Operational wind energy forecast with power assimilation.

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ABSTRACT: The Uruguayan electric system will reach a wind power penetration of 25% by 2016. We developed an hourly operational wind energy forecast model based on real power assimilation that combine persistence statistical model and numerical WRF forecast. The persistence coefficient X_k (0 to 1) was defined and computed to measure the best approach, weighting the numerical and persistence statistic with dependence on the forecast time horizon k. The calibration of this coefficient X_k show similarities in all the GMT initialization 00,06,12,18, and same decrease of X_k as a function of tie horizon was computed for all wind farms analyzed. The model developed with real power assimilation of the last hour, have a determinant impact in the skill of the wind power forecast, the new model improve the forecast with statistical signification form one to six hour of time horizon.

KEY WORDS: wind energy; power assimilation; forecast.

1 INTRODUCTION

Wind farms analyzed in the present work are in the south-central region of South America (Uruguay). The data were provided by the national public utility of Uruguay (UTE). By 2016, the projected installed wind power capacity in the country will reach a penetration factor in the electrical system of 24%. This factor is defined as a relationship of power capacity of this new renewable resource. At the present time when this work is write there are a total of 382.8 MW of wind farms installed in the country. Figure 1 present the location of wind farm installed in Uruguay at April 2015, Table 1 present a description of wind turbines model and nominal power installed in each wind farm.

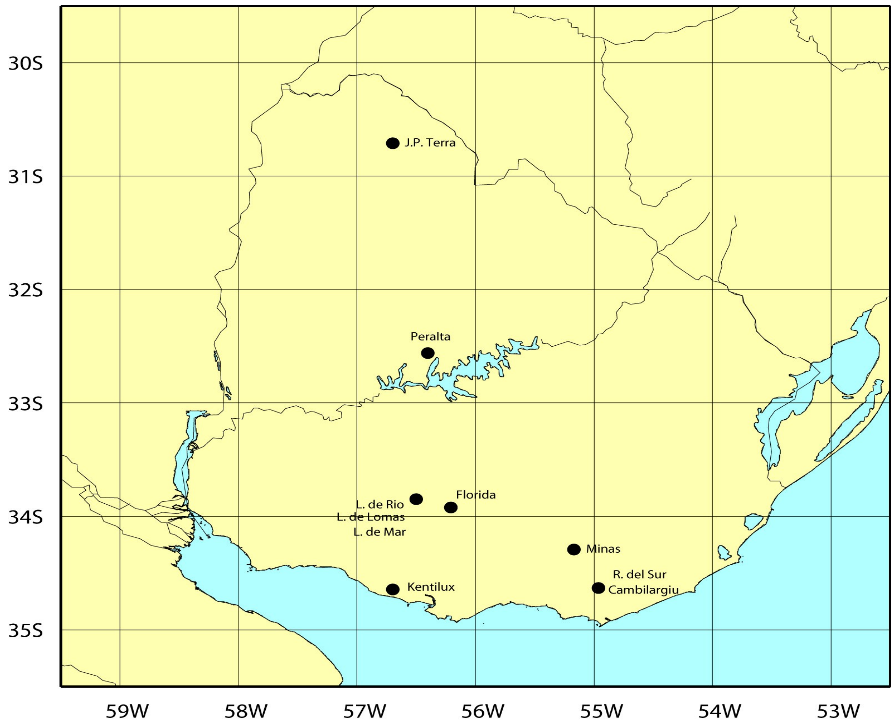

Figure 1. Wind farms installed in Uruguay April 2015.

