Wind Power Plant Condition Monitoring

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Abstract: - Wind Power Plants (*WPP*) is the fastest growing energy sector. *WPP* consisting from a single turbine to as many as several hundred turbines. The acceptance of wind-generated power by the financial and developer communities from *Romania* as a viable enterprise is influenced by the risk associated with the capital equipment reliability. Increased risk or at least the perception of increased risk is generally accompanied by increased financial fees or interest rates. Wind turbine system reliability is considered to be an important component in any wind energy project. All above has developed the interest and need for maintenance services for wind turbines (*WT*). The aim of this paper is to identify the matters from maintenance in *WPP* areas and to do a literature review of the major aspects in a wind turbine that should be monitored.

Key-Words: - Wind Power Plants, Predictive Maintenance, Condition Monitoring.

1 Introduction

UE is the World-Class leader in wind-powered energy, owning more than 60% of the world's market. A study of *Erste Bank* consider *Romania* and expecially the *Dobrogea Region* with *Constanța* and *Tulcea* counties as the second best place in Europe to build *WPP* due to its large wind potential. *Romania* has the highest wind potential in *South Eastern Europe* of *12000 MW*. In the first half of *2008* more than *2000 MW* got a connection requests. The necessity to increase the use of the renewable energy sources in the energy balance of *Romania* will most probably lead to such legislative changes which would make.

2 Theoretical Apects of *WPP*

A wind turbine (*WT*) is a rotating machine which converts the kinetic energy from wind (P_{wind}) into mechanical energy (P_{mec}). If the mechanical energy is then converted to electricity (P_{el}), the machine is called wind power converter, figure *1*.
The kinetic energy stored is proportional to the rotational inertia and the square of rotor speed. Thus, increasing the speed to twice the original value means that the kinetic energy increment is four times higher.

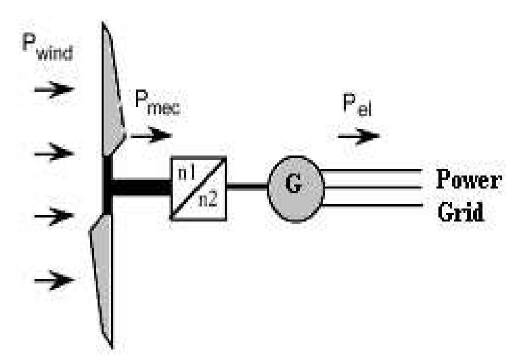

Fig.1. Wind Power Conversion

Mechanically, the turbine must be protected from rotational speeds above some value that could lead to catastrophic failure. An important issue for wind turbines is the efficiency. In fairly steady conditions, the power extracted from the air stream by the turbine blades can be characterized by the *Betz's formula*: $P_{el} = c_p \cdot \eta \cdot P_{wind}$ [*WA*] where: η is the installation yield; *Cp* itself is not a constant for a given airfoil, but rather is dependent on a parameter, called the tip-speed ratio, which is the ratio of the speed of the type of the blade to the speed of the moving air stream [1].

3 Technological Aspects of *WPP*

WT are subject to unpredictable conditions such as wind speed, wind direction and temperature. All these have impact in constantly changing loads and rotational speeds. Larger turbines are grouped together into wind power plant (*WPP*), which provides bulk power to the electrical grid. Wind energy technology has become not only a mature renewable energy technology, but also a mature electricity generating technology. Utility-scale turbines range in size from hundreds kilowatts to as large as several megawatts. A lot of different concepts have been developed and tested [2]-[5]. These developments have led to conceive many wind energy conversion systems schemes based on many criteria such: project size, *WT* models and age of turbines, fixed speed or variable speed wind turbine, environmental conditions and implementation site (onshore or offshore), the rate of produced power (small or large wind turbine), islanded or grid connected *WT*.

3.1 Major Components of *WT*

Modern *WT* falls into two basic groups: the horizontal-axis variety, and the vertical-axis design. The structure consists of the tower, the nacelle and the rotor that it carries, figure *2*.

