Using the seasonal diversity between renewable energy sources to mitigate the effects of Wind generation uncertainties.

D. S. Ramos, E. Guarnier, and L. T. Witzler

***Abstract*— The wind generators in the Brazilian electricity market have made their projects feasible through PPA's from regulated market where the average prices are lower, however the risks are taken by the consumers. This behavior is associated with the highest risk from uncertainty in the wind generation, which is naturally intermittent, becoming difficult to reach the contractual obligations. This paper illustrates the potential benefit in the introduction of an energy reallocation mechanism (ERM), similar to that existent in Brazil for hydro generators. This encourages wind farm owners to increase their trading activities to reach a more efficient market position and to improve the liquidity in the free electricity market. The investigation is made through simulations which calculate the maximum profitability of wind farms with and without such mechanism.**

***Index Terms* — Power System Economics, Wind Energy.**

I. Introduction

The wind energy participation in the Brazilian energy matrix has increased in the last years, particularly in the last public auctions where energy from new projects is purchased to supply the regulated market through the interconnected system. Even though, the wind energy is facing problems to make projects feasible in the free market. The reason is the risk management which is assumed by the investor in the free market, while in the regulated market the risk is mitigated by the distribution companies. These companies are allowed to pass on the financial impact to the consumer. The factor that is discouraging the wind generator to invest in the free market, is the combination of generation unpredictability and nonexistence of a "hedge" mechanism to manage the risk in the wind generation.

The hydroelectric power generation also suffers with the same issue, the unpredictability and volatility of water flows. Otherwise, this source has a special mechanism, called as energy reallocation mechanism (ERM), in order to mitigate the generation's risk. This mechanism shares the risk of a low generation between all hydro generators, catching the complementary between different drainage basin. The ERM implementation decreases the financial impact associated with the hydrologic risk that comes from the centralized dispatch. The last one is peculiar to the interconnected Brazilian system.

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The absence of a mechanism to mitigate investor's risk and the growing of investments in alternative sources as Wind Power Plant encourages the large generators and traders to analyze the complementary among sources. In order to define investments and commercialization strategy, seeking to increase profitability, they are analyzing the seasonal generation of these sources. Furthermore, considering assets in the same portfolio, the seasonality can become a natural "hedge", working as a mechanism for risk mitigation.

II. Theoretical Basis

A. Thermal Complementation

The thermal complementation in a system composed mainly by hydro power plants, is used to operate the system in order to work in the point of maximal economic efficiency. Therefore, due to seasonal water affluences which reflect in the energy production over the time, the hydroelectric capacity is sized to ensure the demand in the critical hydrologic scenario. This capacity makes the system able to produce an additional amount of energy when the hydrology is more favorable, allowing an additional recovery of energy without the needs for thermal dispatch at no cost.

The function of thermal power plants in the Brazilian energy matrix is to ensure the energy supply in a critical hydrologic period. It operates under thermal complementation to allow the optimum operation and reliable supply of the expected demand during periods of low water flow. The thermal plants also have to work as a power complement in peak hours increasing the supply certainty.

Considering the economical point of view, the hydrothermal works in an optimized way when the use of water economic future cost to supply the demand is higher than the variable cost of thermal generation.

The hydro generation economic cost is known as "Value of water", reflecting in the marginal operating cost of the system. The short-term market price (SMP) is the marginal cost limited by floor and roof values. Other important consideration in the hydrothermal system is the capacity factor (CF), which represents the average dispatch in a period of time. This is one of the most important operational characteristic that should be taken in account to evaluate a thermal project.

The CF is influenced by: the combustible contract, which in some cases has the minimum consume "take or pay"; the

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operational model of the plant in the interconnected system; the nature of the generation system; the technology adopted and the fuel price.

