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Review of Modeling and Simulation Technologies Application to Wind Turbines Drive Train

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Abstract: In this paper, a review of past and recent developments in the wind turbine drive train is being studied. The objective is to review some of the basic approaches of drive train configuration in wind turbines and to identify drive train models including the modeling and simulation results of these models. In recent years, considerable effort has been devoted to modeling, design, and control of wind turbine including drive train .The number of publications on computational strategies (multibody dynamics) are widely used for design and simulation of wind turbines components has been steadily increasing. Lists and reviews many contributes of design and simulation method are given in survey papers [1], [2].

Keywords: Wind energy, wind turbine, drive train, wind turbine gearbox, gear dynamics, multibody modeling, multibody dynamics, planetary stag and Gear contact.

1. INTRODUCTION

The call for improved renewable energy technologies are increasing due to the global warming .The wind has been harnessed as an energy source for over 1000 years. The overview goes back to the earliest publication on the predecessors of wind turbines, which are the windmills. These wind driven machines were mainly used for grinding grain and pumping water [3]. Their evolution led to the application of wind power for generating electricity near the end of the 19th.The majority of wind turbines currently in operation have the conventional Danish concept design that is, the three bladed rotor of such turbines is indirectly coupled with an electrical generator via a gearbox [4].

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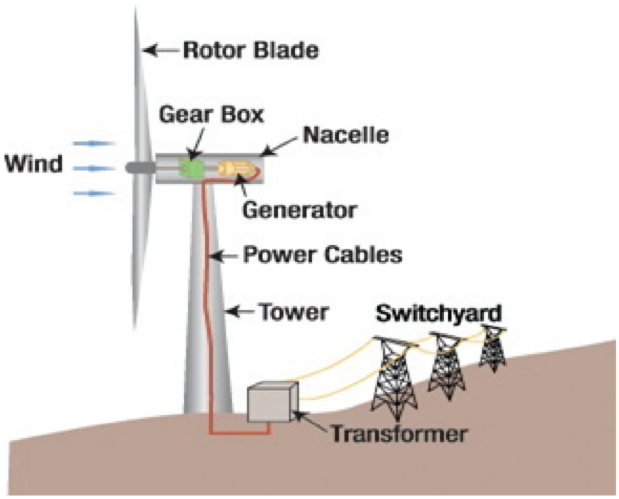

Figure 1: Horizontal wind turbines.

The development of a consistent modelling approach to correctly describe the dynamic behavior of a complex drive train in a wind turbine [5] in each type of wind turbines (vertical and horizontal), which has the same concepts put different in configurations with focus in horizontal type which widely use.

2. WIND TURBINE DRIVE TRAINS

The term "drive train" encompasses all rotating parts, from the rotor hub to the electrical generator [6].The rotor hub introduces the mechanical energy from the wind into the drive train as a load vector with six components. Only the torque component is needed in the generator to produce electricity. The other loads are transferred through the drive train towards the tower.

David and Graham [7] have presented an operational comparison of direct driven and gearbox-driven wind turbines. The results suggest that there may be a technical advantage when using direct drive machines over more established gearbox-driven designs.

2.1 Drive Train subsystem

The drive train comprises the main mechanical rotating parts of the wind turbine (the turbine rotor, the gearbox system, and the rotor of the electric generator) extracts the aerodynamic torque that the wind exerts on the blades and delivers to the generator. Many modern researchers have contributed analysis drive train [8], [9] compute the following subsystems rotor, gearbox and generator.

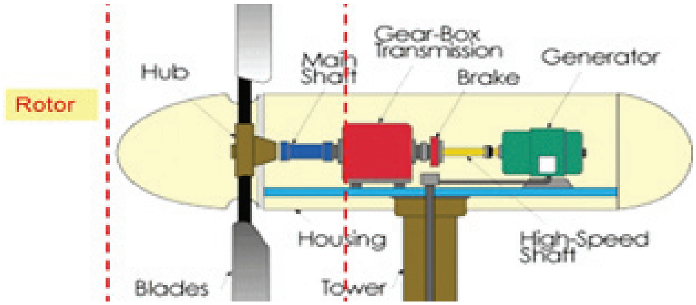

Figure 2: Wind Turbine Drive Train.