Wind Farm	**Wind Turbine model**	**Nominal Power installed in wind Farm [MW]**	**Lat**	**Lon**
CARA	Vestas V90/V80	20	-34.638	-54.962
KENT	Vestas V90 y otros.	17.2	-34.734	-56.577
RSUR	Gamesa G90	50	-34.505	-54.902
MIN1	Vestas V112	42	-34.465	-55.307
FLO1	Nordex N117	50.4	-34.072	-56.028
LRLM	Vestas V112	86	-33.876	-56.378
CPE1	Gamesa G97	50	-32,570	-56.444
JPTE	Nordex N117	67.2	-30.409	-58.640

Table 1. Wind Farms installed in Uruguay power and model description

CARA: Wind Farm E. Cambilargiu I y II
KENT: Wind Farm Magdalena (KENTILUX S.A.)
RSUR: Wind Farm Maldonado (Renovables del Sur S.A.)
MIN1: Wind Farm Minas I (Generación Eólica Minas S.A)
FLO1: Wind Farm Florida 1 (POLESINE SA.)
LRLM: Wind Farms:
- Parque Eólico Pintado II (Luz de Río S.A.)
- Parque Eólico Pintado I (Luz de Lomas S.A.)
(Luz de Mar S.A)
CPE1: Wind Farm Cuchila de Peralta I (Palmatir S.A.)
JPTE: Wind Farm Juan Pablo Terra (UTE)

Thus, it is of interest to conduct numerical simulation of the near-surface atmosphere. Wind energy is a resource with significant fluctuation over short periods. That is, there are substantial hourly variations of mean energy input to the grid [1], which indicates that wind energy must be complemented by other energy resources, such as those of a hydraulic or thermal power plant. A wind energy forecast gives information on the future to assist the dispatch of electrical power with minimal cost, using an objective function.

In the Uruguayan electric system, the frequency is 50 Hz, and physical interconnection with Argentina permits a maximum power exchange of 2000 MW. A grid interconnection with Brazil is under construction with capacity 500 MW, in addition to the actual 70 MW interconnection. There is an additional investment for converting the frequency to 60 Hz. By the end of 2014, total installed power generation capacity in Uruguay will be 3405 MW, including 343 MW of wind energy. By the end of 2016, total installed wind energy power in the Uruguayan system will be 931 MW.

Then, in 2 years, the country will have a wind energy penetration about 20%. This is a small system compared with neighboring countries such as Argentina, with 31.072 MW total installed power, and Brazil with 120.973 MW. This provides an opportunity to exchange energy by interconnection. It will be possible to export marginal energy in excess of demand and import energy required to meet the total demand. Forecast developed help regional energy exchange, and optimal dispatch plan.

2 WIND ENERGY FORECAST

2.1 *WRF operational forecast*

The operational forecast model developed is based on numerical simulations from the mesoscale numerical model Weather Research and Forecasting (WRF) from the National Centers for Environmental Prediction (NCEP) [2]. The simulations use initial and boundary conditions in the bigger domain, of the Global Forecast System (GFS) from the National Oceanic and Atmospheric Administration (NOAA) National Weather Service NCEP. The data are periodically downloaded from NOAA [3]. Initial and boundary conditions are provided by the NOAA GFS at 00:00, 06:00, 12:00 and 18:00 GMT [4].

WRF simulates fluxes of momentum, heat and mass in the boundary layer. This makes it possible to generate a wind profile at levels of interest to wind energy applications. Model Output Statistics (MOS) were developed, which use WRF model simulations as input information [5]. Figure 2 shows daily steps of the forecast from the operational model related to the various initialization hours, local time in Uruguay GMT-3 (UY).

http://www.fing.edu.uy/cluster/eolica/				
Global observational data	00:00 GMT 21:00 UY	06:00 GMT 03:00 UY	12:00 GMT 09:00 UY	18:00 GMT 15:00 UY
NOAA-GFS Initial condition available public on line	03:15 UY	09:15 UY	15:15 UY	21:15 UY
Download in Cluster FING start WRF running	03:30 UY	09:30 UY	15:30 UY	21:30UY
MOS (Model Output Stadisctic)	09:00 UY	15:00 UY	21:00 UY	03:00 UY
Time Horizon of Numerical Wind Power Forecast	09:00-14:00 UY	15:00-20:00 UY	21:00-02:00 UY	03:00-08:00 UY

Figure 2. Time steps of operational numerical wind power forecast, for short time horizon.

