Wind Power Plant Data Monitoring and Evaluating

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Abstract: - Smart grid technologies possess great potential to modify costumer performance with respect to energy consumption, in both automatically and non-automatically This paper provides a statistical analysis of the performance of a wind power plant through monitoring the obtained data, evaluating the system performance and predicting possible measures that can be undertaken.

The monitoring equipment was placed at key locations throughout the wind plant, most specifically at the points of connection with the transmission system. Real and reactive powers, along with three-phase voltages at the interconnection point, were sampled and stored. Results have been valuable to evaluate the probability of wind power variations, capacity factors, as well as to analyze ancillary service requirements with real wind power plant output.

Key-Words: - Wind power plant, Power System, Monitoring, Statistics, Smart grid, Ancillary service

1 Introduction

Electrical systems must be designed and operated in order to accommodate a change in the consumption, a trip of a conventional production unit, a fault on a transmission line as well as to absorb a certain amount of unregulated and fluctuating production from renewable energy sources (RES), especially wind power.

In the last 20 years, the use of wind power has grown steadily throughout the world. The development of production technology is improving the wind turbine performance. As a result of these developments, and the measures to promote the construction of renewable resources, more utilities are seriously examining the wind option. As wind plants grow in size and number, questions about their possible impacts on the electrical grid become more complex.

The intermittent nature of the wind resource, together with short-term power fluctuations, are the two principal issues facing a utility with wind power plants in its power grid. Power fluctuations might also affect wind power's participation in the bulk-power market by affecting its ancillary-services requirements in a competitive business environment. [1].

Smart technology allows to monitor parameters of these plants, and to use the real data of wind power to assess their impact on the quality parameters of electricity [2]. Power quality monitoring and analyzing as part of smart grids philosophy consist in evaluating the situation through measuring the power, calculating the energy consumption, analyzing presence of sags/swells, in order to drive the change into taking actions: running less equipment, design/install a filter, install power factor correction, etc. In [3] a literature review of the major aspects that should be monitored in a wind turbine for maintenance purpose is presented. In [4,5,6] are reported IEC Technical Reports of wind plant performance. In [7] is presented one of the first studies performed to assess and analyze the parameters of wind power plants. Numerous applications on the impact of Wind Power Plant on power quality have been reported in many domains [8,9,10]. In [11] is developed a planning tool to support large scale wind power integration into the electrical energy supply system for the short-term prediction from 1 hour up to 72 hours. In [12] the data for electricity supplied to grid is used for calculating the emission reductions.

Variable renewable energy forecasting technology is an area that requires further research in particular to better forecast extreme and ramping events and to identify the forecast information format and content required to get the best operational performance from the portfolio of generation [13].

This paper has two main objectives:

1. To present the data collected from monitoring a wind power plant.

2. To analyze the monitored data in order to evaluate the probability of wind power fluctuations, the probability distribution function of wind power plant output variations and Peak-Period Capacity Factors.

Results of these analyses can provide data on the potential effects of wind power plants on power system regulation. Such information enables utilities to better understand the regulation requirements for wind power plants and assists utilities in planning and operating the electric grid to integrate wind power into the power system.

2 Wind Generation in Kosovo

The Republic of Kosovo has enormous natural sources of coal, which constitutes the major source of electricity generation. Actually the energy production in Kosovo is formed by 1478MW installed thermal power and 46.9 MW installed hydropower with a total of 1524.9MW [14]. Important steps have been taken in the field of renewable energy. The government encourages the building of renewable resources, particularly wind power plant. Energy Regulatory Authority of Kosovo has licensed the Kosovo-German company for renewable energy Wind Power Sh.a to construct the first wind power plant in the Mount of Golesh. Golesh Wind Power plant includes three wind turbines with a capacity of 450kW each, so the total installed capacity is 1.35MW. The wind turbines and generators are type Siemens ANBONUS 690V. The diameter of the propellers is 53m, while the height of the tower is 32.7m. Utilization coefficient is 0.81. The generators are connected through the transformers 690V /10kV to 10kV busbar, where the monitoring equipment is installed, and then with the substation Magura TS 35/10 kV. The substation is part of the distribution system in this region.

3 The Monitored Data

In 2007, the Kosovo Energy Corporation (KEK) established the Automated Meter Reading (AMR) Center for remote command and reading of multifunctional meters. Smart Meters are installed in the whole territory of Kosovo. This service does the parameterization of meters, modems, communication architecture, meter management and maintenance of the entire communication system [15].

