EVALUATION OF WIND PARKS OUTPUT POWER FORECAST ERROR AND WAYS TO DECREASE IT

Kaupo Toom[1], Andres Annuk[1], Alo Allik[1], Jaanus Uiga[1], Toivo Kabanen[2]
[1]Estonian University of Life Sciences; [2]Tallinn University of Technology Tartu College, Estonia
kaupo.toom@emu.ee

Abstract. From a socio-economic perspective, better forecasting will reduce the total generation costs due to the more optimal dispatch of power plants. The operators of the wind parks integrated into the transmission network are responsible for presenting a 24h-forecast of their output power to the transmission system operator (TSO). The real wind power differs from the forecast one. This difference needs balancing by the rest of the energy system. In Estonian conditions, it means regulating the capacity of oil-shale-fuelled power plants, which induces an accelerated wear, additional emissions and fuel consumption of the power plants. Wind park output power is particularly difficult to forecast at wind speeds of 6 – 10 $m \cdot s^{-1}$ due to the fact that electricity generation of wind turbines changes markedly between these speeds. The most relevant metrics to measure forecast errors are Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The absolute errors of the forecast are dependent on the forecasted wind power generation. Thus, most of the prediction problems lie in the higher end of wind output values.

Keywords: wind park, wind power, forecast error, production charts.

Introduction

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 more distant 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 [1]. 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 constructed 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 [2]. 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 the 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 amplitude as large as tens of megawatts per minute, which may result in emergency situations for the network if the need for forecast is neglected. The reason why generation is particularly difficult to forecast at wind speeds of 6 – 10 $m \cdot s^{-1}$ is that electricity generation of wind turbines changes markedly between these speeds.

Forecasting wind power as accurately as possible is important to wind power producers bidding in their production in an electricity market as well as to the system operator. In a market based setup the wind power producers will normally pay for the costs of balancing the wind power. Therefore, the more accurate the forecast of wind power, the lower the balancing costs to the wind power producers will be.

As a rule, the wind park capacity is predicted for 24 h ahead. The time span of 24 hours enables to plan the necessary changes to the reserve capacities. Nevertheless, the wind power forecast is bound to involve some error. The forecast error is estimated by three methods: Root Mean Square Error (RMSE) (1), Mean Absolute Percentage Error (MAPE) (2) and Mean Percentage Error (MPE) (3) [3].

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(P_a - P_f)^2}\ , \tag{1}$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_a - P_f}{P_a}\right|\cdot 100\ , \tag{2}$$

$$MPE = \frac{1}{n}\sum_{t=1}^{n}\frac{P_a - P_f}{P_a}\cdot 100, \tag{3}$$

where P_a – actual wind park output power;
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 [4].

To evaluate forecast errors for wind park output error, we used the production chart of Pakri wind park as of 2009-2011 and the forecast data chart of average power data for 1-hour time intervals. We divided the yearly data to four quarters and chose random quarters of those three years to create a discretionary year. The year (hereinafter "the chosen year") consists of quarterly data 1.1.2011 – 31.03.2011, 1.4.2009 – 30.6.2009, 1.7.2010 – 30.9.2010 and 1.10.2009 – 31.12.2009.

In Pakri wind park there are 8 Nordex N-90 2.3 MW wind units with the total capacity of 18.4 MW. The wind park is situated on the sea shore, where the wind conditions are the best, and where wind parks are built right now in Estonia [5]. To generalize the results we used a proportional unit (pu). The proportional unit is a non-dimensional value, having the range of 0...1. The value 1 corresponds to the rated power of the wind park.

