WIND TURBINES OPERATION AND MAINTENANCE: PROBLEMS AND SOLUTIONS

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REZUMAT. In ultimii ani in Romania centralele eoliene au cunoscut o dezvoltare semnificativa, de la 10 MW la sfarsitul anului 2008, capacitatea totala de producere instalata si disponibila a energiei eoliene a ajuns la peste 1000 MW la inceputul anului 2012. O data cu cresterea numarului de turbine eoliene in functiune creste si necesitatea unei mentenante planificate in detaliu si a unei monitorizari constante a paremetrilor acesteia. In aceasta lucrarea se face o analiza a functionarii centralelor eoliene din punctul de vedere al problemelor aparute in operarea acestora, a mentenantei necesare la intervale de timp bine stabilite si de asemenea, pe baza experientei in exploatare, se pot evidentia solutii viabile pentru optimizarea productiei de energie eoliana.

Cuvinte cheie: optimizarea productiei, mentenanta preventiva, analiza performantelor

ABSTRACT. In the recent years, wind power in Romania has developed significantly, from 10 MW at the end of 2008, the total production capacity available of installed wind power has grown to over 1000 MW in early 2012. With the increasing number of wind turbines in operation, increases the need for detailed planned maintenance and a constant monitoring of its parameters. In this paper an analysis is made on wind farms operation in terms of problems encountered in their operation, the necessary maintenance intervals and also, based on the experience in their operation, solutions will be highlighted for optimization of wind energy production.

Keywords: production optimization, scheduled maintenance, performance analysis.

1. INTRODUCTION

Wind power in Europe has grown significantly : annual installations of wind power have increased steadily over the last 17 years from 814 MW in 1995 to 9,616 MW in 2011. Also, more renewable power capacity was installed during 2011 than any other year, an increase of 37.7% compared to 2010. The EU's total installed power capacity was increased by 35,468 MW net to 895,878 MW, with wind power increasing its share of installed capacity to 10.5% (93,957 MW), and renewable capacity increasing its share to 31.1% [1]. Romania has doubled it's wind energy installed capacity in 2011, exceeding the threshold of 1000 MW to early 2012[2].

Correlated with this sudden development, new problems arise in the operation of the wind turbines (WT). Some factors have to be taken into account: weather conditions (e.g.: wind speed, ambiental temperatures, ice, snow conditions) and scheduled maintenance in order to have an overall picture of the estimated production. Even so, often unplanned events arise such as: external incidents (e.g: grid faults, ice on blades, snow storm) or internal incidents (e.g: turbine components failure) that affect the wind farm energy production. For the Operation and Mainetance (O&M) department the availability assessment is of utmost importance. Based on this forecast, the Energy Managemet department will sell different amounts of energy on the Day Ahead Market (DAM). Thus, it is the duty of the O&M department to take all actions necessary to maximize production and minimize the occurrence of accidental shutdowns. In order to accomplish these requirements some studies have to be made, based on previous operation reports, and records taken from the Supervisory Control and Data Acquisition (SCADA) system.

In order to better understand the magnitude of the problem (energy losses) at the end of each year an estimated budgeted production has to be established for each month of the comming year based on some factors: average wind speed at the site of the Wind Farms (WF), power limitation by order of the TSO, weather conditions, technical non-availability of turbines, grid losses: between the WTG's and the Point of coupling (PoC), external and internal grid availability.

The goal of the O&M department is to reach or even exceed the budgeted production with minimum maintenance costs. O&M costs include: regular maintenance, repairs, insurance, spare parts and administration, but also performance monitoring. Taking into consideration that the O&M department is one of the principal cost elements and one that is present during the whole life cycle of the WTG after the commissioinig phase, maintenance strategies as descbribed in [3] are needed in order to reduce the overall costs and increase the availability of the WF. To succeed in achieving this target it is necessary for a good collaboration between the field technicians, the dispatchers and the supervisors.

Today's wind power maintenance is mainly scheduled maintenance. Sheduled, or time-based maintenance activities should, at a minimum, be followed according to the turbine manufacturer's manual, supplemented by additional time-based items prescribed as a result of the real-world experience of the maintenance contractor.