Considering that the hydrothermal system optimal operation is linked with the water reservoir operation, the following points can be briefed:

i. Given the storage reservoir in the beginning of the month, and the influent flow of the previous month, obtain the SMP value;
ii. Dispatch all thermal plants with generation cost bellow "spot" price;
iii. Supply the energy demand with hydroelectric power.

B. Analogy with Wind Power Plants

Considering a system that presents representative participation of Wind energy, is possible modeling the wind generation as a hydro power plant without reservoir. These plants have low operational and maintenance costs (which can be neglected for practical purposes of comparison) and also no fuel cost. These power plants are been treated as thermal plants without operational cost. The operation is described in the following points:

i. With the reservoir storage in the beginning of the month and the influent flow of the last month, obtain the correspondent "Spot" price of the system;
ii. Dispatch in the base all wind power plants, respecting the average monthly availability, which is variable in the year and dependent on the region where they are implanted;
iii. Dispatch in the base all thermal power plants with generation cost lower than the system SMP;
iv. Supply the energy demand with hydroelectric power.

According to a future justification, this methodology results in a very inaccurate and extremely optimistic values, because it models each wind power plant considering the average generation (the generation considered in each month is always the same). It does not take in consideration the natural uncertainty in the wind generation, which results in a very different amount, when compared with the average value. Therefore, the variation in the generation needs to be carefully investigated, considering the wind's complementarity between regions.

III. Wind Data Treatments

It can be argued that the most relevant factor for the success of this paper is the quality of the wind data used to develop the project. Knowing the frequency of climatic events like "El Nino" or "La Nina", which present cycles of five or six years and extreme occurrences every eleven years, in average, is necessary to use at least a historic of several decades to represent the main characteristics of wind dynamics.

In order to develop the study, data from two sources was used: Vestas Meso-scale Model and NOAA (National Oceanic and Atmospheric Administration) historic data.

The Mesoscale time series is used to provide a better understanding of the long term climatology from a specific location. The mesoscale time series contains hourly values of modeled wind speed, wind direction, temperature and density derived from a mesoscale model simulation performed by Vestas.

The Weather Research and Forecasting model (WRF3.3) is run over the selected site to produce the long term climatological wind dataset. The WRF model utilizes a nested grid layout where the coarsest model grid (27 km) was selected to capture the effects of synoptic weather events on the wind resource and an inner 9km grid to capture the most energetic mesoscale motions. For sites with very complex terrain, fine 3 km and 1 km grids can also be used to simulate the effect of local terrain and local scale atmospheric circulations. The WRF model is initialized every 48 hours using data from the Global Forecast System (GFS) Analysis with boundary conditions updated every 6 hours. Since January 2000, the National Center for Environmental Prediction (NCEP) has maintained the GFS databases, which provide gridded analysis datasets by assimilating observations from satellite, airborne data, and ground-based instruments on horizontal grid of 1º by 1 º at 6 hour intervals.

The WRF model is run with 62 vertical levels on a stretched vertical grid suitable for wind resource assessment. To ensure the boundary layer winds are effectively modeled, 17 of these vertical levels are located within the lowest kilometer above the surface. Normally the geographically closest model grid point is used for creating the long term time series, but sometimes the choice is performed manually using the topographically representative model grid point to improve the correlation between the mesoscale modeled and local measurement data.

Based on the wind data, the energy calculation was performed regarding Vestas V112 3.0 MW at 110m hub height which is an IEC class II wind turbine. The calculation was performed for the period between 1st January 1948 and 31 December 2008.

In order to better represent the Brazilian wind energy potential, 11 points were chosen: two in Ceará; two in Rio Grande do Norte; four in Bahia and three in the Rio Grande do Sul.

The Figure 1 illustrates the average wind power plant generation seasonality of all points. The chart shows that the majority of the parks generate a bigger amount of energy in the dry season (May to November), with values around 160% of the average generation. In the other side, during the rainy season the generation reaches 40%. The wind farms in the Brazilian south presented less variation in the year if compared with other region.