2.1.1 The rotor.

The rotor under typically consists of a hub and blades. In a wind turbine, more subsystems are included such as, the pitch system, but these are not model. Since the aerodynamics of the blade is responsible for its main function specifically energy conversion, it is also the driving aspect for the design.

2.1.2 The gearbox

In a typical modern wind turbine, the design ranges of the rotational speed of the rotor (several tens of rotations per minute) and the generator (more than thousand rotations per minute) don't overlap. The function of the gearbox is to overcome this speed difference, increasing rotational speed towards required rotational speed of the generator; this will be elaborated more in the following sections.

2.1.3 The generator

In a typical modern wind turbine, the generator is the element that convert mechanical power on to electrical power[10] .Some studies talk about the dynamic analysis of the drive train including generator and his relation with the accurate design result such that [11]. Various types of generators exist but they all have the general characteristic that the size of the generator is related to the torque to be developed.

2.2 Drive Train configurations

This section describes the basic configuration of the most common wind turbines drive train present in the industry today Drive train is composed of the following components: hub, main bearing, main shaft, gearbox, brake, and generator. These components form a functional unit and should, therefore,

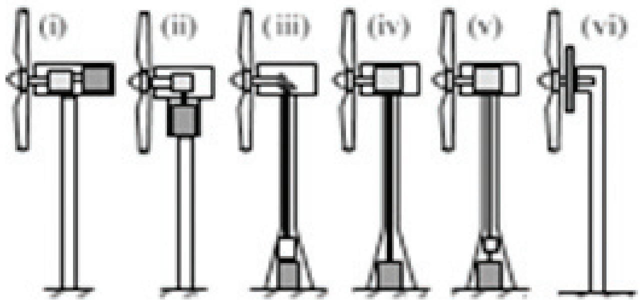

Figure 3: Drive Train Configurations.

always be considered together. There are several possibilities for the drive train configurations such as.

(i) Gearbox and generator in the nacelle –standard.
(ii) Generator vertical in the tower head
(iii) Gearbox in the tower foot.
(iv) Gearbox in the nacelle and generator in the tower foot.
(v) Generator in the tower foot and two separate gearboxes.
(vi) Generator directly driven by the rotor (without gearbox).

Currently, most operating turbines follow the modular configuration (i). All individual components of the drivetrain are mounted onto the bedplate, and. The bedplate is designed to be torsional-stiff. Nevertheless, there is debate surrounding the bedplate's actual behavior that suggests that it should not be as stiff as it should be, and that its flexibilities influence not only the interaction

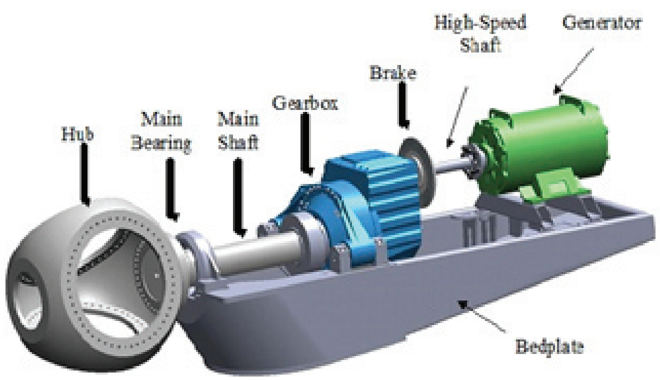

Figure 4: Modular Drivetrain Configuration.

between the different components of the drive train but also its vibrational behavior [12].

2.3 Drive Train models

Many efforts have been made regarding the modeling and simulation of wind turbines and their main components. The mechanical system of the wind turbines have been studied in several publications [13], [14]. Specifically the drive train and its performance has been evaluated during short circuits [15] and transient stability [16], [17]. However, the potential contribution of the drive train to the inertial response was not well covered. The drive train of wind turbine is composed of soft shafts, elastic couplings, and rigid elements with inertia such as generator. The model to describe the whole wind turbine drive train system is obtained by simply interconnecting the models of the individual subsystems previously described [6].

Drive train can be modeled using the so-called Multi-body System (MBS) approach. This lumped mass model provides a suitable representation for the low frequency torsional modes. The following four types of drive train models are usually available in the power system analysis [18].

