of historical data taken in the exercise carried out is 336 h. The mean payoff is the expected payoff as the probability assigned to each hourly payoff is one. Since losses are neglected, $P_{gh} = P_{dh}$. The mean payoff for 336 h is given by,

$$\begin{aligned} \text{Mean}[\text{Payoff}] &= \text{Mean}[\sum_{h=1}^{336}[((p)(P_{gh})) \\ &\quad - ((MCP_h)(P_{gh} - BG_h)) - (BG_h \times BP_h)]] \\ &= [p(\text{Mean}(P_{gh})) - \text{Mean}[(MCP_h)(P_{gh})] \\ &\quad - [\text{Mean}(MCP_h)\text{Mean}(BG_h))] - \text{Mean}[((BG_h)(BP_h))] \end{aligned} \tag{6}$$

The standard deviation in payoff is given by,

$$\begin{aligned} \text{Std}(\text{Payoff}) = {} & [(p^2\text{var}(\text{load})) + \text{var}((\text{load} - BG_h) \times \text{MCP}) \\ & + \text{var}(BG_h \times BP_h) - 2p\,\text{cov}[(\text{load}), ((\text{load} - BG_h) \\ & \times \text{MCP}) - 2p\,\text{cov}(load, (BG_h \times BP_h) \\ & + 2\text{cov}((\text{load} - BG_h) \times \text{MCP}), (BG_h \times BP_h)]^{0.5} \end{aligned} \tag{7}$$

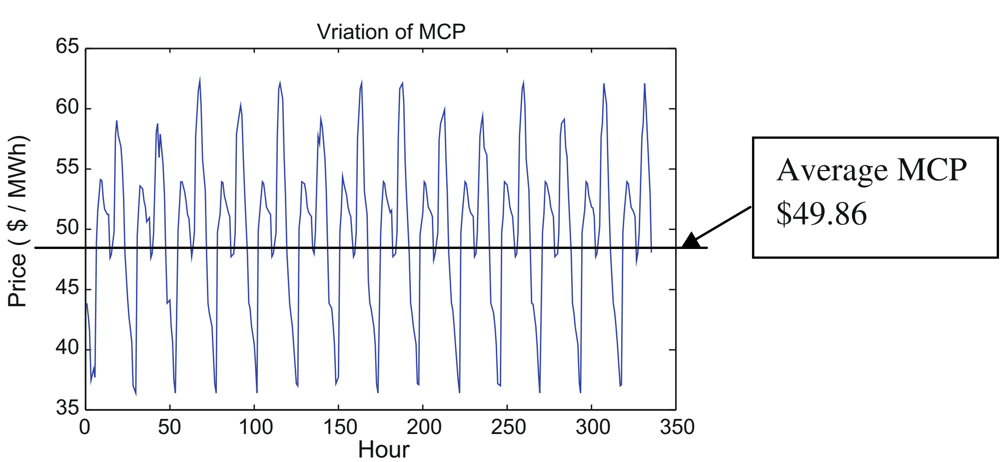

Fig. 5. Variation of MCP compared to average MCP of \$49.86.

Table 1
System data.

Mean(load) MW	Mean((load − BG) × MCP) BG = 35 MW, P = $59.506	Variance (load)	Variance ((load − BG) × MCP)	Covariance (load,((load − BG) × MCP))
88.76	2737	72.7	573220	6416

If RAROC is maximised, average payoff and standard deviation are comparable and hence, economic capital, (Mean(Payoff) − 1.65(Standard deviation of payoff)), is far less than mean payoff. Thus, risk is minimised and payoff is risk-constrained. The other approach is payoff maximisation. In this case the mean payoff is high compared to the standard deviation. The economic capital is comparable to the mean payoff. This case occurs when the RAROC is just greater than unity. The payoff for this case is maximised and the risk is high.

Let, the tariff of loyal load = $59.506 and the fixed bilateral quantity for 336 h = 35 MW. For the historical data of MCP and load shown in Figs. 4 and 5, bilateral price is varied and RAROC is determined using 3, 6, and 7. The two values of bilateral prices are of importance, one for maximised RAROC and the other for RAROC just greater than unity. The system data used to evaluate mean (6) and standard deviation (7) is given in Table 1. The variation of RAROC and bilateral price is given in Table 2 and Fig. 6.

