Minimizing Market Risk by Trading Hydro-Wind Portfolio: A Complementarity Approach

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***Abstract*— In many regions around the world (e.g. Norway, Canada and Brazil) it has been observed that exist a natural synergism in the seasonal generation profile of hydro and wind power plants, which permits the implementation of trading strategies to take advantage of this peculiarity. This paper proposes a model to analyze hydro-wind complementarity and the portfolio effect on financial profits and risk exposures. The model, which aims at to find the optimal portfolio and the amount of energy volume allocation in contracts, is optimized through Genetic Algorithm technique and uses the CVaR risk measure. It is applied to check the complementarity effect among one hydro and ten wind power plants spread over the Brazilian territory. Results obtained show strong benefit for some wind power producers when associate with hydro producers, since their risk profiles are minimized, constraint by their firm energy certificate level.**

***Index Terms*- Renewable Energy, Complementarity, Trading Strategy**

I. INTRODUCTION

RENEWABLES power plants are playing a key role in the actual energy markets expansion around the world, accounting for almost half of the estimated 208 gigawatts (GW) of electric capacity added globally during 2011, in which wind and solar photovoltaic accounted, respectively, for almost 40% and 30% of new renewable capacity followed by hydropower (nearly 25%). Around 50 countries, leading by China, EUA, India, U.K., Germany and Canada, added expressive wind capacity during 2011 [1].

These rapidly growth of wind power plants worldwide can be seen as a global power matrix diversification phenomenon that brings to light the question about the effect of this resource expansion over the existing power matrices (especially, for those typically hydro or thermo electricity systems) and over generator companies business strategy decisions.

On this matter, for example, [2] studies the impact of wind power expansion on the Canadian hydro market and how complementarity improves the risk profile of energy inputs and in [3] is proposed an Energy Reallocation Mechanism (ERM) design, similar to the one existent in Brazil for hydro generators, in order to incentivize wind farm owners to increase their trading activities in the British energy market. See more on this theme in [4], [5], [6] and [7].

Instead of focusing on analyzing the impact of wind expansion over hydro or thermo electricity markets, in this study we confine ourselves in the Companies' viewpoint on trading strategies accounting hydro-wind complementarity approach.

Hydro and wind power plants have stochastic production and seasonal generation profiles given their dependence on climatic conditions that are seasonal and intermittent by nature. Due to these factors, most companies are reluctant for trading long-term contracts from each source individually, since it could result on important financial risks to be faced as consequence of exposures to the Spot Market Price.

At the same time, considering that for large generator companies the diversification by investing in wind power plants can be seen as business opportunity, we propose a model which embeds the hydro-wind complementarity effect allowing analysis of how a portfolio composed by these sources can increase companies' financial profits while mitigating risk exposures.

The proposed model, which aims at to find the optimal portfolio and the amount of energy volume allocation in contracts, is optimized through Genetic Algorithm technique and uses the CVaR risk measure as a constraint for representing the agent risk-aversion.

In the Brazilian energy market, wind power capacity has been rapidly expanded chiefly due to the local government incentives [8], and its installed capacity is estimated to grow from 1.8 GW in 2012 up to 11.5 GW in 2020, over half in the Northeastern region [9], [10].

As a result of these positive market conditions large typically hydro generators companies are diversifying their assets portfolio by investing in wind power plants. In this scenario, we propose a Brazilian case study for our model application, where we test the combination of one hydropower plant with ten wind power plants in different locations.

In [11] and [12] trading strategies for renewables portfolios based on Electricity Trading Companies perspective are discussed. Our paper differs from them by using Genetic Algorithm optimization technique and, based on the generator's perspective, focusing on wind-hydro portfolio selection and the optimal energy allocation strategy.

Given the wide variety of weather patterns in Brazil's territory, different locations of wind power plants are considered.

The paper is organized as follows. In Section II we introduce a Brazilian energy market overview, the mainly regulatory issues and local trading aspects. The model for portfolio optimization and optimal energy allocation strategy is presented in detail in Section III. Section IV presents the data used for creating scenarios of electricity prices and the hydropower plant and 10 wind power plants generations, which support, in the next Section V, case of study illustration. Section VI concludes the study.

II. BRAZILIAN ENERGY MARKET

A. Overview

Brazil is a big country, 8.5million km^{2,} with a wide variety of weather patterns and abundance of water resources. Over 70% of electricity comes from hydro sources.