2.3.1 One-mass model

In the one-mass or lumped model, all types of windmill drive train components are lumped together and work as a single rotating mass as shown in figure 5. The single rotating mass (which includes the blades, hub, gearbox and generator rotor) is modeled by multibody dynamic.

The full description of one mass model and its utilization can be found in [19], [20] including the equation that is based on the second law of Newton.

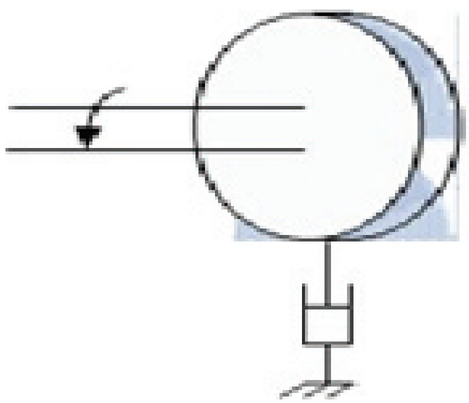

Figure 5: One mass drive train model.

2.3.2 Two-mass model

The two-mass model is sufficient to observe the interaction of a multi-machine system. The rotational speed, torque, and moment of inertia of the rotor blade shaft and the generator rotor shaft are separated but linked with a gearbox turn ratio. The two masses are described as one for the wind turbine blades and gear box and the other one describe the generator as shown in figure 6. The full description of the two mass model and its utilization can founding [21], [22]. The two-mass model may be more suitable for transient stability analysis compared with the one-mass model [23].

2.3.3 Three-mass model

The basic three-mass model shown in Fig. 7.

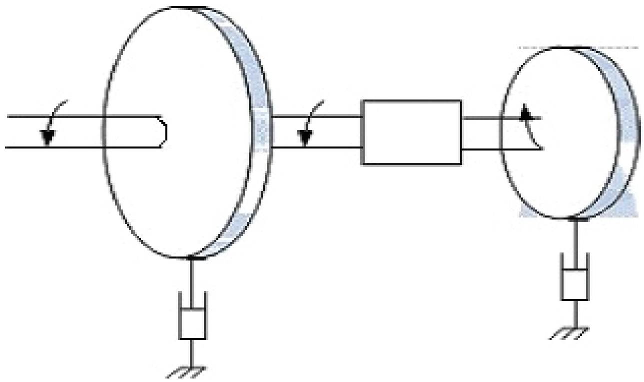

Figure 6: Two masses drive train model.

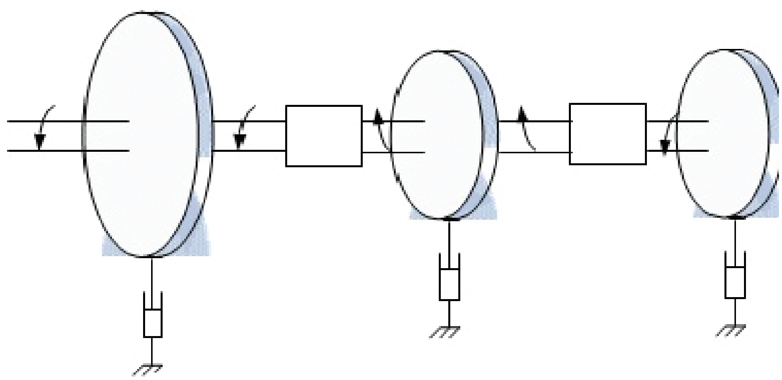

Figure 7: Three masses drive train model.

The turbine inertia can be calculated from the combined weight of the three blades and hub. Therefore, the mutual damping between the hub and the blades is ignored in the three-mass model. Individual blade torque

Sharing cannot be considered in this model. Instead, it is assumed that the three-blade turbine has uniform weight distribution for simplicity.

This model has three masses, which are a wind turbine, hub, and generator rotor with different stiffness and damping coefficients of low speed and high speed shafts as shown in figure 7. The full description of three mass model and its utilization can be found in [24], [25].

Comparing between the two and three mass in the modeling are the damping effect of the wind turbine blades besides the impact of the shaft's stiffness [26].

