Multistage Linkage Based Eclipse Gearbox for Wind Mill Applications - A Review

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Abstract — *A wind energy conversion system consists of a number of components to transform the wind energy to electrical energy. Such a system consists of rotor that extract energy from the wind, gearbox is used for transfer high torque generated by the rotor to low torque required for the generator, and a generator to convert the mechanical energy into electrical energy. Wind turbine gearbox reliability is a well documented industry-wide concern. The Eclipse Gearbox is a high-reliability; novel gear set that can significantly reduce reliability problems occurred in the traditional gearbox. In eclipse gearbox one gear rotates and provides a circular path for another gear. A rotational gear is attached on high torque shaft. Another gear is engaged with the rotating gear and translates on a circular path. The second gear is attached with linkages to a low torque shaft that resembles a crankshaft.*

Keywords — *Eclipse gearbox, Reliability of gearbox, Crankshaft, Traditional gearbox, Wind turbine*

I. Introduction

The fastest growing renewable energy source is wind power. Wind power is presently responsible for about 1.5% of the world's electricity use.

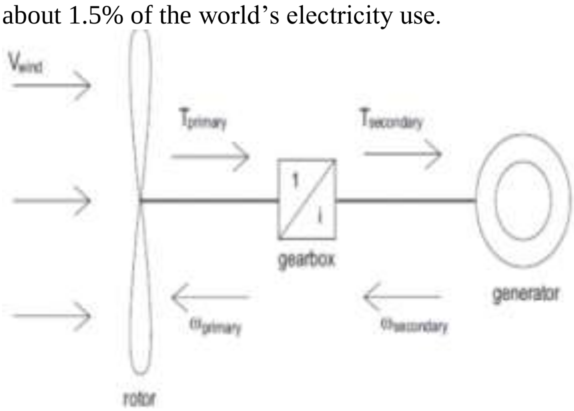

Fig 1: Wind Energy Conversion Systems

Because of high interest in wind energy, it becomes more important to increase the efficiency of wind energy conversion systems (WECS), also called wind turbines. The complete system required to convert the energy in the wind to electricity is called a wind energy conversion system (WECS).

Such a system consists of a rotor to capture the energy in the wind, a gearbox configuration to increase speed of the rotational speed of the shaft and a generator to convert the mechanical energy into electrical energy. The efficiency of the total system is not only determined by the efficiencies of the gearbox and generator, but also the energy that can be extracted from the wind. A wind energy conversion system consists of a number of components to transform the energy in the wind to electrical energy. One of the components is the rotor, which is the component that gives energy from the wind.

II. Literature Review

[1] Miltenovic, V., Velimirovic M., Banic, M [2] discussed regarding new concept of wind turbine power transmission, which instead of multiplicators with constant transmission ratio, uses variable transmission ratio (CVT) is increasing. In order to exceed multiplicators with constant transmission ratio disadvantages, new concept of wind turbine power transmission anticipates differential power transmission and power transmitters with variable transmission ratio (CVT) instead of multiplicators with constant transmission ratio. It is used for adjusting turbine impeller work with generator work. The capacity of power generation increase in wind turbines but generated many technical problems.

[2] M. J. Verdonschot[3] worked in Modeling and Control of wind turbines using a Continuously Variable Transmission. In that, Conventional variable speed wind turbines obtain their variable speed operation by a controlling the generator torque. This control uses the power electronics that connect the generator to the electrical grid. The range of variable speed in these systems is limited and the power electronics are one of the main sources of failure in wind turbines. Therefore, the possibility of using a continuously variable transmission for the control of a wind turbine is investigated.

[3] P. C. Sen [4] discussed regarding Power Electronics as a solution of reliability problem in that variable speed operation of the generator results in the production of current with a variable frequency. The frequency of the produced current is determined by the electrical angular speed of the generator. When the frequency of the generator varies too much, in the order of 2 Hz, circuit breakers cause the generator to disconnect from the system, preventing damage to the grid. Power electronics is a technology that is developing rapidly. Higher current and voltage ratings are available, efficiency increases and costs decrease. The biggest disadvantage of power electronics is reliability. Power electronics do not show signs of degrading, therefore failures cannot be predicted and these sudden failures are very expensive to repair.

[4] Terry Lester [5] discussed about Wind turbine gearbox reliability, premature gearbox failures present major issues in the wind energy industry. Gearbox unreliability and high repair costs combine to result in critical negative effects on the cost of wind energy production. Lost revenues result from long down-times when energy cannot be produced, the substantial expense of the large crane needed to lift a replacement gearbox into place and the cost of the gearbox itself. The gearbox is the critical component prone to failure in the load path between the turbine and the generator.

