Performance and Fault diagnosis of Horizontal Axis Wind Turbine Components

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Abstract— With recent surge in fossil fuel prices and demand for cleaner renewable energy sources, Wind Turbine has become an alternative approach for power generation technology. Therefore operation, maintenance and repair techniques will be developed for efficient wind power generation. Failure analysis can support operation, management of spare components and accessories in wind plants, maintenance and repair of wind turbine. In this paper author aiming at eye of wind plants i.e. structure, function and analysis of common faults to find out fault laws, fault causes and effect on their corresponding performance measures.

Key words: wind power generation, wind turbine, faults diagnosis, gear box, optimization, turbine performance

I. INTRODUCTION

The energy and environmental situations of India, China and Arab countries reflect many similarities and share serious common problems. In particular in the middle East countries these include almost total dependence on imported oil products as the primary energy source, rapidly growing population data escalating the for energy, and only rudimentary efforts currently underway to mitigate the greenhouse and other adverse environmental effects of energy utilization.

Wind power is renewable, pollution free, short construction period, flexible operation and easy maintenance. The advantage of wind power is generally recognized and therefore it is sustained high growth in recent year.

For INDIA wind speed value lies between 5 km/hr to 15-20 km/hr. These low and seasonal winds imply high cost of exploitation of wind energy. Calculations based on the performance of the typical windmill have indicated that a unit of energy derived from a windmill will be at least several times more expensive than energy derivable from electric distribution lines at the standard rates. [1]

Statistics show that time for fault diagnosis takes of 70% to 90% of the total time, while the repair time takes up only about 10% to 30%. [2] Fault diagnosis systems have been successfully applied in much kind of technical processes to improve operation reliability and safety systems.

II. PERFORMANCE EVOLUTION OF WIND TURBINE

The Betz's theory as reminded in [3], allows calculating the power that the wind transmit to a turbine rotor. Fig. 1a show a scheme of a flow tube and Fig. 1b shows a graph of the threshold for different wind turbine the fluid in the flow tube bumps on an obstacle constituted by a plane perpendicular axis of a rotor of a wind turbine and with section A(see Fig. 1a).the velocity of the fluid (v) near the plane of the rotor (section A)is lower respect to its velocity at the beginning of the flow tube (v_1 in section A_1);the behaviour of the pressure is the opposite .The fluid delivers energy when it passes through the section and pressure drops sharply, this is true considering the hypothesis of a plane of the rotor (with section A) with infinitesimal thickness .Thanks to Δp a power is transferred to the rotor. From the section A_1 to the section A_2, the pressure increase and, in proximity of the section A_2, it is equal to the atmospheric pressure.

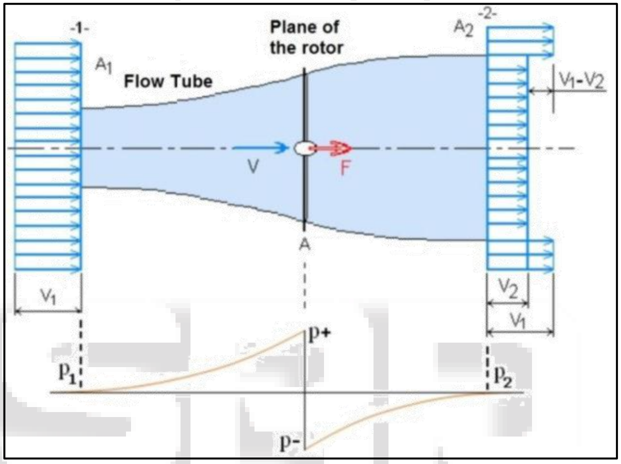

Fig. 1(a): Pressure profile along the flow tube

The hypotheses of the Betz's theory are the following:

- The fluid flow that through the section A not interacts with the other fluid flow in the tube;
- The velocity is uniform in every flow tube section, perpendicular to the axis of the tube; the velocity changes between A_1 and A_2 (v_1 and v_2 in the Fig. 1a).The rotor is schematised as a disc with infinitesimal thickness with section A and uniform structure;
- The fluid dynamic situation is not influenced by the turbine on the A_1 and A_2 sections; the pressure, on two sections, is equal to the atmospheric pressure $p_0 = p_1 = p_2$;
- The rotor plane is the unique obstacle during the flow wind motion from section A_1 to section A_2;
- The wind is stationary and constant varying the altitudes;
- The wind flow motion is straight;
- The compressibility of the fluid is neglected; the fluid density ρ is constant.