The denominator of (3) is equated to zero to get the point of maximum value of RAROC. Solving using system data of mean, variance and covariance given in Table 1, we get BP = $60.50 and $84.91. If BP is taken as $84.91 (greater than the fixed tariff) the payoff is negative. The minimised value of RAROC can be evaluated by equating first derivative of RAROC w.r.t. bilateral price to zero.

With reference to Table 2, retailer may go for bilateral contract of quantity of 35 MW for the range of bilateral price of $40–$60.50 to ensure risk-constrained payoff. The retailer can take decision depending upon its discretion of risk. The next section presents step-by-step procedure to evaluate bilateral contract for single-retailer case.

Table 2
Variation of RAROC w.r.t. BP.

Bilateral contract price (BP) ($/MWh)	RAROC
45.00	1.79
50.00	2.16
55.00	3.21
56.00	3.70
57.00	4.47
58.00	5.86
59.00	9.07
60.00	24.82
60.50	**991.00**
61.00	−24.02

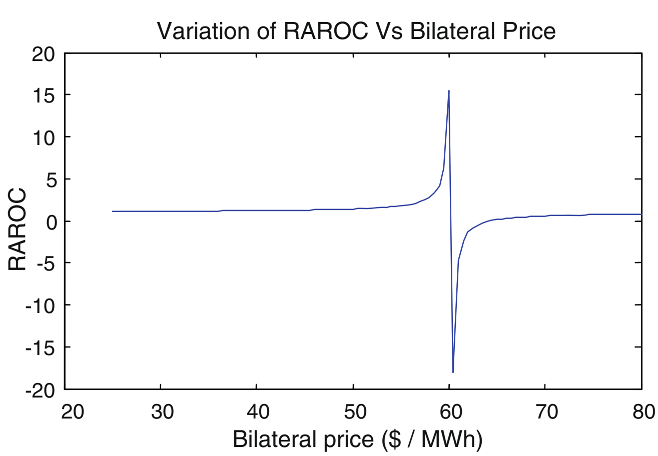

Fig. 6. Variation of RAROC with bilateral price.

5.2. Solution and results

Consider a market model shown in Fig. 2. The retailer has particular loyal consumers and it purchases power from spot market at MCP and through bilateral contract. The problem is solved to get range of bilateral quantity and price as deterministic variable for known values of load, MCP and tariff.

The procedure to get the solution is as follows:

- Load and MCP data for 336 h (2 weeks) is prerequisite.
- Evaluate maximum and minimum values of load and MCP.
- Lower and upper limits of bilateral price and quantity are set with reference to minimum and maximum price and load values in two weeks time, respectively.
- The bilateral price and quantity is varied in the range between lower and upper limits, and average payoff, standard deviation in payoff and RAROC are calculated using 6, 7, and 3.
- The values of bilateral contract, for which RAROC $\geqslant 1$, are taken and scattered plot of bilateral price and quantity is obtained.
- Referring to scattered plot, the retailer can bid bilateral contract on an hourly basis fixed for a period of couple of weeks or so. This bilateral contract ensures that the retailer gets risk-constrained payoff.
- The algorithm is evaluated for different values of fixed tariff.

The system data of load and MCP is given in Section 5.1 and the model used is given in Fig. 3. The distribution charges, taxes, ancillary service charges and other charges, although are not taken into consideration while developing model, can be suitably accounted.

The retailer may be interested to maximise its payoff instead of going for risk-constrained payoff. Table 3 gives the range of bilateral contract for the tariff of $59.50. The tabulated results show that the standard deviation minimisation does not mean that the payoff is maximised. The advantage of the RAROC based

Table 3
Bilateral price and quantity for the tariff of $59.50.