*The tower***.** Generally, it is better to have a high tower, as wind speed increase further away from the ground. Because wind speed increases with height, taller towers enable *WT* to capture more energy and generate more electricity. Towers are made from tubular steel or steel lattice.

Blades. A typical *WT* has a *3* blade turbine more than *60* meters in diameter, turning around *10* and *20* rotations per minute (*rpm).*The blades are generally made from glass fiber reinforced plastic. The reinforcement can also be carbon fiber or laminated wood. Some blades have advanced techniques for lightning protection built into the blade.

*Hub***.** The hub is the centered construction, which connects the blades to the main shaft. The hub is usually made out of cast iron. Inside the hub is electrical and mechanical equipment for controlling the blades. The blades and the hub together are called the *rotor.*

Pitch system. Closely interconnected to the rotor blades is the pitch system. The objective of the pitch system is to regulate output power at high operational wind speeds.

The nacelle is the housing for the drive train, gearbox, and the electric generator at the top of the tower.

Drive train The drive train basically consists of the shaft and the bearings and occasionally a clutch between the gearbox and the generator. The shaft goes into the nacelle from the hub, where the blades are connected, and connects to the gearbox. The shaft rotates with low speed and needs to be geared up, which is done in the gearbox. On the other side of the gearbox the high-speed shaft exits into the generator. The bearing that is mentioned as a part of the drive train is present if the *WT* is constructed with a *main bearing*. Another way of designing the *WT* is by implementing the main bearing directly into the gearbox

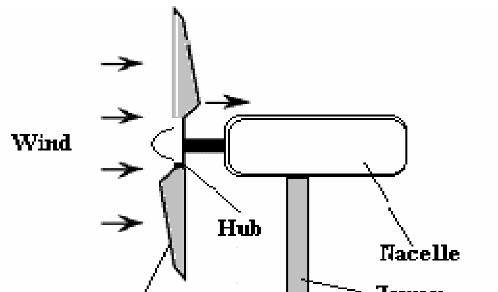

Fig.2. Main parts to *WT*

Gearbox. Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about *30* to 60 *rpm* to about 1000 to 1800 *rpm*, the rotational speed required by most generators to produce electricity. The gearbox is a costly (and heavy) part of the wind turbine. The design of the gearbox is subject to many changes. At the moment a common solution is to use a planetary stage gear which has a feature of being very compact. Via a high-speed shaft the gearbox is then connected to an electric generator.
Generator. The generator transforms the rotational energy into electrical energy. It is connected to the electrical system and supplies the transformed energy to the electrical system. The type of generator used in the *WT* varies, but usually it is an induction generator or a double fed induction generator.
Electrical system This is basically all equipment required to deliver and control the electrical energy that follows from the generator to the grid. Modern designs let the power output from the generator pass through a set of power electronic components to control the power and the frequency before supplying it to the power grid.

3.2 Control System to *WT*

Controlling the power (and hence, torque) extracted from the moving air stream is the primary means for protecting the turbine from over-speed under all but emergency shutdown conditions. The control system is made out of a main computer inside the nacelle or in the tower structure. The function of the control system is only to supervise the system so that performance at the moment is optimized, the safety of the system is maintained and alarms are reported in case some sensor signal is above a set parameter limit value, figure *3*.
*Sensors***.** In a typical turbine there are about *30* to *50* monitoring sensors; more modern *WT* have more sensors, about *2000*. These sensors include wind measurement equipment as well as sensors for temperature, wind direction, vibrations, revolutions, cable twist etc. The sensors are connected to the control system.
*Brakes***.** Mechanical brakes are essential for safety reasons during high winds and repair. Mechanical brakes are provided for stopping the turbine in emergency conditions, but are not used in normal operations. The mechanical brake system consists of a disc break in conjunction with the gearbox. Aerodynamic brakes are essential when the blades are pitched into a position where as less wind force as possible is absorbed.

