Risk Constrained Short Term Electricity Procurement for Open Access Consumer in India

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***Abstract*—Open access is a major power sector reform in energy deficit India, and encourages short term trading for meeting variations in demand. An open access large consumer in India, can participate in short term trading through bilateral contracts, power exchanges (PXs) or unscheduled interchange (UI) transactions. In addition, it needs to satisfy obligations of renewable purchase. Prices of PX's day ahead market are uncertain, while UI charges for frequency variations vary widely due to real time deviations in withdrawals. Considering these uncertainties in the backdrop of Indian power sector, this work proposes an optimal short term power procurement strategy for large consumer, from available trading options. A small self generation facility and demand flexibility is also considered. A practical case study of Indian open access consumer is considered to show the effectiveness of proposed approach.**

***Keywords*—risk management, mean variance optimization, unscheduled interchange (UI); RPO; India.**

I. Introduction

Major power sector reforms in India include bulk electricity trading and introduction to open access [1], [2]. Presently, country is targeting to move towards implementation of open access at fullest, and putting in efforts to encourage healthy short term power markets. Short term trading facilitates electricity providers and bulk power consumers to balance their portfolios on day ahead basis and to adjust their fluctuating power demands. This necessitates effective planning by market participants for their efficient functioning.

In India, short term trading contracts include electricity transactions performed over periods less than a year, through bilateral contracts, Power Exchanges (PXs) and Unscheduled Interchange (UI) [3]. Term Ahead Market (TAM) and Day Ahead Market (DAM) are executed through PXs [4]. There is no balancing market in India, and real-time balancing takes place through UI mechanism. UI is accounted in the short term transactions as charges imposed for deviating from the scheduled withdrawal or injections [3]. Share of short term trading in annual electricity procurement for the Indian power market is continuously increasing, from 8 % in 2008-09 to 11 % in 2013-14 [3]. This reflects growing competition and changing market structure.

Unlike other countries, open access is limited to bulk power consumers in India. These bulk power consumers are connected to high voltage network and can participate in wholesale markets to fulfil their electricity requirements. Additionally, these open access consumers have to commit purchase of a specified percentage of their demand from renewable sources to fulfill Renewable Purchase Obligations (RPO) either by Feed in Tariff (FiT) type contracts or by Renewable Energy Certificates (RECs) [5].

While trading through DAM, they face volatility in prices. The DAM prices are evaluated from auction based on demand supply bids, and thus vary widely. UI rates depend on grid frequency and can have large and unpredictable variations in real time [6]. The volatility of spot market prices and UI rates introduces risk of cost variation for these consumers. Thus, to make efficient trading plans, it is necessary and important to address these risk concerns in procurement strategies of open access consumers in India.

Considering the fundamental differences in operation of Indian power sector from other developed markets, this work aims to propose appropriate procurement strategies for an Indian open access large consumer from available trading options, considering uncertainties of UI charges and DAM prices, under RPO obligations.

This paper focuses on the problem of an open access consumer in India, aiming an optimal short term power procurement strategy from available options, for a future time period, under the uncertainties of UI charges and DAM prices. This consumer is considered as an obligated entity to fulfill RPO. The consumer balances its flexible demand from UI to minimize penalty. The overall problem is of cost minimization, while uncertainties have been addressed with variance. To express the effectiveness of approach, an Indian case study is considered.

II. Short Term Trading in Indian Scenario

Short term transactions, both bilateral and market based, are important mechanisms in Indian power sector. Unlike long term Power Purchase Agreements (PPAs), consumer has minimum cost opportunities with short term trading. An open access consumer can procure its short term fluctuating demand from available choices. It freely participates and bids in the market, instead of contracting through aggregators, which offer large scale demand aggregation. A snapshot of the short-term trading environment through different mechanisms for open access large consumers is presented as hence.