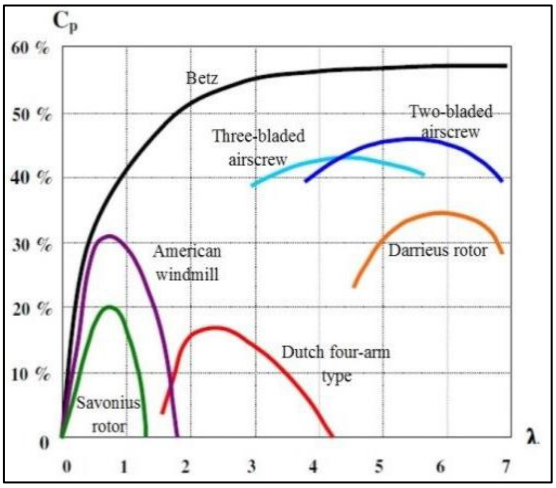

Fig. 1(b): Coefficint of Power

The relationship between the extracted power and the power possessed by the flow pipe on a section eual to A, in the absence of the rotor, defines the coefficint of the performance (or Power):

$$Cp = \frac{\rho A v_1^3 2a(1-a^2)}{\frac{1}{2}\rho A v_1^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: v = fluid velocity on the plain of the rotor with section equal to A; p = p+ (p- Δp = p- , see Fig. 1a) is the pressure on the plane of the rotor; v_1 and v_2 = wind speeds on sections A_1 and A_2 respectively; p_0 = atmospheric pressure; ρ = Fluid density; a = Interference factor.

The coefficient of the performance (C_p) and the interference factor (a) depends on the turbine construction mode and on the wind speed. The Betz's Theory neglects all phenomena of friction and turbulence induced by the rotation of the rotor. In the real situation, the value of the coefficient of performance (C_p) is smaller than ideal one.

In following formulas used to generate simulation graphs are shown:

$$Cp = \frac{2P}{\rho A v^3} \quad ; \qquad Ct = \frac{4M}{\rho D A v^2}; \qquad P = M\omega;$$

$$U = R\omega \; ; \qquad \lambda = \frac{U}{v}$$

III. TYPICAL FAULTS IN WIND TURBINE

With the continuous improvement and updating in technology of Wind Power development. According to the way of Power adjustment, the Horizontal Axis Wind turbine unit consists of Rotor, Pitch system, Gear box, Cabin, Breaking system, yaw system, Aerodynamic shaped blade, Generator, Electrical inverter system, Main control system, Sensors, Hydraulic system, Tower and Foundations with subsystems .

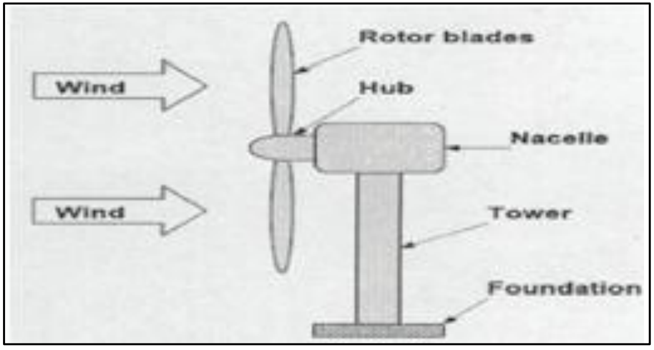

Fig. 2(a):

