Possibilities for Correcting Forecast Errors by Cutting off Production Chart Peaks

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Abstract. In this paper we describe a conception for the mitigation of wind power fluctuations by cutting off production chart peaks.
The rapid growth of wind energetics has been induced by several factors. Although the government support may be the main incentive, other important motives include the increasing network access fees and strict requirements set for ensuring the balancing capacity of production.
However, such capacity has the tendency of being underdeveloped. The possibilities of the operating oil-shale plants for providing the capacity to balance the wind parks are running out. Sudden changes in the oil-shale plant output contribute to additional CO_2 emissions, increased fuel consumption and decreased boiler efficiency. Under the circumstances, the transmission system operator (TSO) can face the need to reduce the power output of the wind parks. The operators of the wind parks integrated into the transmission network are responsible for presenting to TSO a 24 h forecast of their output power.
The forecast error is mainly specified in terms of Mean Absolute Percentage Error (MAPE), which for Estonian wind parks is about 20% on average. For forecast error estimation we have also applied the notion of Mean Percentage Error (MPE). Estimation of Pakri wind park data shows divergent actual forecast errors for different values of output power. For the values approximating the rated power of the wind park, the actual output power is larger than predicted. This situation clearly arises when the proportional output power is over 80% and MAPE is quite evenly distributed around 19.2%. In good wind conditions, for the relative output power value of 80%, the share of energy lost by cutting off production chart peaks amounts to 8.6% of the total energy production. The share is rapidly decreasing with declining wind conditions. Nevertheless, the average share of energy lost does not exceed 5%. The cut off energy might be applicable for heat production in boiler houses, although it is cheaper than the energy supplied to the electrical network.

Key words: Wind park, wind power, forecast error, production charts

INTRODUCTION

The development of wind energetics is speeding up. Favourable governmental regulations and new possibilities opened up in economy to construct wind parks enhance the development of this field. At the end of 2006, the European Union (EU) set its renewable energy target at 20% of overall energy consumption by year 2020 and at least 20% reduction in greenhouse gases (GHG) (A renew..., 2007). According to European Wind Energy Association (EWEA), by year 2020 the proportion of wind energy could be as high as 14.3% of EU electricity demand, 180 GW capacity of installed wind turbines (Pure..., 2009), while by the end of year 2008 the total in EU was 65 GW and it met 4.2% of EU electricity demand (Wind..., 2008). Thus, the triple increase is expected to take place within the next 11 years. All this capacity will be integrated into the grid that already includes conventional power plants like coal, oil-shale, gas or nuclear power plants.

The targets in Estonia for renewable electricity supply have been set at 5,1% (ca 400 GW h^{-1}) of gross inland consumption by 2010 and 25% by 2020, while the current share of wind power in Estonia is 115 MW (as of October 2009) (Eesti..., 2009). As onshore wind power production development in Estonia is quite limited, the offshore wind park projects will have a huge role to play in the near future if the targets set are aimed at. Also, the new Estonian Electricity Sector Development Plan of up to 2018 (Estonian..., 2009), where a 30% share of wind generation in total installed capacity has been foreseen by 2018, means a substantial share of power being generated onshore and offshore in the near future.

Different EU support schemes have rendered wind energetics economically attractive and have instigated a competition between the many wind park developers to establish new facilities. The faster the project is implemented, the more advantage is gained over the competing agents. An extra large increase in wind capacity is foreseen in offshore wind parks. The growing demand for wind generators has induced a rise in their price.

Today, in addition to the economic profitability, there is another major factor contributing to the fast growth of wind power development – that of the looming increase in the electric transmission network access fee. Meanwhile, the number of plots with good wind conditions is decreasing, and the availability of sufficient network transmission capacity has become crucial. The cost of establishing electrical networks may be of the same range as that of a wind park itself (Landsberg et al., 2005). In addition to the network related expenses, Estonian TSO requires fast-start generating units to be installed together with new connections of wind power, i.e. all new wind parks connected to the grid after 1st of July 2007, are obliged to have fast regulated power plants in Estonian territory. Up to now, the installation of wind parks meant very few additional expenses beside the initial capital costs. The later the project is started, the larger are the additional expenses involved. Although there is a theoretical possibility that one will be able to buy the balancing capacity required, its price and availability is undefined today.

