Operational Planning Constrained by Financial Requirements

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Abstract-- **This paper focuses on the future cash revenue flows required for an expected stock profile. It is these future cash flow requirements that determine the bidding strategy implemented by a Generation Company, GENCO. Based on forecasted information of competitors' product consumptions, forecasted demand, forecasted fuel prices, and expected transmission capabilities, each GENCO makes output decisions. Two cases of study are presented.**

Index Terms—**Real Options Analysis, Net Present Value.**

I. INTRODUCTION

THE objective of the expansion decision process is to maximize the profit in future periods commensurate with the risk and return expected by each company within an industry window. Each generation company, GENCO, has a given production cost, market niche and competitive advantage as a portfolio to maximize its profit in future periods. As it is the GENCOs' production that drives the risk and return profile, each competitive player needs to know the other competitor's strategic decisions to set bidding profiles and thus, maximize profit. Each GENCO potentially uses different techniques to forecast the competitor's decisions (product mix) when trying to determine its own production mix.

The input consists of forecasts of competitor's products based on historical consumption, the forecasted demand, the forecasted prices of each fuel type, and the expected transmission capabilities. While not all information has an impact in each future period, some, such as transmission capability, have a dramatic impact for a short period with profound price movements.

The dynamic simulation focuses on the interactions between competitors and the resulting option value of the generation asset. Each GENCO in the market starts with an initial state based on the type of asset owned, the capital requirements, and the operational costs. Each GENCO then finds output decisions based on expectations of the major factors as listed previously. Each GENCO adjustments its bidding decisions accordingly. There may be or may not be equilibrium after interactions occur. The uncertainties of these factors are modeled as real options to properly value the assets into the future periods.

Real Option Analysis, ROA, has been use for valuating generation assets in a market environment. First models neglected operational unit's constraints, such as ramp up/down and maximum time on/off, becoming a pure financial modeling. Neglecting operational constraints may have a significant impact on value the generation assets [1]. When these constraints are taken into consideration, the valuation problem is path-dependent. Hence, the decision to turn on or off the generating unit not only depends of fuel and electricity prices but also on unit's status. Several methodologies have been proposed for handling the technical unit's constraints. Tseng et al. [2] apply Monte Carlo simulation in the option pricing. Doug Gardner and Yiping Zhuang [1] use stochastic dynamic programming instead. These, as well as other reported papers make emphasis in modeling the electricity price and fuel prices [3][4].

Considering operational characteristics seems similar to the traditional unit commitment, which finds the optimal scheduling strategy. However, what ROA does, is to determine the optimal bidding strategy rather than the optimal schedule. Under specific conditions, these two objectives can be equivalent.

With the unbundling of the electric power industry, the generation unit has become a multi-product device. Generation owners may have additional means of generating revenues. Rajaraman et al. in [5] describes the multi-period optimal bidding strategy for a generator under exogenous uncertain energy and reserve prices. Finding the optimal market-responsive generator commitment and dispatch policy in response to exogenous uncertain prices for energy and reserves is analogous to exercising a sequence of financial options [6].

The optimal bidding is deficient if additional factors are neglected, for example transmission congestion and competitor's behavior. Rajaraman et al. in [5] treats transmission congestions by modeling locational prices that are consistent with the structure of the transmission congestion and the transmission network. Shi-jie et al. in [7] and [8] also use locational prices for valuating transmission assets. They refer to price difference between two points as locational spreads.

This paper focuses on the future cash revenue flows required for an expected stock profile [9] (as determined by Capital Assets Pricing Model, CAPM, Arbitrage Pricing Theory, APT, etc.). It is these future cash flow requirements that determine the bidding strategy implemented by a

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GENCO. For simplicity's sake, the future cash flows are dependent on a single commodity, electric energy, although a generating unit is a multi-product device. The remainder of the paper is organized as follows. The next section presents the CAPM. Next, ROA in the electric power industry is introduced. A linear programming mathematical model is then presented. Numerical example follows. The final section concludes the paper.

II. Capital Asset Pricing Method (CAPM)

CAPM is an important tool used to analyze the relationship between risk and rate of return [9][10]. An average-risk stock is defined as one that tends to move up and down in step with the general market as measured by some index such as the Dow Jones Industrials, the S&P 500, or the New York Stock Exchange Index [11].

If a stock is in equilibrium, then its required rate of return, r, must be equal to its expected rate of return, $\hat{r}$. Further, its required return is equal to a risk free rate, r_f, plus a risk premium, whereas the expected return on a constant growth stock is the stock's dividend yield D_1/P_o, plus its expected growth rate, g.

$$r = r_f + (r_m - r_f)\beta = \frac{D_1}{P_o} + g = \hat{r} \tag{1}$$

Fig. 1 shows the security market line, SML, as a function of risk (β). The riskless return has a β=0, where the SML crosses the expected return axis.