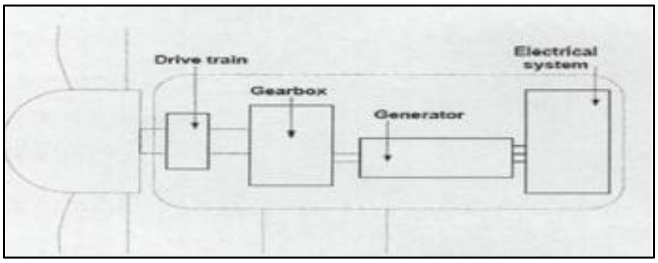

Fig. 2(b)

Fig. 2(a) & 2(b) : structure of wind turbine;Certesy of Google.

A. *Wind rotor*

As the long term work in the wind, rain, snow and other harsh environments, the units may easily lead to the rotor imbalance, blades and hub corrosion, damage and faults. In contrast, the fault rate of the blades and hub is relatively small. The choice of rotor is based mainly on the pump's load characteristics [4].

B. *Pitch system*

Pitch system regulate the power by changing the blade angle. The pitch system can be divided into hydraulic pitch and electrical pitch by the deriving force. Electrical pitch is more flexible and can be easily controlled, so it has a wider use. It changes the blade angle by fixing slewing bearing for pitch drive motor between the blade and hub, which can change the blade lift to control the torque and power of the blade.

Pitch system mainly has four tasks:

- Avoid the sympathetic vibration speed to minimize the impact of static and dynamic load by reasonably changing the blade angle when the turbine starts or stop.
- By adjusting the blade angle control the fan speed in the vicinity of the rated speed.
- When the safety chain is open, the rotor blade back is used as aerodynamic brakes to make the blade back to the parking position.
- Attenuate the rotor vibration to minimize the mechanical load of the fan.

C. *Yaw system*

The wind direction is changing with time, and wind generators must be windward to use the wind energy by maximum efficiency. Therefore, the cabin must also change to follow the changing wind direction to insure that it is windward, and this is realised by the yaw system. Yaw system is a indispensable part of the horizontal axis wind turbine, which plays a very important role in the use of wind.

Yaw system is generally divided into active and passive yaw system, and passive yaw system is relying on the wind to complete action the wind rotor through the relevant agencies; Active yaw refers to the use of electric or hydraulic drag to complete the action of wind, which has two forms: gear driving and sliding. For large grid wind turbine, it usually uses the gear driving of the passive yaw system.

Yaw system's common faults are not accurate positioning, yaw gear tooth wear, abnormal noise, yaw limit switch fault and lubricant leakage, etc.

D. Gear Box

Gear box is one of the key components in wind turbine and the fault of gear box is lead to wind turbine shut down inevitably. So what must be done is making timely and accurate diagnosis to gear box. A web oriented expert system is developed by C# on the .NET platforms which will save the faults diagnosis time significantly [5]. Gear Box fault will be directly affects the safety and the operation of the overall wind turbine, are summarised in Fig. 3[5].