The Brazilian Power System (BPS) has near 121 GW of total installed capacity (70% of hydro, 19% thermo and 9% alternatives – e.g. biomass and wind) and the federal government is aiming to increase it up to 60% on this decade due to the local economics growing forecast.

In this perspective, wind power capacity should increases 10 times and so, alternatives sources should represent 17% of the total amount in 2019 [9].

For planning and operation purposes, BPS is divided in two blocks: The National Interconnect System (NIS), which covers almost all Brazilian territory - 87% of the total energy demand -, and the Isolates Systems, mainly in the North region. In turn, the NIS is divided in four main geoelectric regions (submarkets): North, South, Northeast and Southeast-Midwest.

The BPS is a hydrothermal system with centralized scheduling operated by The National Independent System Operator (NISO). In such system, also named 'tight pool' model, operational planning has per objective to minimize the expected total cost, accounting as variable decisions the hydro and thermoelectricity generation dispatches.

The operation is computed by a multi-stage stochastic optimization model (named Newave) that takes into account a detailed representation of hydro and thermo plants, the capacity expansion, the demand forecast and inflow uncertainties in order to determine the thermo and hydro optimal dispatch [13], [14]. Due to the innumerous combinations for this problem, the hydro is simplified with the representation of 4 equivalent systems, related with the geoeletric regions.

Through Newave, the decision support stochastic model, hydro and thermo power plants are dispatched by the NISO and, as a result of this computation, the system marginal operating costs are obtained. Thus, limited by pre-defined cap and floor prices, the correspondent spot prices are reached. We used information from Newave in our study as it is the same model used by NISO.

B. Regulatory Rules

From the generators perspective, one basic regulatory rule lies on the obligation that all financial contracts be ballasted by the Firm Energy Certificate (FEC), an energy credit given by the regulator to facilitate the electricity trading for each generating unit plant in the system.

The system's total firm energy is calculated based on a simulation of hydrological scenarios, whereby the total system credit is obtained when the system marginal operating cost equals to the system marginal expansion cost, with an additional constrain that limits in 5% the probability of energy deficit in any submarket. Then, for each power plant is given a proportion of the total credit, in simplistic terms, according to the benefit that each unit brings to the system, especially under adverse conditions.

In a more general fashion, FEC can be understandable as the maximum amount of energy a project can sell through bilateral contracts and, in practice, it works as a constrain for trading energy contracts.

A company owning a number of generation units has the maximum volume to be allocated in contracts equal to the sum of all units' FECs, which explains why jointing different sources in the same portfolio is an important strategy for business development.

On the consumer's side, regulation requires that all load needs should be ballasted by supply contracts, subject a penalties if under estimated.

Another important regulatory matter, specific for the case of hydro power plants, is the Energy Reallocation Mechanism (ERM), which mitigates the generation's risk, as they are exposure to the unpredictability and volatility of water flows. This mechanism shares the risk of a low generation between all hydro generators, catching the hydrological complementary among different basins. As a result, the ERM decreases the financial impact associated with the hydrologic risk that comes from the centralized dispatch.

In the case of wind power plants, there is no such mechanism to mitigate the generation's risk, and so, this fact gives rise to an increasing interest for seeking business strategy agreements to analyze the complementary among sources, as the seasonality generation patterns can become a natural 'hedge', working as a risk mitigation mechanism and cash flow stabilization.

In [3] the ERM is discussed in detail and the idea is applied for British wind power plants and in [15] the ERM concept is discussed for a Brazilian cases where it is simulated for a set composed only by wind power plants and another with wind and hydro participation, where the perform results show the benefits of the complementarity when the generation is shared among these plants.

C. Energy Trading

For generation companies, production uncertainty represents financial risks to be faced from the stage of investment decisions up to the energy trading strategies development. The higher the uncertainty of the production and the electricity price, the higher should be the impact over company's decisions.

The uncertain seasonal production and its correlation with demand and spot price affect decisions over the amount of energy that should be allocated in derivatives contracts (forward and futures). An inappropriate decision now could result in spot market exposures in the future.

Because of these facts, companies are creating strategies to hedge their positions by diversifying in renewable sources or buying/selling derivatives contracts [11], [12], [16] and [17].

Renewable sources like hydro and wind power plants have different generation profiles. In Brazil, monthly average production of wind plants, located in the northeast region (best wind potential conditions), tends to increase from June to November whereas hydro plants production increases during the wet season that goes from December to April.