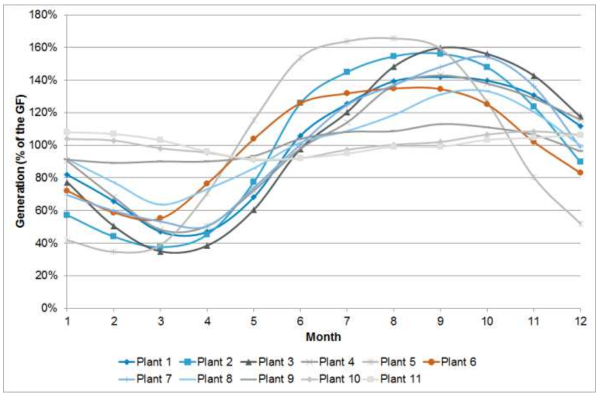

Fig. 1. Seasonal average generation of 11 wind farms.

The seasonality of the generation presented in the figure above, clearly demonstrates the complementarity among wind and hydro variation along the year, that have the predominant production in .

The figure 2 presents the average annual energy generation from 11 points in 62 years of wind historic. The generation differences between regions can be identified. Moments of low energy production in some areas are compensated with generation above the average value in others regions, which works as a natural hedge between plants in the same country.

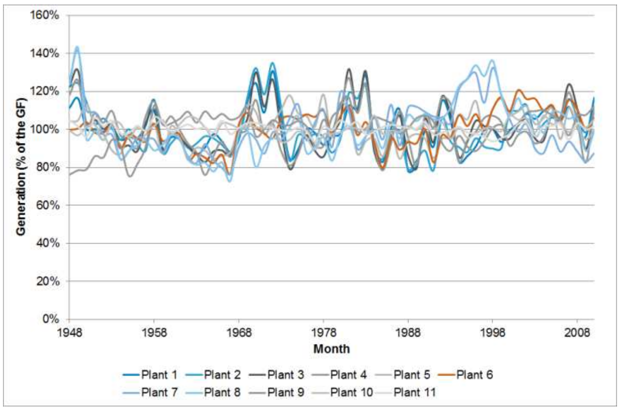

Fig. 2. Anual average generation of 11 wind farms.

IV. Introduction to the Brazilian Energy Reallocation Mechanism

The Brazilian generation mix is dominated by hydro generation, with over 75% of the Interconnected System's total generation in 2011 being from hydro sources. Also, a number of hydro power plants from different owners are located in the same river cascade, and many of the reservoirs are multiannual. The combined effect of those characteristics led to a decision being made several years ago that the generation dispatch in Brazil should be centralized, which means that the decision of how much each power plant generates at any given time is made by the system operator (Operador Nacional do Sistema Elétrico – ONS), and the goal is the optimization of the hydro resources.

Each hydro-electric power plant is given an energy credit, referred here as firm energy certificates (FEC), to facilitate the electricity trade. The system's total firm energy is calculated based on a simulation of hydrological scenarios, whereby the total system credit equals the demand that could be supplied in 95% of the scenarios. Each power plant is then given a proportion of the total credit, in simplistic terms, according to its marginal impact on the total system capacity.

The centralized dispatch increases significantly the hydro generators' risk to exposure to the wholesale short-term market prices – which present extreme volatility – since they are not able to generate electricity according to their contract portfolio.

As a consequence, a multilateral Energy Reallocation Mechanism (ERM) was introduced to manage the risk faced by hydro generators. The ERM ensures that, under normal operating conditions, hydro generators would receive the income associated with their firm energy by reallocating generation from those in surplus to those in deficit. To ensure fairness and transparency, the ERM rules form part of the short-term energy market (SM).

