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Integrated Risk Management Model for Portfolio Selection in Multiple Markets

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Abstract— **Risk management is a serious challenge for generating companies (gencos), because of price uncertainty in production resource procurement and selling generation outcome. Managing risk of either trading side without considering other may lead to inefficient risk management. Considering interrelated nature of market uncertainties this paper proposes integrated risk management framework for strategic trading decision making in all involved markets, in order to maximize overall expected profits. Spot and contract markets have been considered as available trading options in involved markets. Mean variance portfolio theory has been applied to solve the problem. The results from a realistic case study illustrates that decisions based on proposed approach provide better trade-off in terms of profit and risk. Revenue and cost side correlation give a new insight for diversification in portfolio selection in different trading side markets.**

Index Terms-- **Price uncertainty, electricity market, fuel market, emission market, mean variance portfolio theory, risk management.**

I. Introduction

In a deregulated environment the electricity markets are significantly affected by other energy and emission markets. The reason being dominant production process is still the thermal conversion of fossil fuels such as gas, oil and coal which emit the majority of carbon dioxide into the atmosphere. Due to direct link of energy commodities and climate change, price fluctuations in energy emission and electricity market are interrelated [1].

Electricity prices are predominantly influenced by marginal cost of generation by fossil fuels which was earlier calculated based on the fuel cost required to generate electricity, but with the introduction of Emission trading schemes in power industry this cost has been increased [3]-[4]. To emit in the environment utilities need to procure emission permits, as per European Union Emissions Trading Schemes (EU-ETS) [5]. This scheme is divided into compliance periods (phases) with continuously increasing emission reduction targets. The upcoming phase of EUETS puts an end to free allocation of emission allowances and shifted to full auction mechanism for the power industry [6]. This will boost the demand and consequentially increase volatility in emission permit prices [7]. The price volatility of fossil fuels and emission permits, along with the difficulty of forecasting, puts power producers at risk from fluctuating production cost [8].

Power producers trade in electricity markets to sale their generation outcomes. The electricity markets are volatile and uncertain in nature. Gencos have to control the risk of volatile electricity prices to secure future profits. A usual way to hedge against price uncertainty in markets is signing forwards before spot market trading occurs. To secure maximum revenue gencos strategically decide their trading proportion in available options considering involved risk [9].

While managing risk to secure their trading position, power producers strongly consider the market price risks associated with electricity trading side and tend to overlook the cost side risks, associated with price uncertainty of production resources [9]. The uncertainty regarding cost of production resources is critical to the decision-making concerning efficient risk management.

Impact of fuel market uncertainties on electric energy allocation has been analyzed [10]-[11]. Correlation of electricity, emission and fuel markets prices impacts the selection of fuel mix for generation technologies in the power sector [12]-[13]. Much of the existing risk and uncertainty literature emphasis on uncertainties of particular trading side, rather than a multidimensional treatment of uncertainty. However, no research considers mutual impact of involved upstream and downstream market uncertainties on each other to identify genco's optimum trading position in true sense.

This work formulates a portfolio selection approach based on integrated risk management framework which considers the risk of both upstream and downstream trading sides, involving their inter-dependencies. Mean-variance theory has been applied for portfolio selection to best represent the impact of correlation between upstream (fuel and emission) and downstream electricity markets. The simulations give a new insight to diversify trading in fuel, emission and electricity markets. The results based on realistic case study demonstrate that genco can take the advantage of usually

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correlated electricity, fuel and emission market prices in order to maximize lesser risky profit opportunities.

II. Problem Description and Formulation

A considered price taker fossil-fuel based genco procures production resources such as fuel and emission permits *via* certain contracts and spot market and sells its generation out come in electricity market *via* pool and bilateral contracts. The genco wishes to maximize net profit attained from trading in all involved markets, by coordinating three portfolios of interrelated markets over specified period of time at a controlled level of risk.