The data recorded from the wind power plant include real power and reactive power to/from KEK, as well as bus voltage at the grid-interconnection point. The wind speeds and directions, temperature, and barometric pressure are also recorded. All recorded data have identification (ID) and transmitted every 15 minute to the AMR Center in KEK. Each record has the date and time (day, hour, minute).

4 Analysis of monitored data

The recorded data of real power and reactive power to/from KEK, as well as bus voltage at the grid-interconnection point for the period 2010-2011 will be used to analyze the fluctuations of power produced from wind power plant and to study how time diversity affect the electrical system parameters.

Analysis will focus on two typical months with the greatest and the lowest power production. The analysis will also attempt to detect Capacity Value of Wind Generation [16].

5 Energy and power produced by the Wind Power Plant's Golesh

The Golesh Wind Power plant includes three wind turbines with a capacity of 450kW each, so the total installed capacity is 1.35MW. In Figure 1 is given the monthly energy produced by the wind power plant of Golesh during the period of one year (from March 2010 to February 2011) superimposed with the monthly peak power.

The monthly output power varies considerably. In general, wind resources during the months of July and August are less favorable for producing energy compared the other months. The total energy produced by Golesh Wind Power during the period of one year is about 920MWh.

Analyzing the figure 1 we can see that the monthly energy production varies considerably; the ratio of the highest monthly production to the lowest one is more than four times. Analyzing the data we can find that the energy production from wind power plants is higher in winter season than in summer one. So, the maximum production is on December 2010 and the minimum production is on July 2011.

Figures 2.a,b shown the variation of active power production by wind plant during the months with maximum and minimum production using stacked line charts. The stacked line charts allows easy identification and comparison of the trends and patterns in our data.

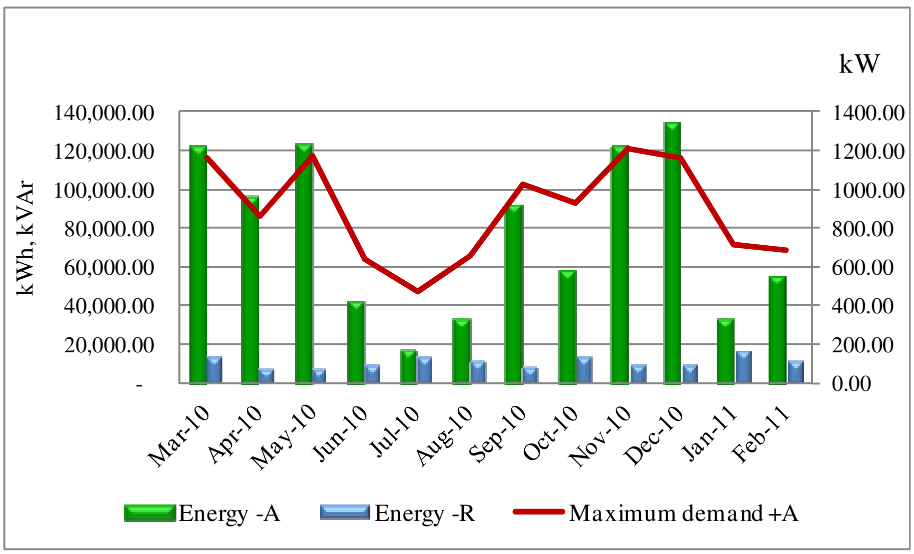
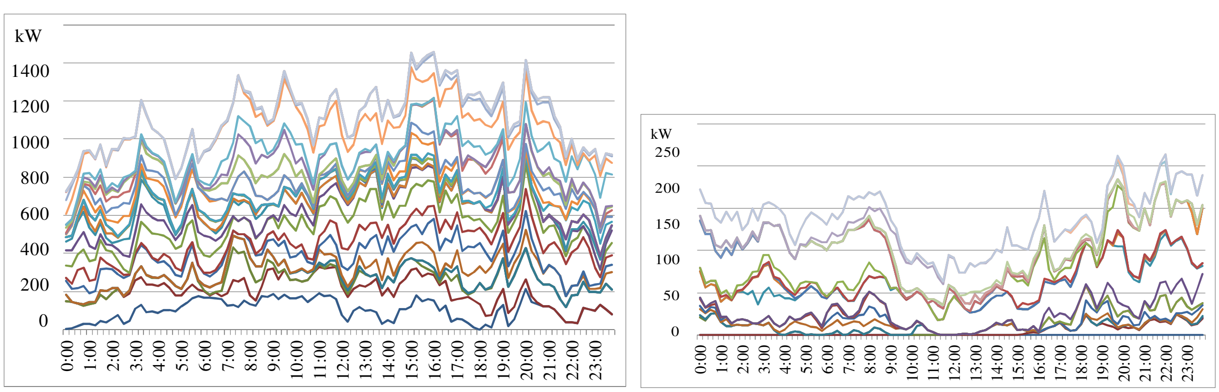