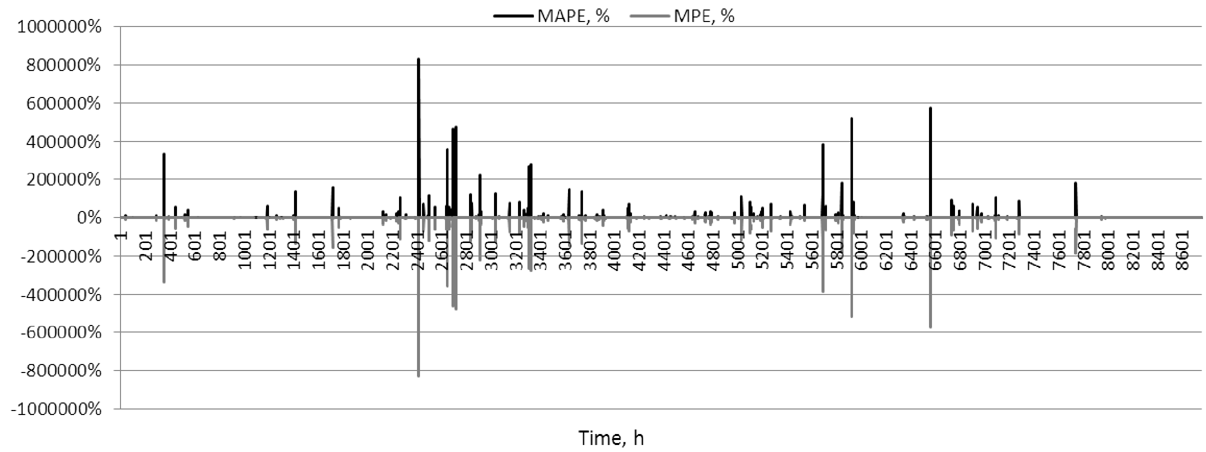

Fig. 1. **Pakri wind park MAPE and MPE chart**

Figure 1 shows, that MAPE and MPE are very big sometimes. Therefore, we did not use extreme data values (only the values, which were smaller than 300 %) for calculating MAPE average results.

When we look at MAPE and other values 0…0.1 pu, then the average MAPE was 4222 % and the maximum was 828851 %. The average forecast RMSE was 0.03 pu. For example, when the data 0…0.1 were not included, only 0.1…1, then the average MAPE was already 84 % and increasing fast. But the problem is, that this is only the percent. Real energy values are mostly small. When a rather small value is divided with a very small value, then the percent is enormous. If MAPE is over 100 %, then bigger MPE values are negative. When wind power is more than 0.7 pu, then MAPE is relatively small, considering differences in the major energy amounts.

The figure shows as if MPE values are mostly negative, but actually proportionally over and under the forecasted values (positive and negative MPE values) are relatively equal. Our chosen year showed 51.2 % as produced more than forecasted, 47.6 % as produced less and 1.2 % precisely as forecasted (0 MW forecasted and 0 MW produced).

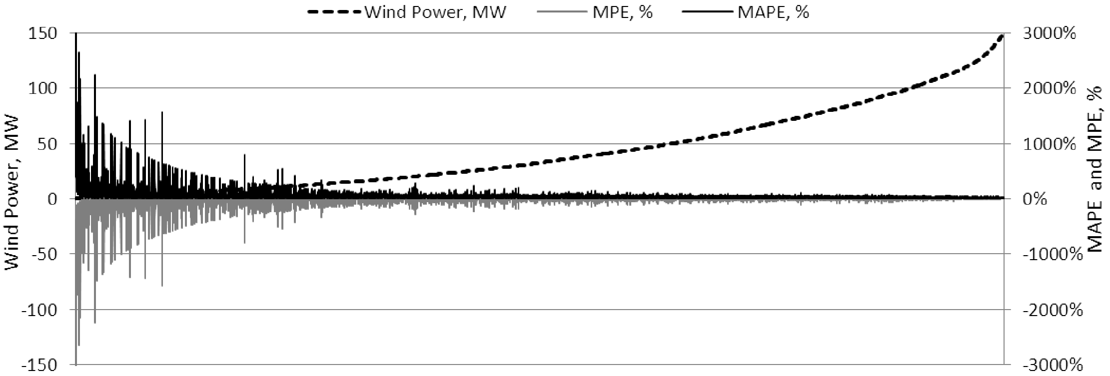

Fig. 2. **Sorted increasing summary of wind power production, MPE and MAPE in Estonia (1/1/2011–31/12/2011) [6]**