Spot market prices of electricity, fuel and emission trading are uncertain. Uncertainty in fuel and emission permit prices adds risk to cost side, while uncertainty in electricity prices makes revenue risky. A mean-variance approach has been used for portfolio selection in interrelated markets. This approach comprehensively reflects the impact of correlation for integrated decision making *vis-a-vis* other approaches. Quantum of power traded in pool and bilateral markets, fuel and emission permits procured from spot and contract markets are decision variables of the problem. Genco plans its portfolio in medium-term time horizon (months to year), for a presumed generation satisfying operational, fuel and emission constraints and considering the markets to be completely liquid.

A. Revenue from Electricity Market

Fossil fuel Genco aims to fix its future trading plan for the planning period *I*, for an optimal allocation of its scheduled generation P_i^G between spot market and bilateral contracts. Revenue generated from the spot market R^S and bilateral contract market R^B are calculated as

$$R^S = t\sum_{i=1}^{I} \lambda_i^S P_i^S \tag{1}$$

$$R^B = t\sum_{i=1}^{I} \lambda_i^B P_i^B \tag{2}$$

where λ_i^S is spot market price and λ_i^B is bilateral contract price, while P_i^S and P_i^B are power traded in spot market and bilateral contract respectively, each for i^{th} trading interval of *t* hours.

B. Electricity Generation Cost

For the considered planning period genco procures fuel and emission permits from their respective markets. Amount of fuel consumed to generate *p* units of electricity is calculated from heat rate characteristics of generator

$$\phi(p) = a\ p^2 + b\ p + c \tag{3}$$

where *a, b* and *c* are heat rate coefficients. Thus, quantum of fuel required to generate P_i^G power is

$$Fuel_i = \phi\left(P_i^G\right) \tag{4}$$

Emission permits required for certain generation can be calculated in terms of CO_2 emissions, as the product of quantum of fuel consumed and emission factor e_f [3]. Each unit of emission permit gives the holder a right to emit 1 ton CO_2 emissions. Thus, emitted CO_2 in tons are

$$CO_{2i} = e_f \phi\left(P_i^G\right) \tag{5}$$

Gencos' requirement for fuel and emission permits to generate P_i^G power at certain trading interval can be met through certain contracts and purchase from spot market. Total quantum of fuel and emission permits $Fuel_i$ and CO_{2i} procured from spot trading is $Fuel_i^S$ & CO_{2i}^S and certain contracts is $Fuel_i^B$ & CO_{2i}^B, respectively. Total fuel cost (*FC*) and emission cost (*EC*) for purchasing fuel and emission permits from contracts at prices $\lambda_i^{F,B}$, $\lambda_i^{E,B}$ and from spot trading at market clearing prices $\lambda_i^{F,S}$, $\lambda_i^{E,S}$ respectively, is

$$FC = t\sum_{i=1}^{I} Fuel_i^B\ \lambda_i^{F,B} + t\sum_{i=1}^{I} Fuel_i^S\ \lambda_i^{F,S} \tag{6}$$

$$EC = t\sum_{i=1}^{I} CO_{2i}^B\ \lambda_i^{E,B} + t\sum_{i=1}^{I} CO_{2i}^S\ \lambda_i^{E,S} \tag{7}$$

C. Total Profit

Total profit of Genco π_C can be calculated as the difference of revenue generated by selling electricity in different contracts and involved generation cost, as

Profit = (Revenue – Cost)

$$\pi_c = R^S + R^B - FC\ - EC \tag{8}$$

D. Mean-Variance Portfolio Theory

In Markowitz mean variance theory, the average value of forecast is considered as expected value and its variance is considered as a measure of risk. This theory seeks to reduce the variance of expected profit function [14]. This also considers dependencies of risk factors affecting the profit function and highlights the importance of correlation between trades. For portfolio optimization, selection of any trade is solely not dependent on the characteristics that were unique to it. Rather, its co-movement with other uncertain trades is also important [14].