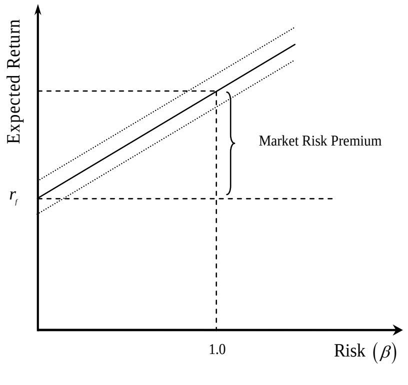

Fig. 1. The security market line

β indicates how sensitive a security's returns are to changes in the return on the market portfolio. If a security's β=1.0, its return tend to track the market portfolio.

If the market portfolio increases/decreases by 10%, the stock also tends to move up/down by 10%. If a stock has a $\beta <$ 1.0, it will tend to rise/fall less than the market. For instance, assume a stock has a β=0.5. If the market portfolio increases by 10%, the stock will tend to move up only 5%.

A stock with $\beta > 1.0$ will rise/fall more than the market. For example, a stock with a β=1.5 will tend to rise/fall by 15% when the market portfolio increases/decreases 10%.

The utility's forecasted market clearing price is essential in its market strategy. Price variations are the result of competitors' interaction and system conditions. Competitors' decisions are strongly correlated with input price variations. Even when the forecasted prices reflect the normal stochastic variations in system operating conditions, the forecasted prices may not be accurate enough to guarantee a winning decision. The producer has to live with the uncertainty of negative profits. Possible losses may occur due to the difference between the spot price at delivery time and the forecasted price.

There exist two basic models that can be used to determine the risk management benefits of alternative strategies. The first is to conduct a historical analysis and determine how a given strategy would have performed had it been employed in the past. Historical information would be used to simulate the future cash flows. The second method would be conducted a forward-looking analysis by forecasting future system and market variables.

The planning of scheduling for a GENCO will determine the future cash flows. These need to recover costs, fixed and variable, plus an additional expected return.

Operational constraints of the generating units, the interest rate, forecasted electricity and fuel prices error deviation, among others, will create a SML bandwidth instead of a strict SML, as depicted in Fig 1.

III. Real Options analysis

Real options have become an important tool on valuation of power generation asset. Real options represent opportunities to act which provide their holder with the right, but not the obligation, to exchange the value of the cash flow stream of underlying asset against the value of the cash flow stream of an exercise asset [12].

The financial concepts applied to the electricity market results in the spark spread option. The spark spread option is based on the difference between the electricity price, p_E^t, and the price of a particular fuel, p_F^t, used to generate it [8]. The spark spread payoff associated with a specific heat rate, H is defined as:

$$payoff = p_E^t - Hp_F^t \tag{2}$$

A generation asset's value over a period of time is commonly estimated by a series of European call spark spread options.

$$\sum_{t=1}^{T} E(p_E^t, p_F^t, T) = \sum_{t=1}^{T} \max(p_E^t - Hp_F^t, 0) \tag{3}$$

Each period has an associated cost and revenue. It is common practice to distribute the fixed costs within the existing periods. It means that fixed costs are periodized over its useful economic life. Fixed costs as well as variable costs must be covered during the periods when bids are accepted by the market. For instance, when the fixed costs are covered during the fist periods seems more favorable, but this is disputable given that profits strongly depend on spot prices, which may be higher in later periods. However, selling during the earliest period with a lower profit provides additional flexibility since they have extra periods to adapt their strategy base on new market information. Hence there exists a trade-off of when to scheduling output becoming a timing problem.

Real Options could be used to take the uncertainty due to different factors such as uncertainty about an opponent's bid, uncertainty about future demand, and uncertainty about future failures and inefficiencies in power plant operation, and uncertainty about congestion on transmission lines, and reduce all these uncertainties to a single number.

IV. MODEL AND SOLUTION

How can a GENCO gauge the expected cash flows of revenue that would result from a specific strategy? These cash flows are not exogenous at all. The future cash flows depend upon future scheduling decisions, however the fixed cost are certain to be incurred and those have to be recover.