Figure 2 presents the cumulative output power of Estonian wind power plants, to give a better explanation of the trends. MAPE and MPE are significantly big, if the wind power is small. Also the biggest MAPE values come from the negative MPE values. Negative MPE values mean, that forecast is greater than production. Figure 1 and 2 show, that MAPE is not always the best way to analyse all wind data.

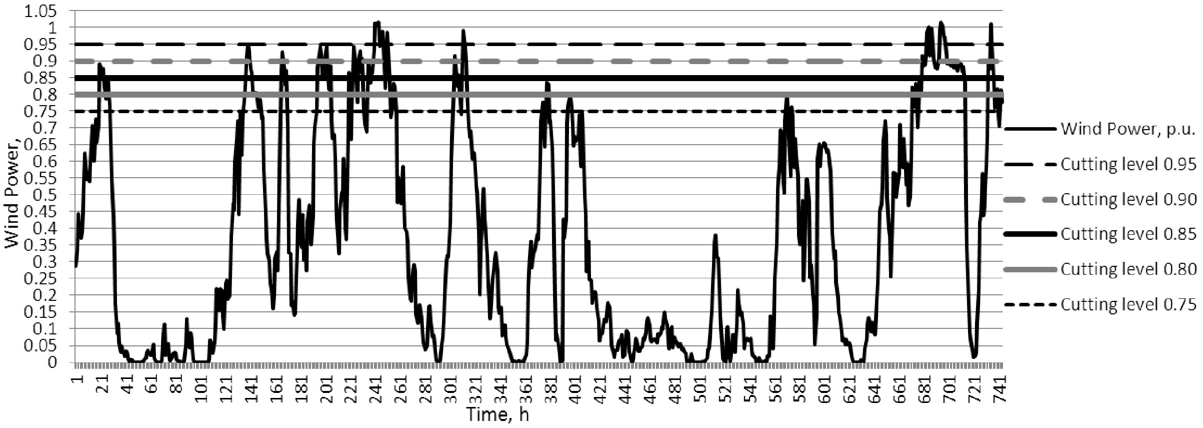

Fig. 3. **Pakri wind park power production and cutting levels (1/1/2011–31/1/2011)**

Figure 3 presents one option for compensating for the forecast error, which is cutting off wind park production chart peaks [7; 8]. Cut-off energy from power peaks from production charts can be used for hydrogen production – the technology which is considered in the paper [9]. By this technology it is possible to store energy, and during wind lull periods to produce electrical energy again.

Wind energy usage in heat grids is observed in the present paper [10]. It appears that wind energy usage in heat networks compared with electrical networks is, in some aspects, somehow simple. But now some problems arise due to the different needs of production and consumption charts (different season – different consumption). As in Estonia today the bigger mounted energy storages with suitable efficiency (hydro-pumped storage stations etc.) are non-existent, we have heating networks that use local fuels or gas for distant heating. In the above-mentioned study the whole amount of wind energy directed to heat network is considered.

Results and discussions

The results of cutting off production chart peaks in different levels are given in Table 1.