1) Expected Profit

The expected profit is obtained from (6) considering expected values for future prices of different markets, for each trading interval as

$$\pi_c^{Exp} = Exp_{\lambda_i^S, \lambda_i^{F,S}, \lambda_i^{E,S}\ \ \forall i}\left\{R^S + R^B - FC - EC\right\} \tag{9}$$

Contract prices of all considered markets λ_i^B, $\lambda_i^{F,B}$ and $\lambda_i^{E,B}$ are deterministic, *i.e.* known at the time of planning, so expected values are not relevant in their case. Thus, expected profit is

$$\begin{aligned}\pi_C^{Exp} = &t\sum_{i=1}^{I} E\left(\lambda_i^S\right)P_i^S - t\sum_{i=1}^{I}\left(Fuel_i^S\ E\left(\lambda_i^{F,S}\right) + CO_{2i}^S\ E\left(\lambda_i^{F,S}\right)\right)\\ &+ t\sum_{i=1}^{I}\left(\lambda_i^B P_i^B - Fuel_i^B\ \lambda_i^{F,B} - CO_{2i}^B\ \lambda_i^{F,B}\right)\end{aligned} \tag{10}$$

Expected values of different market prices, $E\left(\lambda_i^S\right)$, $E\left(\lambda_i^{F,S}\right)$ and $E\left(\lambda_i^{E,S}\right)$ for each trading interval are calculated as mean of their respective price vectors.

2) Uncertainty Model

Total risk of profit function can be evaluated considering variance of profit. Different uncertain markets prices are considered to be correlated. Their individual uncertainty and correlation with other markets has been calculated using variance-covariance matrix between different spot market prices for each trading interval.

$$\begin{aligned}\pi_C^{Var} = \ & t^2\sum_{i=1}^{I}\left(P_i^S\right)^2 Var\left(\lambda_i^S\right) + t^2\sum_{i=1}^{I}\left(Fuel_i^S\right)^2 Var\left(\lambda_i^{F,S}\right) \\ & + t^2\sum_{i=1}^{I}\left(CO_{2i}^S\right)^2 Var\left(\lambda_i^{E,S}\right) \\ & - 2t^2\sum_{i=1}^{I} Fuel_i^S P_i^S Cov\left(\lambda_i^S, \lambda_i^{F,S}\right) \\ & - 2t^2\sum_{i=1}^{I} CO_{2i}^S P_i^S Cov\left(\lambda_i^S, \lambda_i^{E,S}\right) \\ & + 2t^2\sum_{i=1}^{I} Fuel_i^S CO_{2i}^S Cov\left(\lambda_i^{E,S}, \lambda_i^{F,S}\right)\end{aligned} \quad (11)$$

Variance of market prices, $Var\left(\lambda_i^S\right)$, $Var\left(\lambda_i^{F,S}\right)$, $Var\left(\lambda_i^{E,S}\right)$ and covariance between price vectors of different markets $Cov\left(\lambda_i^S, \lambda_i^{F,S}\right)$, $Cov\left(\lambda_i^S, \lambda_i^{E,S}\right)$, $Cov\left(\lambda_i^{F,S}, \lambda_i^{E,S}\right)$ for each trading interval *i*, can be statistically calculated [15]. The covariance represents the correlation between two market prices, *i.e.* how the two prices are mutually co-related, over each time interval. The expected values of uncertain prices (10) and their variance-covariances (11) can be obtained through forecasting. As the contribution of this work lies in portfolio selection modeling, these are statistically estimated based on historical data.

Genco's portfolio is optimized to maximize profit for a minimum risk level. Weight on risk minimization depends upon Genco's risk taking desire, represented by risk weighing factor *β*. Higher values of *β* represents a strong risk averse nature of Genco which selects portfolio with lesser risk in expected profit. There exists a trade-off between profit and risk. As the Genco seeks higher profit it has to bear higher risk while if it seeks to reduce risk of expected portfolio profit it has to compromise with profit.