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A. *Power Exchange Transactions*

PX transactions are a part of short term trading [3]. In India, trading takes place for physical delivery and no financial contracts exists. Despite that majority transactions occur through long term PPAs, short term trading is important in balancing short term needs of utilities. PXs have a major role in this. Here, contracts with definite expiry period can be traded on a weekly, monthly or yearly basis in advance. TAM transactions are for physical delivery of electricity for more than one day. DAM transactions are traded in power exchanges through double sided anonymous auction bidding process [7]. In such markets, demand supply forces decide the prices. After DAM transactions, intra-day or contingency contracts are traded for utilizing residual capacity [4], [7].

B. *UI Mechanism*

India is generation deficit country and grid frequency is used to vary widely due to fluctuating demand. To maintain frequency in a narrow band, a penalty based mechanism was introduced in 2002 [8]. As per Indian Electricity Grid Code (IEGC), present frequency band is 49.7-50.05 Hz [9]. Participants, deviate from scheduled generation or withdrawal when frequency is beyond the prescribed frequency band, are penalized. UI rate increases linearly for frequency below 50 Hz. The deviations are determined in 15-minute time blocks through sophisticated metering [3]. For a consumer, over withdrawal during times of low grid frequency results in penalty, while under withdrawal supporting low grid frequency, results in revenue earning.

According to Deviation Settlement Mechanism and Related Matters Regulation 2014, additional UI charges are implemented for a market participating consumer who withdraws over 12 % of its scheduled demand or 150 MW [9]. For under withdrawal over 12 % or 150 MW, UI charges are zero to discourage consumers from using UI as revenue earning tool.

C. *Trading Under RPO*

A large consumer participating in the Indian electricity market has mandatory RPO obligations to purchase a fixed percentage of its annual demand from renewable energy sources *via* FiT contracts and trading of RECs [10]. REC is a market based instrument traded through closed double sided auction in PXs within the forbearance and floor price once in a month [11]. One REC is quantified as 1 MWh of electricity injected into the grid from renewable energy sources. A consumer may also enter FiT contracts with the designated renewable energy generators. FiT is a long term PPA with a preferential tariff decided by state regulators, for renewable energy fed into the grid [10].

III. Problem Description and Formulation

An Indian open access large consumer is assumed to participate in short term power trading through bilateral contracts and DAM or spot market to procure its known demand at minimum cost. It has a self generation unit of small size. For the considered planning period *T,* it needs to satisfy RPO as an obligated entity, by entering into either FiT contracts or REC purchase. It is assumed that such consumer has some flexible demand, which it can shift by altering its demand pattern. DAM prices and UI charges are considered uncertain and modeled through variance. The overall problem for the large consumer is of cost minimization while managing the risk of UI charges and DAM prices [12], [13]. It is to be noted that FiT contracts are long term contracts, considered in the problem to fulfill RPO on consumer. Historical data has been taken to model uncertainty in UI rates and DAM prices, while policy changes have been neglected.

A. *Power procurement from bilateral contracts*

Total cost of buying from bilateral contracts, for time period *T* is given by C^b,

$$C^b = \sum_{t=1}^{T} \lambda_t^b P_t^b \tag{1}$$

$$P^{b,\min} v_t \le P_t^b \le P^{b,\max} v_t \tag{2}$$

where P_t^b is power purchased from bilateral contract at time *t*, with $P^{b,\min}$ and $P^{b,\max}$ as minimum and maximum power purchase limits. v_t is binary variable which is 1 if contract is selected, otherwise 0.

B. *Power procurement from spot market*

P_t^d is power purchased from spot market at time *t*. Assuming that pool prices follow normal probability distribution, with an average of $\lambda_t^{d\,\exp}$ and a variance of $\lambda_t^{d\,\mathrm{var}}, \forall t$ total cost of power purchase from spot market in time period *T* can be calculated as

$$C^d = \sum_{t=1}^{T} \lambda_t^{d\,\exp} P_t^d \tag{3}$$

$$P_t^d \ge 0 \tag{4}$$

C. *Power procurement from FiT contracts*

Total cost of buying power from FiT contract for time period *T* is given by C^f,

$$C^f = \sum_{t=1}^{T} FiT\ P_t^f \tag{5}$$

$$0 \le P_t^f \le P^{f,\max} \tag{6}$$

where FiT is price of the contract (assumed fixed throughout planning period), P_t^f is purchased power with $P^{f,\max}$ as maximum power purchase constraint.