These activities comprise time-based turbine visits set at minimum 6 month intervals, and include visual inspections, measurements, replacements of different components of the wind turbine such as[4]:

- Hydraulic system: check oil level, replace air filter, measure pressure in brake system;
- Yaw bearing system: lubricate the yaw teeth, ckeck teeh for damage;
- Service lift: replacement of the motor;
- Crane: ckeck brake functions, check cables, suspensions, crane block;
- Generator: check bush length, rotating contacts, noise in the bearings, replacement of brushes;
- Gear box: perform thickness measurements, check oil level, possible defects in the paint scheme;
- Pitch system: inspect cylinder support, securing bolt, check hydraulic system for leackage;
- Nose cone: check for lose bolts in fiberglass connections, check for cracks;
- Blades: visual inspection, check for cracks, inspect torque tightness.

These activities are essential, and their effectiveness can be greatly enhanced by the feedback obtained from coordinated predictive maintenance activities. It is even possible that some time-based activities may be reduced in frequency and scheduled only when indicated by the test results from the predictive maintenance activities.

2. KEY PERFORMANCE INDICATORS

2.1. General Definitions:

- Capacity Factor (CF)

Ratio between the Produced Energy (E) during a certain period (T) and the energy that would be produced ideally if the WTG had worked at Rated Power (P) for the same period, express as percentage. In formulas [5]:

$$CF = \frac{E}{P \times T} \times 100\% \tag{1}$$

This factor is affected by the average wind speed and operation stoppages.

- Equivalent Hours (H_{EQ})

Number of hours during which a WTG should operate at P to produce the same energy E it has produced during the observation time that normally is one year. In formulas:

$$H_{EQ} = \frac{E}{P} = \frac{CF}{100} \times T \tag{2}$$

2.2. Unavailability time:

- External-External Unavailability Time (T_{UEE})

Time during which the WTG cannot operate because of causes external to the WTG and external to the plant (e.g. external grid constraints and outages, weather conditions out of specification etc.).

- External-Internal Unavailability Time (T_{UEI})

Time during which the WTG cannot operate because of causes external to the WTG but internal to the plant (e.g. substation problems, internal grid problems, etc.).

- External Unavailability Time (T_{UE})

Time during which the WTG cannot operate because of any cause external to the WTG. In formulas:

$$T_{UE} = T_{UEI} + T_{UEE} \tag{3}$$

- Internal Planned (predictive or Scheduled) Maintenance Unavailability Time (T_{UIP})

Time during which the WTG is stopped because of scheduled maintenance. This type of maintenance normally consists of periodic activities to maintain the WTG in full working order, or occasional activities to modify something to improve the WTG performance and activities to determine the condition of in-service equipment.

In all cases the activities can be scheduled in advance and it isn't related to faults.

- Internal Unplanned (or Unscheduled) Unavailability Time (T_{UIU})

Time during which the WTG is stopped due to a fault situation, including the repairing time.

- Internal Internal Unavailability Time (T_{UII})

Time during which the WTG is stopped due to untwisting the power cables.

- Internal Unavailability Time (TUI)

Time during which the WTG cannot operate because of any cause internal to the WTG, planned maintenance or fault situation. In formulas:

$$T_{UI} = T_{UIU} + T_{UIP} + T_{UII} \quad (4)$$

- Total Unavailability Time (TUT)

Time during which the WTG cannot operate because of any cause, internal or external. In formulas:

$$T_{UT} = T_{UIU} + T_{UIP} + T_{UII} + T_{UEI} + T_{UEE} = T_{UI} + T_{UE} \quad (5)$$

2.3. Performance Indicators Based on Energy

- Missed Energy (EXX) :

It is the energy that would be produced by a WTG during time periods in which the WTG is unavailable or operates below its capacity. Missed energy is an important value to calculate economic loss due to the unavailability or inefficiency.

Methods to determine the missed energy:

1) Multiplying the average power produced by the WTG when it has been available, for the Unavailability Time. This method is a good approximation when it's not possible to apply the methods below. In formulas :

$$EXX = \frac{E}{T - T_{UT}} \times T_{UXX} \quad (6)$$

2) Using the correlation between the production of the stopped WTG and the surrounding WTGs during those time periods in which all are available. This method is applicable when there is a group of WTGs quite close each other and only one of them is stopped whereas the others are operating normally.