Pitching, braking and yawing are features within the turbine that commonly rely on *hydraulic systems*.
Yaw system (yaw drive, yaw motor). Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. The yaw system contains bearings, gearwheels, brakes and a yaw motor.

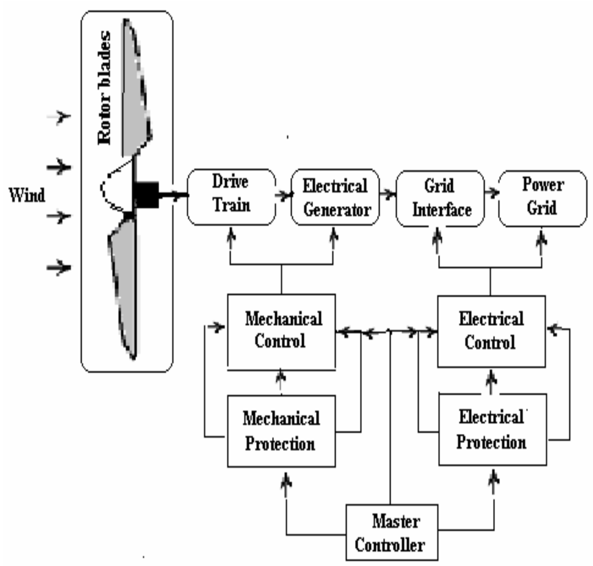

Fig.3. *WPP* model with control elements

4 Critical Components and Failure

WPP plants, both the new and used ones, consist of many components that can fail due to a variety of reasons [6]-[8]. Reliability is the most critical factor in sustaining the efficiency of *WPP*.
For study, the first step is to define *WPP* as system, with the end-point at its based substation. The following main level is the *WT*, the subsequent level corresponds to the main components of *WT* such as tower, foundation, rotor, nacelle and control system. Each of these components or subsystems has other components. The second step is to identify failure (table 1)and to evaluate failure rates per component, with the aim of finding causes and consequences.
It is a relationship between wind turbine topologies, failure mode analysis such as failure rates, causes and consequences of failures, downtimes, etc. The subassemblies with the highest failure frequencies are, in descending order of significance, are: electrical system, rotor (blades and hub), converter (i.e. electrical control, electronics, inverter), electrical generator, hydraulics and gearbox.
The main components (i.e. gearbox, generators and wind blades) constitute almost *90%* of all maintenance and operational costs.

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Larger wind turbines have a lower reliability than smaller ones. To understand failures it is important to understand how the system works, and what the main interactions between domains are, for instance mechanical and electrical. The failure of a system provides information about the operation and interaction among parts that is usually not intended by the designer.

Table 1. Failure in *WT*

WT Subsystem		**Failure**
The tower Foundation		Tower oscillations Resonances; Fatigue; Clearance; Cracks;
Rotor	Blades Hub Pitch System	Surface roughness; Iicing; Imbalance; Fatigue; Iimpending cracks; Faults in pitch adjustment; Rotor asymmetries; Degradation of rotor aerodynamics.
Nacelle	**Drive train** Bearing, Shafts	Wear, pitting; Deformation of outer face and rolling elements of bearing; Broken bearing; Fatigue; Impending cracks of shafts;
	Gearbox	Tooth wear or breaking; Eccentricity of gear wheels; Cracked gear tooth;
	The electric generator	Stator insulation failure; Cracks in rotor bars; Overheating;
	Electrical system Transformer, Switchgear, Cables, Power electric converter	Broken wires; Breakdown of the insulation of an electrical wire or other electrical component;
Control System	**Yaw System** Yaw drive Yaw motor	Yaw angle offset.

5 Maintenance and Condition Monitoring Technology of *WPP*

The service and maintenance of *WPP* in the megawatt range will increase because of the damage cases that have already occurred.