D. *REC purchase*

Cost of purchasing non solar RECs in the time period T is given by C^{REC},

$$C^{REC} = \sum_{t=1}^{T} \lambda^{r\,\exp} REC \tag{7}$$

$$0 \le REC \le n \tag{8}$$

where REC is the number of RECs purchased, with an upper limit of *n,* and $\lambda^{r\exp}$ is the expected non solar REC price. For short term planning (about a month) this can be considered deterministic.

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E. *Cost of Self Generation*

Assuming a small generation unit installed onsite, generation cost in the time period T is given by C^g,

$$C^g = \sum_{t=1}^{T} c_t^s + c\,u_t + b\,P_t^g + a\,(P_t^g)^2 \tag{9}$$

A quadratic cost function has been used to calculate production cost. Here, c, b and a are no load, linear and quadratic cost coefficients respectively, and c^{su} is constant start up cost. P_t^g is self generated power at time t. c_t^{su} start up cost at time t when unit starts can be given as

$$c_t^{su} \geq c^{su}(u_t - u_{t-1}) \tag{10}$$

u_t is 1 if unit is on otherwise 0. Operating constraints of the generation unit is given as

$$P^{g,\min} u_t \leq P_t^g \leq P^{g,\max} u_t \tag{11}$$

Ramping limits for the generation unit are expressed as

$$P_t^g - P_{t-1}^g \leq R^{up} u_t \tag{12}$$

$$P_{t-1}^g - P_t^g \leq R^{dn} u_{t-1} \tag{13}$$

R^{up} and R^{dn} are ramp up and ramp down limits.

F. *UI Charge*

UI charge for the time period T is given by C^{ui}

$$C^{ui} = \sum_{t=1}^{T} \lambda_t^{u\exp} UI_t \tag{14}$$

UI_t is deviation from scheduled power at time t which is a free variable. $\lambda_t^{u\exp}$ is expected UI rate at time t. Constraints on UI_t can be expressed depending on the deviation settlement mechanism [9] as

$$-\delta * SI_t \leq UI_t \leq \delta * SI_t \tag{15}$$

where SI_t is the actual demand and δ is the percentage of deviation caused by the consumer if SI_t has been scheduled.

G. *Cost Modelling*

Total cost of power procurement with UI charge in the given time period T is given as:

$$C^{\exp} = C^d + C^b + C^g + C^{REC} + C^f + C^{ui} \tag{16}$$

C^{ui} has been included in the cost modeling as done for the generation side in [14].

H. *Risk Modelling*

Risk arising due to the uncertainty of spot market prices and UI rate, C^{risk}, can be modeled as variance of cost,

$$C^{risk} = \sum_{t=1}^{T} \lambda_t^{u\,\mathrm{var}} (UI_t)^2 + \sum_{t=1}^{T} \lambda_t^{d\,\mathrm{var}} (P_t^d)^2 + 2\sum_{t=1}^{T} \lambda_t^{\mathrm{cov}} UI_t\, P_t^d \tag{17}$$

$\lambda_t^{u\,\mathrm{var}}$ is the variance of UI rate. λ_t^{cov} is the covariance of spot market price and UI rate.