3) Combining the Power Curve of the WTG with the wind speed measured at its hub height (the Power Curve represents, through a table and a graph, the power output of a WTG as a function of the wind speed at hub height). This method requires wind speed data which can be obtained either from a meteorological mast or from WTGs anemometers, applying the required adjustments to obtain reliable wind data for the position of the WTG under analysis.

Methods 2 and 3 allow to calculate the value of missed energy either when the WTG is unavailable or when it operates with a limitation in its power.[5]

- Producible Energy (E_P)

It is the energy that would be produced if the WTG had not any unavailability. The Producible Energy is the sum of the Produced Energy and the total Missed Energy (EUT). In formulas:

$$E_P = E + EUT \quad (7)$$

- Energy Availability (A_{en})

The Energy Availability is the ratio between Produced Energy and the Producible Energy, expressed as percentage:

$$A_{en} = \frac{E}{E_P} \times 100 = \frac{E}{E + EUT} \times 100 \quad (8)$$

3.OPERATION ANALYSIS

Wind turbines are remote power plants, unmanned, which, unlike conventional power stations are very much exposed to highly variable, harsh weather conditions, ranging from calm to severe winds and conditions ranging from tropical heat, lightning, arctic cold, hail and snow. In addition, because of these external variations, wind turbines undergo constantly changing loads, unlike conventional power plants. All of these characteristics will be emphasised by the analysis made on two month of operation presented below. For these analysis 5 turbines were chosen from a specific WF. The study period is two months.

The WF is located in Tulcea county, near Agighiol village. These Gamesa G90 turbines have a rated power of 2 MW[6].

Table 1

Production data

WT	Budgeted production [MWH]	Delivered energy [MWh]	Producible energy [MWh]	Availability [%]	Capacity factor [%]
T1	1017.41	797.66	1135.16	72.12	0.34
T2	1017.41	842.22	1309.54	72.32	0.37
T3	1017.41	957.61	955.04	73.99	0.40
T4	1017.41	504.56	1128.91	67.56	0.26
T5	1017.41	683.93	1237.30	67.45	0.33

Table 2

Lost hours by category

WT	T_{UEE}	T_{UEI}	T_{UIP}	T_{UIU}	T_{UII}	$T-T_{UT}$
T1	354.42	0	30.46	16.11	0	1039.01
T2	276.7	0	28.6	91.76	0	1042.94
T3	278.66	0	26.74	63.01	0	1071.59
T4	360.01	0	9.66	95.02	0	975.31
T5	380.38	0	1.73	86.98	0	973.96

Table 3

Lost energy by category [MWh]

WT	E_{UEE}	E_{UEI}	E_{UIP}	E_{UIU}	E_{UII}	$E_{lack\ of\ wind}$
T1	406.47	0	16.69	8.51	0	-211.92
T2	371.54	0	9.24	81.85	0	-287.44
T3	253.20	0	26.17	69.27	0	-288.84
T4	405.26	0	13.75	69.83	0	24.01
T5	452.12	0	0.75	85.30	0	-204.68

From the data presented in table 1 it can be observed that the delivered energy is less than the budgeted production. This conlcusion could be taken even from the capacity factor or the availability column. The reasons for this low production are shown in the second table: many eternal-external events such as: ice on blades or low temperature on environment. Also, in the case of T1, T2, T3 and T5 there were no losses due to lack of resources. During the study period there was also a scheduled maintenance.

Another important guideline in determining the good operation of he WTG's is the comparision of the theoretical power curve provided by the manufacturer [6] against the actual produced power curve.

The actual produced power curve is based on recorded data provided by SCADA: ten minutes records comprised of the wind speed (m/s) and the produced power (MW).

