Impact of Short Term Electricity Procurement of an Open Access Consumer on Indian Grid

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***Abstract*—Unscheduled Interchange (UI) mechanism has emerged as a powerful tool for maintaining grid discipline, penalizing the market players, causing deviations in the system. A buyer pays UI penalty for over-withdrawal of power more than the scheduled one based on the grid condition. Such buyers having demand fluctuations may end up paying UI penalty at the real time. This paper proposes a planning model for a large open access consumer in India, purchasing from bilateral contracts and multiple Day Ahead Markets (DAMs). The proposed model can shift consumer's expected demand by accounting the UI deviations to minimize procurement cost. A small self generation unit and renewable purchase obligations are also considered. This work considers price uncertainty of both markets. The overall problem of cost and risk minimization is handled by mean variance approach. Results indicate that the consumer can plan demand scheduling for the planning period as well as can help in improving grid frequency at the real time.**

***Keywords*—Open access consumer; mean variance approach; unscheduled interchange (UI); Indian system;**

I. Introduction

Indian power sector has undergone through reforms in the past few decades to improve functional, financial and technical performance. Policy makers have brought in major regulatory changes for success of electricity market in India. Bold regulatory aspects of Electricity Act, 2003 have changed the scenario of Indian electric industry [1], [2]. The act introduced open access and facilitated competitive bulk power trading [3]. Open access allows non-discriminatory access to the transmission and distribution lines to support power trading for fair and competitive power market. These reforms have further liberalized the power sector with the flexible entry of multiple market participants. To bring in efficiency in competitive power markets for consumer benefit by better economic performance, short term trading is necessary. In comparison to long term power contracts, power exchange based transactions during short term are succeeded to bring in transparency and competition in power markets.

Short term power trading contracts in India include electricity trading for a period less than a year, likewise short term bilateral contracts, Power Exchanges (PXs) and Unscheduled Interchange (UI) [4]. Short term bilateral contracts are mostly the inter-state or inter-regional contracts approved by Central Electricity Regulatory Commission (CERC) approved licensee. PXs are the trading platforms for spot trading, various type of products like Term Ahead Market (TAM) and Day Ahead Market (DAM) are traded by continuous bidding or auctions [5],[6]. There are two PXs in India, one is Indian Energy Exchange (IEX) and another is Power Exchange of India (PXIL). UI mechanism penalizes generators or consumers for deviating from scheduled injections or withdrawals respectively and supports real time grid frequency balancing. Even if present share of short term trading in annual electricity procurement in Indian power market is approximately 9% in 2014-15 [4], this growing trend cannot be neglected by the market participants who can trade electricity at market deciding price and can achieve proficiency through selection of favorable options. If these market participants are large consumers, they can benefit from the transparency in the price of electricity and can meet their demand fluctuations.

Open access consumers in India can be the private industries, government-owned companies, etc. with access to the grid. Demand profiles of these consumers can be forecasted before scheduling. As Indian power system is generation deficit, over-withdrawal at the real time can worsen the grid frequency. This, in turn, can increase the penalty for the consumer. On the other hand, the same consumer can help in improving the grid frequency at the real time by under withdrawing when grid frequency is falling below 50 Hz. Large consumers are capable of scheduling their consumption as they can control their demand with flexible electricity consumption in response to price fluctuations and penalties. This can help in grid frequency balancing as well. The open access consumers also have the obligations to purchase a specified percentage of their demand from renewable sources to fulfill Renewable Purchase Obligations (RPO) [7].

This work aims to propose procurement strategy for an open access consumer in short term trading market with consumption scheduling to address the real time grid frequency imbalances. Keeping in mind that short term trading is a means to bring in perfect competition and market efficiency while improving the quality of supply, this work considers optimal electricity procurement problem for large consumers under the UI penalty mechanism. Uncertainty of day ahead spot markets, and obligations of renewable purchase are also considered. This cost and risk minimizing problem analyzes the real time contributions of the planning model on the system frequency. The problem has been implemented by the mean variance approach for an Indian case study. The consumer introduces shift in its demand using flexibility in its projected demand, accounting the UI deviations.