Fig.1 Energy produced during the period of one year and the monthly peak power

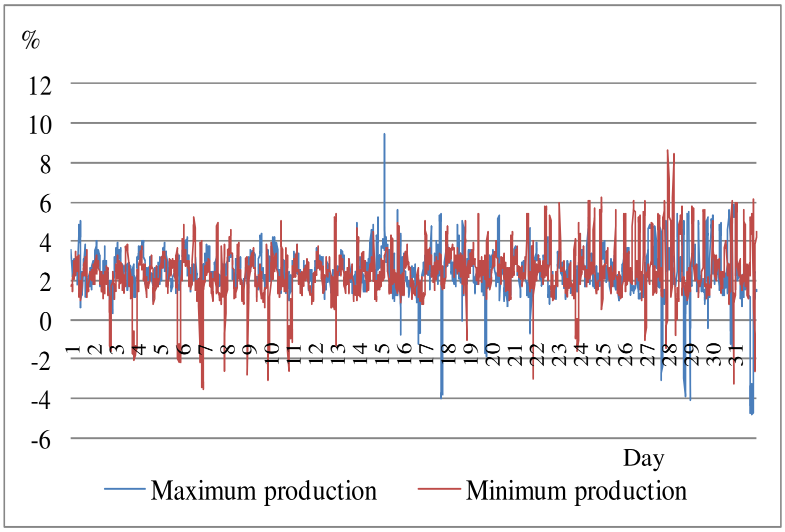


(a) (b)

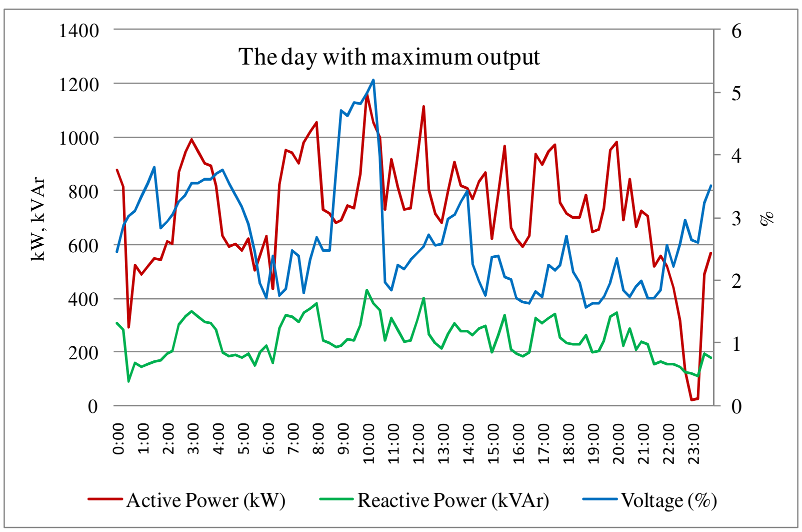
Fig.2. The hourly active power produced by wind plant during the months with (a) maximum and (b) minimum production

Analyzing the figure 2.a we can see that the hourly peak production occurs in the morning hours; a secondary peak occurs around afternoon. Figure 2,b shows a different pattern. A minimum production around noon is evident in minimum production month. The day with maximum output during the period under the consideration was 24 December 2010.

In figure 3 are presented the variation of the voltage at the point of interconnection of wind power with the distribution system for the maximum and minimum production months.



(a)

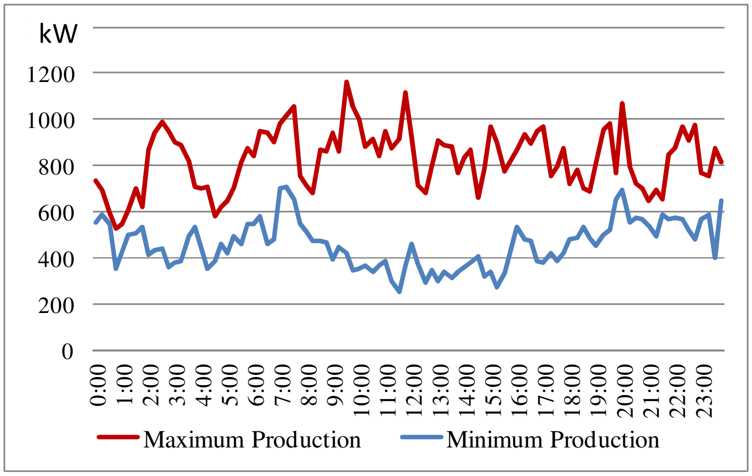


(b)