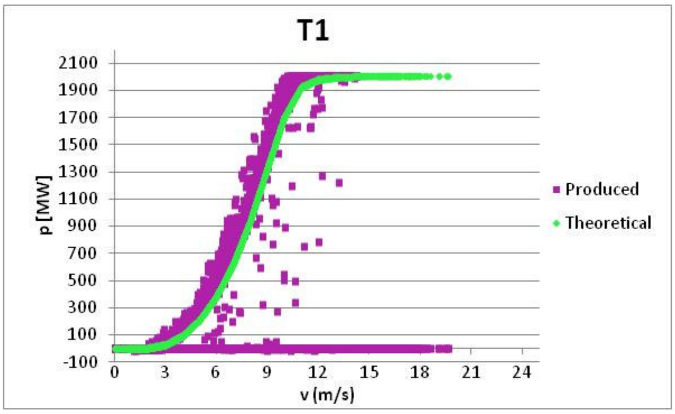

Fig. 1.a

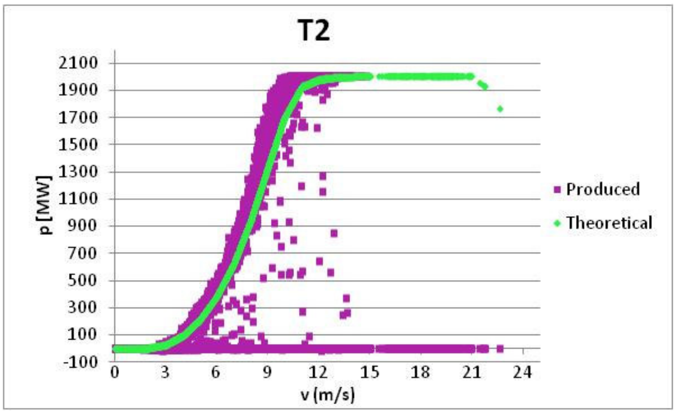

Fig. 1.b

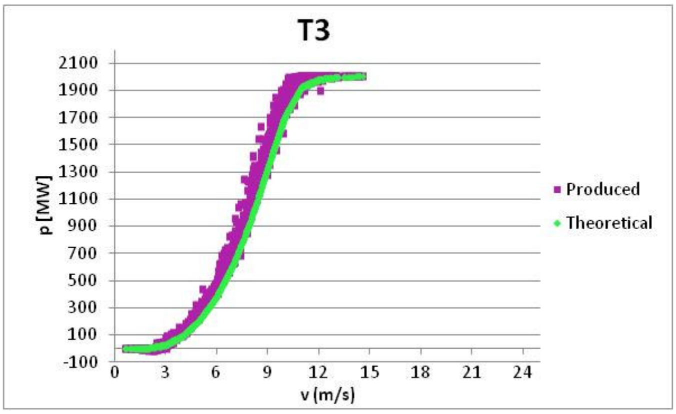

Fig. 1.c

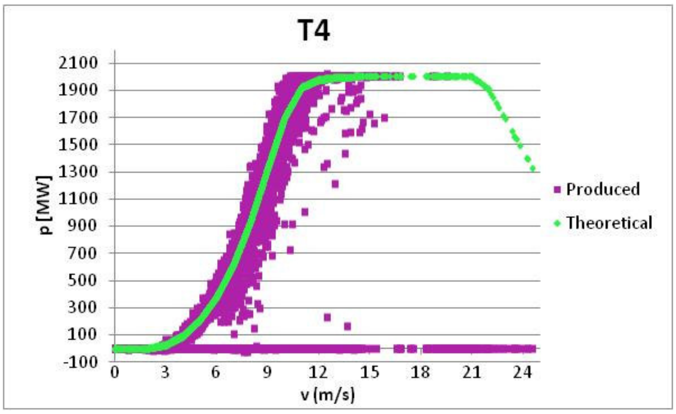

Fig. 1.d

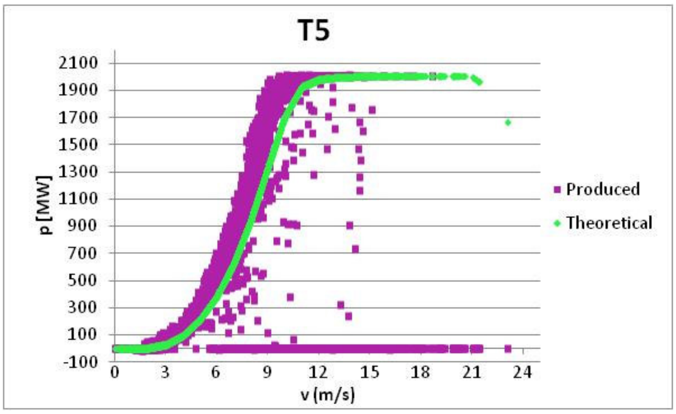

Fig. 1.e
Fig. 1. Theoretical versus actual power curve

Analyzing these graphs, T3 has the best actual power curve in comparision with the theoretical curve.