Table 1

Cutting off production chart peaks

Cutting level, pu	Wind power, pu	Remaining energy, %	MAPE, %	Forecast RMSE, pu	Forecast RMSE decreasing %
No cutting	0.277	100	52.2	0.125	-
0.95	0.267	94.8	52.4	0.124	2.9
0.90	0.261	92.0	52.6	0.122	4.3
0.85	0.245	84.3	53.3	0.119	6.8
0.80	0.234	79.0	53.7	0.116	9.0
0.75	0.218	71.2	54.8	0.115	10.3

In Table 1 the remaining energy, average wind power, forecast RMSE and MAPE are calculated at different cutting levels. The forecast error decreases when the cutting off production chart peaks. MAPE does not change significantly. The average forecast RMSE in Pakri wind park without cutting was 0.125 pu. The average forecast error in Estonia is about 0.134. For example, the forecast RMSE in Germany is 0.106 and Denmark is 0.084 [11]. This is due to bigger total wind parks output power; also developers have more experience in prediction.

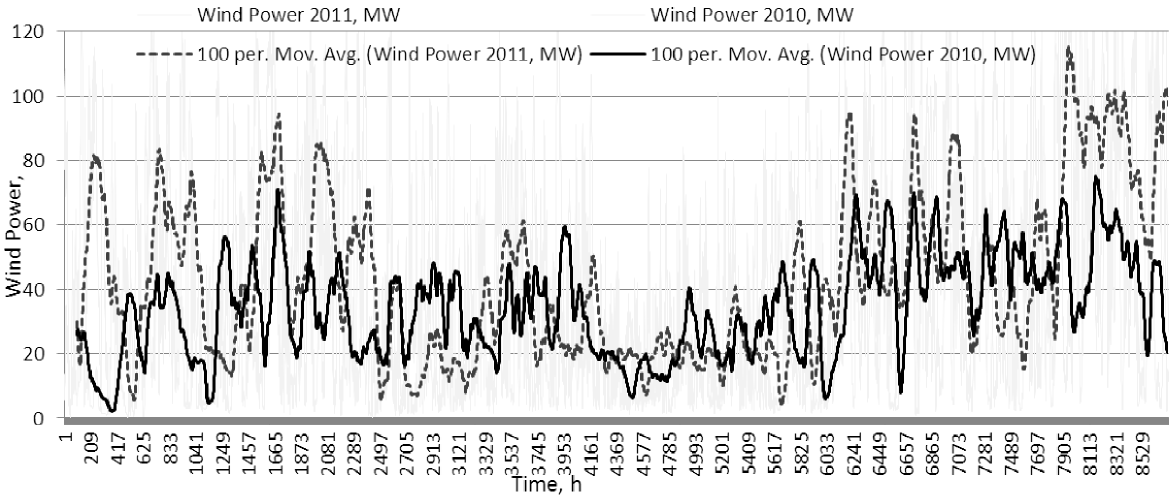

Fig. 4. **Summary of wind power production in Estonia (1.01.2010–31.12.2011)**

Figure 4 displays a 100 period trendline moving average to facilitate trend observation. The figure shows, that for Estonian wind parks the year 2011 was more productive than 2010. In summer months the production is lower than during the rest of the year. In Table 2 there is the summary of these 2 years. The third row is the wind data from TransnetBW GmbH, that is TSO in Baden-Württemberg (South Germany). The actual and forecasting data were all integer numbers, but the magnitude is still valid [12].

Table 2

Summary of 2010 and 2011

Year	Average wind power, MW	Maximum wind power, MW	Average MAPE, %	Average forecast RMSE, MW	Maximum forecast RMSE, MW
2010	34.2	127.8	50.5	11.7	92.4
2011	43.3	161.7	53.0	11.4	83.6
2011 Germany	48.0	458.0	46.6	15.5	230.0

Table 2 shows that the maximum forecast error can sometimes be about 77 % of Estonian wind parks actual total output power. In Pakri wind park the maximum was 74 %. But the average forecast RMSE is considerably worse than for German wind parks.

In Table 3 there are examples of wind power in different wind parks in Estonia.

Table 3

Largest wind parks in Estonia

Wind park	Wind power, MW	Rated power, MW
Pakri	15.03	18.4
Viru-Nigula	20.89	24
Esivere	3.03	8
Rõuste	6.56	8
Aulepa	25.94	39
Tooma	8.99	16
Virtsu	5.08	6.9
SUM	**85.52**	**120.3**

The data are collected from Estonian TSO SCADA 3/3/2012 on 20:54.