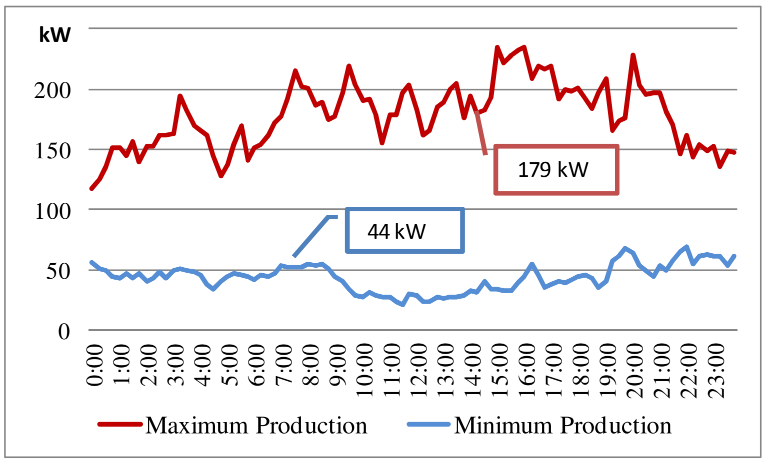
Fig.3 (a) The fluctuation of the voltage at connection bus (%) and (b) wind power production and the voltage for the maximum day output.

The figure 3,a shows the fluctuation of the voltage at 10kV busbar expressed in percent for the maximum and minimum production months. Because wind power can change considerably the fluctuation of the voltage can be very large The day with maximum output during the period under the consideration was 24 December 2010. In figure 3, b are shown the active and reactive power as well as the voltage fluctuation for the maximum day output. The voltage fluctuation follows the active and reactive power ones.

The figures 4.a,b show the maximum and average hourly outputs of wind power for months with maximum and minimum production.



(a)



(b)

Fig.4. (a) The maximum hourly output of wind power; (b) The average hourly output and the average output of wind power

The capacity factors of wind power approximately can be calculated as average outputs over the months. This approximation is reasonably accurate [17]. In case of maximum and minimum production months, the capacity factors are respectively 179kW (or 13.26% of installed capacity) and 44kW (or 3.2% of installed capacity).

6 Wind power fluctuations

Wind power plant injects variable power into the electric power system, which causes change/fluctuation of system parameters. In this paper we will evaluate the nature of wind power fluctuations by statistics and distribution analysis regarding (a) the step changes and (b) the sloping rates of power level.

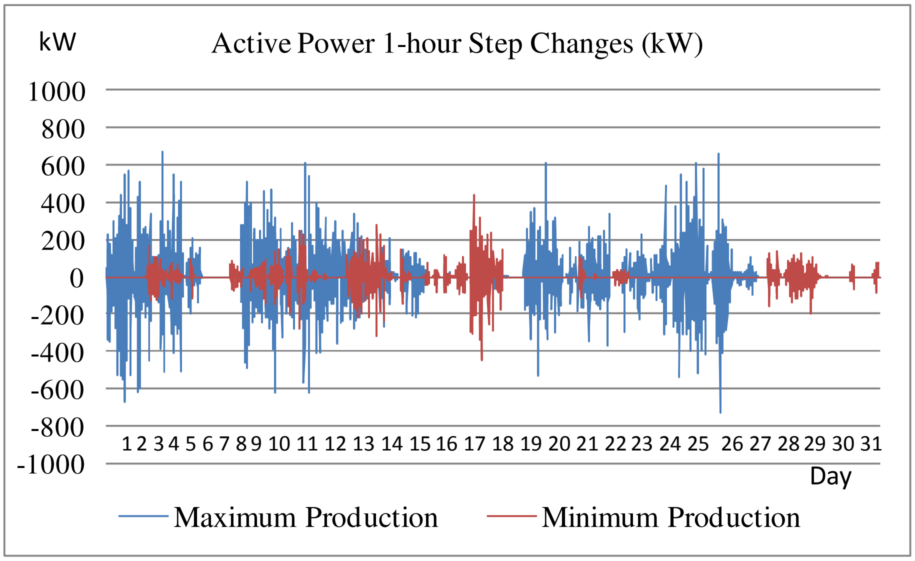
7 Step Changes of the wind power production

To quantify the performance of the wind resource, we calculate the differences in produced power between two successive times. The figures 5.a,b show the active power step changes for two time intervals (15-minute and 1-hour) for months with maximum and minimum production, while the figures 6.a,b show the reactive power step changes for two time intervals (15-minute and 1-hour) for months with maximum and minimum production.