Predictability is most important both at times of high wind power production and for a time horizon of up to 6 hours ahead, which gives enough time to react to varying production[6].

2.2 *Power assimilation, conjugate model statistical and numerical WRF forecast*

The statistical models were based on a time series approach [7]. These types of models only take as input past values of forecast variables (e.g., wind speed, wind power generation). These methods are based on past production data. A simple model with excellent skill over a very short forecast horizon (1 to 4 hours) is the persistence model. Persistence models assume that power production at a future time will be the same as a previous one: $\hat{P}(t+k/t)=P(t)$, with $\hat{P}(t+k/t)$ the power forecast for time t + k made at time t, and P (t) the measured power at t.

The sensibility with initialization time 00:00, 06:00, 12:00 and 18:00GMT was analyzed for farms with new technology and long-term power generation in Uruguay, Emanuelle Cambilargiu and Kentilux. Kentilux is on relatively flat terrain, whereas Emanuelle Cambilargiu is atop a ridge with relatively steep slopes. Electrical energy produced and input to the electrical grid is from the transformation of available kinetic energy in the atmospheric boundary layer from airflow. Kentilux wind farm is on the Río de la Plata coast San Jose, Uruguay. This farm is currently composed of five wind turbines of model Vestas V90-2 MW and four Vestas V100-1.8 MW, with total installed power of 17.2 MW. Emanuelle Cambilargiu farm is atop Caracoles Ridge in Maldonado. Its total installed power is 20 MW. There are 10 Vestas V80 2MW wind turbines aligned on the ridge.

Reference [8] describes some statistical methods considered in the ANEMOS project for short-term forecasting of wind power. We present here a short-term operational wind energy forecast with a horizon of 6 hours and the combined model, which links the numerical atmosphere circulation and persistence models. There are four daily outputs of the numerical model, related to the initial conditions of the general circulation model at 00:00, 06:00, 12:00 and 18:00GMT. $P_{Numerical}$ is the wind energy forecast, based on the MOS from WRF simulation. A combined model is defined for each initial condition. Then for the combined model the X_k persistence coefficient (which varies from 0 to 1) is calibrated minimizing the MAE of the period of calibration. This is done to combine the real-time wind power P (t) at t with $P_{numerical.}$ Figure 3 shows the process of calibration, and the computed X_k coefficient for the two wind farms analyzed.