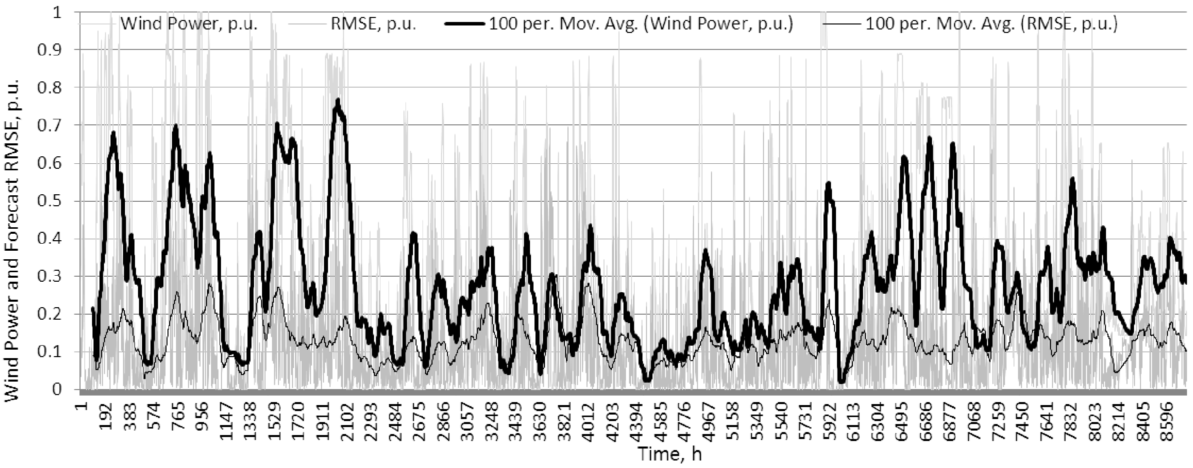

Fig. 5. **Forecast RMSE in pu by periods of time**

Figure 5 shows, that Pakri wind park output power is similar to all wind parks summary in Estonia (Fig. 4).

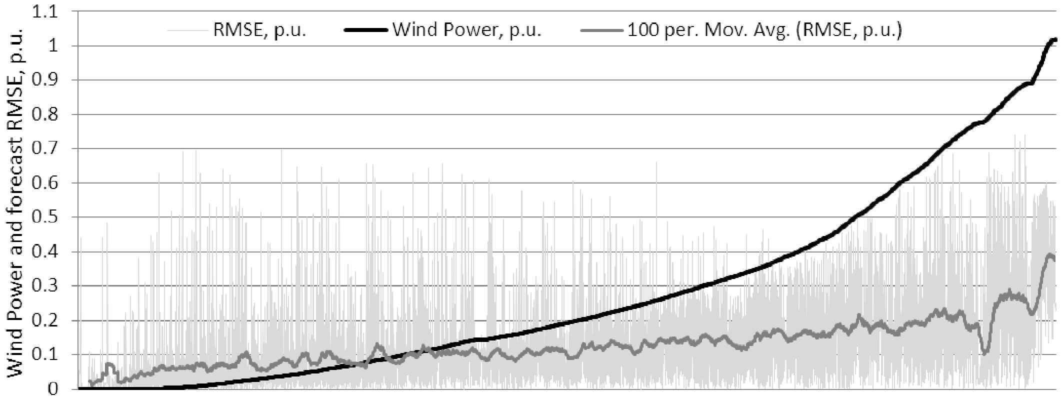

Fig. 6. **Sorted increasing summary of wind power production and forecast RMSE**

Figure 6 displays a sorted increasing wind power and forecast RMSE 100 period trendline moving average to facilitate trend observation. The figure shows, that RMSE values often exceed 0.5 line (168 hours per year – 2 %). The maximum RMSE is 0.74. In Table 4 the presented average forecast RMSE is divided into four ranges.