2.3.4 Six-mass model

The basic six-mass drive train model is presented in Fig 8. The six-mass model system has six inertias: three blade inertias, hub inertia, gearbox inertia, and generator inertia represent angular positions of the blades, hub, gearbox and generator. The flexibility between adjacent masses is expressed by the spring constants and there are a mutual damping existing between adjacent masses. The model system needs generator torque, and three individual aerodynamic torques acting on each blade. The sum of the blade torques is the turbine torque. It is assumed that the aerodynamic torques acting on the hub and gearbox are zero [27].

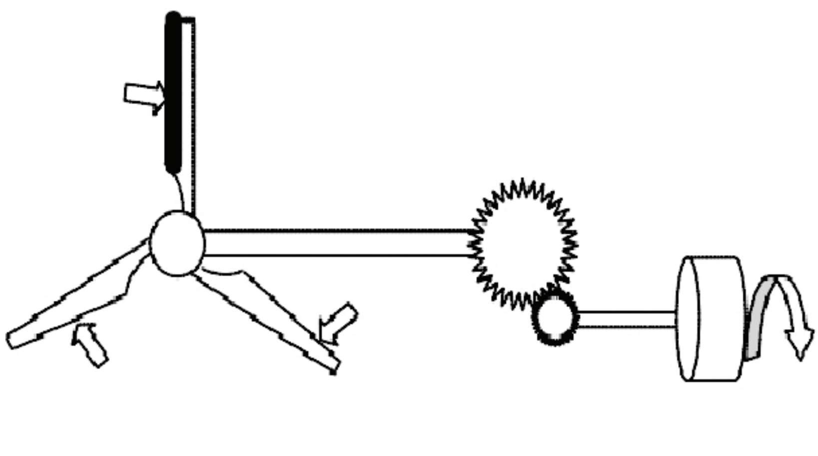

Figure 8: Six masses drive train model.

A six, three and a two-mass models and simulation compared with each other found in [28]. The authors argue that a six-mass model are needed for the precise transient analysis of the wind turbine system, and they develop a way to transform a six mass model into a two-mass model.

3. GEAR BOX IN DRIVE TRAIN

The gearbox is one of the most expensive components of the wind turbine system. The gearboxes converting the low speed rotation of the wind turbine rotor (typically less than 100 rpm) to a high speed suitable to the generator.
A gearbox typically consists of multiple stages, where the maximum ratio of every stage depends on the type of stage. The model of the gearbox consists of minimum zero and maximum three stages. Both types of stages can be combined throughout the gearbox; however, the last stage should be of the parallel type as shown in figure 9.

Modern studies found that 20-25% of all wind turbine damages existed in the gearbox due its location between the two large rotating masses; the propeller and the generator dynamic torque peaks (up to 3.5) Several hypotheses have been offered to explain gearbox failure, including the absence of a number of load cases relevant to the design process; the transfer of no torsional loads between the different components of the drivetrain; the lack of a uniform standardization of bearing-life analysis calculations; and poor communication between wind turbine designers, gearbox suppliers, and bearing providers.

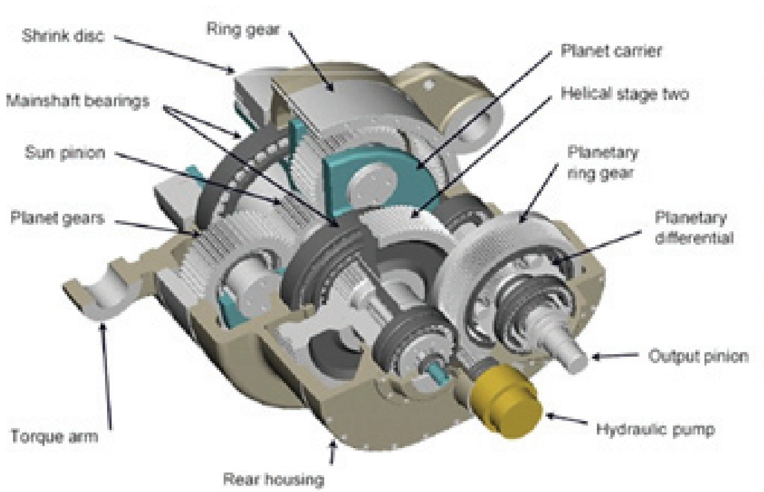

Figure 9: Modular Drivetrain Configuration.