Because wind speed can change considerably during an hour, hourly active power step changes can be very large. It is clear that, for shorter intervals, power step changes are smaller (fig.5.a) than for the larger ones (fig.5.b).

On the other hand, during the maximum power production, because the wind power can change considerably the step changes are larger (fig.5,a) than for the minimum one (fig.5.b).

The figures 6.a,b show that the step changes of reactive power are larger then the step changes of active power. On the other hand, the step changes of reactive power do not depend much from the fact that the month is with maximum or minimum production.



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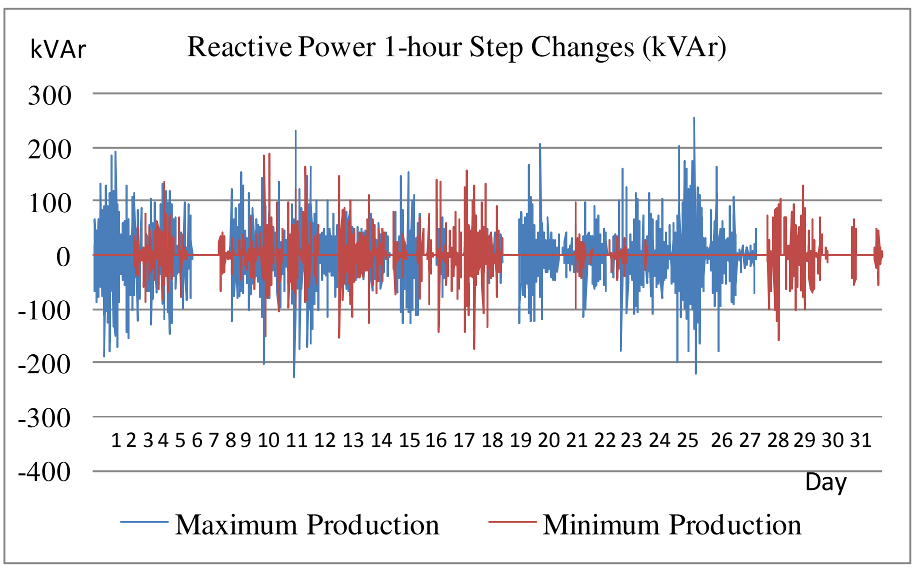

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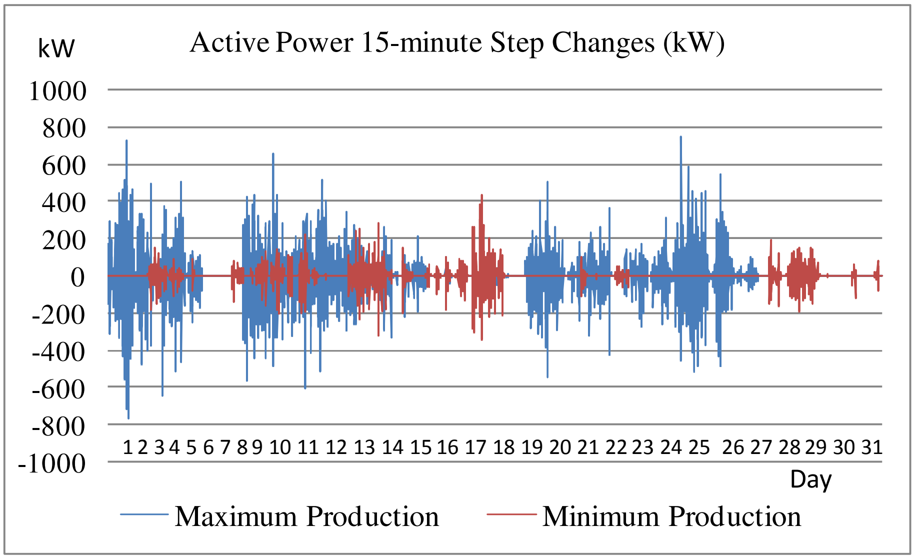
Fig.5. Active power Step Changes for two time intervals (15-minute and 1-hour) for months with maximum and minimum output