Tariff = $59.50, bilateral price varied between $25 and $80, bilateral quantity varied between 25 and 55 MW					
	RAROC	Standard deviation $	Average payoff $	Bilateral price $/MWh	Bilateral quantity MW
Minimum RAROC	1.11	137.15	2166.90	**25.00**	**55.00**
Maximum RAROC	63479.00	265.23	437.63	**60.50**	**34.00**
Maximum payoff	1.11	137.15	2166.90	25.00	55.00
Minimum standard deviation	0.79	137.15	−858.07	80.00	55.00

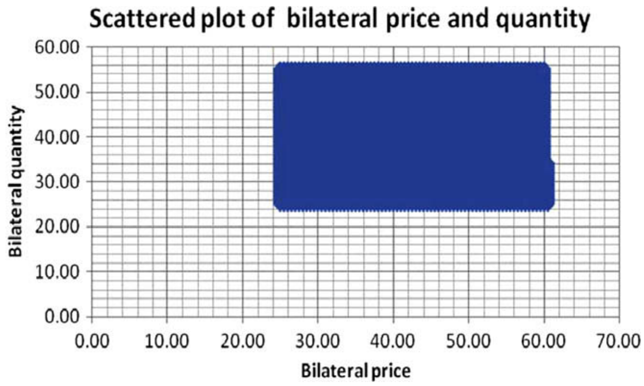

Fig. 7. Scattered plot of bilateral price and quantity for tariff = $59.50.

risk-quantification is that if the bilateral contract is within the range of Table 3, payoff is ensured to be "risk-constrained".

As the bilateral price should be as low as possible, its lower range is equal to lowest value taken i.e. $25 and similarly, the bilateral quantity should be as high possible, the higher range is equal to the highest value of 55 MW (Table 3). Thus, the retailer is interested in knowing minimum bilateral quantity and the maximum bilateral price (Fig. 7).

Table 4 gives the range of bilateral contract for the tariff of $50. Fig. 8 gives the scattered plot of bilateral price and quantity. The retailer has less flexibility in going for bilateral contract for risk-constrained payoff as compared to the tariff of $59.50, and for tariff of $45 (Fig. 9) the choice for the retailer is further reduced.

The problem formulated in this section is for no-competition case. The next section presents the case of competing retailers.

6. Evaluation of bilateral contract for electricity retailer in case of competition: Two retailer case

In case of competition, a retailer submits bid in competition with other retailers. This bid will be for switching load which is taken for the financial settlement with the one who bids lower. The market structure/model assumed for the retailing competition is given in Fig. 3. The retailer 1 is assumed to be doing business in this market model and is competing with retailer 2. The procedure used to get the solution is as follows;

- Load and price data for 336 h (2 weeks) is perquisite.
- Lower and upper limits of bilateral quantity and price are set with reference to minimum and maximum price and load values evaluated for the case of no-competition for particular value of tariff. The results demonstrated are for tariff of $50.
- Set switching load = 30 MW and vary switching load bid to determine the range of bilateral contract.
- Carry out the exercise for different values of switching load.

6.1. Results

The competing retailer will bid for the switching load. The retailer has its own estimation of the competitor's bid. Let, the loyal load tariff be $50 and switching load be 30 MW. If retailer does not win switching load bid, then its bilateral contract must be in the range corresponding to the case of no-competition (refer Table 4) and thus risk-constrained payoff is ensured for the retailer. If it wins the switcher bid i.e. its bid is less than competition, the bilateral contract range gets modified within the limits of no-competition case (refer Table 5).

If switching load price is far less than the average MCP of $49.86, the average payoff is reduced and the range of bilateral price is lower as compared to the case of no-competition. Rather the retailer can bid higher bilateral price but it has to compromise for the average payoff. For the bid of $45, the range of bilateral contact is same as in case of no-competition and the average pay off of the retailer is reduced because it bids for switching load at $45 as compared to loyal load tariff of $50. Now if switching load is increased to 60 MW with tariff of loyal load $50, the retailer has negative average payoff (loss) for the switching load bid of $30 and $35 (refer Table 6). For this switching load the retailer can bid in the

Table 4
Bilateral price and quantity for the tariff of $50.

Tariff = $50, bilateral price varied between $25 and $80, bilateral quantity varied between 25 and 55 MW					
	RAROC	Standard deviation $	Average payoff $	Bilateral price $/MWh	Bilateral quantity MW
Minimum RAROC	1.35	209.42	1323.60	25.00	55.00
Maximum RAROC	4277.20	301.29	497.240	36.50	40.50
Maximum payoff	1.35	209.42	1323.60	25.00	55.00
Minimum standard deviation	0.83	209.42	−1701.40	80.00	55.00

