LITERATURE REVIEW SAMPLE

Structural Study of Wind Turbine

Fluid structural interaction on a wind turbine and the theory of Finite element has been widely studied in various studies. Stolarski (2012) and other researchers from the University of Minnesota, Department of Civil engineering developed a novel computation model meant for describing the structural behavior of wind turbines through the application of behaviors typical of the shell structure. They used the ratio of a spam length which was approximately 45 meters and a cord length of between 1 to 3 meters which is more common among the structural beams than shells. However, both the shell and beam models are used to analyze wind turbine blades.

On the other hand, Hsu and Bazilevs (2012) presented their aerodynamics and fluid-structure interaction (FSI) computation methodologies that allowed dynamics, fully coupled 3D FSI simulation of wind turbines at full scale. For the interaction of wind and flexible blades, they used a nonmatching interface discretization approach whereby the aerodynamics is created using a low-order finite element based technique. Therefore, the theory of finite element analysis can be related to this work of Hsu and Bazilevs (2012) in the process of simplifying the complex problem to small manageable problems.

The rotor blades of Hsu and Bazilevs are designed as thin composite shell discretized using NURB-based isogeometric analysis (IGA) (Hsu & Bazilevs, 2012).

Hsu and Bazilevs (2012) found that when FEM and IGA gives a combination of efficiency, accuracy, and the flexibility of the computational procedures for wind turbines FSI. Finite element analysis has assisted in the achievement of this efficiency and accuracy by making things easier than they were before. But according to Stolarski (2012), when the aim is to capture more power from the wind, these wind turbine producers increase the length of the blade to 45 meters and longer. He adds that an increase in blade length leads to an increase in mass, blade flexibility and structural forces. Also, Stolarski says that this has a likelihood of decreasing operating lifetime that is caused by damage in fatigue. He explains that for the manufacturers to account for all those factors, they require a better understanding of how blades respond to static and dynamic forces. The work of and Hsu and Bazilevs (2012) are similar in terms of flexibility and accuracy of the computation procedures. These two different scholars made the same kind of observation regarding what should be done to increase efficiency through an understanding of how the blades react to static forces. In both cases, it is evident that in order to achieve flexibility and efficiency in the fluid-structural interaction. Hsu, Akkerman, and Bazilevs (2014) did a validation study using the national renewable energy laboratory phase VI wind turbine was presented. The aerodynamic simulations were performed using the finite element arbitrary with a variational multiscale formulation argued to have weakly enforced essential boundary conditions. Also, Hsu, Akkerman, and Bazilevs (2014) seem to have applied the theory of finite element analysis by performing aerodynamic simulations using the finite element arbitrary. In all the cases, the rotor is assumed to be rigid, and its rotation is agreed. This seems to reflect the works of Hsu and Bazilevs specifically about the issue of the rotor. However, Hsu, Akkerman, and Bazilevs (2014) argue that the rotor only models are done for a wide range of wind situations, and computational results compared with experimental findings in all cases.

According to Barnes, Morozov (2016) structural optimization techniques are frequently used as part of a design process for composite wind turbine blades. Usually, this is achieved through the modification of material placed within a standard structural design. However, less attention has been put to the possibility of varying internal geometry in the creation of novel structure configuration. For this reason, it is clear those other scholars such as the works of Hsu, Akkerman, and Bazilevs (2014) and Stolarski (2012) have not paid attention to the varying internal geometry in the creation of good structure configuration. The structural focus of most researchers fails to recognize this issue of internal geometry where a series of wind turbine blade design with differing structural configuration is created and compared to investigate the consequences of allowing various aspects of the internal structural geometry are to be varied. Barnes, Morozov (2016) deeply investigated the geometry of the structural spur by modifying the width of the spar caps, as well as how many and location of the shear web including the spanwise starting and ending locations. Here, they also considered the location and the extent of trailing edge reinforcements are also found together with the material thickness distribution of the spar and trailing edge reinforcement. On the other hand, Hsu and Bazilevs argued that the interaction that exists between the rotor and tower is controlled using nonoverlapping sliding interface problem approach. To handle such kind of problems, it is necessary to apply the theory of finite element analysis to simplify and make work easier. Here, Hsu and Bazilevs say that both moving and stationary domain preparations of sleekness are used. Therefore, at the fluid-structure sliding boundary, the kinematics and grip continuity is applied weakly which is the main ingredient for the proposed statistical methodology.

According to MacPhee and Beyene (2015), active control blade pitch for wind turbines is good in terms of increasing efficiency, especially for parts and over-load operations.