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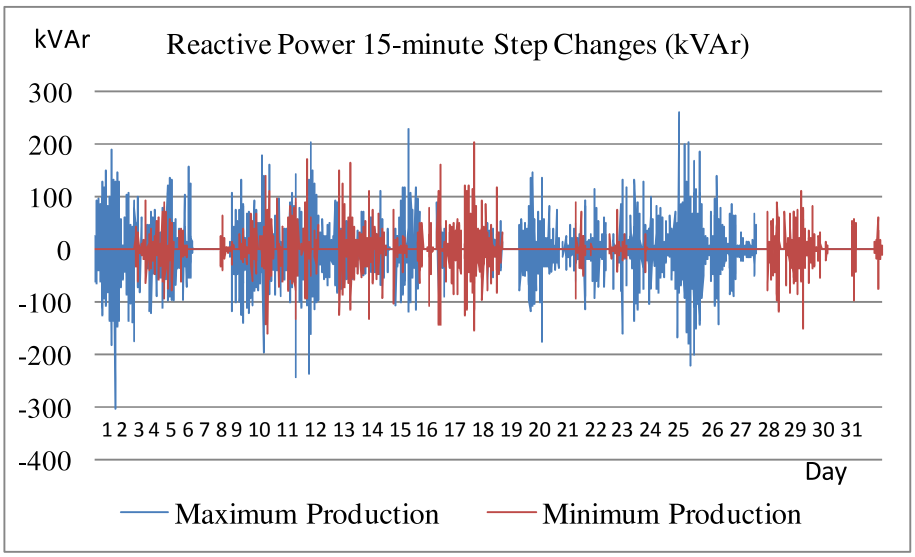


(b)

Fig.6. Reactive power Step Changes for two time intervals (15-minute and 1-hour) for months with maximum and minimum output

To evaluate statistically the behavior of a wind power plant we calculated the maximum step changes in both decreasing and increasing directions as well as their average values and standard deviations, for two time intervals 15-minute and 1-hour.

The results of these calculations are shown in Table 1, 2.

We can see that the positive and the negative step changes have about the same absolute maximum values, absolute average values and standard deviations.

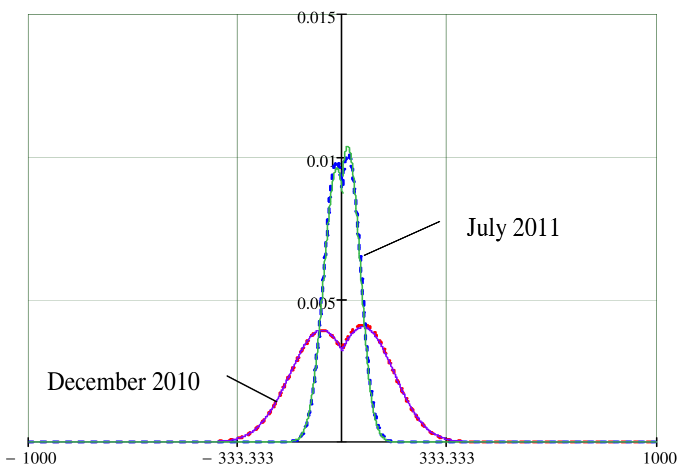
In Figure 7,a,b are plotted the step change distribution functions of active and reactive power for two time intervals 15 minutes and 1 hour for months with the maximum and the minimum production. Low probability to zero confirms the intermittent nature of the wind resource.

Table 1. Maximum, Mean and Standard Deviation of wind active power Step Changes

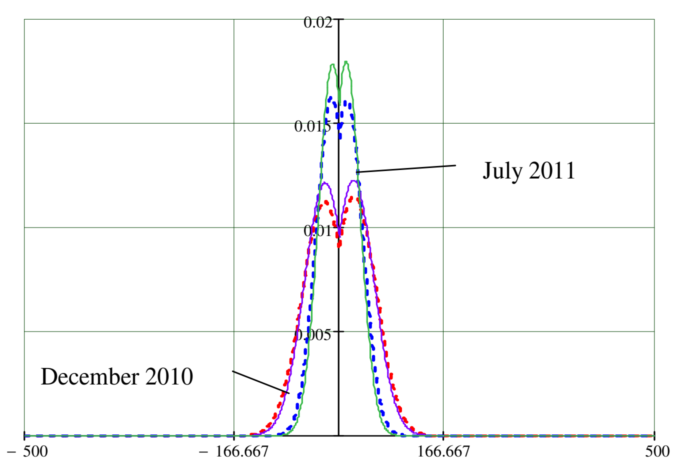
Month	Max. Increase	Mean Increase	Stdev. Increase	Max. Decrease	Mean Decrease	Stdev. Decrease
15-minute step power (kW)						
December 2010	751.2	65.28468	96.82111	-764.7	-65.3754	102.3881
July 2011	434.7	18.64007	39.51051	-338.7	-18.6773	40.49456
1-hour step power (kW)						
December 2010	664.2	65.1117	98.8897	-735	-65.6094	101.7572
July 2011	320.4	17.6078	38.49283	-445.5	-17.9015	41.55072