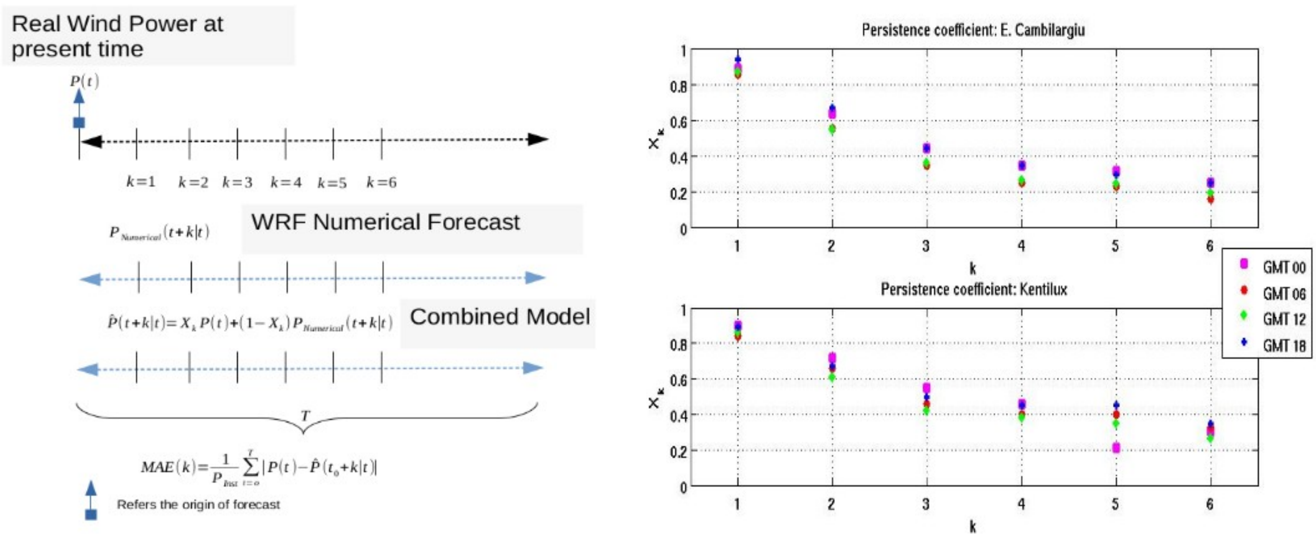

Figure 3. Calibration process of Persistence coefficient X_k

X_k persistence coefficient computed have similar decrease comportment with time horizon increase, and for different initialization time have been computed similar values, in both wind farm analyzed, for all the time horizon analyzed.

Figure 4 show the X_k persistence coefficient computed for seven different wind farms installed in Uruguay, for 00:00, 06:00 12:00 and 18:00 GMT the dispersion in computed values for the same time horizon show the need of calibrate the model for specific application, more long period of power production need to be used to determine

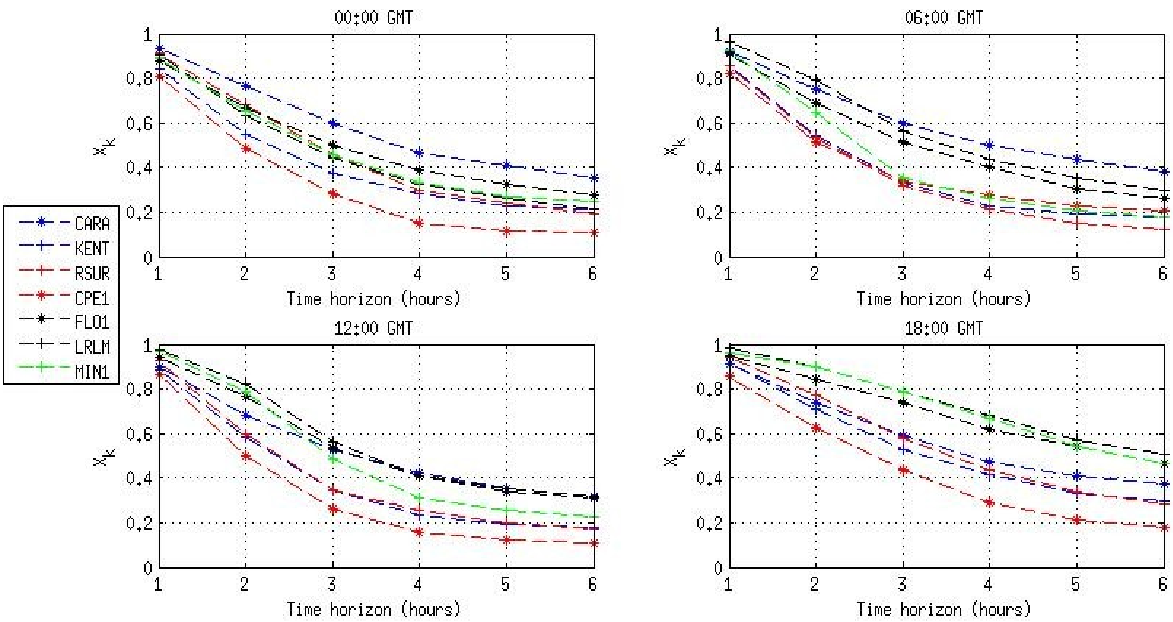

Figure 4. Persistence coefficient X_k for 00:00, 06:00, 12:00 and 18:00 GMT.