[5] Gold, A [6] discussed regarding CVT History, Categories, Efficiency, Positive Engagement CVT: Problem correction class, problem elimination class, tooth conforming family.

III. WIND TURBINES

A wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Wind turbines, like windmills, are usually mounted on a tower to capture the most energy.

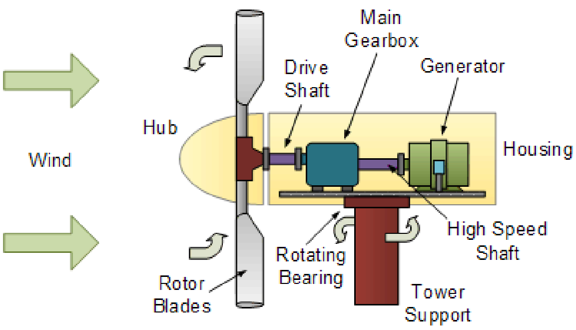

Fig 2: Wind Turbine [8]

Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Wind turbines are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more above ground, they can take advantage of faster and less turbulent wind. A blade acts much like an airplane wing. When the wind blows, a pocket of low-pressure air forms on the downwind side of the blade. The low-pressure air pocket then pulls the blade toward it, causing the rotor to turn. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. Wind turbines can be used to produce electricity for a single home or building, or they can be connected to an electricity grid for more widespread electricity distribution. [7]

IV. COMPONENTS OF A WIND TURBINE

- The nacelle contains the key components of the wind turbine, including the gearbox, and the electrical generator.
- The tower of the wind turbine carries the nacelle and the rotor. Generally, it is an advantage to have a high tower, since wind speeds increase farther away from the ground.
- The rotor blades capture wind energy and transfer its power to the rotor hub.
- The generator converts the mechanical energy of the rotating shaft to electrical energy
- The gearbox increases the rotational speed of the shaft for the generator. [9]

V. GEARBOX

Premature gearbox failures present major issues in the wind energy industry. Gearbox unreliability and high repair costs combine to result in critical negative effects on the cost of wind energy production. Lost revenues result from

- Long down-times when energy cannot be produced,
- The substantial expense of the large crane needed to lift a replacement gearbox into place and
- The cost of the gearbox itself

Fig 3: Wind Turbine Gearbox [11]

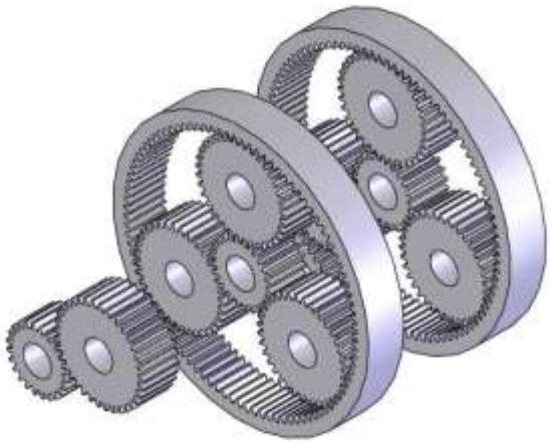

Fig 4: Traditional Wind Turbine Gearbox

Traditional wind turbine gearboxes utilize a two-stage planetary gear with a one-stage parallel shaft. The substantial ring gear forces are distributed to the sun gear through the planetary gears, where the ring gear and sun gear forces are equal in magnitude. The planet gear bearing forces are the sum of the ring gear and sun gear forces. The combination of large forces and limited bearing size create a critical failure point.

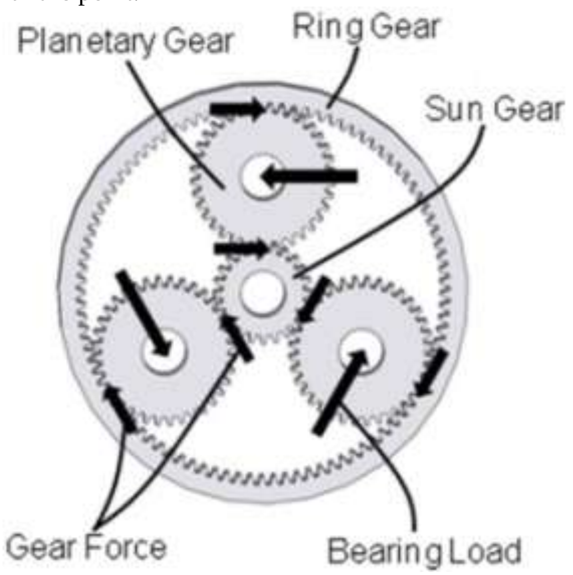

Fig 5: Planetary Gear Set Loads

Advanced lubrication systems and other planetary gear improvements have not resulted in increased service life. As such, the physical limits of planetary gear sets have been reached. Traditional designs have a finite space for the bearings required to carry the loads of the planetary gears. [10]

VI. Eclipse Gearbox

The gearbox is the critical component prone to failure in the load path between the turbine and the generator. Traditional wind turbine gearboxes commute an indirect path through a multi-stage planetary system. Introduced here is a gearbox that features a shortened load path through a single pair of gears combined with linkages and a crankshaft.