The market for maintenance services has been dominated by the original equipment manufacturers. Recommenddations and strategic insights to meet the challenges and opportunities of this market will prove to be invaluable for all market players in the wind energy market. Predictive maintenance (*PdM*) is generally defined as a type of maintenance that emphasizes early prediction of failure using non-destructive techniques. A good *PdM* program can identify needed repairs before they become more costly or lead to a catastrophic failure [9]. Gates pointed out that *PdM* can also save on the cost of non required maintenance. The defaults can be detected early and consequences be restricted [10]-[16].

Vibration Monitoring. It is applicable for monitoring the wheels and bearings of the gearbox, bearings of the generator and the main bearing. To distinguish failures from sudden peak loads caused by strong wind, the vibration monitoring system should only store comparable data taken under comparable weather and load conditions. There are two primary groups of vibration frequencies in a wind turbine: gear mesh frequencies and bearing defect frequencies. It is possible to monitor vibrations on the turbine structure at the base and on the nacelle. This provides information concerning structural bending and the aerodynamic effect of the wind.

*Vibration Instrumentation***.** *WT* are instrumented with one or more externally mounted accelerometers or velocity transducers which provides a once-per-turn speed reference. Direct vibration is usually monitored, and frequency analysis can be added, figure *4*. The type of sensors used depend on the frequency range, relevant for the monitoring: position transducers for the low frequency range; velocity sensors in the middle frequency area; accelero-meters in the high frequency range; Spectral Emitted Energy sensors for very high frequencies (acoustic vibrations).

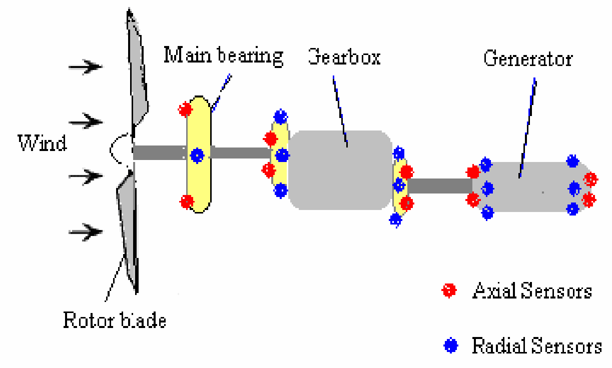

Fig.4. Vibration sensors

The vibration sensors are rigid mounted to the component of interest and return an analog signal proportional to the instantaneous local motion. An acquisition device that has a high sampling rate, high dynamic range, and antialiasing is ideal for this type of measurement.

Lube Oil Quality Monitoring. Oil is a key component in wind systems because improper lubrication can reduce efficiency and cause mechanical failures. Most bearing and gear wear results from incorrect oil lubrication and can lead to more serious costly damage in the turbine drive train. Water contamination of industrial oils plays a major role in this contamination. High moisture levels can cause components to overheat, corrode, or fatally malfunction. This monitoring consists of oil particle counting and moistness measurements. Oil analysis may have two purposes: safeguarding the oil quality (contamination by parts, moist) and safeguarding the components involved (characterization of parts).

*Instrumentation***.** Oil analysis is mostly executed off line, by taking samples. However for safeguarding the oil quality, application of on-line sensors is increasing. Sensors are nowadays available, at an acceptable price level for part counting and moist. Besides this, safeguarding the state of the oil filter (pressure loss over the filter) is mostly applied nowadays for hydraulic as well as for lubrication oil. Characterization of parts is often only performed in case of abnormalities. In case of excessive filter pollution, oil contamination or change in component character-ristic, characterization of parts can give an indication of components with excessive wear.

Strain Monitoring. It is a common technique for determining structural health, is becoming increasingly more important in the wind turbine industry. Strain measurement can be very useful for life time prediction and safeguarding of the stress level, especially for the blades.

