

# Cost Optimization of Large Scale Industries

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## Abstract

A major problem faced by bulk power consumers is the fluctuation of pool prices. There are three sources of power. Spot Market, Bilateral Contracts and power from self-producing facilities. The cost of energy from later two sources is generally constant. But the cost of pool price is variable. Hence, this unreliability is the major cause of risk faced by large consumers. This problem is resolved by a program developed in GAMS Software. The practical scenario is optimized for amount of power to be taken from the three sources that fulfils the demand of power through the entire day. The bilateral contract is a “take-or-pay” situation in which once the price is decided it will not vary. Therefore this does not poses a risk, and hence not discussed here. The amount of power self-produced and cost incurred for that is discussed here. The risk of cost variance is calculated. Finally the total cost which is sum of all above parameters is optimized for best solution and minimizing the total cost. In the final equation i.e. the total cost a constant to balance the risk and cost is added. Finally the procurement mix is discussed in the theory for both high as well as low value of risk factor. Hence this method for cost calculation can be very helpful for large consumers to purchase the most efficient amount of energy from any of the three sources to make itself most profitable.

**Keywords: Optimization, Pool Price, Purchase, Risk, Self-Generation**

## LIST OF SYMBOLS

$C_{BP}$  = Cost of buying electricity from the pool  
 $\alpha_t$  = Pool price of electricity at any time interval t,  
 $P_{BP}$  = Amount of power purchased by the large consumer from the pool,  
T = number of hours for which power was drawn by the consumer from the pool.  
 $C_s$  = Self Production cost,  
p, q, r = Quadratic linear and no load cost resp.,  
 $g_t$  = Binary variable showing status of self-producing unit.  
 $c_t^{su}$  = startup cost at hour t,  
 $P_{st}$  = Power gen by self-producing facility.  
 $G_s$  = Gain from selling in the pool,  
 $P_{St}^S$  = Power self produced and sold to the pool.  
 $\alpha_t$  = Pool price of electricity at any time interval t  
 $C_{risk}^2$  = Variation in cost,  
 $V_{kl}^{exp}$  = Covariance matrix of pool prices,  
y, z = Covariance matrix indices.  
 $P_{By}$  = Power bought from the pool during the  $y^{th}$  hour,  
 $P_{Sy}^S$  = Power self-produced and sold in  $y^{th}$  hour.  
 $C^{exp}$  = Expected total net cost.  
 $\alpha_t^{exp}$  = expected pool price.  
 $\lambda$  = weight to properly balance cost and risk.

## I. INTRODUCTION

This paper aims at minimizing the cost of power that a bulk consumer has to pay for buying power from various sources in order to run his utility. As we all know that electricity is an important part of manufacturing procedure therefore large scale industry will require bulk amount of power for their article production. Hence they will require various sources. It is assumed that the utility purchases most of its power from the pool. The other sources of power are bilateral contracts and self-generation. A factor of price variation is always associated with the electricity power market or the pool. It is a forecasted value just like the future load demand and hence very uncertain. The risk of price fluctuation is considered in the paper in the form of a mathematical equation.

However bilateral contracts follows mainly a take or pay procedure in which once decided the cost per unit and total power demand is fixed and the buyer has to pay the amount even if he does not consumes the power. The cost of self-generation is considering here because the amount of power to be self-generated is dependent on the power that is deficient from the pool. Accordingly the generating unit in the premises of the consumer has to be turned on and off.

The procedure for calculating total cost of electricity has be followed as given in [1]. The method of calculating price by forecasting methods has been adopted as in [2] and [3]. The amount of power demanded was calculated using [4]. It is also necessary to mention that the demand of a bulk consumer does not alters the pool price because the demand of one consumer is comparatively less than the total power available for sell in the pool.

However the price fluctuation that is being considered in the optimization process is studied under [5]. Studying this the variation is calculated using MS office software as given in [6]. The optimization of electricity procurement has been done using a mathematical tool as [7].

The problem of self-scheduling of thermal power producer for self-generation is discussed in [8]. The method of applying for bids and allocation of the power is discussed in [9]. Also, a simple method to calculate procurement cost without any risk consideration has also been discussed in [10].