2.3 *Operational forecast*

In Figure 5 is presented the real output of forecast for 06:00 GMT initialization, blue show the numerical forecast, red the real power production and in black the short-term forecast with a forecast up to 6 hours of time horizon, for operational output Kentilux wind farm for 22 November of 2014 local time, as can be seen real power is assimilated by the operational forecast and new forecast is produced, this 6 hours forecast is produced every hour.

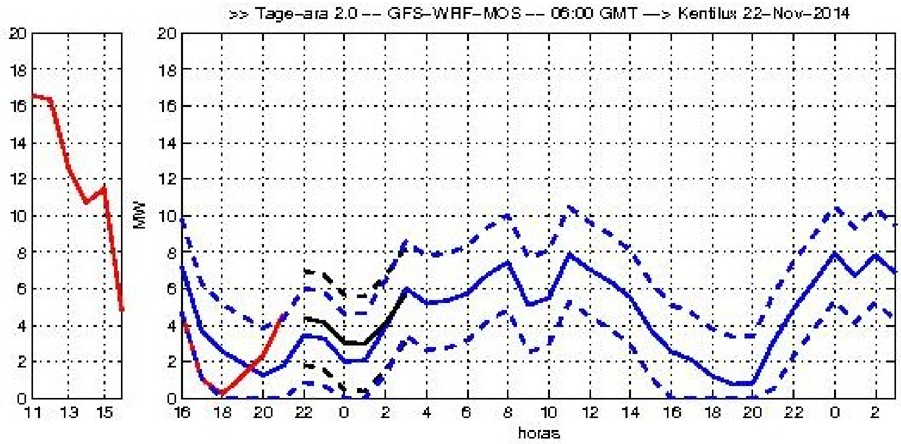

Figure 5. Forecast output on line of Tage.Ara2.0 model www.fing.edu.uy/cluster/eolica for Kentilux wind farm 22/11/2014.

3 POWER ASSIMILATION IMPACT IN SKILL OF FORECAST

In Figure 5 and 6 is presented the impact of power assimilation forecast of the energy production of the two wind farms analized E. Cambilargiu and Kentilux the histograms and box plot in dependence with time horizon, of the numerical forecast model for May 2014 for the first six hours of forecast, with assimilation and without assimilation.