To manage the risk evaluated from (11), a Genco selects a tradeoff between profit and risk. To maximize profit and minimize the involved risk, overall objective function Z is:

$$\max_{P_i^S, Fuel_i^S, CO_{2i}^S \ \forall i} Z = \pi_C^{Exp} - \beta\pi_C^{Var} \quad (12)$$

$$\text{s.t. } P_i^G = P_i^S + P_i^B \quad \forall i \quad (13)$$

$$Fuel_i = Fuel_i^B + Fuel_i^S \quad \forall i \quad (14)$$

$$CO_{2i} = CO_{2i}^B + CO_{2i}^S \quad \forall i \quad (15)$$

$$P_{Min}^B u_i \le P_i^B \le P_{Max}^B u_i \quad \forall i \quad (16)$$

$$CO_2^{Min} v_i \le CO_{2i}^B \le CO_2^{Max} v_i \quad \forall i \quad (17)$$

$$Fuel^{Min} w_i \le Fuel_i^B \le Fuel^{Max} w_i \quad \forall i \quad (18)$$

$$u_i, v_i, w_i \in \{0,1\} \quad \forall i \quad (19)$$

where (13), (14) and (15) are balancing constraints for electricity fuel and emission permits trading. (16), (17) and (18) are limiting constraints on contract trading in all markets and (19) is variable declaration constraint. Binary variables in (19) represent selection state of a contract in particular trading interval.

Final portfolio selection depends upon the scores of objective function Z obtained for each portfolio, varying with the risk taking desire of Genco. Higher values of Z are assigned to portfolios with more attractive tradeoff between profit and risk.

III. Results and Analysis

A coal fired generation company located at Norway has been considered for case study (specifications shown in Table I). Based on the fuel type, emission factors are estimated for CO_2 emissions [16]. The planning period is considered one year and trading interval is one week. Genco sells its total capacity as scheduled generation in day-ahead spot market and through bilateral contract. For procuring fuel and emission permits, it trades in spot and contract markets of fuel and emission permits. Contract specifications of three markets are as shown in Table II.

TABLE I GENERATING UNIT SPECIFICATIONS

Fuel Type	Coal
Generation capacity	500 MW
Quadratic heat-rate coefficient	0.000604 MBtu/MW^2
Linear heat-rate coefficient	7.768 MBtu/MW
No-load heat-rate coefficient	1116.14 MBtu
Emission Factor	0.0955 tCO_2/MBtu

TABLE II SPECIFICATIONS OF CONTRACTS IN FUEL, EMISSION AND ELECTRICITY MARKET

Commodity	Contract Prices	Min.	Max.
Electricity	34 (€/MWh)	50 MWh	400 MWh
Coal	2.5 (€/MBtu)	1000 MBtu	4500 MBtu
EUA	14 (€/tCO_2)	100 tCO_2	450 tCO_2

E. Data

The analysis is made by using historical data from 2008 to 2012, of electricity from Nordpool [17], of coal from World Bank Commodity Price [18] and emission as spot European Union Allowance (EUA) from Bluenext exchange [19]. These are shown in Figs. 1 and 2, for electricity, fuel and emission markets, respectively. Expected values of prices for each market $E\left(\lambda_i^S\right)$, $E\left(\lambda_i^{F,S}\right)$, and $E\left(\lambda_i^{E,S}\right)$ are considered as the average of price vectors for each trading interval. Each EUA represents a right to emit 1 ton of CO_2 in the atmosphere.

Variance-covariances used in (11), between the price vectors of different markets have been calculated, for each trading interval, by appropriate functions in MATLAB® [20]. For the presented case there exists 52 matrices of order 3×3, which are not shown due to space limitation. To show the effectiveness of the co-movement of markets, average correlation coefficients between electricity coal and emission permit markets for entire planning period, are represented in Tables III.

TABLE III CORRELATION COEFFICIENTS BETWEEN ELECTRICITY, FUEL AND CARBON PRICES

	Electricity price	Coal price	EUA price
Electricity price	1.00	0.48	0.58
Coal price	0.48	1.00	0.67
EUA price	0.58	0.67	1.00

The diagonal elements represent correlation between same markets so are 1. For the considered case, high correlation between electricity and emission permits market prices, and a lesser correlation of electricity prices with fuel prices has been observed. This may vary depending upon considered data. It should be noted here that a complete auction based purchase mechanism for power sector would lead to a higher correlation between electricity and emission prices.