During the high period of wind plants productions, spot price is in general also high and the opposite occurs during the wet period (as the Brazilian generation mix has huge hydro participation, hydro production is negatively correlated to spot price).

In Fig. 1 is shown the typical hydro and wind generation profiles in the Brazilian regions, represented by their percentage of the Long Term Average (LTA) generation. Hydro Generation profile is represented in terms of Affluent Natural Energy, which is the electricity energy amount that can be generated from the natural inflow of hydroelectric exploitation under the specific condition of 65% reservoir level.

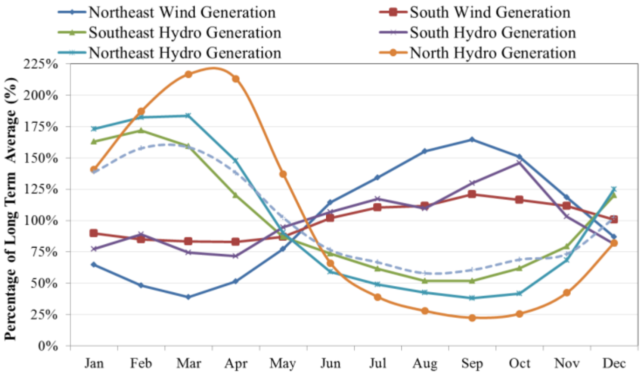

Fig. 1. Typical Hydro and Wind Generation Profiles

The basic contract commercialized in the BPS is named contract by quantity, where the delivery volume profile, the time maturity and the price are fixed in advance. Companies can allocate up to their equivalent FEC in such contracts that are normally long-term contracts.

Under a condition where the generation is higher than the overall volume allocated in contracts, the power plants sell the surplus automatically in the Spot Market (SM); on the other hand, under an opposite conditions, where the generation is lower than the volume allocated in contracts, they should buy the difference in the SM.

These facts in addition to the seasonal and uncertain energy production make all generators averse to sell high amount of its firm energy as yearly firm contract, searching for trading strategies to avoid Spot Market Price risk exposures. On the other hand, long-term contracts such as Purchase Power Agreements (PPA) are the most common type of contracts searched by consumers and distributors in BPS.

III. THE OPTIMIZATION MODEL

In this paper, a new methodology and the associated simulation model are presented. The model embeds the hydro-wind generation complementarity effect, allowing analysis of how a portfolio composed by both sources can increase financial profits through risk exposures mitigating.

The model has as its goal to find the optimal amount of energy that can be allocated in contracts by quantity of long-term and flat delivery. The objective function is the maximization of the total revenue subjected to a risk constraint. Optimization is run through Genetic Algorithm technique. Conditional Value-at-Risk (CVaR) is modeled as risk measure.

Briefly, CVaR can be understood as the conditional average of the quantiles which values are lower than alfa percent (α%) of worst scenarios. While Value-at-Risk measure defines the value that split the results distribution between α% of best scenarios and (1- α) % of worst scenarios, CVaR defines the average of these (1- α)% worst scenarios. For more on CVaR discussions see [18].

A CVaR at confidence level of 95% of the revenue function is used as risk constraint in the simulations. The model aims to maximize CVaR while maximize also the expected revenue, using as decision variable the volume allocation in contracts.

The spot prices forecast is calculated through the Brazilian model of long-term dispatch optimization (Newave).

The model gives as result the expected revenue and the correspondent risk value, as mentioned before. It can be done through the analysis of one or more power plants. In our case of study we consider a portfolio composed by a Hydro and a Wind power plants subjected to the standard market rules.

In order to evaluate the financial benefit of the natural hedge among these sources, the model take into account the seasonal generation scenarios of each power plant, account the trading strategy in terms of volume allocated, price and delivery contract and check it against the spot price forecast scenarios, constrained by the total FEC.

The model main steps follow the routine: (i) for each scenario, the power plant or portfolio overall generation is measured; (ii) all production volume is compared with the volume allocated in contracts and the FEC constrain; (iii) the surplus or deficit is checked and the difference of generated and volume allocated is settled by the spot market price; (iv) fixed contract revenue and scenarios of the spot market results are summed to determine the total revenue; (v) the routine is repeated for all scenarios and the expected revenue and correspondent CVaR for a given risk-aversion parameter are obtained.