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By this, consumer can help in improving the grid frequency through its demand scheduling.

II. UI Mechanism

UI Mechanism introduced in 2002 as part of Availability Based Tariff (ABT) has become an essential element of short term power trading in India. ABT, a rational tariff structure, which was designed for generating stations, has carried forward UI as a unique and important element [8]. In UI mechanism, sellers and buyers of electricity have to pay penalty for causing deviations at the real time for unhealthy grid frequency. UI mechanism has a sole objective of maintaining grid frequency in the narrow band as per Indian Electricity Grid Code (IEGC). Present band is 49.90 Hz to 50.05 Hz [9]. This band has been specified to maintain the grid frequency at a safe level in the generation deficit Indian power system. In this mechanism, an electricity supplier has to pay penalty for under-injection of electricity than the scheduled injection and an electricity consumer has to pay penalty for over-withdrawal of electricity than the scheduled withdrawal at the real time. These deviations from the scheduled injection or withdrawal are determined through special metering in 15-minute time block. The scheduling of injection and withdrawal is done through load dispatch centres. State Load Dispatch Centres (SLDCs) manage the transmission system in their respective grids while Regional Load Dispatch Centres (RLDCs) manage and operate regional grids. RLDCs prepare the dispatch and withdrawal schedule for the suppliers and consumers considering availability, network constraints, and securities. CERC specifies the penalty rates according to grid frequency.

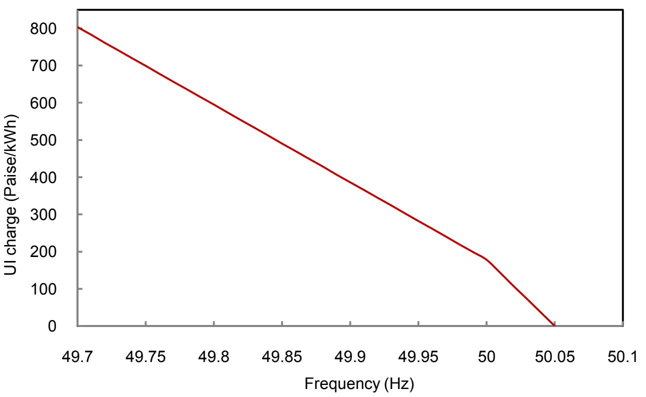

Fig. 1. UI Curve According to Deviation Settlement Mechanism, 2014

Fig. 1 shows the UI curve according to Deviation Settlement Mechanism and Related Matters Regulation (DSM) 2014, considering consumer is over withdrawing within the permissible deviation that is less than the minimum of 12% of scheduled interchange or 150 MW for frequency band 49.7 Hz to 50.05 Hz. According to this mechanism, additional UI charges are levied for a consumer who withdraws over 12 % of its scheduled demand or 150 MW [10]. UI charges for under withdrawal over 12 % or 150 MW are zero. This discourages consumers for manipulating the trading for earning benefits.

III. Problem Description and Formulation

In India, open access large consumer or Distribution Company (discom) participating in the short term power market, are obligated entities to fulfill RPO. In this work, considered entities are participating in DAM through both the power exchanges and are large enough to impact the grid frequency. The consumer has some percentage of flexibility in its base demand to address the projected variations. Self generation and bilateral contracts are also the available options. These entities are planning their consumption schedule in order to get minimum cost. In order to get informed decision strategy for minimizing over all procurement cost, uncertainty considerations of prices of both DAMs are necessary and important. The uncertainty of both the market prices has been modeled through variance. The overall problem for the large consumer is of cost minimization while managing the risk of multiple DAM prices [11]. UI rate has been calculated using the grid frequency while solving the problem. Policy change issues can be neglected.