The main aspect of this paper is to allow large scale industries to purchase electricity most efficiently by keeping the point of pool price fluctuation in mind. It provides a solution that is necessary before one decides to go for purchasing power for pool.

## II. MATHEMATICAL MODEL

### A. Buying from Pool

The equation that describes the cost of purchasing power from the electricity market like IEX for a period of time is given by,

$$C_{BP} = \sum_{t=1}^T \alpha_t P_{Bt} \quad (1)$$

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### B. Selling to the Pool

The procurer if has a facility to produce power in his own premises and is producing surplus power then he can sell it back to the pool and earn some revenue. In this way he has to pay less for buying electricity from the pool.

The equation that describes the cost of self-generation is

$$G_s = \sum_{t=1}^T \alpha_t P_{St}^S \quad (2)$$

### C. Cost of Self-Generation

If an owner has installed generating units in his area than in order to run them he will have to bear the operating cost. This cost depends on the factor whether the unit is on for a particular time period or not. The binary variables take care of this as it automatically turns 1 and 0 as and when required within the GAMS model itself. The cost is given by,

$$C_s = \sum_{t=1}^T (r b_t + q P_{st} + p P_{st}^2 + c_t^{su}) \quad (3)$$

### D. Price Variation

Variation in price of per unit electrical energy is only associated with the pool. Hence this factor must also be considered for price optimization and it is given by,

$$C_{risk}^2 = \sum_{k=1}^T \sum_{l=1}^T (P_{By} - P_{Sy}^S) V_{yz}^{exp} (P_{Bz} - P_{Sz}^S) \quad (4)$$

### E. Other Factors

Some of the PPA (Power Purchase Agreement) has mentioned in it about the rebates applicable if the net bill is paid before due date. Also there is a fine for the late surcharge as given in [11].

### F. Total Expected Bill

The net expected cost for power purchase by any large consumer from pool and self-generation is given by,

$$C^{exp} = \sum_{t=1}^T \alpha_t^{exp} (P_{Bt} - P_{St}^S) + C_s + \lambda C_{risk}^2 \quad (5)$$

### G. Problem Formulation

The optimization problem solved in this paper aims at minimizing the total bill, which is given by the equation below. It aims at minimizing tc, where tc is equal to

$$C^{exp} = \sum_{t=1}^T \alpha_t^{exp} (P_{Bt} - P_{St}^S) + C_s + \lambda C_{risk}^2 \quad (6)$$

Subject to,

$$P_{dt} = P_{bt} + P_{st}^C \quad (7)$$

$$P_{st} = P_{st}^s + P_{st}^C \quad (8)$$

$$c_t^{su} < c^{su} (g_t - g_{t-1}) \quad (9)$$

$$P_{st} \geq P_{st}^{\min} u_t \quad (10)$$

$$P_{st} \leq P^{\max} u_t \tag{11}$$

$$P_{st} - P_{st-1} \geq R^{\text{up}} u_t \tag{12}$$

$$P_{st-1} - P_{st} \leq R^{\text{dw}} * u_{t-1} \tag{13}$$

Where  $P_{dt}$  is power demand in hour  $t$ ,  $P_{bt}$  is power bought in hour  $t$ ,  $P_{st}^C$  is power self-produced and consumed,  $P_{st}^S$  is power self-produced and sold to the pool,  $P^{\min}$  is the min power that must be produced if unit is turned on,  $P^{\max}$  is maximum power limit of generating from any unit,  $R^{\text{up}}$  and  $R^{\text{dw}}$  are ramping up and ramping down limit respectively.

The above equation is a mixed integer type linear programming and the objective equation (6) includes cost of buying and selling to the pool, cost of self generation and cost variation consideration. The various constraints to which our obj function implies are given below it. (7) gives that under all conditions power demand must be satisfied. The power self-produced must be equal to the power self-consumed and sold (8), (9) allows to calculate startup cost perfectly, (10) and (11) implies that power self-produced during an hour must be greater than min power and less than max power generated resp., eq (12) and (13) discusses about the ramping up and ramping down limit.