Fluctuations in wind capacity are balanced by power plants of fast regulated output such as gas turbines and hydro power plants, or storage facilities such as pumped-storage hydro power plants and compressed air power plants. The conventional fossil fuel based thermal power plants are not easy to use for balancing large capacities of wind power, and nuclear power plants are totally unsuitable in this respect. In the territory of Estonia, the resources available for balancing the wind power by oil-shale power plants are becoming exhausted, and the same is true about the hydro power plants in Latvia. The fastest way to provide for the additional fast regulated capacity is to establish gas turbine plants and a pumped-storage hydro power plant in the further future.

TSOs are authorised to reduce wind park production peaks, which they occasionally also resort to in extreme conditions, when the balancing required cannot be achieved by other measures (Lepa et al., 2009). It can be presumed that the need for cutting off peak loads is increasing fast. In Estonia, the first reserve plant of 120 MW in capacity will be erected as late as 2013, and by this time, even the most conservative forecast suggests that the capacity of wind parks will have been increased to about 590 MW (Eesti..., 2009).

The method of cutting off production chart peaks could be applied systematically to correct forecast errors, whereas the energy cut-off might be applicable for heat energy production in boiler houses.

MATERIALS AND METHODS

The capacity produced by power plants at any given moment of time must be equal to the consumption capacity. With conventional fossil fuel based energy system the power balance is well maintained. The accuracy of consumption capacity forecast is high enough and it is by these charts that the output of thermal power plants is adjusted. On the contrary, the stochastic fluctuations in the wind park output power may have the amplitude as large as tens of megawatts per minute and this may result in emergency situations for the network if the need for forecast is neglected.

As a rule, wind park capacity is predicted for 24 h ahead. The time span of 24 hours enables to plan necessary changes to the reserve capacities. Nevertheless, the wind power forecast is bound to involve some error. The forecast error is estimated by 2 main methods: Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) (1) (Rosen et al., 2007). In this paper we also report on the use of Mean Percentage Error (MPE) (2).

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_a - P_f}{P_a}\right| \cdot 100, \tag{1}$$

$$MPE = \frac{1}{n}\sum_{t=1}^{n}\frac{P_a - P_f}{P_a} \cdot 100, \tag{2}$$

where P_a – actual wind park output power and P_f – predicted wind park output power.

While MPE shows the polarity of error, MAPE expresses the range of it. It is reasonable to use MPE for estimating the polarity of forecast error in the short time intervals of data-series. The MAPE values may vary significantly, but an average of 20% can be achieved (Agabus & Tammoja, 2009).

For the estimation of the forecast error of wind generators' output power we used the production chart of Pakri wind park as of 2008 and the forecast data chart of average power data for 1-hour time intervals. The Pakri wind park includes 8

Nordex N-90 2.3 MW wind generators with the total capacity of 18.4 MW. For the purpose of generalization we use the proportional unit of power, p.u.

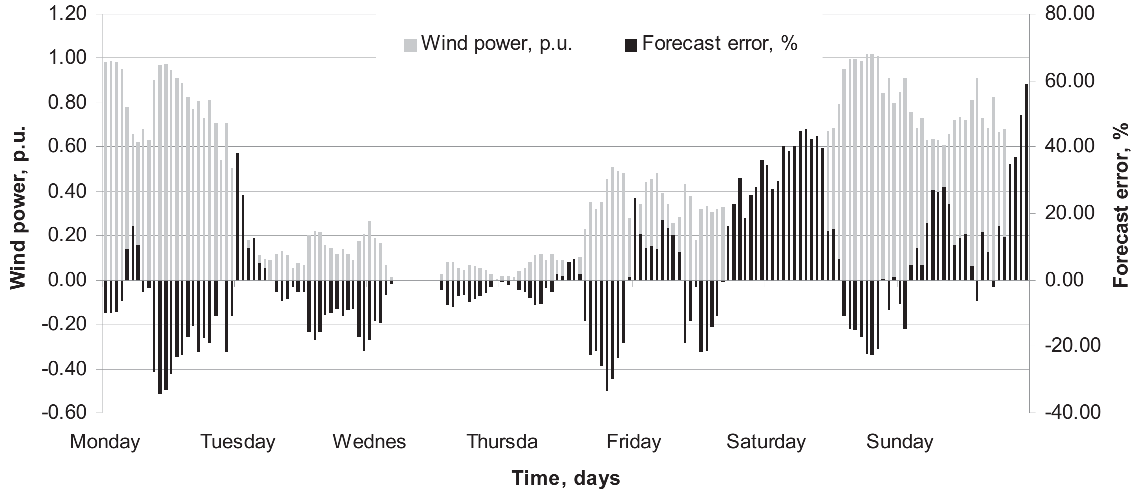

Fig. 1. Pakri wind park production chart with forecast error chart (6/10/2008-12/10/2008).