Fig. 2 illustrates the overall model conception, when applied for a hydro-wind portfolio selling the total amount of volume through contracts by quantity.

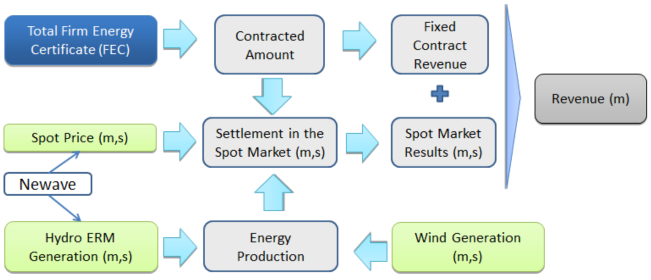

Fig. 2 Flowchart of a Hydro-Wind Portfolio Revenue Model

The model also can be run by considering the volume allocation in terms of the correspondent percentage of the FEC negotiated in the PPA. The routine is repeated varying the contractual percentage of FEC allocated in a PPA until the maximum revenue is reached, respecting the risk criteria whether analyzing one power plant or a portfolio.

The PPA's Price and the generation seasonality are inputs of the model. The routine is delimited to the total installed capacity of the power plant or the group. The next steps are presented with more details as follow.

The Wind and Hydro generations are calculated by (1) and (2):

$$G^{W}_{m,s} = FEC^{W} \cdot f^{LTA}_{m,s} \cdot h_m \tag{1}$$

$$G^{H}_{m,s} = FEC^{H} \cdot f^{ERM}_{m,s} \cdot h_m \tag{2}$$

Where: $\mathrm{G^{W}_{m,s}}$ and $\mathrm{G^{H}_{m,s}}$ are, respectively, the Wind and Hydro Generation for each m month and s scenario [MWh]; FEC is the Firm Energy Certificate [MWavg]; $\mathrm{f^{ERM}_{m,s}}$ is the ERM factor [%]; $\mathrm{f^{LTA}_{m,s}}$ is the percentage of the LTA generation factor [%]; $\mathrm{h_m}$ is the number of hours in each m month.

The Wind generation is calculated for each month and scenario. It is calculated multiplying the monthly percentage of the long-term average generation by its maximum FEC.

The hydro generation is calculated based on the ERM factor, which is defined summing the hydro power plants generation bellowing to this mechanism ($\mathrm{G^{ERM}_{m,s}}$) divided by the total FEC of them ($\mathrm{FEC^{ERM}_{m}}$), as (3):

$$\mathrm{f^{ERM}_{m,s}} = \frac{\mathrm{G^{ERM}_{m,s}}}{\mathrm{FEC^{ERM}_{m}}} \tag{3}$$

The monthly nominal volume allocated in a contract ($\mathrm{V^{C}_{m}}$) negotiated in a long-term PPA with flat delivery is assumed to be in terms of the percentage (α_m) of the portfolio FEC as presented in (4):

$$\mathrm{V^{C}_{m}} = \alpha_\mathrm{m} \cdot \mathrm{FEC} \cdot \mathrm{h_m} \tag{4}$$

The monthly accounting ($\Delta\mathrm{A_{m,s}}$), representing the net exposure to the SM, for each scenario, is found by the difference of the total portfolio generation ($\mathrm{G^{T}_{m,s}}$) and the overall volume allocated in contracts (5):

$$\Delta\mathrm{A_{m,s}} = \mathrm{G^{T}_{m,s}} - \textstyle\sum_\mathrm{c} \mathrm{V^{C}_{m}} \tag{5}$$

After accounting the difference of generation and volume contracted constrained by the correspondent FEC, the SM financial results ($\Delta\mathrm{SM_{m,s}}$) are obtained by (6):

$$\Delta\mathrm{SM_{m,s}} = \Delta\mathrm{A_{m,s}} \cdot \pi^\mathrm{SMP}_\mathrm{m,s} \tag{6}$$

Where ($\pi^\mathrm{SMP}_\mathrm{m,s}$) is the spot market price [R$/MWh].

A positive accounting value means an energy volume surplus that should be sold in the SM and then increases the company's total revenue. On the other hand, if the accounting value is negative, the company needs to purchase a correspondent energy volume in the SM to supply the deficit.