The Eclipse Gearbox overcomes the limitations of the planetary gear set and offers a practical high-reliability gearbox for 200 kW to 10 MW wind turbines. It is a single-stage gearbox that can distribute the loads through multiple linkages.

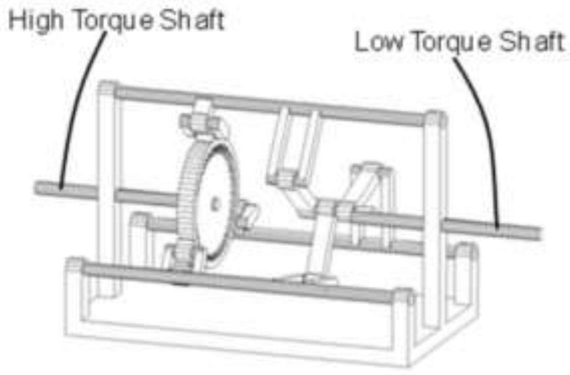

Fig 6: Eclipse Gearbox
(Simplified illustration)

A simplified version of the Eclipse Gearbox is illustrated in figure. One gear rotates and provides a circular path for another gear. The second gear oscillates on a circular path, gear is connected with linkages to the output crankshaft. The load path gets with the high torque shaft and ends with the low torque shaft. [10]

The crankshaft and a minimum of three linkages are required to control the translational motion of the translational gear. Additional linkages are used to distribute the translational gear reaction loads. The Eclipse accommodates speed ratios up to 150 to 1 in a single stage. This speed ratio is based on the practical limit to the gear tooth size.

Speed ratio = $-N_s / N_T - N_s$ to 1

Where NS is the number of teeth on the spur gear and NT is the number of teeth of the translating gear.

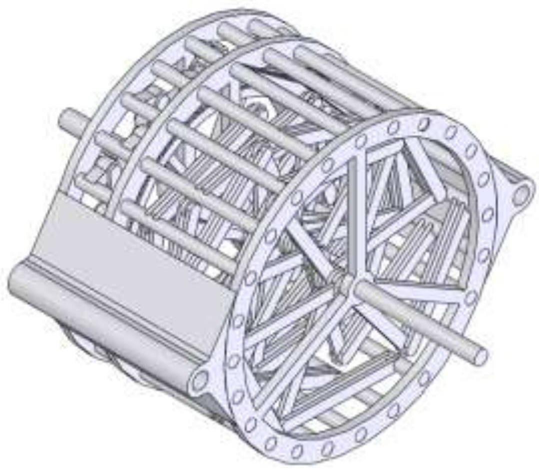

Fig 7: 1.6 MW Eclipse Gearbox

The endurance life and power rating of the Eclipse Drive Train are dependent on the number of linkages and the sizing of the bearings and gears. In comparing, for traditional gearboxes to be sized for successful operation in high power wind turbines, their cost, weight and size would be preventive. The link load cycle for a 1.6 MW gearbox is illustrated to show the distributed load through different linkages depicting an input torque of 600,000 lb-ft. The addition of the linkage loads are equal to 75 percent of the bearing forces in the planetary gears of a traditional planetary gear set.

The linkages are designed with respect to fabrication tolerances, joint free play and stiffness to maintain evenly distributed linkage loads throughout the Eclipse system, irrespective of the loads applied to the windmill blades. The linkages act in parallel to distribute the translational gear loads. The gear loads are distributed over multiple bearings. The bearings in the linkages revolve back and forth about 15 degrees. The high and low torque shafts rotate a complete 360 degrees. The gear tooth stresses are substantially reduced due to the loads being distributed over a greater number of teeth. The lower gear tooth stresses substantially increase the fatigue life of the gears. The mechanical design efficiency of the Eclipse Drive train results in significantly greater efficiency than traditional planetary gearboxes, due to the decreased number of energy dissipating components and to the fact that energy travels though only one set of gears and bearings.[12]

VII. Conclusions

The main objective of the eclipse gearbox is to significantly reduced reliability problems occurred in the traditional gearbox. The gear tooth stresses are substantially reduced due to the loads being distributed over a greater number of teeth. The lower gear tooth stresses substantially increase the fatigue life and torque capacity of the gears.

All these advantages combined with long endurance life, and operating efficiency dramatically solve the gearbox reliability problems.

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