I. *Demand Modelling*

Demand constraint of the consumer at time t can be modeled as:

$$SI_t + UI_t = P_t^g + P_t^b + P_t^d + P_t^f \tag{18}$$

SI_t is deterministic in nature. UI_t term is included in total power procurement, P^T, as

$$\sum_{t=1}^{T} SI_t + \sum_{t=1}^{T} UI_t = P^T \tag{19}$$

The consumer can also reduce its demand up to a certain level which has been assumed as $P^{T,\min}$, in time period T.

$$P^{T,\min} \leq P^T \tag{20}$$

J. *RPO Modelling*

The consumer can purchase power from FiT contracts (Eqns. (5) and (6)) or can purchase RECs [11] (Eqns. (7) and (8)) to achieve RPO as

$$REC + \sum_{t=1}^{T} P_t^f \geq RPO\, P^T \tag{21}$$

$$REC \leq RPO\, P^T \tag{22}$$

where RPO is the quantum of power to be purchased under RPO target for consumer under the planning period T.

K. *Objective Function*

Objective function of the problem can be defined as a multi objective minimization problem:

$$\underset{P_t^d, P_t^b, P_t^g, P_t^f, UI_t, u_t, v_t, c_t^s, REC \ \forall t}{\text{Minimize}} \quad C^{\exp} + \alpha\, C^{risk} \tag{23}$$

where α is the risk weighing positive factor [12]. (23) is to be maximized for different values of α subject to constraints, (2), (4), (6), (8), (10-13), (15) and (18-22). The overall problem is a mixed-integer quadratic programming problem which is multilateral non convex in nature. Thus global optimality is not guaranteed. The problem can be linearized by various methods but not the focus of this work.

IV. Case Study and Results

A large consumer in western regional grid of India plans its withdrawal schedules for a month from DAM, one bilateral contract, FiT and self generation unit. Here, 12% demand flexibility in response to UI variations is considered available for real time balancing. Considering each hour as trading interval, total trading intervals for the month are 672. Monthly demand of the consumer is shown in Fig. 1. Minimum monthly demand limit is 660000 MWh. Price and volume data for one available bilateral contract is shown in Table I. Data for self generation unit is given in Table II. FiT and RPO have been considered as 5000 Rs./MW and 10% respectively, estimated based on present western state values [15]. Maximum limit of FiT is considered as 700 MW. Expected values of spot market price and UI rate are calculated as mean of five year (2011-2015) values from the Indian Energy Exchange (IEX) [7], and are shown in Fig.2. Non solar REC price from the last five year (2011-2015) for the month are assumed at Rs. 1890 [7]. Maximum number of RECs that can be purchased by the consumer is 50000.

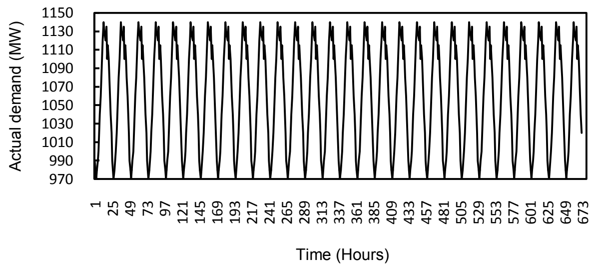

Fig. 1. Electricity demand of the consumer in the month

Expected UI rate has been calculated from the UI summary data taken from Western Regional Load Dispatch Centre (WRLDC) website [15].

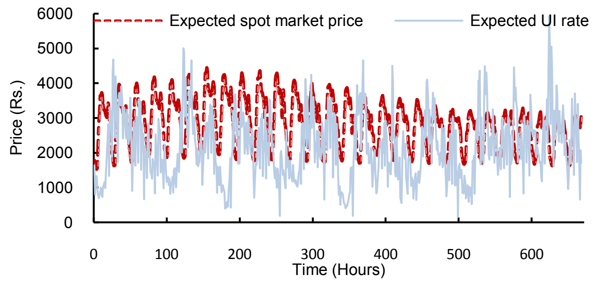

Fig. 2. Expected UI rate and spot market price

Correlation between spot market prices and UI rate is shown in Fig. 3. Average standard deviation for UI rate and spot market price for entire month is 1255.349 Rs./MWh and 692.4845 Rs./MWh respectively. Both positive and negative correlation exists with random and intricate pattern in the time horizon.