The monthly allocated energy of the plants is its share of the sum of the plants generation that are part of the ERM. The share of each plant is determined by the ratio of the Plants Firm Energy and ERM total Firm Energy. Equation (1) below defines the Allocated Energy of the plants.

$$EnerAloc_{PP} = FEC_{PP} * Gene\_ERM/FEC\_ERM \qquad (1)$$

Where:

$$Gene\_ERM = \sum_{\forall\, PP\, \in ERM} Gene_{PP} \qquad (2)$$

$$FEC_{MRE} = \sum_{\forall\, PP\, \in ERM} FEC_{PP} \qquad (3)$$

The SM arrangements created a commercial environment very different to that in place before Brazilian electrical sector institutional restructuring (1998). Of particular concern has always been the SM price exposure that hydro generators could have as a result of system optimization - when a generator was instructed to increase or reduce output relative to its firm energy to optimize water use across the whole system.

If the generator was instructed in any settlement period to generate well below its firm energy level (and was contracted up to its firm energy) it would face an exposure of this shortfall valued at the difference between its contract price and the SMP.

The treatment of generators' exposure to hydrological risk is crucial for the financial viability of the industry and was a key factor in privatization and the attraction of new entrants. Simulations carried out by Market Players of existing assets indicated that under conditions prevailing at that time, the impact of SMP exposure on any individual generator as a result of severe hydrological conditions could be sufficient to drive it into bankruptcy.

It is a consensus in Brazil that the scale and nature of the risks involved are such that, at present, hydro generators would be unable to manage this risk effectively by commercially negotiated bilateral contracts alone. Therefore, this multilateral mechanism must be used to manage the effects of this "optimization" exposure.

The ERM operates as following:

• The ERM guarantees hydro generators their entitled firm energy provided that, in aggregate, hydro generators within the ERM produced enough to meet their total firm energy. It reallocates output from power plants generating above their firm levels to those generating below.

• If the verified total hydro generation exceeds total firm energy (i.e. "secondary energy" was produced), the total of the surplus is shared by all hydro generators in proportion to their firm energy.

• If the verified total hydro generation is lower than the total firm energy, the firm energy allowance of each hydro power plant is reduced in the proportion of the ratio between verified total generation and total firm energy. This means that, even if one hydro power plant individually generated more than its firm energy, its firm energy will be reduced regardless. This guarantees that the risks for an individual generator in adverse hydrological conditions is lower than if each generator had an exposure related to its own generation.

• In order to ensure generators would remain incentivized to maximize their units' availabilities, whenever the observed technical unavailability is above a normal acceptable level, their entitled firm energy reduced in proportion to their actual availability.

• The price at which the reallocation is made is low, reflecting hydro generators' variable operational costs and royalties only. It is set at this level to make hydro generators indifferent as to the level of output they produce, since they will be assured of the income associated with their firm energy under normal system conditions. The ERM is settled on a daily basis against profiled firm energy.

V. Simulation Model

The economic and financial model developed in this paper is based on generation prices (SMP) projection, which is calculated by the Brazilian model of long-term dispatch optimization. The power plants in the portfolio need to follow usual commercialization rules in order to reach bilateral PPAs. When the plant has energy deficit, it needs to purchase the difference in the short-term market (SM). In the other side, when the player has energy surplus it sells energy in the same market.

The optimal contracted volume is calculated considering the SMP projection and the power plant generation of the portfolio and system (when applicable the ERM or other mechanism of risk mitigation). Therefore, the model developed estimate the risk revenue of one or more power plant and analysis the operation of one portfolio (Hydro and Wind power plants) subjected to market rules. Analyzing the portfolio and the complementary between sources is possible determine the "hedge" when the FEC of the group is commercialized against the individual source commercialization. The figure 1 present the work flow of the model developed.

The principal steps of the model follow the routine described: the power plant generation (or energy allocated when applicable) is measured and compared with the contractual amount (contracted volume); the deficit and surplus are determined and accounted in the SM; after the accounting is determined the SMP turning possible valorize the surplus and deficit.