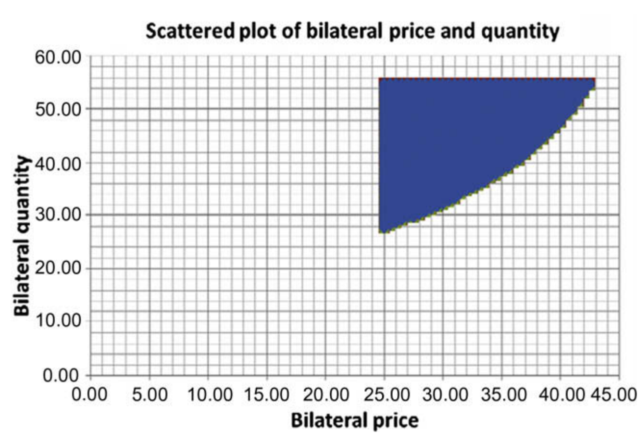

Fig. 8. Scattered plot of bilateral price and quantity for tariff = $50.

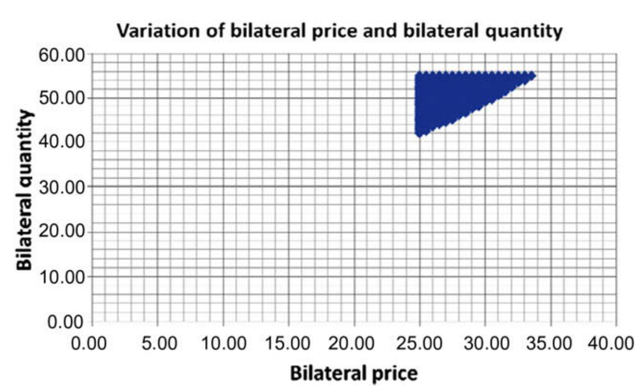

Fig. 9. Scattered plot of bilateral price and quantity for tariff = $45. (Range of bilateral contract to get risk-constrained payoff is 42–55 MW and $25–$35.5).

Table 5
Range of bilateral contract for switching load bid. Loyal consumer tariff = 50$/MWh, switching load = 30 MW.

Switching load bid $/MWh	Average payoff for pessimistic and optimistic solution ($)		Range of bilateral price $/MWh		Range of bilateral quantity MW	
	Pessimistic	Optimistic	Minimum	Maximum	Minimum	Maximum
30	528	720	29	36.50	49.50	55.00
35	540	870	28.00	36.500	40.50	55.00
40	544	1020	25.50	36.50	40.50	55.00
45	548	1170	25.00	36.50	40.50	55.00

Table 6
Range of bilateral contract for switching load bid. Loyal consumer tariff = 50$/MWh, switching load = 60 MW.

Switching load bid $/MWh	Average payoff for pessimistic and optimistic solution ($)		Range of bilateral Price $/MWh		Range of bilateral quantity MW	
	Pessimistic	Optimistic	Minimum	Maximum	Minimum	Maximum
30	Average payoff is negative					
35	Average payoff is negative					
40	627	721	34.50	36.50	40.50	53.00
45	627	1021	27.50	36.50	40.50	55.00

range of $40–$45. In such a case its average payoff is reduced as compared to the case of no-competition. The quantity of switching load and the price affects the average payoff and bilateral contract range. Thus, the retailer can evaluate the range of bilateral contract for the two cases (competition and no-competition) and can decide range of switching load price it can bid. The switching load price can be evaluated using this algorithm to get a desired range of payoff.

7. Conclusions

The methodology developed enables a retailer to evaluate bilateral quantity and associated price. The retailer gets the bilateral quantity and price range for which the payoff is risk-constrained. The risk is quantified using Risk Adjusted Recovery on Capital (RAROC) and the results show that this approach is better suited as compared to conventional variance method of risk-quantification, to ensure the risk-constrained payoff. The exercise gives a range of bilateral quantity and associated price for two cases: No-competition (single-retailer case) and competition. The risk-averse retailer will choose high RAROC for which payoff is risk-constrained and a retailer, who is ready to take risk, will choose RAROC just greater than unity for which payoff is maximised. The range of bilateral contract for both the types of retailer behaviour is evaluated. The methodology enables retailer to make a choice about bilateral transactions for ensuring a risk-constrained payoff.