The monthly fixed revenue ($\mathrm{R^{C}_{m}}$) of one contract by quantity is calculated as follows (7):

$$\mathrm{R^{C}_{m}} = \mathrm{V^{C}_{m}} \cdot \pi^\mathrm{C}_\mathrm{m} \cdot \mathrm{h_m} \tag{7}$$

Where: $\pi^\mathrm{C}_\mathrm{m}$ is the monthly contract price [R$].

The process routine is ended up by computing the monthly revenue, represented by ($\mathrm{R^{T}_{m,s}}$) and as presented in (8):

$$R^{T}_{m,s} = R^{C}_{m} + \Delta SM_{m,s} \tag{8}$$

The expected revenue ($\mathbb{E}[\mathrm{R}]$), which represents the average value of all simulated revenues by month and all spot price and generation scenarios, is calculated as (9):

$$\mathbb{E}[\mathrm{R}] = \sum_{m=1}^{M} \sum_{s=1}^{S} p_s \cdot R^{T}_{m,s} \cdot (1+r)^{-m} \tag{9}$$

Where: $\mathrm{p_s}$ is the probability of each scenario.

IV. DATA AND SCENARIOS

In this study we use real data from Brazilian energy market. We work with a planning horizon of 8 years (From 2013 to 2020), one hydro power plant and ten wind power plants. Scenarios of spot prices, hydropower dispatches and all wind expected generations are forecasted as follows.

A. *Electricity prices*

As explained in the Section II. A. , Newave Model provides as output the system marginal operating costs, from which spot price forecast can be obtained.

Then, by using historical series of hydrological conditions and setting configurations of, among others, market capacity expansion forecast, we run the Newave model and obtained 61 series of electricity prices (or spot prices) from January 2013 to December of 2020, in a monthly basis.

B. *Hydro power plant dispatch*

An existing Hydro power plant located in the Southeast market, with 60 MW of installed capacity and 30 MWavg[1] of FEC is studied.

An additional result from the electricity price simulation is represented by the scenarios of hydro power plant dispatch, which embeds the ERM effect.

As done for the electricity prices, 61 generation allocation scenarios for the hydro power plant were created. The same array size of spot price, given their time dependency, it means, the first scenario of spot price is dependent of the first scenario

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[1] MWavg = MW average = average power in the observation period.

of hydro allocation and so on.

Although the generation uncertainty of hydro power plants is more stable as they participate to ERM sharing generation risks with all hydro system, selling energy production through long-term contracts still risky, partly because of the seasonal generation uncertainty and partly because of the negative correlation among production and spot prices.

C. Wind power plant generation

As wind power plants played a low participation into the system matrix until the recently years, it has not been inserted in the Newave model by planners, and so, its generation forecast cannot be done by means of Newave, in a same way done for hydro and thermo dispatches.

In this sense, we transformed wind inflows into wind production by collecting some points of Brazilian regions (where we have a long term historical wind data) and crossing it with one commercial wind turbine power curve and therefore obtaining hypothetical wind power plants productions for the planning horizon.

In order to better represent the Brazilian wind energy potential, 10 points were chosen: two in Ceará, two in Rio Grande do Norte, four in Bahia and three in the Rio Grande do Sul. These are the States with huge investments in wind power plants. For all points, the historical wind data from 1st January 1948 to 31th December 2008 were obtained.

In TABLE I the main parameters of wind power plants are detailed.

TABLE I

Plant	*Installed Capacity (MW)*	*FEC (MWavg)*	*Location (State)*	*Submarket*
1	30.0	14.7	Ceará	Northeast
2	30.0	11.4	Ceará	Northeast
3	30.0	13.4	Rio Grande do Norte	Northeast
4	30.0	15.1	Rio Grande do Norte	Northeast
5	30.0	12.2	Bahia	Northeast
6	30.0	16.8	Bahia	Northeast
7	30.0	9.8	Bahia	Northeast
8	30.0	11.2	Bahia	Northeast
9	30.0	11.8	Rio Grande do Sul	South
10	30.0	12.2	Rio Grande do Sul	South

The wind data used to develop this study was obtained by Vestas Meso-scale Model 1 and NOAA (National Oceanic and Atmospheric Administration). The energy production representation was performed considering the commercial Vestas V112 wind turbine (3.0 MW of Potential, 110m hub height, an IEC class II wind turbine). The wind energy production was obtained by crossing wind speed against wind turbine power curve and simulating one wind farm of 30MW of installed capacity.