There is an unfortunate result of this practice which is added upfront and maintenance cost, making these schemes economically viable especially in large-scale applications. Their study is different from the above-listed scholars in such a way that it investigates novel concepts for wind turbine design where the blade is purposefully built of a flexible material which can easily adapt its geometry according to the local wind conditions. Unlike the case of Hsu and Bazilevs, MacPhee and Beyene (2015) their concept of design acts as low cost and simplistic passive pitch control mechanism. By the use of a finite fluid-structure interaction solver, the aeroelastic response. Finite element theory analysis has been employed here as well by the use of finite fluid-structure interaction solver. They also added that the aeroelastic response of a turbine like that is analyzed and compared to experimental data collection from wind tunnel test which was part of their project. They found out that the flexible rotor is extremely superior to a geometrically similar rigid one regarding the size of its operational envelope as well as maximal and average torque production. By the use of processing tools, MacPhee and Beyene (2015), said that the performance improvements are attributed to passive deflection of the airfoil, which acts to delay blade stall and drastically change surface pressure distribution to improve the performance of the turbine. The study conducted by MacPhee and Beyene shows that the flexible rotor is the most superior to the rigid one since due to its ability to change the distribution of surface pressure that consequently leads to improvement in the performance of the turbine.

Muskulus and Schafhirt (2014) argue that wind turbine are complex engineering systems, which are subject to loads which are highly fluctuating and irregular. These complex engineering problems need to be addressed by simplifying them by the use of finite element analysis theory. They added that the optimal structure of wind turbines especially their tower, support structures and foundation systems are a non-trivial task.

They suggest that computer-aided approaches can greatly assist in finding better and more viable solutions. Musculus and Schafhirt however, did a review where they identified the challenges and possible solutions for the structural optimization of wind turbines.

Their review discussed the literature and finally gave some recommendations to help in future research in this area. Musculus and Schafhirt listed some challenges that are experienced in the design of wind turbine structure in their review. One of the problems they noticed is that of nonlinearity. Wind turbines are said to exhibit nonlinear effects and time history dependence which results from the unsteadiness in the flow and structural nonlinearities. Another issue noticed by Muskulus and Schafhirt concerning the complex environment. They argued that wind turbines are subject to complex and highly fluctuating environmental conditions. Thirdly was the fatigue as design-driven. Here they explained that a great number of that a wind turbine propeller experiences during its lifespan shows that wind turbine structures are exposed to an important foundation of quasi-periodic excitation. Specialized analysis software whereby the analysis of wind turbines is usually based on numerical problems and load simulation. Other concerns that were addressed by Muskulus and Schafhirt include the tightly attached and highly interconnected systems as well as the main design variables and constraints. The work of Muskulus and Schafhirt has paid more attention to various aspects of structural elements of wind turbines unlike MacPhee and Beyene (2015) and Hsu, Akkerman, and Bazilevs (2014). This is due to the fact that they managed to address the challenges with the structure of the wind turbines, state of the art in design optimization, optimization of the wind turbine structure, and some recommendations to deal with those challenges. The existence of these different problems requires the assistance of finite element theory.

Lee et al. (2017) performed an analysis of FSI to evaluate the aerodynamic and structural features of 3D wind turbines. The FSI analyses were done to acquire the structural response of 3D wind turbine research on the state renewable energy laboratory phase VI wind turbine using the commercial program. They acquired the surface pressure information from the results of computational fluid dynamics which are learned earlier. To conduct the structural evaluation for both of FSI and blade element momentum technique, the structural components of full NREL phase VI wind turbines were able to be developed which is assembled by a rotor, nacelle, tower, and blades. The study of structural analyses by Lee et al. (2017), the wind turbines are said to be not governed by torque force which is the main interest in power efficiency of a wind turbine, but the thrust force. Stolarski (2012) says that when a blade is subjected to aerodynamic forces, it will undergo deformation since the structure is extremely flexible. Due to the complexity of the geometry and the material used in wind turbine today, it is extremely hard to project to what extent the blade will deflect. It is important in the design process hence tools should be developed that are capable of predicting how a turbine blade will respond to these forces.