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References

[1] Stoft S. Power System Economics: Designing Markets for Electricity. New York: Wiley-Interscience; 2002.
[2] Niimura T, Dhaliwal M, Ozawa K. Evaluation of retail electricity supply contracts in deregulated environment. In: Proceedings of IEEE power engineering society summer meeting, vol. 2; July 2001. p. 1058–62.
[3] Chao H, Oren S, Wilson R. Alternative pathway to electricity market reform: a risk-management approach. In: Proceedings of 39th Hawaii international conference on system sciences; 2006.
[4] Gabriel SA, Genc MF, Balakrishnan S. A simulation approach to balancing annual risk and reward in retail electrical power markets. In: Proceedings of IEEE transactions on power systems, vol. 17, no. 4; November 2002.
[5] Ojanen OJ. Comparative analysis of risk management strategies for electricity retailer. Master's thesis. Helsinki Univ. of Technology, Dept. Engineering and Mathematics, Finland; 2002.
[6] Jabr RA. Robust self-scheduling under price uncertainty. In: Proceedings of IEEE transactions on power systems, vol. 20, no. 4; November 2005.
[7] Shebĺe GB, Berleant D. Bounding the composite value at risk for energy service company operation with DEnv, an interval-based algorithm. In: SIAM workshop on validated computing. Toronto; May 2002. p. 166-71.
[8] Liu H, Chen X, Xie J, Yu K, Liao Y. Optimal bidding strategies with risks for LSEs in competitive electricity markets. In: Proceedings of power engineering general society meeting; 2007.
[9] Stoughton NM, Irvine UC, Zechner J. Optimal capital allocation Using RAROC and EVAR. J Financ Intermed http://www.papers.ssrn.com/sol3/papers.cfm.
[10] Hallerbach WG. Capital allocation, portfolio enhancement and performance measurement: a unified approach. In: Proceedings of EURO WGFM 2001, Haarlem NL, Sydney; November 2001.
[11] Prokopczuk M, Rachev S, TrÄuck S. Quantifying risk in the electricity business: a RAROC-based approach. Univ. Karlsruhe Kollegium am Schloss, Karlsruhe, Germany, October 11, 2004. (http://www.pstat.ucsb.edu/research/papers/report10_2004).
[12] Gabriel SA, Conejo AJ, Plazas MA, Balakrishnan S. Optimal price and quantity determination for retail electric power contracts. IEEE Trans Power Syst 2006;21(1):180–7.
[13] Carrión M, Conejo AJ. Forward contracting and selling price determination for a retailer. IEEE Trans Power Syst 2007;22(4):2105–14.
[14] Xu J, Luh PB, White FB, Ni E, Kasiviswanathan K. Power portfolio optimization in deregulated electricity markets with risk management. IEEE Trans Power Syst 2006;21(4):1653–62.
[15] Liu B, Zhou M, Li G. An optimal approach for coordinating scheduling day-ahead and real-time energy. In: Proceedings of international conference on power system technology; 2006.
[16] Ming Z, Gengyin L, Yan Z, Ni Y. Optimal electricity procurement for load service entity incorporating with reserve and risks. In: Proceedings of 2004 international conference on power system technology – POWERCON 2004, Singapore; November 2004.
[17] Yusta JM, Ramírez-Rosado IJ, Dominguez-Navarro JA, Perez-Vidal JM. Optimal electricity price calculation model for retailers in a deregulated market. Int J Electric Power Energy Syst (IJEPES) 2005;27(5):437–47.
[18] Nanduri V, Das TK. A survey of critical research areas in the energy segment of restructured electric power markets. Int J Electric Power Energy Syst (IJEPES) 2009;31(5):181–91.
[19] Munhoz FC, Correia PB. Bidding design for price-taker sellers in bilateral electricity contract. Int J Electric Power Energy Syst (IJEPES) 2008;30(8):491–5.
[20] Soleymani S, Ranjbar AM, Shirani AR. Strategic bidding of generating units in competitive electricity market with considering their reliability. Int J Electric Power Energy Syst (IJEPES) 2008;30(3):193–201.
[21] Karandikar RG, A Khaparde S, Kulkarni SV, CAPM "Quantifying price risk of electricity retailer based on, methodology RAROC. Quantifying price risk of electricity retailer based on CAPM and RAROC methodology. Int J Electric Power Energy Syst (IJEPES) 2007;29(5):1033–49.