Table 2. Maximum, Mean and Standard Deviation of wind Reactive power Step Changes

Month	*Max. Increase*	*Mean Increase*	*Stdev. Increase*	*Max. Decrease*	*Mean Decrease*	*Stdev. Decrease*
15-minute step power (kVAr)						
December 2010	289.8	23.57278	34.70123	-303.3	-23.6219	35.49366
July 2011	210.6	12.10027	24.76643	-170.7	-12.1247	24.50737
1-hour step power (kVAr)						
December 2010	230.7	22.46954	32.51548	-226.5	-22.7132	32.85851
July 2011	184.5	10.7195	22.2207	-173.4	-10.847	22.34626



(a)



(b)

Fig.7 The distribution function of (a) active (b) reactive power for two time intervals for the maximum (red/pink) and the minimum production (blue/green).

The figures 7,a,b show that the curves do not resemble the shape of normal distribution due to a deep in the value zero. The deeps are mainly the result of zero values of the energy produced by the wind power plant. Without the zero value of production, the probability of zero step changes would be zero.

These figures shown also that short-term fluctuations lie in a narrow range and the frequencies of positive and negative power changes are approximately the same.

From the distribution curves for 1 hour time interval, it is evaluated that the changes within the range ±1σ for months with the maximum and the minimum production are respectively 63.4%/70.6% of possible step changes, which is roughly 7% of total capacity of wind power.

Further, 91% / 93.9% of the possible values of the step changes are within the range ± 2σ, or about 20% of total capacity. The 99% of the values are within the range ± 3σ, or about 30% of total capacity. The results are approximate the same also for 15 minutes time interval.

8 The gradual changes of the wind power production

Another way to quantify the behaviour of the wind resource is to investigate persistence of power changes through the gradual changes of the wind power production. So, we calculated the gradual changes of the active and the reactive power for two time intervals (15 minutes and 1 hour) for months with the maximum and the minimum production.

From the Table 1 we find out that the maximum active power change for 1 hour time interval for the month with maximum output is 664.2 kW and -735kW (49% to 56% of the total), while for the month with minimum output is 320.4 kW and -445.5kW (23% to 33% of total capacity).

This is equivalent to a change rate of 166.05kW/15min and -183.75 kW/15min (12% to 14% of the total) for month with maximum power production and 80.1kW/15min and -111.375kW/15min (6% to 8% of total capacity) per month with minimum one. If we compare these values with the step changes for 15 minutes time interval, we find that the gradual change rates are much smaller that the step change rate for the same time interval.

To evaluate statistically the behaviour of a wind power plant we calculated the maximum active and reactive powers gradual changes (kW/15min, kVAr/15min) from the step change data of 1 hour time interval in both decreasing and increasing directions as well as means and standard deviations.

The results of these calculations are shown in Table3,4.

Table 3. Maximum, Mean and Standard Deviation of wind active power gradual change (kW)

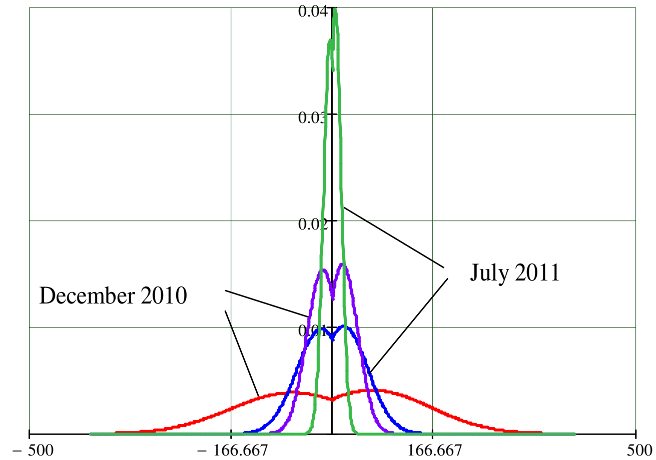
Month	*Max. Increase*	*Mean Increase*	*Stdev. Increase*	*Max. Decrease*	*Mean Decrease*	*Stdev. Decrease*
December 2010	166.65	16.445	25.048	-183.75	-16.214	25.838
July 2011	109.2	4.49	10.01	-111.375	-4.38	10.78