Consider that any quantity produced can be sold in the spot market in the subsequent periods as long as it is priced competitively. The optimization problem is formulated as a maximizing linear program.

$$\underset{P_G^t}{Maximize} \ \sum_{t=1}^{T} \left(P_G^t p_E^t - C\left(P_G^t\right)\right) / (1+r)^t \tag{4}$$

$$S.to \quad HP_G^t \le D^t \qquad \forall t = 1,...,T \tag{5}$$

$$P_E^t \ge H \cdot p_F^t \qquad \forall t = 1,...,T \tag{6}$$

$$P_G^t \ge 0 \qquad \forall t = 1,...,T \tag{7}$$

where the P_G^t is the electric power generated at period *t*, $C\left(P_G^t\right)$ represents the fix and variable cost, D^t is the demand at period *t*, and $(1+r)^t$ is the time value of money, and H a matrix of output coefficients. It is assumed a linear relationship between input and output transformation. This assumption permits to model GENCO's bid in block contracts. The formulation also assumes that there is no limitation on fuel supply.

The cost function is given by the equation:

$$C\left(P_G^t\right) = a + bP_G^t \tag{8}$$

where *a* represents the fixed cost and *b* is the variable costs of production.

A network flow interpretation of the mathematical model is depicted in Fig. 2.

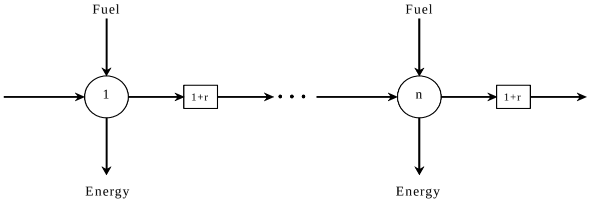

Fig. 2. N-periods production decision network flow

The previous diagram portrays the spark spread option. This option adds value to the power generation assets when the contracted fuel is sold back to the fuel market or swapped, which is beyond the scope of this paper.

It is possible to include additional inputs in the described model permitting to market participants adaptively adjust market strategies as soon as each new piece of information is available.

V. CASE STUDIES

In this section numerical examples are presented. A GENCO is designing the bidding strategically for the next 4 periods. Fixed cost, variable production cost, and an expected rate of return must be recovered. Historical market information was taken from a random electric utility [13].

For the purpose of this example, forecasted electricity spot prices for the upcoming periods are assumed known. Except as noted elsewhere, all other parameters values used are listed in Table I and Table II. Fuel price is assumed constant for all the periods.

TABLE I
EXPECTED DEMAND AND EXPECTED ELECTRICITY PRICES

Period	Demand (MWh)	Price
1	500	20.0
2	600	24.3
3	550	26.5
4	580	28.0

TABLE III
BASE CASE PARAMETER VALUES

Parameter	Value
P_G^{MAX} (MW)	50
a ($)	120
b ($/MWh)	1.0
r_f (%)	8
r_M (%)	12
β	1.2
Fuel ($)	21

The expected rate of return is calculated as follows:

$$\hat{r} = 8\% + (12\% - 8\%)*1.2$$
$$\hat{r} = 12.8\%$$

With the previous information, the optimization program gives the results shown in Table III:

TABLE IIIII
OPTIMAL FORWARD POWER COMMITTED

Period	Power (MWh)
1	0
2	50
3	50
4	50

Prices, committed power, and revenues are shown in Fig. 3.

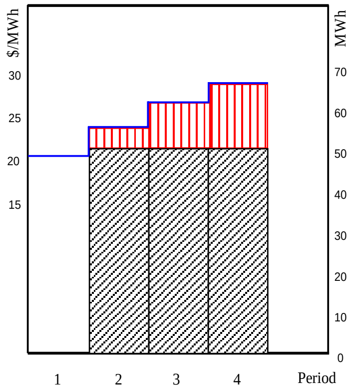

Fig. 3. Expected price of electricity and committed power: case I

From Fig. 3, we can observe that expected price of electricity is lower than the production costs at period 1. It implies that GENCO is not selling energy in such period. The subsequent periods, expected prices seem more favorable allowing him to sell its energy. No selling power in period 1 generates negative profits which are transfer to next periods.

In order to recover the cost acquired at those periods, GENCO will need to raise the bidding price in subsequent periods. This can be done basically in two different ways: distributing in two or more periods or in a single period. Distributing in more than two periods seems more credible which also distribute the risk. However, such decision will depend much on market information. The most disruptive factor that leads to violation of theoretical predictions is information uncertainty on the part of market participants.

From the same Fig. 3 we also observed the price difference between the electricity expected market price and the expected selling price. This information is also provided for the optimization program and is presented in Table IV.

TABLE IVV
PRICE DIFFERENCE AT EACH PERIOD

Period	1	2	3	4
Difference ($)	-	2.549	3.832	4.324

Note that the values take in consideration the time value of the money. For instance, the expected market price at period 2 is $24.3

In this case, it was possible to allocate forward contracts such as the future cash flows recover all the cost and the expected return. However, there exists always the possibility that this condition does not happen. Two alternatives need to be considered: To reduce the expected return or to increase bid prices.