Fig. 1 presents the production chart of Pakri wind park in proportional units of power and the corresponding forecast errors in percentages. The average MAPE for the particular week is 14.5%. When processing the data we took into account the situations where a generator had stopped working for some technical reason. For the estimation of the forecast errors we used data of two weeks, each of which describing different wind conditions in the October and November of 2008. The negative forecast error values show that the actual wind park output power was higher than predicted, i.e. the case of so-called over forecast.

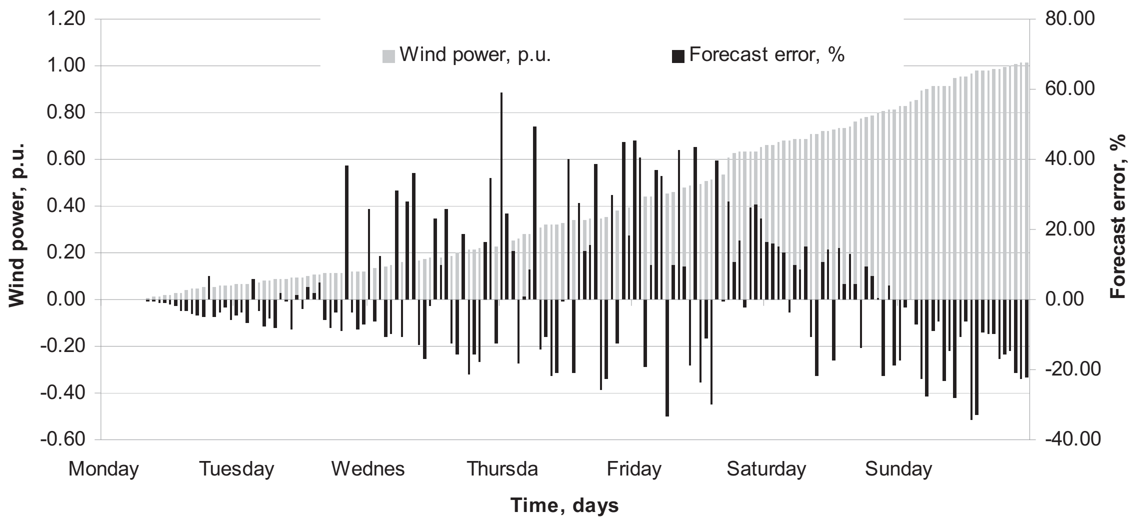

Fig. 2. Sorted data of Pakri wind park production chart with forecast errors (6/10/2008-12/10/2008).

As Fig. 2 well demonstrates, the tendency for over forecast is characteristic of the higher value range of the wind park output power. The increasing wind park capacities are bound to lead to a situation where the cheapest balancing option, i.e. the oil-shale plants will for technical reasons fail to adjust the capacities with sufficient speed.

In oil-shale power plants, the ramp-up speed of one single oil-shale generating unit is 2.5 $MW \cdot min^{-1}$, and the ramp-down speed is 7 $MW \cdot min^{-1}$ (Keel et al., 2009). Even though the regulating capacity of oil-shale power plants is in the range of 50-100% of the rated power, the actual free changeable capacity falls within the range of 10-15% after the regulation by consumption is performed (Keel et al., 2009). The total regulating capacity supply is proportional to the number of generators in operation and although today the oil-shale plants are able to balance the existing wind capacities, the rapid changes in production capacities decrease the efficiency of the plants, increase the CO_2 emissions, add to environmentally hazardous wastes, raise specific fuel consumption and cost price (Palu et al., 2009).

One option for compensating for the forecast error is cutting off wind park production chart peaks.