A. *Power procurement from bilateral contracts*

Total cost of purchasing power from bilateral contracts, for time period *T,* is given by C^B ,

$$C^B = \sum_{t=1}^{T} \lambda_t^B P_t^B \qquad (1)$$

$$P^{B,\min} v_t \le P_t^B \le P^{B,\max} v_t \qquad (2)$$

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 DAMs*

There are two spot markets; IEX and another is PXIL. Power purchased through IEX DAM is $P_{1,t}^{DA}$ and power purchased from PXIL DAM is $P_{2,t}^{DA}$. It is assumed that pool prices follow normal distribution function with average of $\lambda_{1,t}^{DAExp}$ and $\lambda_{2,t}^{DAExp}$ and variance of $\lambda_{1,t}^{DAVar}$ and $\lambda_{2,t}^{DAVar}$, $\forall t$, total cost of purchasing from DAM for time period T is given by C^{DA} ,

$$C^{DA} = \sum_{i=1}^{2} \sum_{t=1}^{T} \lambda_{i,t}^{DAExp} P_{i,t}^{DA} \qquad (3)$$

$$P_{1,t}^{DA} \ge 0 \qquad (4)$$

$$P_{2,t}^{DA} \ge 0 \qquad (5)$$

C. *Renewable Purchase Obligation (RPO)*

A fixed percentage of demand, m , has been considered to be purchased from Feed-in tariff (FiT) contracts to fulfill RPO [7]. C^{RPO} is the cost of purchasing this power.

$$C^{RPO} = m * P^T * \lambda^F \qquad (6)$$

where P^T is the power procurement for the planning period T and λ^F is the fixed cost of purchasing for RPO.

D. Cost of Self Generation

Assuming self generation of electricity by a small thermal unit, generation cost in the time period T is given by C^G ,

$$C^G = \sum_{t=1}^{T} c_t^{su} + c\, u_t + b\, P_t^G + a\,(P_t^G)^2 \tag{7}$$

A quadratic cost function has been used to calculate generation 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, can be given as

$$c_t^{su} \geq c^{su}(u_t - u_{t-1}) \tag{8}$$

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

$$P^{G,\min} u_t \leq P_t^G \leq P^{G,\max} u_t \tag{9}$$

Ramping limits for the generation unit are expressed as

$$P_t^G - P_{t-1}^G \leq R^{up} u_t \tag{10}$$

$$P_{t-1}^G - P_t^G \leq R^{dn} u_{t-1} \tag{11}$$

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

E. UI Charge

UI charge for the time period T is given by C^{UI} . λ_t^u is UI penalty calculated from grid frequency f_t as per UI curve given in Sec. II [12],

$$f_t = 50 - \frac{L_t - [G_t - UI_t]}{PFR * L_t} \tag{12}$$

$$C^{UI} = \sum_{t=1}^{T} \lambda_t^u UI_t \tag{13}$$

f_t is the grid frequency at time t . (12) has been developed from the knowledge of existing grid operation [12]. L_t is system demand at time t . G_t is total available system generation at time t . UI_t is deviation caused by the consumer in the system at time t . PFR is the power deficit - frequency fall ratio which is calculated from the existing grid operational practice . Constraints on UI_t can be expressed depending on the deviation settlement mechanism [10] as

$$-\delta * SI_t \leq UI_t \leq \delta * SI_t \tag{14}$$

where SI_t is a variable which helps in scheduling the demand and δ is the percentage of deviation caused by the consumer if SI_t has been scheduled. SI_t is a free variable and accounts both projected demand variations and system variations for procuring from the available options.

F. Cost Modelling

Total estimated cost of power procurement in the given time period T is given as C^{EXP} ,

$$C^{EXP} = C^B + C^{DA} + C^{RPO} + C^G + C^{UI} \tag{15}$$

C^{EXP} is the expected value of total cost procuring electricity from bilateral, DAMs, FiT contracts, self generation and UI charge for the planning period T . It is to be noted that the estimated cost signifies that the overall cost cannot be known at the time of decision making, due to uncertainty of DAM prices.