Considering the SMP and the revenue from the contractual amount is calculated the total revenue by month and by wind or hydro series. This routine is repeated changing the contractual FEC percentage until reach the maximum revenue, respecting the risk criterion whether analyzing one power plant or group of them (portfolio).

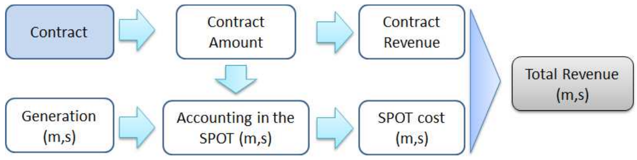

Fig. 3. Simulation model

The PPA's Price and the generation seasonality are inputs of the model. The routine is restricted to the total installed capacity of the power plant or the group. The following step is presented with more details. The Wind and Hydro generation are calculated by the following equations:

$$Gen\_WPP_{m,s} = CF_{m,s} * \ Pow_{installed} \tag{4}$$

$$Gen\_H_{m,s} = Gen_{m,s} \tag{5}$$

$$Gen\_H\_ERM_{m,s} = FEC * ERM\_Factor_{m,s} \tag{6}$$

The Wind generation is calculated for each month and scenario. It is calculated multiplying the Capacity Factor (CF) of the respective month by installed capacity.

The hydro generation, if it is in the ERM group, is calculated multiplying the FEC by the ERM factor. If the hydro power plant is not in the ERM group the generation is calculated by the water's influent flow limited by the installed capacity. In both cases the generation is determined monthly for each hydrologic series. The ERM factor is defined summing the power plants generation in the ERM divided by the sum of FEC in the month as presented in the follow equation:

$$ERM\_Factor_{m,s} = Gene\_ERM_{m,s}/FEC\_\mathrm{ERM}_m \tag{7}$$

The PPA amount in the month ($MPPA_m$) corresponds to part of the FEC allocated in one contract ($\%PPA_m$), as defined in the nest equation:

$$MPPA_m = \%PPA_m \ x \ FEC \tag{8}$$

In this step was considered the option for two deferent contracts: the flat PPA (same energy amount) and seasonal PPA (the energy amount is shared in the rain and dry season). The accounting in the SM verifies the difference between the PPA and generation amount. The accounting was made monthly considering the wind and hydrologic scenario as presented in the next equation:

$$Accounting_{m,s} = MPPA_m - Gen\_Total_{m,s} \tag{9}$$

The Gen_Total is the power plant or portfolio amount generate (Gen_WPP, Gen_H or Gen_H_ERM) in the period of analysis. If the accounting value is negative ($Accounting_{m,s} < 0$), it means energy surplus which can be sold in the SM increasing the contractual revenue. Otherwise, if the accounting value is positive ($Acoounting_{m,s} > 0$) the power plant needs to purchase energy in the SM to supply the deficit in the PPA amount. After the accounting of generation and contract, the following step calculate the SM revenue, as described in the next equation:

$$CostSM_{m,s} = Account_{m,s} \; x \; SMP_{m,s} \qquad (10)$$

The negatives SM cost indicates revenue from surplus negotiation in the SM, otherwise the positive values means the deficit cost.

The PPA revenue ($PPA\_Revenues_m$) is determinate by the contractual amount ($MPPA_m$) multiplied by the PPA's price (PPA_Price_m), as equation (11):

$$PPA\_Revenues_m = MPPA_m \; x \; PPA\_Price_m \qquad (11)$$

In this way the end of the process is calculated the total revenue presented in the equation (12). Note that the occurrences of negative values of CostSM increase the total revenues amount.

$$Total\_Revenues_{m,s} = PPA\_Revenues_m - CostSM_{m,s} \qquad (12)$$

The last step of the model is the calculation of the average month revenues and risk. The average revenue is calculated as presented in the next equation (13).This represent the average value of all simulated revenues in each month, wind and hydro scenario.

$$RecAvg = \frac{\sum_{m=1}^{M}\sum_{s=1}^{S} Total\_Revenues_{m,s}}{M * S} \qquad (13)$$

The parameter applied to measure the risk is the "*Conditional Value-at-Risk*" CVaR (5%), which represent the 5% worst revenues cases estimated in the simulations. Therefore, it calculates the percentage corresponding of 5% lowers estimated revenues values and calculates the average values of this group as a CVaR values. The figure 4 illustrates the CVaR generic definition.