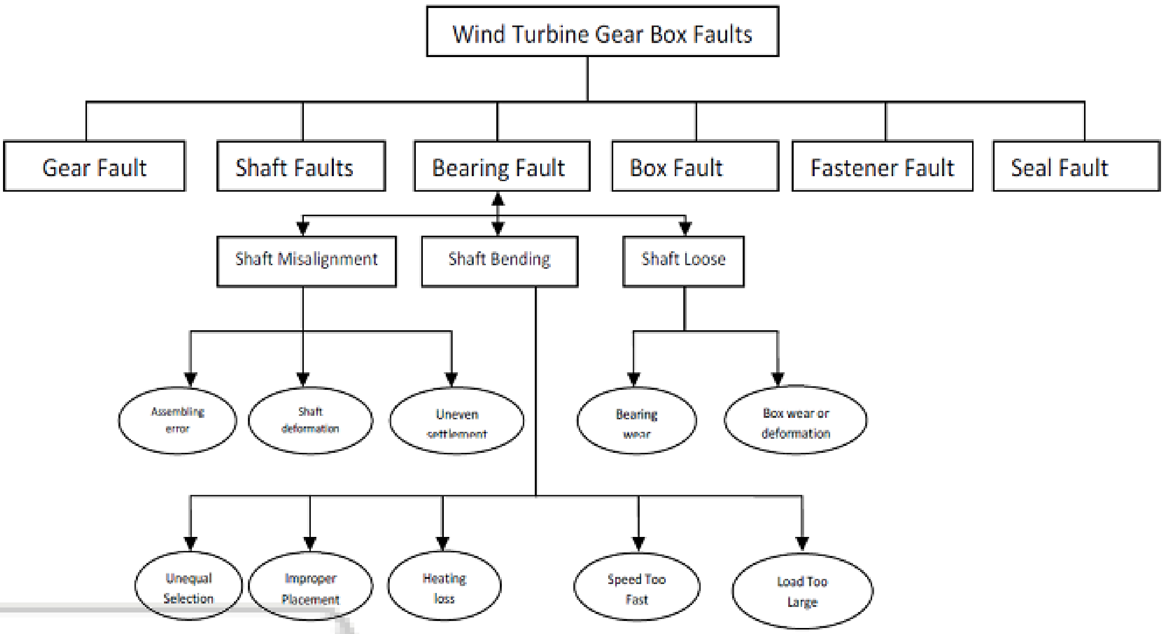

Fig. 3: Wind Turbine Gear Box Fault tree Diagram

E. Generator

Generator transforms mechanical energy into electricity. Generator's types are various, such as cage induction generator, brush ess doubly-fed generator, AC excited generator, synchronous generator. Wind power technology has been developed from fixed pitch wind turbine to variable pitch wind turbine, from constant rate control to variable speed and constant frequency control.

VSCF generating system also has three types including Double-fed asynchronous motor VSCF generating system, synchronous motor VSCF generating system and permanent magnet synchronous motor VSCF generating system. Most manufacturers at home and abroad use Double-Fed asynchronous motor.

Generator's long term operation in the electromagnetic environment may cause some common faults as follows: Generator excessive vibration, too much noise generator overheating, Bearing overheating, abnormal noises and insulation damage, etc.

F. Tower

The tower and foundation play a supporting role, and it is not only the supporting structural parts of the cabin, but also the installation and maintenance personnel channel for up and down the cabin. Generally the tower should have a certain height to obtain more wind energy.

Tower tube and engine room have a small probability of failure, where equipped with vibration sensors, and occasionally because of weather or other failure may cause excessive vibration, which need to stop the unit. But with the increase of unit age, there will be ice, dirt, corrosion, damage and other failure, so there are also needs for regular maintenance.

G. Failure and Downtime frequency

The most troublesome component is the gearbox, closely followed by the control system, and the electric system. This means that the gearbox has the longest downtime compared to the other components.

Table 1 annual failure frequencies and turbine downtimes. These calculations take into account that some turbines use neither hydraulics nor gearboxes. A suitable mearement of the failure's severity considers component failure frequency and average downtime per failure. If, for example, a component fails often but has a very short downtime, this does not noticeably disturb the production compared to a seldom occurring failure that has a long downtime. The most critical components are the drive train, the gearbox, and the yaw system, which take 250-290 h to repair [6].