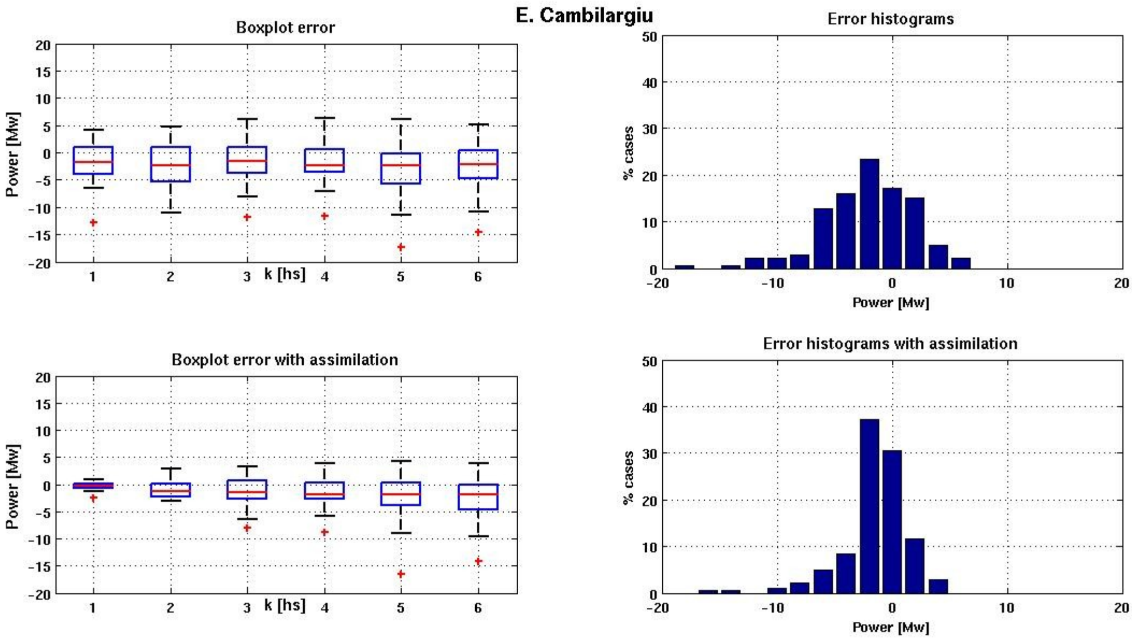

Figure 6. Forecast output of E.Cambilargiu wind farm May 2014

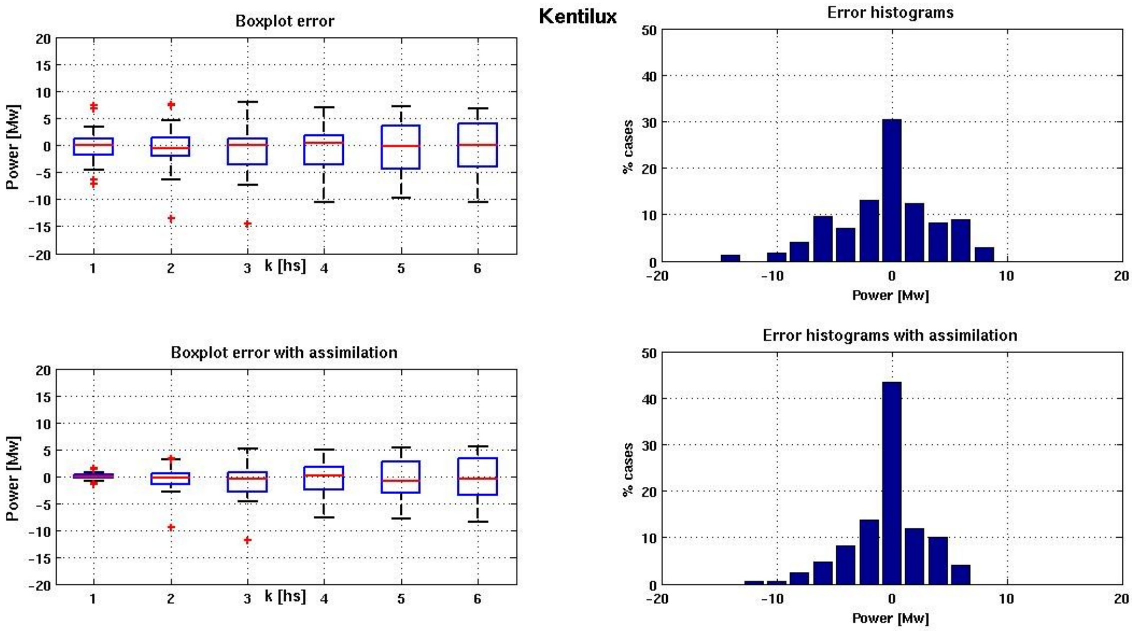

Figure 7. Forecast output of for Kentilux wind farm May 2014

Both histograms, and box plots shows that the power assimilation have a determinant impact in the skill of the wind power forecast, the model developed increase with statistical signification the skill

CONCLUSION

We developed an hourly operational model based on real power assimilation with a conjugate model statistical and numerical WRF forecast the time steps of the model are explicit presented in the work with a description of the chronological logic of the three GMT initialization running. The combined model define the persistence coefficient X_k (0 to 1), this coefficient was computed to measure the best approach, weighting the numerical WRF forecast and statistic forecast (persistence) with dependence on the forecast horizon k, for seven wind farms. The calibration of this coefficient X_k show similarities in all the GMT initialization 00,06,12,18 for the farms analyzed. The model proposed that introduce in the wind power forecast the last real wind power, an it's assimilation, have a determinant impact, the model developed increase with statistical signification the skill when it is compared with the numerical forecast without power assimilation in a time forecast horizon from 1 to 6 hours.

ACKNOWLEDGMENTS

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