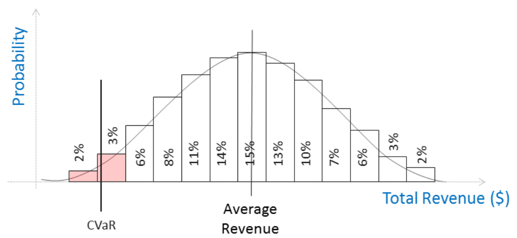

Fig. 4. Average Revenue and CVaR.

The investor seeks the maximization of the portfolio expected revenue which is represented by the average revenues and the risk exposure minimization, which is obtained by the CVaR maximization. It is reach with greater concentration of income around the average value.

VI. Results

Implementing the methodology previously presented, considering the commercial point of view, were made the analysis looking to risk mitigation.

The first step was made simulating the wind energy commercialization without risk mitigation mechanist. The second analysis was made considering the Energy Reallocation Mechanism (MRE), only for wind power plants and the third scenario is considering the MRE among Wind and Hydro power plants.

Based on the Wind data presented before was simulated 11 wind farms with same installed capacity and FEC. The average energy generated in each wind power plant considered was 30 MWavg.

The purpose of this simulation is the minimization of low revenues occurrence which is reached with CVaR maximization, considering the average energy production percentage negotiated as a decision variable.

The PPA price considered in the analysis was R$120/MWh. This value is around the market average price applied to bilateral PPA in the free market.

A. *Wind Power Plants with Mechanism for risk mitigation*

In this first analysis the WPP's Firm Energy Credit (FEC) was calculated through the average generation in the historical. In this step was considered the same FEC value for all WPP, and each one has the same participation in the ERM.

The following figure presents the CVaR value for each WPP without the ERM for different FEC percentage contracted through bilateral PPA.

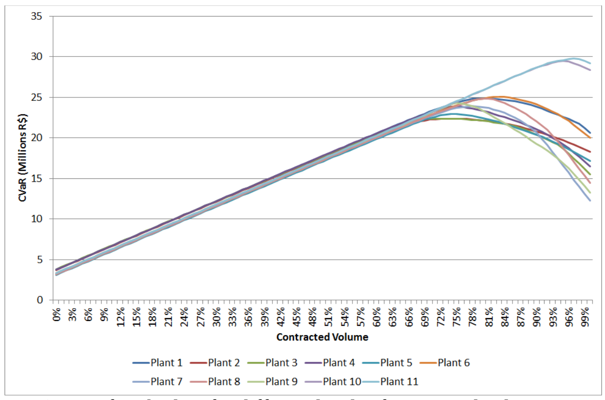

Fig. 5. CVaR of each plant for different levels of contracted volume..

Examining the figure above the WPP 10 and 11 have lower commercialization risks for higher FEC percentage contracted. This characteristic is related with the stability of the wind in these areas during the months and years.

The ERM insertion brings to the system an optimal contractual point, setting each WPP generation profile as the group profile.

The figures 6 and 7 present the optimum contractual FEC percentile for each WPP with and without the ERM application and the economic benefit.