G. Uncertainty Modelling

The uncertainty of DAM prices, C^R, can be modeled as variance of cost, which can be represented as

$$C^R = \sum_{t=1}^{T} \lambda_{1,t}^{DAVar} (P_{1,t}^{DA})^2 + \sum_{t=1}^{T} \lambda_{2,t}^{DAVar} (P_{2,t}^{DA})^2 + 2\sum_{t=1}^{T} \lambda_t^{Cov} (P_{1,t}^{DA})(P_{2,t}^{DA}) \tag{16}$$

λ_t^{Cov} is the covariance of between IEX and PXIL DAM prices. Variance gives the variability of expected cost from the DAMs while covariance gives correlation of variability of cost between the two DAMs. Larger variance denotes larger risk.

H. Demand Balance

Demand can be satisfied in a trading interval from available options.

$$SI_t + UI_t = P_t^G + P_t^B + P_{1,t}^{DA} + P_{2,t}^{DA} \tag{17}$$

$$Pd_t + \Delta Pd_t = SI_t + UI_t \tag{18}$$

Pd_t is base demand of consumer while ΔPd_t denotes the maximum demand fluctuations. These demand fluctuations are assumed to vary in a specified percentage evaluated from demand flexibility range of consumer. (17) denotes that the power procurement from the available options in the trading interval should equal to the estimated demand of the consumer in that interval. The estimated demand of the consumer which is sum of base demand and projected fluctuations should be equal to the scheduled demand which is sum of the shifted demand and UI deviations (18). Total power procurement in the planning period can be written as, P^T ,

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

I. Objective Function

Objective of the problem is to minimize cost and risk. This is a multi-objective optimization problem, where α is the risk weighing positive factor, defines weight on second objective [11].

$$\text{Minimize}_{\,P_t^{di}, P_t^{dp}, P_t^{b}, P_t^{g}, \Delta P_t, UI_t, u_t, v_t, c_t^s \;\; \forall t;} \quad C^{\exp} + \alpha\, C^R \tag{20}$$

(20) is to be minimized for different values of α as desired by decision maker, subject to constraints, (2), (4), (5), (8-11), (12),(14) and (17-19). The problem is a mixed-integer quadratic programming problem and can be solved by commercially available software.

IV. Case Study and Results

An assumed large consumer in western regional grid is planning its weekly electricity procurement from two DAMs and one bilateral contract. It has a small self generation facility. Considering each hour as trading interval, total trading intervals are 168 hours. The estimated electricity demand profile of the consumer for a week is shown in Fig. 2. This varies between 970 MW and 1140 MW. Demand flexibility offered by the consumer is 12 % of the base demand. Consumer can make one bilateral contract. Price for the available bilateral contract is 3000 Rs./MWh with minimum and maximum trading limit 30 MWh and 800 MWh.

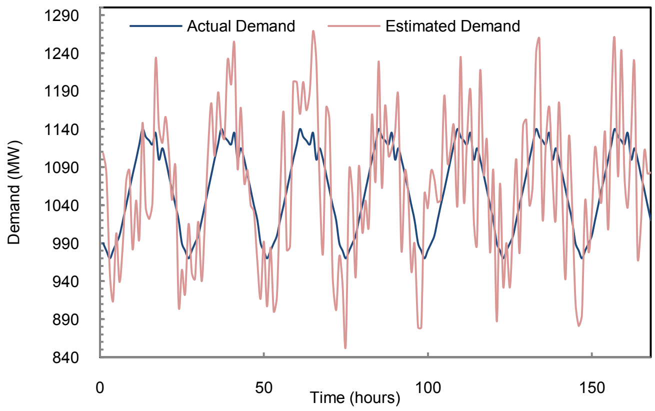

Fig. 2. Estimated electricity demand of the consumer for a week

Expected DAM prices for IEX [13] and PXIL[14] have been calculated from the average of 10 consecutive weeks in a year 2011 as shown in Fig.3. Average price for IEX and PXIL spot market is 3154.307 Rs./MWh and 3182.883 Rs./MWh respectively for the considered planning period. Data for self generation unit is given in Table I. Consumer is purchasing 10 % of its procurement for fulfilling RPO. Cost of purchasing for the RPO is considered as 5000 Rs./MWh.