DOWNTIMES AND FAILURE FREQUENCIES FOR COMPONENTS IN SWEDISH WIND POWER PLANTS 2000–2004

Component	Entire unit	Structure	Yaw system	Hydraulics	Mechanical brakes	Gears	Sensors	Drive train	Control system	Electric system	Generator	Blades/Pitch	Hub	Total
Total downtime per component, 2000-2004 (hours)	2631	1874	20754	6918	1881	30286	8357	3788	28620	22395	13906	14743	50	156202
Average downtime per year (hours/year)	526	375	4151	1384	376	6057	1671	758	5724	4479	2781	2949	10	31240
Average downtime per year per turbine (hours)	0,8	0,6	6,6	2,6	0,6	11,6	2,7	1,2	9,2	7,2	4,5	4,7	0,0	52,4
Distribution of downtime, 2000-2004 (%) (see Fig. 2)	1,7	1,2	13,3	4,4	1,2	19,4	5,4	2,4	18,3	14,3	8,9	9,4	0,0	100,0
Total number of failures per component, 2000-2004	33	18	80	160	15	118	169	13	155	210	66	161	4	1202
Average number of failures per year	6,6	3,6	16,0	32,0	3,0	23,6	33,8	2,6	31,0	42,0	13,2	32,2	0,8	240,4
Average number of failures per year per turbine	0,011	0,006	0,026	0,061	0,005	0,045	0,054	0,004	0,050	0,067	0,021	0,052	0,001	0,402
Distribution of failures, 2000 -2004 (%) (see Fig. 1)	2,7	1,5	6,7	13,3	1,2	9,8	14,1	1,1	12,9	17,5	5,5	13,4	0,3	100,0
Average downtime per failure, 2000-2004 (hours)	79,7	104,1	259,4	43,2	125,4	256,7	49,4	291,4	184,6	106,6	210,7	91,6	12,5	130,0

Table 1: Failure and Downtime Frequency

H. Fault on Blades

There are many ways for ANSYS model analysis, of which the Block Lanczos method is most widely used because of its powerful features. Moreover, it is frequently applied with model of solid units or shell units that is why this paper chose Block Lanczos to perform the model analysis. The vibration modes of the first six orders were extracted with frequency range of 0-9999Hz. The connections of the blades and hub could be regarded as fixed, so it is only need to restrict all DOFs of the root, for model analysis does not require applying loads. At last, after solving with the solver, the vibration modes of all the orders (Fig. 4) and the results of frequencies (Table 2) could be observed in the post-processor [7].

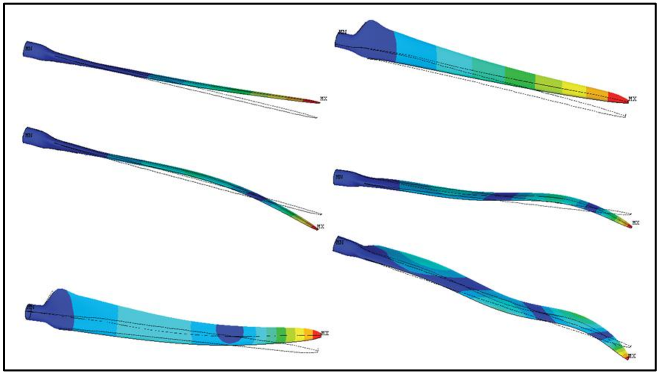

Fig. 4: the first six vibration modes of the blade

Mode orders	**1**	**2**	**3**	**4**	**5**	**6**
Frequencies	5.6309	13.696	19.417	41.257	58.805	68.704

Table 2 frequencies of the first six orders

In the deigned condition with the wind speed V=10m/s, the blade tip speed $V_{tip} = \lambda_0 \cdot V = 7.5 \times 10 = 75$ m/s . The excited frequency of the rotating rotor with three blades shall be calculated as:

$$f = \frac{3\varpi}{2\pi} = \frac{3\times\frac{75}{5}}{2\pi} = 7.16\ Hz.$$

Compared with table 2, it is clearly to see that the first natural frequency is far away from exterior excited frequency. Therefore, no resonance will happen when blades run at rated wind speed.

IV. CONCLUSION

Distribution of downtime component possesses valuable information about faults and shows that most troublesome component is gearbox (About 50% downtime), closely followed by the control system and electric system. So improvement of performance with efficient Horizontal Axis Wind turbine, we have to focus on major critical component faults. The major significance of failure analysis and fault diagnosis of wind turbine is the lower accident rate, reduced maintenance (costs and time) and improving the unit operation efficiency and reliability and providing guidance for designers.

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