To find the optimum decision, objective function (23) is to be minimized with the constraints in equations (2), (4), (6), (8), (10-13), (15), and (18-22). The problem has been solved using SBB-CONOPT under GAMS [16] by Intel® Core™ i3 CPU, 2.00 GHz, and 4 GB RAM computer with an average solution time of 180.34 s.

Efficient frontier of expected procurement cost, as a function of standard deviation of net cost of electricity procurement for different values of α is shown in Fig. 4. 12. Different values of α are taken for plotting the curves. Standard deviation of net cost is the square root of cost variance. Expected cost increases as its standard deviation decreases, which signifies risky procurement requires less investment. Fig. 5 shows the results of electricity procurement by the consumer from different options for entire month. This represents behavior of demand deviation from the actual demand, from UI, for different values of α. Positive value of UI occurs during periods of low UI rates while negative UI suggests reducing consumption up to demand flexibility limit, in order to reduce cost.

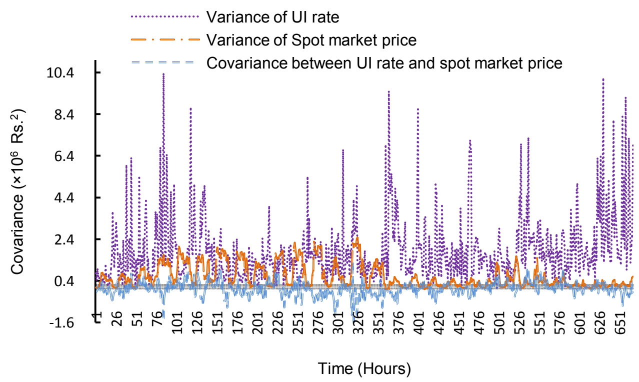

Fig. 3. Covariance between UI rate and spot market price

Both values of UI are decreasing from $\alpha = 0$ to higher values of α but positive values of UI become zero at α =0.00004. Sum of both the values of UI *i.e.* UI net is same till α =0.00004 and starts decreasing afterwards. This is due to lower values of α, that makes procurement from risky spot market and value of UI relatively more than other options. This also results in less investment. The reason for constant value of UI net is due to constant monthly power procurement up to α = 0.00004 which is result of constant monthly FiT procurement up to α =0.00004. For values of α less than 0.00004, power procurement from FiT contracts is less due to more risky behavior and so RECs are purchased for satisfying RPO constraint. RECs purchase is 2019 for $\alpha = 0$ and 741 for value of α = 0.0000001. When α increases beyond α =0.00004, risky behavior decreases exponentially and so power procurement from other sources increase.

TABLE I. DATA FOR BILATERAL CONTRACT

	Price (Rs./MW)	Min. Volume (MW)	Max. Volume (MW)
I Week	2600	30	600
II Week	2800	30	600
III Week	3000	30	600
IV Week	2900	30	600

TABLE II. DATA FOR SELF GENERATION UNIT

Capacity	120 MW
Minimum power output	20 MW
Ramping limit (up/down)	80 MW
Quadratic Cost	0.6 Rs./(MW)^{2}h
Linear Cost	2700 Rs./MWh
No-load Cost	2000 Rs.
Startup Cost	1000 Rs.