TABLE I. 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.

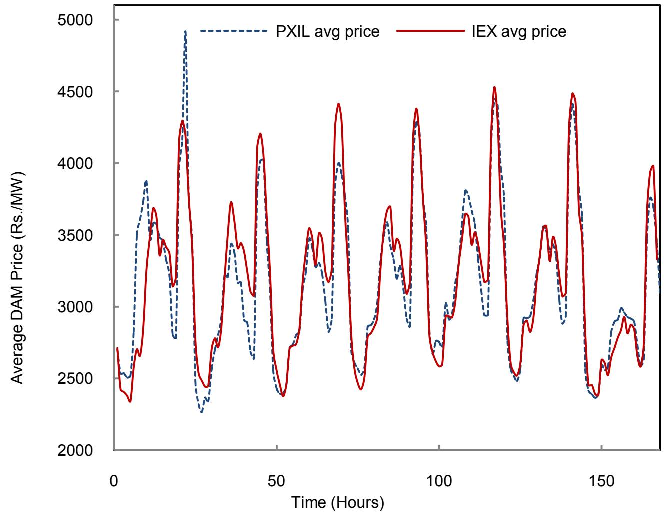

Fig. 3. Expected Average price of DAMs through PXIL and IEX

PFR from the literature can be found as 4% [12]. Total system demand as Indian grid system has been considered is 100GW. Total generation for the nominal grid frequency has been considered as 100 GW. Some pre-existing deviations are considered in the systemTo find the optimum decision, objective (20) is to be minimized with the constraints in equations (2), (4), (5), (8-11), (12), (14) and (17-19). The problem has been solved using SBB-CONOPT under GAMS [15] by Intel® Core™ i3 CPU, 2.00 GHz, and 4 GB RAM computer with an average solution time of 46.38 s.

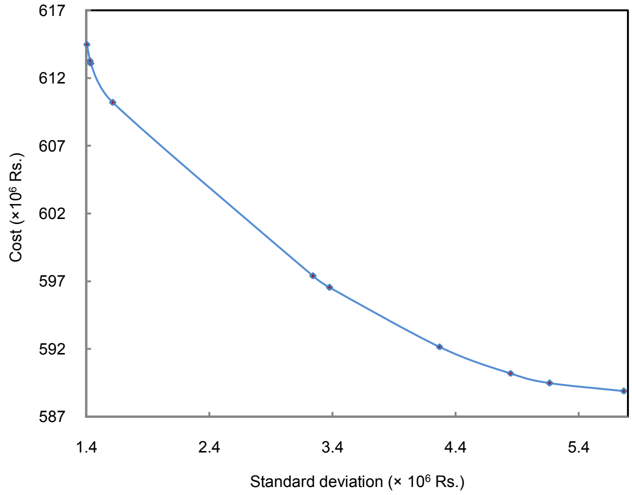

Fig. 4. Efficient Frontier for the Planning Model

Efficient frontier of expected procurement for different values of α is shown in Fig. 4. The cost of purchasing from the given options decreases with the increase of standard deviation *i.e.* risk. So a risk taking consumer can purchase electricity at relatively less cost as compared to the risk-averse consumer. At α =1X10^{-6}, risk decreases drastically to α =4X10^{-6}. The curve starts becoming constant after α =5X10^{-5}. Different values of α are taken for evaluating optimum trade-off between cost and risk. Standard deviation of net cost is the square root of cost variance. Expected cost increases as its standard deviation decreases, which signifies risky procurement require less investment.