Instrumentation. These stress measurements are made with sensors called metal foil strain gages. An acquisition device that can provide voltage excitation and bridge completion for the strain gage is ideal for this measurement. The strain gages can be anywhere on the blade, but the distribution varies with the amount of sensors. Place the sensors in a configuration to optimally model the stress on the blade and take both the flapwise and edgewise directions into account.

By using new fiber-optic sensing technology, monitoring the stress on the blade while rotating is easier and more accurate. The fiber-optic sensors are embedded within the blade to simplify connections from the blade to the data logger and allow little to no degradation of the signal over a long distance.

Acoustic Monitoring. Wind turbine noise impact measurements are most commonly used to ensure that the wind system complies with standards. Acoustic monitoring has a strong relationship with vibration monitoring. While vibration sensors are rigid mounted on the component involved, and register the local motion, the acoustic sensors "listen" to the component.

Instrumentation. Acoustic monitoring uses microphones to measure the noise from the *WT* both internally and externally. An acquisition device that has antialiasing and both a high sampling rate and dynamic range is ideal for this type of measurement. The gearbox and the main bearing are important when monitoring internally, while the overall *WT* noise is monitored externally. From the noise readings, are determined the higher-frequency components to predict possible faults. The noise compliance of the *W*T can be validated by measuring signals like the sound power level and by sending the acoustic data through third-octave analysis.

Heading Monitoring. Internal and external ambient temperatures are common structural health measurements. Temperature measurements of individual components, such as the generator's rotor and stator, are important to diagnose and prevent issues in the *WT*.

Instrumentation. It is a variety of sensors, but the most commonly used sensors for temperature measurement are thermocouples or resistance temperature detectors. An acquisition device that has a narrow input range and cold-junction compensation is ideal for this measurement. Thermography is often applied for monitoring and failure identification of electronic and electric components. The technique is only applied for of line usage and interpretation of the results is always visual.

Electrical Effects Monitoring. Monitoring electrical machines is used to detect unusual phenomena. For accumulators the impedance can be measured to establish the condition and capacity.

Instrumentation. For medium and high voltage grids, a number of techniques are available: discharge measurements, velocity measurements for switches, contact force measurements for switches, oil analysis for transformers. Cabling isolation faults can be detected. These types of inspection measurements do not directly influence the operation of the *WT*.

Power Quality Monitoring. Power quality is a high-interest area for *WT* monitoring because quality can degrade as a result of wind speed, turbulence, and switching events. The following types of analysis most greatly influence power quality: peak power output, reactive power, voltage fluctuations and harmonics. Measurements can be made on the low-voltage side of the turbine's transformers to acquire the necessary data for the required analysis. Mainly, you need to make sure that the alternating voltage and current move in step.

Instrumentation. Transformers are often placed between the generator output and the data acquisition device to scale down the voltage to an acceptable level. Current clamps or current sensors that can convert high amperage into proportional low-voltage outputs are used to measure the output current. Acquisition devices with high voltage and current inputs as well as isolation are ideal for these measurements.

6 Conclusion

WPP have become a focal point in research of renewable energy resources from Romania.

Reliability of *WT* is critical to extract this maximum amount of energy from the wind. Knowledge of *WT* behaviour is crucial when determining a maintenance strategy or maintenance contracts. When the initial contract expires, operators often have insufficient data about the true state and behaviour of their installations to make informed decisions. This puts them at a disadvantage when negotiating new maintenance contracts and maintenance strategy. Operation and availability of *WPP* is to be optimized. *Condition Monitoring System* (i.e. *Vibration*, *Oil Quality*, *Strain*, *Acoustic*, *Heading*, *Electrical Effects* and *Power Quality Monitoring*) in *WPP* will increase the reliability and the cost efficiency of wind energy by: reduced degrees of damage, planned repair actions and condition dependend maintenance, extended maintenance intervals, increased overall lifetime and availability, reduced production losses due to downtime, improved fault diagnosis, advanced methods of remote control and diagnosis, indentification of constructional weak points, support for optimization of *WT* components.

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