Table 4. Maximum, Mean and Standard Deviation of wind Reactive power gradual change (kVAr)

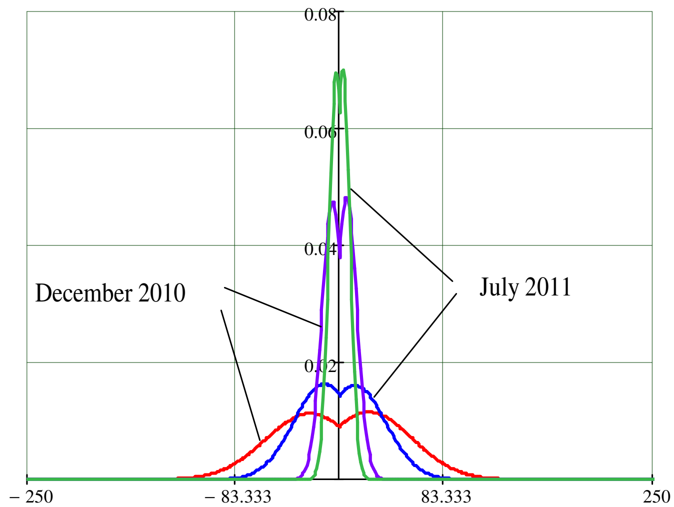
Month	*Max. Increase*	*Mean Increase*	*Stdev. Increase*	*Max. Decrease*	*Mean Decrease*	*Stdev. Decrease*
December 2010	63.975	5.679	8.274	-56.625	-5.609	8.399
July 2011	47.4	2.719	5.682	-43.35	-2.667	5.725

In Figure 8, a, b are plotted the 15 minutes step change distribution functions and 15 minutes gradual change distribution functions for active and reactive power for months with the maximum and the minimum production using the data of 1 hour time interval.

The figures 8,a,b show that the curves resemble with the curves of step changes distribution functions. The distribution curves of gradual changes are thinner, but the changes within ± 1σ differ little from those of step changes (the changes within the range ± 1σ are respectively 63.4% / 70.9%). It is evaluated that the change within the range ±3σ is roughly 99% of the possible values for months with the maximum and the minimum production or ±80kW/15min.



(a)



(b)

Fig.8 The distribution function of (a) active (b) reactive power for 15 minutes step / gradual change using 1 hour time interval distribution functions for months with the maximum (red/pink) and the minimum production (blue/green).

These results suggest that due to changes in the production of Golesh wind power plant it is necessary a regulated power of ± 5.33kW/min. This range will cover 99% of gradual changes of wind power plant.

So, we calculated that the addition ancillary service requirements are about 0.4% of installed capacity of wind power plant.

In a further analysis we will attempt to connect the voltage fluctuations in interconnection buses with real data of reactive power, imposing the rules for reactive power control of wind power plant.

9 Conclusions

Monitoring of wind power helps wind power plant developers, and operators to understand the fluctuations in wind power and how they affect the power quality and cost of energy produced, as well as to analyze ancillary service requirements with real wind power plant output data. Monitoring of Golesh wind power plant shows that:

• The monthly energy production varies considerably; the ratio from the highest monthly production to the lowest one is more than four times. A statistical analysis of step changes and gradual changes for months with the maximum and the minimum production is undertaken, to quantify the wind power fluctuations.

• It is evaluated that the changes within the range ±1σ for months with the maximum and the minimum production are respectively 63.4% / 70.6% of possible step changes, which is roughly 7% of total capacity. Further, 91% / 93.9% of the possible values of the step changes are within the range ± 2σ, or about 20% of total capacity. The 99% of the values are within the range ± 3σ, or about 30% of total capacity. The results are approximate the same also for 15 minutes time interval.

• The distribution curves of gradual changes are thinner, but the changes within ± 1σ differ slightly from those of step changes (the changes within the range ± 1σ are respectively 63.4% / 70.9% of possible step changes). It is evaluated that the change within the range ±3σ is roughly 99% of the possible values for months with the maximum and the minimum production or ±80kW/15min.

• To cover 99% of gradual changes in the production of Golesh wind plant, it is necessary to set another power plant that will be dedicated to the regulation with a regulated power about 0.4% per minute of installed capacity of wind power.

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