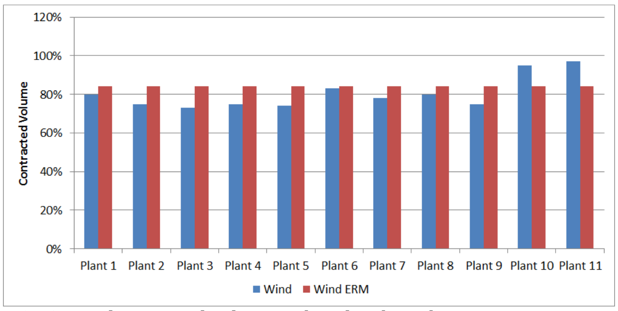

Fig. 6. Optimal contracted volume with and without the ERM.

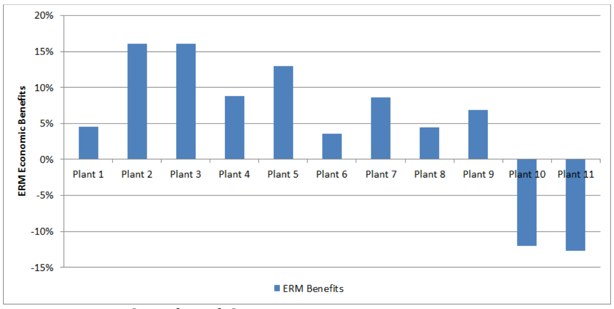

Fig. 7. Economic benefits of the ERM.

The average benefit reached through the ERM insertion was 4,3, with wind plants reaching 16% of benefit. The WPP 10 and 11, due to the stability in the Wind seasonality, presented worst revenues values of risk. These WPP were penalized with the ERM insertion. It means that the WPP 10 and 11 are more stable alone than in the group.

These results demonstrated the fragility of FEC calculation which is the base to calculate the energy allocation in the ERM.

Therefore, the FEC needs to be calculated considering the risk criterion which better represent the contribution of this plant in the ERM, related not only with the average generation but capturing adverse moments.

The main benefits of power plants in the ERM was calculated through the CVaR which represent the 5% average worst scenario revenues value valorize by SMP.

In this way, the ERM was recalculated considering a decrease in the FEC of power plants which are most benefited with the mechanism. Otherwise plants that help to minimize the risk profile of the system have an increase in the FEC. The next equation represents the new power plant FEC.

$$FEC_{PP} = FEC_{avg} * (1 - Ajust_{PP})$$

Where the $Ajust_{PP}$ represents the economic benefit that each power plant has with the average FEC criterion, as shown in the figure 7. The next table represents the previous and the new FEC values.

TABLE I
PREVIOUS AND NEW PGC VALUES.

Plant	FEC	New FEC
Plant 1	30	30,2
Plant 2	30	26,6
Plant 3	30	26,6
Plant 4	30	28,8
Plant 5	30	27,5
Plant 6	30	30,5
Plant 7	30	28,9
Plant 8	30	30,2
Plant 9	30	29,5
Plant 10	30	35,4
Plant 11	30	35,7

The simulation considering the new FEC calculation resulted in the same values of optimal contractual FEC percentage, already represented. Nevertheless, the economic benefits was different, as presented in the next figure:

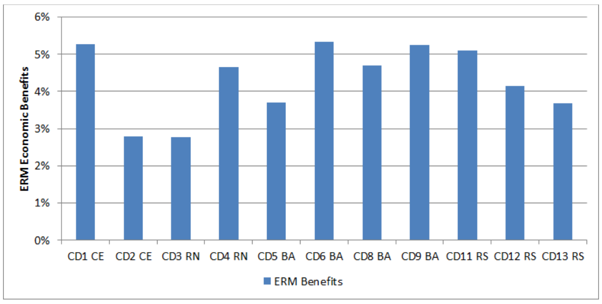

Fig. 8. Economic benefits of the ERM.

The new results demonstrate that all WPP presented earning in the risk revenues with the ERM application. The WPPs which more contribute to the ERM had increased their FEC and as a consequence had increased their potential of energy commercialization. The average benefit with the ERM application was 4,3%.