From the historical wind series for each power plant transformed in energy production, it was calculated their Long Term Average (LTA) energy production and the wind scenarios were create in terms of that. This recourse was done in order to make suitable working with equation (1) in such way that it is possible to find the optimal FEC per hypothetical wind power plants.

The FEC is obtained in accordance with the regulatory framework, which states the yearly FEC as the arithmetic average of the maximum continuous energy delivery capability declared by agent and attested by certificated companies. In this study, for each wind power plant, we calculated the FEC as the historical average production.

Seasonal and uncertain wind energy production makes risky for generators to selling long-term contracts, as the correlation with spot prices can result into the need of facing exposures to the spot market prices, being worthwhile to note that there is a huge difference of the production between dry and wet periods.

V. APPLICATION AND RESULTS

The model application can be summarized in the following way: Assuming the same trading strategy of selling long-term forward contracts and using real data from a hydro power plant and ten possibilities of wind power plants (located in the different regions cited before), all hydro-wind combinations are simulated and the financial results are checked.

We assumed that there is enough demand in the market covering the equivalent energy production of the sum of all firm energy certificated associated to the power plants that we are working with.

The trading strategy for all power plants is assumed to be selling of forward contracts with 8 year's maturity (planning horizon), 110.00 R$/MWh price and same delivery profile.

Financial results are represented in terms of the expected revenue (return) and the CVaR (risk) of the Annual Revenue. We expressed the CVaR in the results by means of the reference revenue, which represents the revenue that a company could obtain without Spot Market Price risk exposures. This reference revenue is market risk-free and allows the portfolio analysis even with FEC increments.

For each plant, individually or composing a hydro-wind portfolio, the FEC percentage traded in long-term contracts are optimized in the same way that CVaR is. Furthermore, for each hypothetical wind power plant the optimal FEC is searched and then added to the hydro company portfolio in order to maximize the CVaR.

Revenue and CVaR are expressed in local currency, Real (R$)[2] and an interest rate of 9.5% per year is used for time discount. Scenarios are considered equally probable.

A. Results

All combinations among the hydro power plant and the 10 wind power plants were checked.

The results of hydro power plant are shown in TABLE II below.

TABLE II

Hydro Power Plant Results	
Contracted Volume	84.8%
Revenue	R$ 30 744 797.26
CVaR	R$ 25 175 367.04

The optimal volume allocated in contracts correspond to

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[2] 1 US$ = 2.05 R$ on January 2013.

84.8% of the FEC, which provide an annual revenue o R$ 30.7 million and a CVaR of R$ 25.1 million.

Taking into account that the hydro power plant reference revenue is R$28.9 million, the mean revenue and CVaR, respectively, 106.4% and 87.1% of its individual reference revenue.

The small difference among revenue and CVaR stems from the fact that hydro power plants participate in the ERM, where market risk exposures are minimized by system generation global effect, notably, when under high system generation scenarios.

The following Fig. 3 presents the results of the percentage contracted optimization of the hydro power plant alone and when it is combined with one of the candidates wind power plants, by varying the wind power plants FEC from 0 up to 35 MWavg.

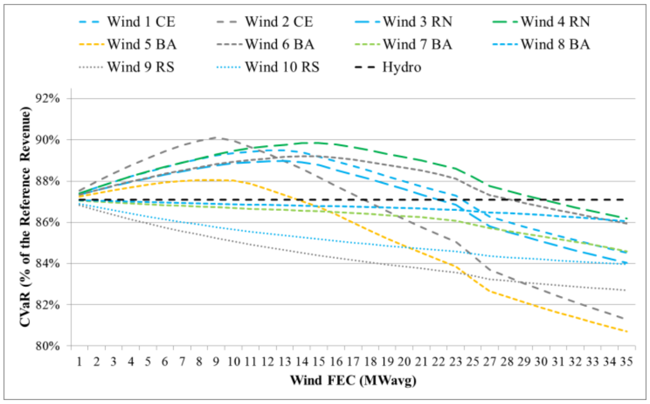

Fig. 3. The effect of Wind FEC level over CVaR.

Note from the graphic that the Wind power plants numbers 7, 8,9 and 10 do not present any CVaR above of the one found for the hydro power plant isolated, then it suggest that it is more beneficial for the company owning the hydro power plant keep itself alone than if associated with any of this group.

For all others wind power plants it is possible to notice that there exists a maximum FEC level point, which represents the FEC level where is optimal an association with hydro power plant as the association brings improvement in their risk profiles.