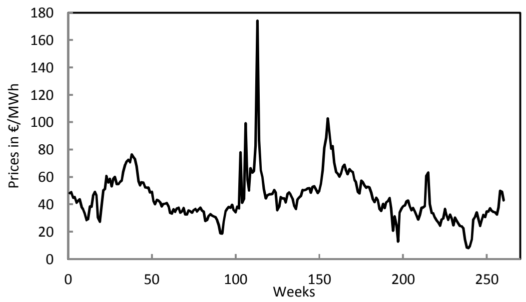

Figure. 1. Weekly Electricity Prices from 2008 to 2012.

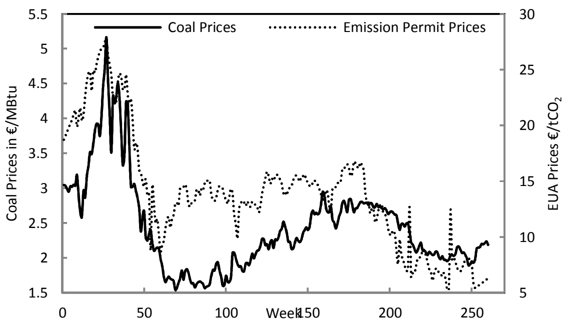

Figure. 2. Weekly Coal and EUA Prices from 2008 to 2012.

F. Scenario Consideration

For analysis, two scenarios are considered: in Scenario I where all markets are uncertain and correlated; in Scenario II all markets are uncertain but do not have any correlation with each other.

G. Simulation

The revenues and generation cost corresponding to different contracts are calculated using (1)-(7) for each trading interval, based on specification shown in Table I and prices of different markets (Figs. 1 to 2). Overall expected profit and involved risk has been calculated using (10) and (11), considering all trading alternatives. On the basis of total expected profit and involved risk, the objective function (12), subject to constraint (13)-(19), is optimized. This MINLP optimization problem has been solved by commercially available software GAMS, on its solver SBB-CONOPT. SBB offers node selections using standard Branch and Bound algorithm and solution is used by NLP algorithm of CONOPT in loop to optimize NLP problem [21].

H. Analysis and Observations

For both considered scenarios optimization is performed multiple times for various values of risk aversion parameter β and the obtained results are shown in Fig. 3 to 6. Each value of β, produces an efficient portfolio, in terms of profit and standard deviation. The contour of these portfolios is known as the efficient frontier (Fig. 3). It represents that with increasing risk averseness, expected profit decreases with risk (standard deviation). It means that higher risk averse genco has to compromise with profit. It has to select an optimum trade-off between profit and risk, according to its risk taking desire, decided by β. For higher risk averseness genco is advised to trade in risk-free contracts in purchase as well as sell side as shown in Fig. 5 and 6. Riskless contracts are generally of less favorable price thus of higher cost and less revenue. So with increasing risk averseness revenue decreases and cost increases this finally decreases profit (Fig. 4).

For considered scenarios the obtained efficient frontiers has a different profit-risk profile for similar values of β. In Scenario I where co-movement between markets is considered, the efficient frontier shows higher profits with lower risks, as compared to Scenario II, *i.e.* better trade-off in terms of profit and risk for similar values of β (Fig. 3). This happens due to positive correlation between upstream and downstream market prices (Table III). A positive correlation between revenue and cost side contracts represents that price fluctuation in upstream markets would be compensated by price fluctuation in downstream markets and thus the total risk to genco is reduced. In such a situation, genco is advised to trade more in commoving trades and thus with consideration of correlation genco enhances trading in electricity spot market and so as in emission and fuel spot market. By this, generation cost variations can be compensated by revenue side variations, so the risk of this situation is better controlled. It is also observed that profit in scenario I is also higher as spot market trading offer higher profit opportunities.

Hence, a genco can take the advantage of usually correlated electricity emission and fuel markets to enhance profit opportunities at lower risk with integrated risk management frame work in involved markets. Correlation considerations are important for the actual realization of trading strategy. If these prices were negatively correlated, then energy allocation in risk free bilateral contract would have increased, and that in spot market would have decreased.

IV. CONCLUSION

This work assist a genco to select optimum trading decision by coordinating interrelated portfolios of upstream and downstream markets for maximizing profit considering their individual and interrelated uncertainties. The proposed integrated approach provides a strategy for comprehensive assessment of uncertainties which is more efficient for overall risk management.