In correlation with the unavailability time (Table 2), the hours when the turbines were out of operation are represented by the points situated on the bottom of the graph, where P=0 and v>3m/s. In this case the turbines were in: Pause, Stop or Emergency mode. If the turbines are in Communication Faultb mode no data is recorded (it is the case of T3 turbine), and there are no points in the bottom. If the turbines recovered from a fault or the power was limited due to an alarm the representation is the independent points. Also, there is a tight connection between the delivered energy and the produced power curve. The turbines that have the actual produced curve more close to the theoretical one have also the biggest delivered energy, for example: T3, T2 and T1. Looking at T4 graph, you can notice that there are a lot of points that are distant from the theoretical curve, thus the low production.

The most relevant information regarding the ways to optimize the energy production and to reduce the unavailability time is the analysis of the most frequent alarms encountered in the operation of the WTG in order to act on parts most frequently damaged.

Table 4

Most frequent five alarms for the entire WF

Number	Alarm	Occurrences	Duration [h]	Energy losses [MWh]
1	DTD (Drive Train Damping) filters 1 alarm	254	789.39	642.098
2	TOP-HUB communication error	162	584.14	340.496
3	Slip Out of Range	128	423.14	303.48
4	Possibly ice on blades	114	2470.98	1389.05
5	Zero degrees HUB	59	1900.28	2580.037

Analyzing the data from Table 4 a few conclusion can be taken:

- The O&M department has to investigate the cause of these alarms;
- Some control parameters have to be changed;
- Depending on the weather situation when these alarm appeared, some correlation could be made;
- In correlation with Tables 2 and 3, the biggest loss of energy and the biggest downtime is from external-external events, such as: ice on blades and low temperature. Thus, the failures triggered by the last two alarms determined the biggest missed energy. Even though the DTD filters 1 alarm occurred more often, the energy losses were not the biggest because the unavailable time for each interruption was low. The first three alarms are in the category internal unplanned, and looking at Table 3 this is the second big missed energy.

The goal of the O&M department is to minimize the energy losses, but in order to accomplish this focus has to be on reducing the occurrences and the duration of the failures. To reduce the occurrences the cause of the fault has to be eliminated and to reduce the duration the field technicians have to be informed at each moment of the situation in order to reach the WTG's in time and to restart them as quick as possible.

4. CONCLUSIONS

✓ For the O&M department it is of utmost importance to reach the targeted energy production imposed at the beginning of the year. This is a big challenge due to the fact that the WT are very much exposed to highly variable, harsh weather conditions and external variations such as constantly changing loads. Evaluating the two months data, the budgeted production was not reached, but this was due mainly to the external-external events. If the weather conditions were better, considerring the high wind speed, the delivered energy would have been greater than the budgeted production.

✓ The maintenance activity is essential and it can significantly enhance the power output of the WF.
The sheduled maintenance has to be followed according to the turbine manufacturer's manual, supplemented by additional time-based items prescribed as a result of the real-world experience of the maintenance contractor.

✓ The quantification measure of the O&M department efficiency is represented by the Key Performance Indicators: unavailability time and missed energy. Thus, these two indictaors have to be as low as possible. For the months in study these indicators were above average.

✓ By making monthly reports and focusing on: the most frequent alarms that lead to the failure of the WT, comparision between the theoretical and the actual power curve, quantifying the energy losses, new solutions can be obtained to optimize the energy production. The power curve graph (theoretical vs. actual) is the quickest indicator of the good operation of the WT. Also, by acting on the causes of the most frequent alarms (e.g.: DTD filters 1 alarm), in the next months the downtime and the losses due to these failures will decrese considerable

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