The results obtained for all wind power plants in combination with the hydro power plant (Hydro-Wind Portfolio) are summarized in TABLE III, from the hydro power plant perspective.

We omitted the results where there is no complementation effect (wind power plants 7 to 10). In TABLE III, the last column '*Delta*' represents the difference between trading wind and hydro power plants production together (portfolio) and the hydro plant alone. Results are expressed in terms of the reference revenue percentage.

The best case for hydro power plant is obtained when associated with 9 MWavg FEC of the wind power plant number 2 (Wind 2 CE). In this case it was obtained a small profit increase of 3% over the reference revenue, which represents an amount of R$ 871 035.00.

Under the conditions of our simulations, the energy trading benefits for the hydro power plant associated with wind power plants is marginal, even in the best case, as the hydro power plant participates in the ERM which stabilize their generation.

TABLE III

Plant	*FEC*	*Hydro-Wind Portfolio*		*Hydro Delta*	
		Contract	*CVaR*	*Contract*	*CVaR*
Wind 1 CE	12	89.5%	86.5%	2.4%	1.7%
Wind 2 CE	9	90.1%	87.3%	3,0%	2.5%
Wind 3 RN	13	89.0%	86,0%	1.9%	1.2%
Wind 4 RN	15	89.8%	87.2%	2.8%	2.4%
Wind 5 BA	9	88.1%	85.6%	1,0%	0.8%
Wind 6 BA	14	89.2%	87.0%	2.1%	2.2%

However, from the wind power plants viewpoint, when the complementarity is analyzed, it is possible to observe the benefits of their association with hydro plant in terms of CVaR maximization (see TABLE IV).

TABLE IV

Plant	*FEC*	*Wind*	*Hydro-Wind*	*Delta*
		CVaR	*CVaR*	*CVaR*
Wind 1 CE	12	67.60%	86.5%	21.9%
Wind 2 CE	9	62.30%	87.3%	27.8%
Wind 3 RN	13	66.90%	86,0%	22.1%
Wind 4 RN	15	71.40%	87.2%	18.4%
Wind 5 BA	9	65.00%	85.6%	23.1%
Wind 6 BA	14	74.10%	87.0%	15.1%

Such results imply that for Wind power plants viewpoint, an association with hydro power plants is beneficial as it improve the revenue risk profile. It also suggests that wind power plants also take advantage from the stabilization provided by the ERM for hydro power plants.

In this analysis, a hydro-wind portfolio association is better for wind power plants perspectives than for hydro power plants.

Although the portfolio return in our simulations didn't bring any expressive results, the risk approach provides an interesting result. It is possible to observe that hydro-wind complementarity effect act over the market risk exposures.

For companies point of view, that is an important result as the cash-flow of wind power plants become less instable and risky, opening opportunities to invest in such projects as their production can be hedge by the association with its own hydro power plants.

Furthermore, from both, hydro and wind, perspectives, the model provides an important information for trading strategies development, since it finds the optimal percentage of the power plant FEC which brings the best results in terms of revenues maximization and/or risk minimization.

VI. CONCLUSIONS

The results obtained show that the complementarity effect depends also on the FEC level and not only on the seasonality generation profiles and their correlation.

Through the application of our model it was possible to determine whether the complementary is beneficial or not and how it can increase generators profits and mitigate risk exposures when trading both sources together.

Furthermore, through the combination of hydro and wind complementary power plants, for some cases, we found that generators can allocate more energy volume in contracts than if trading their production in a separately fashion.

In conclusion, the performance results suggest the complementarity approach as an alternative for business strategy development for renewable generators companies, especially from the perspective of wind power plants since their association with hydro power plant can minimize their risk exposures on the Spot Market Price.

The main idea embeds in our model, besides been developed for Brazilian Market, can be adopted for applications in others energy markets since it works with complementarity approach among different renewables sources.

It can be done by crossing-correlation among wind and hydro inflows and checking trading strategies for selling the electricity production as one block instead of in a separately fashion. Applications of stochastic optimization models to deal with uncertainty of price and generation can be used for that.

Future work on complementarity approach is under development, focusing the complementary hydro-wind effect by considering run-of-river hydro power plants and with no participation in the ERM. The annual seasonality profile and the negative cross-correlation among wind speed and hydro inflows are the crux of the matter.

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