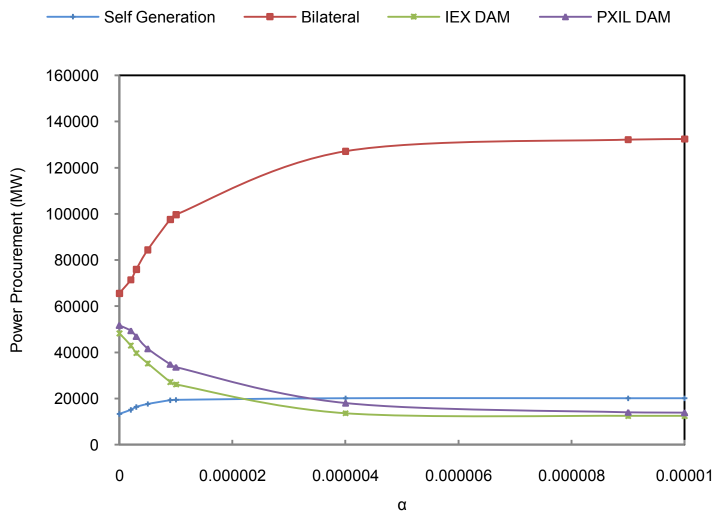

Fig. 5. Power procurement from different options at different values of α

Fig. 5 shows electricity procurement by the consumer from different options for the planning period. Power allocation for the risky assets like IEX market and PXIL market both start decreasing as the value of α starts increasing i.e. risk starts decreasing as shown in Fig. 5. So the purchase from these markets is maximum at $\alpha=0$. On the other hand, power purchase from other options like bilateral contract and self generation starts increasing as the value of α starts increasing. These become constant at the higher values of α . UI allocation and scheduled demand are unaffected from the values of risk.

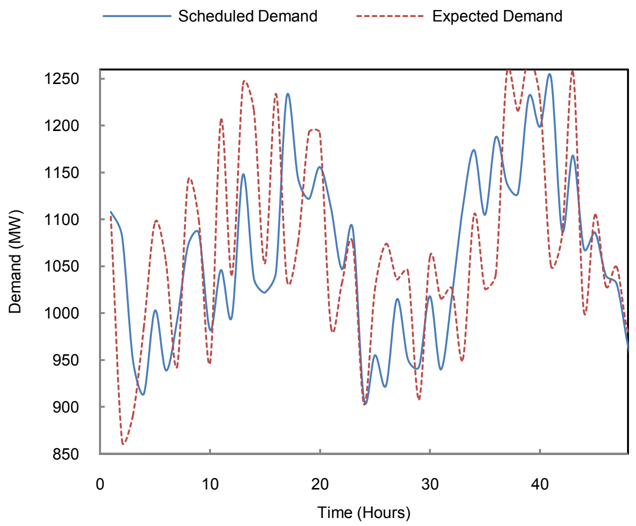

Fig. 6. Demand Scheduling by the consumer for 48 hours.

Fig. 6 shows the scheduled demand for any α value. Only two days have been considered for better understanding. This curve shows that the scheduled demand has been shifted as compared to the expected demand to account the UI deviations. This shift may be increase or decrease in the expected demand.