Table 4

Average forecast RMSE

Wind Power, pu	**0 – 0.25**	**0.25 – 0.5**	**0.5 – 0.75**	**0.75 – 1**
Average forecast RMSE, pu	0.0860	0.1509	0.1941	0.2557
Number of hours of Wind Power, %	58.2	21.3	11.2	9.3

Table 4 shows that for 79.5 % of the year the wind park output power is under 0.5 pu. If we are cutting in level 0.9 pu, then the number of hours of wind power is 2.3 %.

Conclusions

1. According to the measurement data in Pakri wind park, the average MAPE was 52.2 % and the average forecast RMSE was 0.128 pu.
2. The higher the wind park output power, the lower MAPE becomes, and vice versa. The forecast error increases as the wind park output power increases.
3. 79.5 % of the year, Pakri wind park output power was under 0.5 pu.
4. The forecast error decreases as the production chart peaks are cut off. MAPE and MPE do not change significantly.
5. Estonian average wind power is better than in Germany, considering the size of the wind parks. But the average forecast RMSE is considerably worse than for the German wind parks.

References

1. Lepa, J., Annuk, A., Kokin, E., Põder, V. & Jürjenson, K. Energy production and consumption charts in energy system. 2009. Ed. by A. Raukas. Oil Shale, No. 26(3S), pp.309-318.
2. Eesti elektrisüsteemi tootmisseadmete piisavuse aruanne 2009. Elering OÜ. Tallinn, 2009. 20 p. (in Estonian) [online] [02.03.2012]. Available: http://elering.ee/tootmispiisavuse-aruanded/.
3. Rosen, J., Tietze-Stöckingen, I. & Rentz, O. Model-based analysis of effects from large-scale wind power production. 2007. Energy, No. 32(4), pp. 575-583.
4. Agabus, H. & Tammoja, H. Wind power production estimation through short-term forecast. 2009. Ed. by A. Raukas. Oil Shale, No. 26(3S), pp. 208-219.
5. Pakri Wind Park. [online] [02.03.2012]. Available: http://www.4energia.ee/projektid/pakri-tuulepark/.
6. Planned and actual generation of windparks. [online] [02.03.2012]. Available at: http://elering.ee/tuuleparkide-tegelik-ja-planeeritud-toodang/.
7. Annuk, A., Tammoja, H., Agabus, H., Toom, K. & Tamm, T. Possibilities for Correcting Forecast Errors by Cutting off Production Chart Peaks. Agronomy Research, 2010. Ed. by R. Lillak, No. 8(S1), pp. 25-32.
8. Toom, K., Jürjenson, K., Juhanson, T., & Annuk, A. Cutting wind generator power chart peaks to mitigate power forecast error. Engineering for rural development 10, Jelgava, 2011. No. 10, pp. 294-298.
9. Andrijanovitš, A., Egorov, E., Lehtla, M., Vinnikov, D. New Method for Stabilization of Wind Power Generation Using Energy Storage Technology. Agronomy Research, 2010. Ed. by R. Lillak, No. 8 (S1) pp. 12-24.
10. Lepa, J., Annuk, A., Toom, K., Jürjenson, K., Pennar, M., Palge, V. Wind Power in Heat Energy Systems. Agronomy Research, 2010. Ed. by R. Lillak, No. 8(S1), pp. 141–148.
11. Wind power in Estonia. Elering OÜ. 2010. [online] [02.03.2012]. Available: http://elering.ee/tuuleenergia-uuring/
12. Wind power in South-Germany. [online] [05.03.2012]. Available: http://transnetbw.com/key-figures/renewable-energies-res/wind-infeed/?app=wind&activeTab=csv&auswahl=month&selectMonat=3