Now, consider that the price in period 1 = $23.6 and in period 2 = $20.3. The optimal solution is shown in Table V.

TABLE V
OPTIMAL FORWARD POWER COMMITED WITH NEW EXPECTED PRICES OF ELECTRICITY

Period	Power (MWh)
1	50
2	0
3	50
4	50

From Table V we can see that due to lower expected price of electricity at period 2, GENCO's decision is not to sell. Thus, GENCO is incurring in negative profits at that period. The negative profits are essentially the periodized fixed costs. Form the unit's operational viewpoint, it can be said that the unit is banking. Prices as well as committed power and revenues for the 4 periods are shown in Fig. 4.

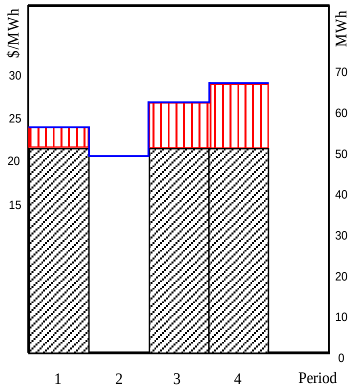

Fig. 4. Expected price and committed power: case II

The future profits per period for both cases are shown in Table VI.

TABLE VI
FUTURE EXPECTED PROFITS

Period	Case I ($)	Case II ($)
1	-	115.248
2	129.678	-
3	191.604	191.604
4	216.188	216.188
NPV	10.526	10.78

From Table VI we observe that the NPVs are different. The difference is due to time value of money between selling today (period 1) and selling tomorrow (period 2) since the values at period 3 and 4 are the same. In both cases, the fixed costs are fully recovered.

VI. UNCERTAINTY

Simple capital budgeting analysis, based on the assumption of a given time flows of receipts, is perfectly valid if future production plants are known. However, this assumption neglects futures events introducing substantial uncertainty in the decision making process. Uncertainty is best thought of as representing a spectrum of unknown situations, ranging from perfect knowledge of the likelihood of all the possible outcomes at one end to no knowledge of the likelihood of possible outcomes at the other.

By taking in consideration uncertainty, the company will gain a flexibility option allowing him to modify operations depending on how conditions develop as time progresses.

Decision trees have been a traditional tool for analyzing and valuating embedded options when uncertainty is considered. Setting up a decision tree forces the GENCOS´s decision maker to consider embedded options.

In this document we basically are evaluating a single path of the decision tree. The branch at each new node, assumes the same rate of return and external variables are forecasted with accuracy, price of electricity.

Our approach, LP optimal committed power for multiple time periods can be expanded by using the decision tree. For each path, we form a LP problem to forecast the optimal decision that maximizes profits.

The introduction of uncertainty for fuel and electricity price for a given period *t* can be graphically represented as follows:

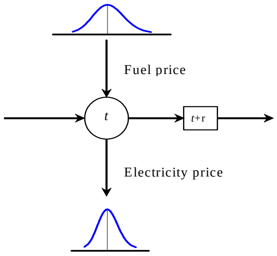

Fig. 5 Expected fuel and electricity price at period *t*

Other exogenous variables can be modeled similarly to fuel or electricity price variables depending whether it is a input or output variable. Additionally, different rate of return inter-period would also be simulated.

VII. SUMMARY

GENCOs operational planning is not only constrained for its technical operational limits and fuel inventory, but also for the financial requirements.

A GENCOs financial requirement is the expected rate of return within a specific period of time. According with CAPM in order to increase the expected rate of return, GENCOs portfolio will be exposing to higher risk.

By committing forward contracts in the earliest deadline, the company will gain a flexibility option allowing him to modify operations depending on how conditions develop as time progresses. One of these options is to modify financial requirements, expected rate of return, in order to obtain a higher profit.

In order to reduce risk in the allocation on forward contracts a less expected return may be chosen otherwise the expected electricity price must be higher.

Another alternative would be to increment the number of periods. This generally is an option for investment decisions. However, for operational decision this condition is not available; bookkeeping time is fixed usually quarterly.

The previous analysis can be applied to any price taker forward contract, intermediate load unit, or contracts within a bandwidth at the money from financial option viewpoint. Peak generators need as well as any other unit to recover the full cost in a certain period of time. This justify why for some periods electricity prices experience sparks unless other allocating mechanism helps GENCOs to recover all the costs smoothly.

An intertemporal LP optimization program has been proposed in this document. The problem is formulated as deterministic optimization problem since a single path of a decision tree is evaluated. However, the incorporation of uncertainty was discussed and it is issue of future work.

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