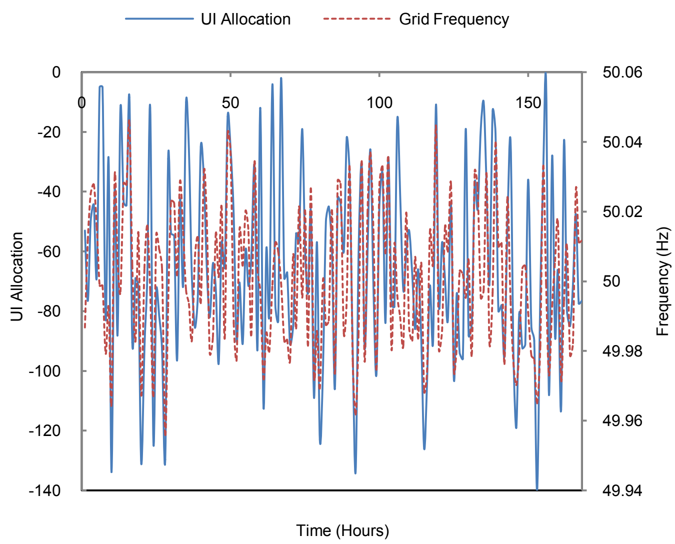

Fig. 7. Frequency and UI Allocation for Planning Period

Fig. 7 shows the frequency variation and UI allocation for the planning period. As a linear relation between frequency and UI penalty has been considered for this work instead of the piecewise UI curve, one can see the effects of linearity of frequency on the UI allocation. UI allocation is always negative to improve the grid frequency. When grid frequency is below 50 Hz, UI allocation is more negative at that time. On the other hand, when grid frequency is above 50 Hz, UI allocation is less negative. This means that at worst grid conditions, consumer underwithdraws, which help in improving grid frequency. It is more evident in Fig. 8.

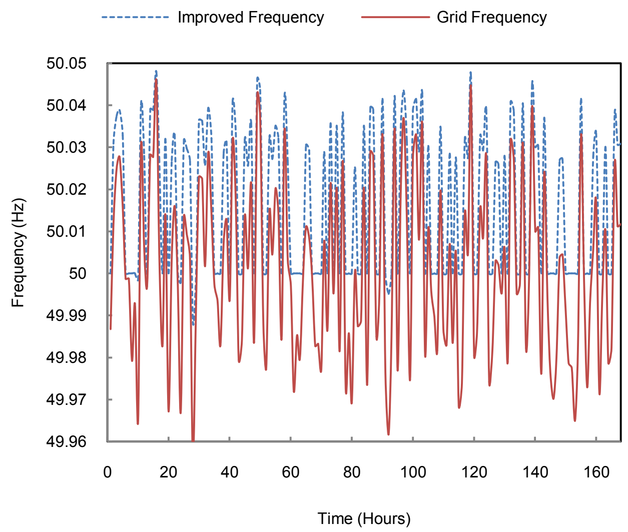

Fig. 8. Impact of Planning model on the Grid Frequency

Fig. 8 shows that the grid frequency is supported by the consumer response. When grid frequency is falling at a dangerous low level, then consumer can under withdraw which results in improving frequency at the real time. At these low values of frequency, consumer has shifted its demand into other hours in the considered period which can be decreased at the real time.

With the given model, consumer decides its minimum cost electricity procurement for a week. The system, where grid frequency is low due to system imbalances, consumer response plays an important role in improving grid frequency. Demand scheduling is done such that expected variations in base demand as well as UI deviations are accounted. The programming model deters the consumer from causing unnecessary demand decrease at real time due to volume restrictions as per DSM 2014 [10]. This model if implemented for a retailer can help in better managing its resources while participating in demand response. The model can be useful for the state owned distribution companies for better planning of electricity procurement avoiding load shedding as a real time balancing mechanism and implementing demand response programs.

V. CONCLUSION

This paper proposes a planning model for a large consumer among trading options like bilateral contract, self generation and multiple DAMs. Demand flexibility at the real time accounts for UI mechanism. Estimated variations in the base demand were also considered while scheduling the demand of the consumer. Risk arising due to the uncertain DAM price was modeled by mean variance approach. The consumer can schedule its withdrawal before a week for optimal power purchase. Results indicate the procurement from DAMs higher at higher risk values which decreases with decreasing risk. Procurement from bilateral contracts and self generation increases with the increasing risk values. Results highlight that flexibility in demand due to demand fluctuations can help in improving grid frequency. The present problem considers UI as a part of planning to show the impact of consumer demand response on grid frequency however implementation of this problem in two separate sections planning and real time operation highlighting the impact of UI would be taken in future work.

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