### H. Case study

The price forecast is displayed below.

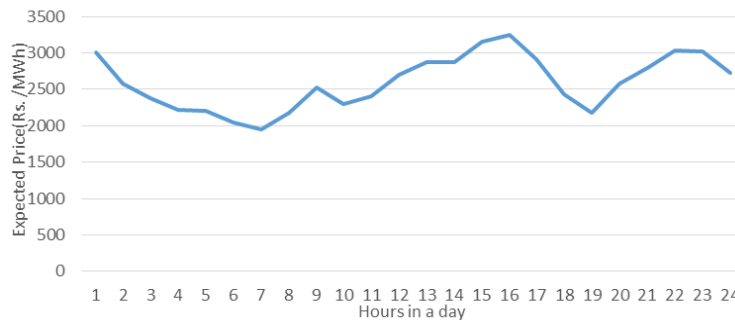


Fig. 1: Expected pool price during a day

The power demand is depicted below.

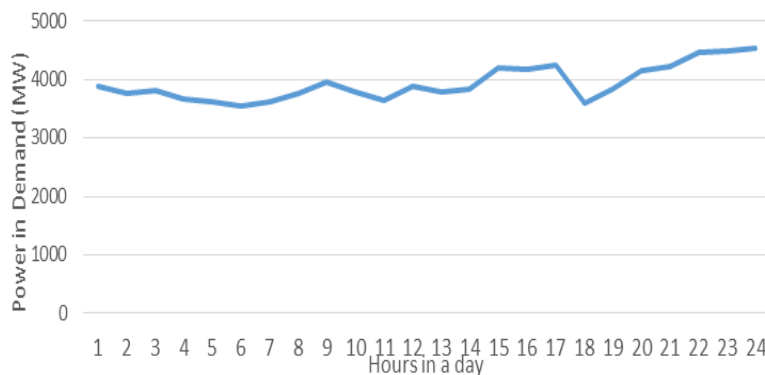


Fig. 2: Power demand by a consumer during a day.

The co-variance matrix is as below.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Fig. 3: Structure of Co-variance matrix

The data for self-production is taken as follows

Table - 1  
Data for Self Production

Capacity	130.00 MW
Minimum power output	20.00 MW
Ramping limit (all)	80.00 MW/h
Quadratic cost	0.01 h/(MW) <sup>2</sup> h
Linear cost	28.00 h/MWh
No-load cost	400.00 Rs
Startup cost	200.00 Rs.

Finally the above data are used to obtain the following result,

### III. RESULT

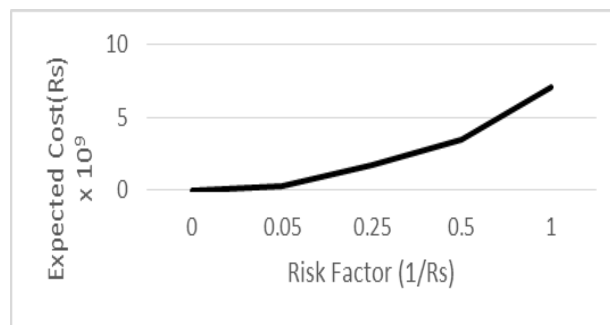


Fig. 4: Expected cost against risk factor

Thus from the graph we can see that considering low risk certainly gives low value of expected cost but if the pool price varies or deviates from the pre calculated value than at that time the consumer may not have enough balance to cope up with the risk. Hence he may suffer huge loss. At the same time a preservative consumer who consider risk very efficiently will take high value of risk factor and then calculate the total cost. It is certain that he will get a high value of the total cost but that will keep him safe from the adverse effects of pool price variation of pool price.

### IV. CONCLUSION

This paper discussed about the power purchase scenario of large consumer and discussed about the risk associated with power procurement in bulk amount. An attempt has been made to keep the procedure simple as well as consider all necessary points without leaving anything and hence the method is developed. This paper discussed about the various cost associated with the power procurement.

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