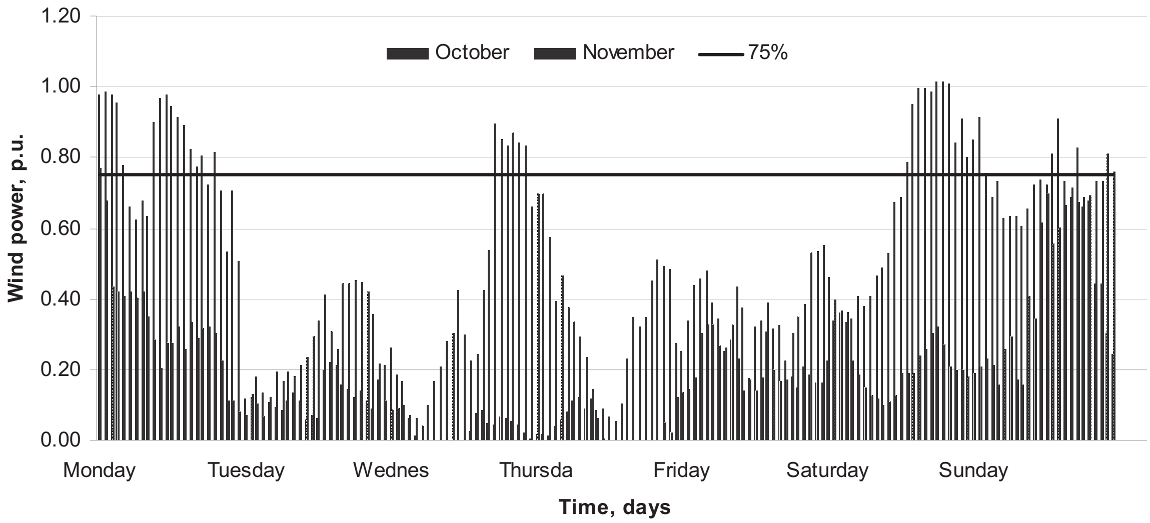

Fig. 3. Production charts of Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008). Horizontal line reflects the 75% capacity.

In the analysis of the performance of wind turbines it is feasible to apply the concept of coefficient of maximum (or nominal) power usage that may be described as

$$k_m = \frac{W_m}{P_m \cdot t_n} \cdot 100, \qquad (3)$$

where W_m is energy produced by the wind turbine in the time period t_n, and P_m is maximum power (sum of the nominal power of the wind turbines). Here, $P_m t_n$ is the energy amount that would have been produced by all the generators working at nominal power for time t_n.

The data presented in the charts of Fig. 3 are based on rather different wind conditions, with the coefficient of maximum power usage being 42% and 33%, respectively. Fig. 2 shows that the prevailing over forecast is over 75% of the rated power. When cutting the chart peaks in Fig. 3 at the level of 75% rated power, the remaining amount of energy is 89.6% in the former and 96.4% in the latter case. With the higher coefficient of maximum power usage the energy losses after cutting the chart peaks are more significant.

RESULTS AND DISCUSSION

To make more substantial general conclusions in the estimation of forecast errors, we observed Pakri wind park data of 2 periods, those of 6/10/2008-12/10/2008 and 3/11/2008-9/11/2008 together. The data is classified and sorted in the ascending order, and the capacity interval of 0-1 is divided into four subsections. Fig. 4 presents the proportional power by step 0.25 on the horizontal axis and the MPE and MAPE values on the vertical axis. The value of MAPE in the given interval of 0-1 is 14.4%.

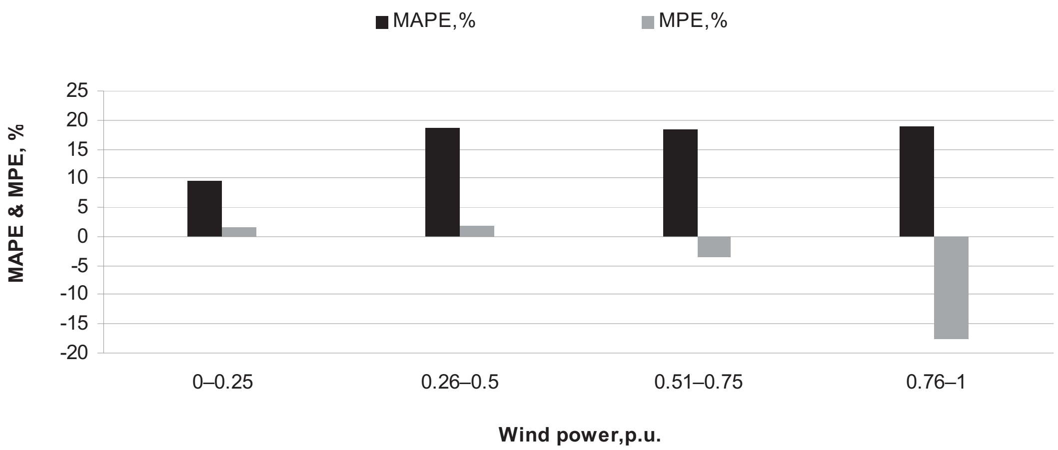

Fig. 4. MAPE and MPE of proportional power in Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008).