Wind turbine gearboxes therefore should use higher safety factors compared to gearboxes used in stationary power generation [29].

Modern gearbox consists of two planetary gear transmission stages as shown in figure 9, one spur gear wheel transmission, and stable shaft carrying the gears, magnetic bearing and the casing [30].

3.1 Gear box modeling and simulation

Different multibody modelling techniques of different levels of complexity for describing modal behavior of wind turbine gearboxes. For early design stages, torsional multibody models are a suitable fast solution [31]. However, insights in gearbox modal behavior by means of these models is very limited. The full flexible models were found to be the most accurate. It was shown that the coupling structures between the FE models [32] and the rest of the multibody model had a significant influence on the overall gearbox modal behavior [33]. In order to refine the design and hence increase the long-term reliability, there has been increasing interest in utilizing time domain simulations in the prediction of gearbox design loads [34].

3.2 Gear box planetary gear

Planetary gears are effective power transmission elements in wind turbine where high torque to weight ratios, large speed Increase in compact volume, co-axial shaft arrangements, high Reliability and superior efficiency are required. The

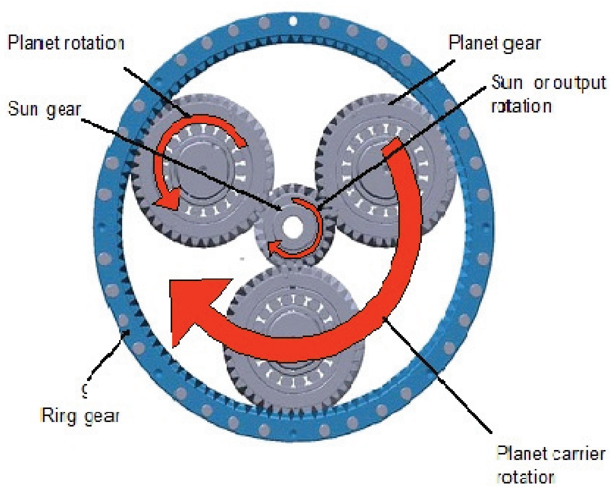

Figure 10: Model of planetary gear.

natural frequencies are the most important parameter in the design of planet gears carrier for dynamic loading conditions [35].

The epicyclical or planetary gear system under consideration consists of five gears: the ring wheel, which is an internal gear, the sun and the three planets that attached to the planet carrier. Only planetary gears with a fixed ring gear are considered. Figure 9 shows a planetary arrangement [36].

The planetary box is more complicated than the parallel shaft, because it is composed of three moving components per stage. These components include the planet gear, the planet carrier, and the sun pinion. The ring gear is also part of the planetary box however; it fixed to the gearbox housing. The planetary gear system is used in wind turbines because it yields a high torque density. This means it transfers more torque for the same amount of material required in the design [37].

There are a number of disadvantages to the planetary gear system. One disadvantage of the planetary system is that it is not suitable for very high rotational speeds because it is susceptible to dynamic instabilities. Therefore, they aren't used in the last stage(s) of a wind turbine gearbox.

3.3 Gears modeling and design in gear box

Gears is the most element used in gearbox .the dynamic behaviour of geard system is highly affected by operating conditions. Current wind turbine gears standards, such as ISO/IEC 61400-4 and ANSI/AGMA/ AWEA 6006-A03 [38].

Manufacturing deviations create nonlinearity in the dynamic behavior of the gears as indicated by gear researchers [39], [40]. Wind turbine geometrical

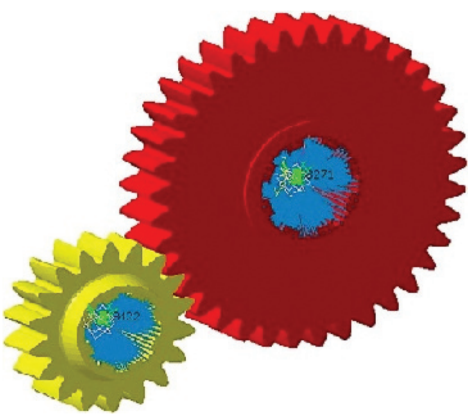

Figure 11: Two spur gear modeling.