Hsu, Akkerman, and Bazilevs (2014) wrote that through enabling more understanding of the physics behind the wind turbine interaction through detailed fluid-structure interaction simulation. Competence in developing more optimized wind turbines as well as more yielding farm layouts. Numerical simulation tools are an invaluable way of gaining new insights into these issues with the possibility of integrating many physical models influencing the performance of the wind turbine. Currently, the integrated numerical simulation tools employed by the wind energy industry apply the simplified empirical or parameterized models to compute the aerodynamic forces on the turbine blades. Simplified numerical models are computationally efficient, but significant details of the flow fields and nonlinearity in the interaction of the flow of air, and rotor blades are not resolved. Coupled fluid-structure interaction (FSI) simulations are required for accurate modeling of wind turbines, and also provides some input parameters to verify and to improve the parameterized model. Here, the issue of nonlinearity as mentioned is similar to one of the problems stated by Muskulus and Schafhirt (2014) regarding the negative effects of structural interaction simulation in wind turbines. The works of different scholars have given focus to some of the pro and cons of this type of structures. The literature has extensively managed to address how the FSI wind turbines operate and the means available for increasing its efficiency. Various scholars such as Lee et al. (2017) and MacPhee and Beyene (2015) have emphasized in the importance of understanding how static forces work and the aerodynamic forces if someone have to know the best way to improve the efficiency of the wind turbine. On the other hand, Hsu, Akkerman, and Bazilevs (2014) made a significant attempt to improve the understanding of the readers regarding how wind turbines operate and the necessary tools required to increase its efficiency. The literature has covered and addressed a wide range of various type of study conducted in relation to the structural study of the wind turbine. People like Muskulus and Schafhirt (2014) covered an area of the study while listing the negative outcomes or what results due to the use of fluid-structure interaction simulations. However, they went ahead and described the various causes of these problems together with the necessary recommendations best for ensuring some improvements. Among the recommended solutions is the application of finite element analysis theory which is very efficient in reducing complex problems into simpler issues that can easily be handled. Efficiency and accuracy are very crucial in this matter and therefore, necessary measures need to be put in place according to Muskulus and Schafhirt. On the other hand, Lee et al. (2017) said that the wind turbines are not governed by torque forces which is the main form of power efficiency in the wind turbines. The structural design of the FSI determines its level of efficiency according to Lee et al. (2017).

The finite element analysis is also known as the finite element method (FEM) which is a numerical method of finding solutions to engineering problems and mathematical physics (Plaza et al., 2015). This theory explains a technique involving the subdivision of large mathematical or engineering problems into smaller and simpler parts which are referred to as the finite elements. In the structural study of wind turbines, finite elements theory is a necessary tool to understand in order to comprehend the types of engineering problems involved in this area (Plaza et al., 2015). Most of the engineering problems that exist in the fluid-structural interactions are subdivided into small and separate problems that are easy to deal with. The literature regarding finite element analysis theory is wide enough for a researcher to have a broad range of options for this study and proper understanding. Many researchers have attempted to give a proper and detailed understanding of the finite element theory of analysis. However, as the literature indicates, there is some relationship between the theory of finite element analysis and the structural study of wind turbines. According to Lee et al. (2017) and Muskulus and Schafhirt (2014), the problem of nonlinearity in the structural study of wind turbines creates some engineering and mathematical complexities, to solve these issues, there is the need for a broad understanding of the finite element analysis theory. They all emphasize on this since the big problems are broken down into small mathematical and engineering problems that are easily manageable.

According to MacPhee and Beyene (2015), The Finite Element Method is one of most important in developments computation methods. Within few decades, this technique has evolved from applications in structural engineering to most of the computational approach for science and technology areas. For many purpose computation, class of finite elements is researched and developed into finite analysis program (Wang et al., 2015). The theory of finite element analysis indicates that big engineering problems especially those associated with the structural elements of the wind turbines can be solved using finite element analysis. The beam theory has been including effective of shear force, therefore, the cross-section is not a plane, and it is warped after deformation (Wang et al., 2015). Generally, solutions based on finite element theories are limited to simple geometry and loading because the solving governing differential equation is very difficult and cannot found solutions when geometry, boundary condition or loading of a problem are complex. On the other hand, MacPhee and Beyene (2015) argue that in wind turbine technology, the turbine blades play an important role as it directly comes in contact with the wind. Wind turbine blades are shaped to generate maximum power from the wind at minimum cost (Plaza et al., 2015). The blades should be designed for longer life as they are subjected to continuous fatigue loads.

According to Bo and Yu (2016), Wind turbines provide an alternative way of generating energy from the power of wind. At windy places where the wind speeds are so high, sufficient amount of energy can be harnessed by making use of wind turbines (Kim, Hansen, & Branner, 2013). The blades of such turbines are so designed that they generate lift from wind and thus rotate. In their review of the literature, they stated that the failure in flap wise bending during the normal operating condition of the wind turbine. The model is based on an extreme analysis of the load response process in conjunction with a representation of the governing tensile strength of the blade material. The probability of failure in flap wise bending of the blade is calculated by means of a first order reliability method, and contributions to this probability from all local maxima of the load response process over the operational life are integrated (Kim, Hansen, & Branner, 2013).

The literature has focused on the issue of fluid-structural interaction (FSI) in details while covering all aspects. Different researchers have had various opinions and research is thoroughly conducted to give insight regarding the wind turbines and their structural composition. Finite element analysis theory has also been discussed in details as well as the relationship between the theory and various research outcomes from different scholars.

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