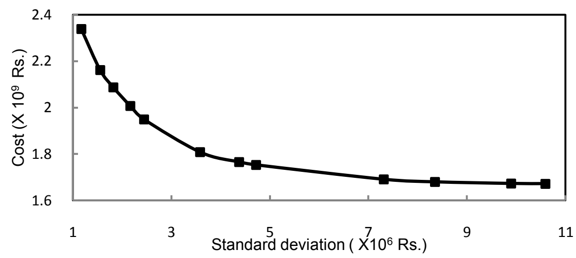

Fig. 4. Expected cost v/s standard deviation

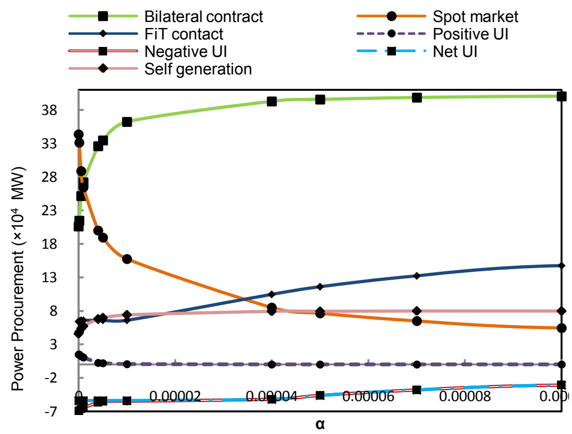

Fig. 5. Power procurement from different sources at different values of α

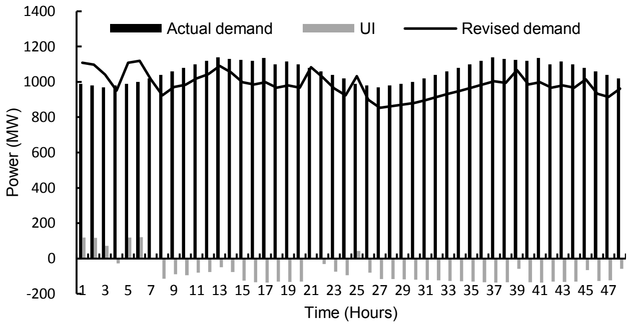

Fig. 6. Demand pattern for α =0 for 48 hours

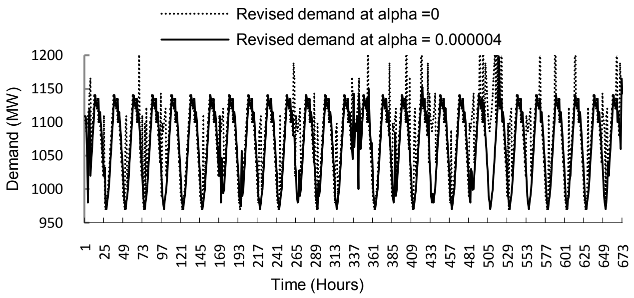

Fig. 7. Demand pattern for α =0 and 0.000004

The procurement strategy suggests consumer to shift its demand from scheduled one. Fig. 6 shows the revised demand of the consumer for α =0. This helps to attain minimum cost position by the decision maker. Fig. 7 shows comparison in demand alteration for α =0 and α =0.000004. For clarity in representation, results for only two days are shown in the two figures, though similar results are obtained for whole planning period. Revised demand is the sum of the actual demand and unscheduled deviation (UI). Negative UI values signify decrease in actual demand while positive UI value represents increased actual demand. Revised total monthly demand is 660000 MW up to α =0.00004, which then increases to 698348.9MW till α =0.0005. Revised total monthly demand reduces with percentage reduction 2.2% (α = 0.0005) to 7.5 % (α = 0) in the actual total monthly demand. The initially increasing and then reducing total demand represents consumers increasing preference for risk. The increasing demand represent negative correlation between DAM and UI prices. Due to UI value, flexibility introduced in demand for the consumer varies from +2.1% to -9.7%.

With the given model consumer is capable to decide its minimum cost electricity procurement strategy and monthly demand profile under uncertain grid and market scenario, while also fulfilling RPO. The Indian context and differing opportunities for players may be useful for countries adopting similar market structure.

V. Conclusion

In this paper, decision making model has been designed for electricity procurement and demand planning by a large consumer for short term trading in India, under uncertain DAM prices and UI charges under RPO obligations. Results indicate that procurement from DAM and with positive and negative value of UI is more at lower values of risk aversion, though it decreases with risk aversion and shifts towards risk free options. The results suggest reducing consumption at real time to get minimum cost, though this demand alteration is higher for lower risk aversion levels and reduces with increasing risk aversion. UI value has introduced notable demand flexibility for the consumer. For future work, this scheduling strategy can be used to participate in demand response programs.

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