B. ERM among Hydro and Wind power plants.

The second option analyzed was the implementation of the mechanism for risk mitigation among Wind and Hydro power plants. This mechanism should be able to capture the complementarity among wind and rivers flow.

To make the simulation was considered WPPs ERM sum equal to the HPP ERM sum. The figures 9 and 10 represent the optimal contractual percentile of power plant with and without ERM mechanism and the economic benefit per plant.

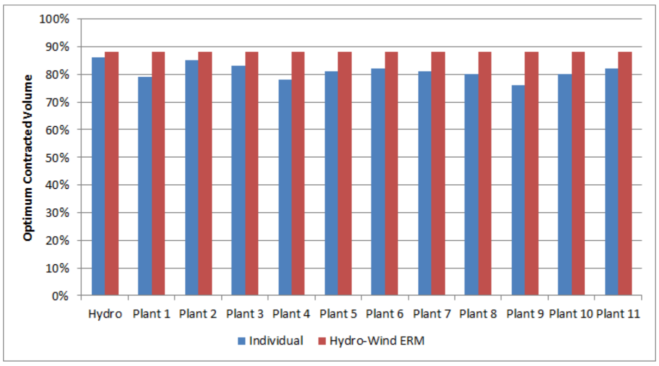

Fig. 9. Optimal contracted volume with and without the Hydro-Wind ERM.

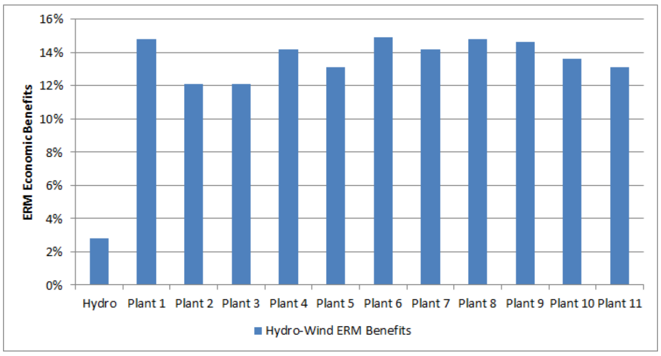

Fig. 10. Economic benefits of the Hydro-Wind ERM.

All power plants presented economic benefits with ERM implementation. The hydroelectric, which already has the ERM, presented lowers benefits. Otherwise the WPP presented increase in the risk revenues, which the average value with ERM implementation was 13,8%. The average economic benefit among all power plants was 8,0%.

The results presented are acceptable only when the Wind and Hydro power plants have the similar installed capacity. This scenario is not realistic yet, today the hydro participation in the electrical matrix is around 75% against 1,4 % of wind energy.

In the actual scenario the earning in ERM implementation would be more expressive to WPP. In this case the wind generation capture the hydro ERM stability, without contribute to the global risk mitigation.

Furthermore, is important highlight the wind energy FEC calculation, which defines the participation in the ERM. The calculation independent of the methodology needs to consider the generation in the risk scenario.

VII. Conclusions

As shown in this work, from the use of tools to support business decision made and taking advantage of its applicability to various analyzes it was possible, in light of the risk-return analysis, conduct two case studies, to recap, the effect a hypothetical ERM-Wind and the effect of an MRE Hydro-Wind. The obtained results showed in a general way, the importance of analyzing the combined effect of plants and sources and showed that a simplistic analysis may mask real situations that can lead the decision maker to incur errors that undermine the financial performance of its portfolio.

The use of longer and reliable wind series is one of the strengths of the study. From these data it was possible to carry out risk assessments of revenue for investors.

Finally, we conclude that the ERM is a mechanism that produces good results for wind farms because it reduces the variability of revenue from each plant by the capture of its complementarity. To implement this mechanism, it is important that the Firm Energy Credits (FEC) calculation uses the risk parameters of the plants generation. Therefore plants that have better behaved profiles generation will also benefit by implementing the mechanism.

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IX. Biographies

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