manufacturing imperfections of gears can be classified in four general categories:

1 Tooth profile deviations (assembly independent)
2 Misalignment (assembly dependent)
3 Backlash (assembly dependent)
4 Mesh phasing (assembly dependent)

The influence of each category investigated in [41]. Finding that every categories have direct relation with the design of gear that affected choosing gearbox modeling method. Contact modeling is an active research area in the field of multibody (MB) dynamics. Despite a large number of publications, e.g. [42], [43], [44]. Describing in detail different contact methodologies for continuous contacts and impacts. The accuracy of the proposed reduction strategy has shown by means of comparison between a non-linear FE simulation and a model reduced with a large number of Eigen modes at force level [45]. Future work will concentrate on the implementation of an automatic switching strategy.

3.4 Gear box Brakes

Brakes are mechanical devices designed to slow or stop an output of gear train. In wind turbines, there are typically two distinctive brake classifications; aerodynamic brakes, and mechanical brakes [12].

The brake as a frictional device can induce a nonlinear incrementally increased torque as it is applied to stop the turbine. There is also a possibility of inducing additional vibrations to gearbox and drivetrain. The modeling of brake generally neglects these two phenomena, and is represented by a linearly increasing incremental torque against the rotational motion. This incremental peak accompany a maximum braking torque. The rate at which this peak reached is related directly to the magnitude of the torsional forces induced on the drive train to oppose its inertial behavior [46].

3.5 Gear box mounting

Modeling gearbox bushings used in wind turbine drive trains are important parameter when design and modeling drive train gear box due to its relation with Eigen frequency of the drive train. Comparison between three different models, a linear, a non-linear and a hydrodynamic bushing discuss [47].

All three models are capable of displaying the main dynamic characteristics of the gearbox bushing in an adequate way, and the relatively simple linear and non-linear models are easily competitive with the more complex hydrodynamic model on accuracy.

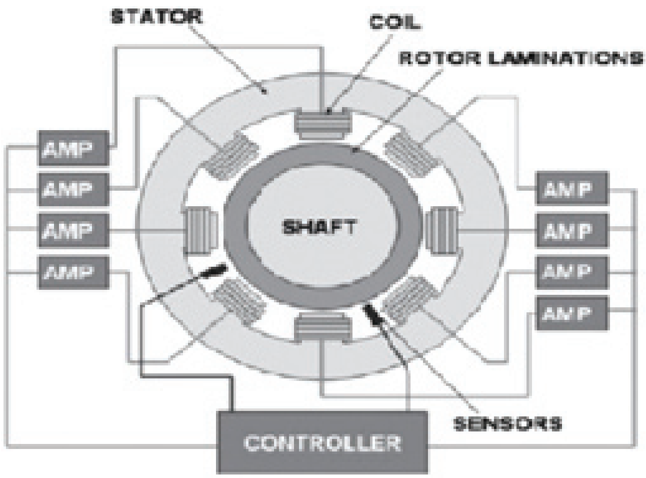

Figure 12: Schematic of magnetic bearing.

4. DRIVE TRAIN BEARING

A very promising potential solution to the shaft misalignment problem may come from the aerospace and centrifuge uranium enrichment industries in the form of bearing. Rolling element bearings, still used in wind turbines, are hindered by their relatively short lifetime when subjected to high loads. Both foil and magnetic bearings offer longer lifetimes, with magnetic bearings outperforming foil bearings when used in large rotating machinery under high loads and a relatively low speed [48]. Large, heavily loaded, and relatively slow rotating provides a nearly perfect description of a modern utility scale wind turbine generator.

Benefits of magnetic bearings include durability and damage tolerance, much smaller frictional losses, and Magnetic bearings offer the potential to eliminate lubricating oil systems and avoid bearing Wear [28].

5. CONCLUSION

This article summarizes in part the history of wind turbine drive train models, which used in simulation, and design of drive trains. A focus devoted to modelling gearboxes and mountings, which constitute the most expensive components in the wind turbine system.

Also a discussion was included about recent trends for modifications of gear models and gear design and its impact on net power of wind turbine. Finally a discussion about bearing history and its use in drive trains and how is magnetic bearing being widely used to eliminate the draw backs of ordinary one in terms of dynamics.

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