As Fig. 4 shows, MPE is negative in the proportional power range of 0.75-1. The MPE is 1.6%, 1.8%, -3.6%, and -17.4% for the wind park proportional power ranges of 0-0.25, 0.26-0.5, 0,50-0.75, 0.76-1.0, respectively. The values of MAPE are thereby 9.5%, 18.5%, 18.4%, 18.8%. In the last three quarters, the MAPE values approximate 18.5%. The low value of MPE in the two middle quarters suggests that in these quarters the prediction error features a changeable sign.

For more detailed analysis we can observe the interval 0.77-1 in Fig. 5. Fig. 5 makes it obvious that in the 0.8-1 range of proportional power, MPE is steadily negative and approximates the value of -18.0%, while MAPE is 19.2%. It thus provides statistical proof for over forecast in the interval of 0.8-1.

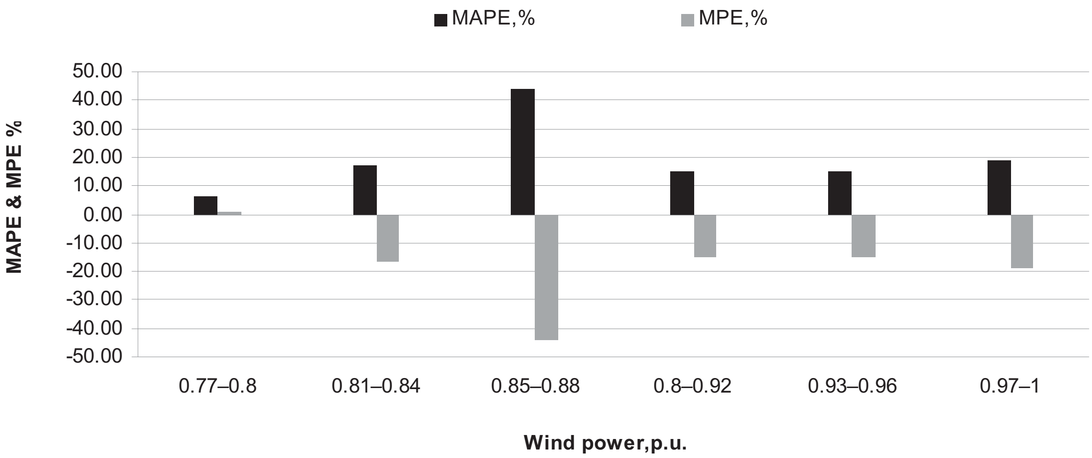

Fig. 5. MAPE and MPE of proportional power in Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008) in interval 0.77-1 by step 0.04.

After cutting production chart peaks at the level of 80% rated power, the MAPE decreased from 14.4% to 13.7%. Although it is quite a small change, it eliminates the production chart range of 0-0.8, where MAPE is higher than the average of the whole chart.

Table 1. Results of cutting Pakri wind park production chart peaks by 80% rated power in different months

Period	Average wind speed v, $m \cdot s^{-1}$	$k_{m100\%}$	Remained energy $W_{80\%}$, %	$k_{m80\%}$
November 2008	8.36	47.4	91.4	43.3
October 2008	8.27	46.7	93.3	43.6
September 2008	6.63	28.5	96.7	27.5
June 2006	5.64	19.0	97.6	18.5
July 2006	5.58	14.0	99.9	14.0
August 2006	6.72	24.2	96.0	23.2
June 2005	5.48	17.0	97.3	16.6

Table 1 shows that in November 2008 with extraordinarily high coefficient of maximum power usage, the share of the cut-off energy is 8.6%. However, by the 80% value of rated power the share of cut-off energy approximates 5% on the average.

CONCLUSIONS

1. All along the power range of the whole wind park, MPE and its sign feature divergent values. Comparing the MPE and MAPE values of some narrow interval of power of the production chart, it is possible to estimate the stability of forecast

error. The larger the difference between the absolute MPE and MAPE values, the more frequent is a change in the forecast error sign in the given interval.

2. In the 0.8-1 range of proportional power, the actual capacity of wind park is larger than the forecast one, whereas MAPE is 19.2% in this interval and MPE is -18.0%. Cutting the production chart peaks by the 80% proportional power, the value of MAPE in the interval 0.8-1 approaches zero.

3. By very good wind conditions, it is reasonable to cut the wind park production chart at the 80% level of rated power, whereas the share of the cut-off energy is 8.6% of the total energy produced and with less favourable wind conditions, it is decreasing fast. In Pakri wind park, the average share of cut-off energy should not exceed 5% of the total energy production.

4. The energy from cutting off the wind park production chart peaks could be used for the production of heat energy in boiler houses.

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