It is observed from case study that with provided alternative strategy considering interrelated nature of markets, genco can attain better trading position in terms of profit and risk. It is suggested that investing more in spot markets reduces the overall risk because of correlated nature of electricity emission and fuel markets. This happens because different trading side (upstream and downstream) commoving trades compensate the price fluctuations of each other and

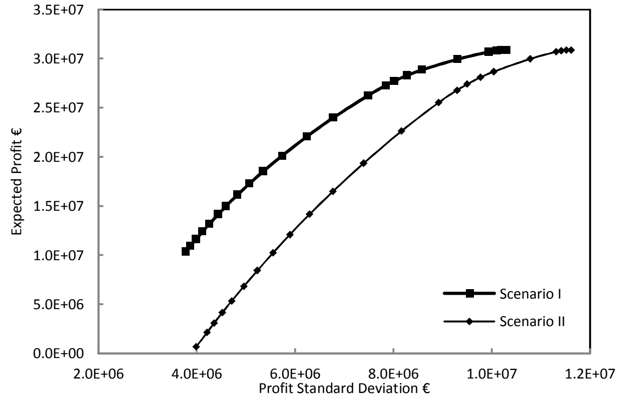

Figure. 3 Efficient frontier

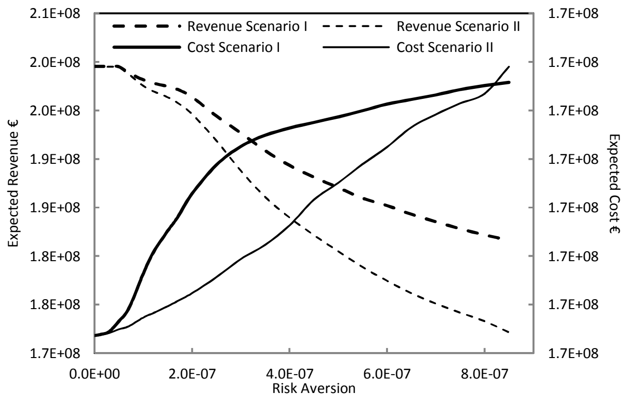

Figure. 4 Expected revenue and cost

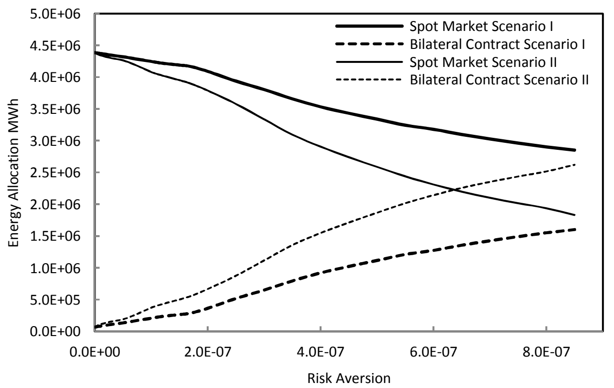

Figure. 5 Energy allocation in different trades of electricity market

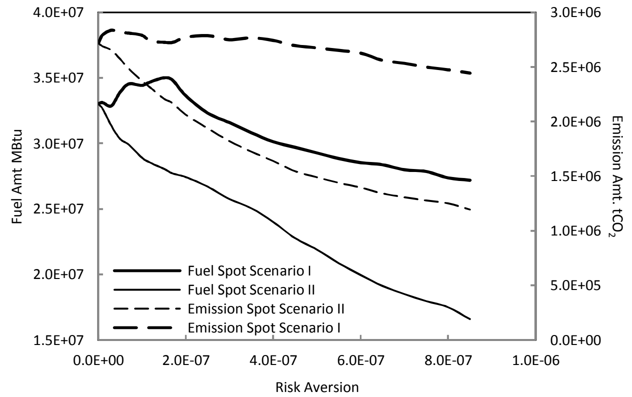

Figure. 6 Fuel and EUA purchased from spot markets

behave as risk hedge to each other. This provides higher profit opportunities to genco for lesser risk.

V. ACKNOWLEDGEMENT

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