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Optimization of the Underframe of the Sultan Wind Turbine V5 Using the Optimization Topology Method

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Keywords

manufacture, safety factor, sultan wind turbine, topology optimization

Abstract

Sultan wind turbine is one of the products of the New Renewable Energy Engineering Lab, Faculty of Engineering Untirta which has developed from year to year until now. To keep up with industrial developments in today's era, renewal is needed to improve and update the technology contained in the sultan wind turbine. In particular, today's optimization topologies are seen as providing the possibility to realize truly manufacturing-optimized designs through topology optimization. A topological optimization is an approach that is considered powerful in design because it contributes to designs that can save energy, materials ,and time that cannot be achieved economically using other manufacturing processes. A topological optimization, as it is often called, computer configuration of the best material over 3D space, usually represented as a grid, to satisfy or optimize physical parameters. Designers using these automated systems often seek to understand the interaction of physical constraints with the final design and their implications for other physical characteristics. Such understanding is a challenge to using a visualization approach to explore the design solution space. The essence of our new approach is to summarize an ensemble of solutions by automatically selecting a set of examples and parameterizing a design space.

1. INTRODUCTION

The manufacture of the prototype of the sultan wind turbine v.1 began in 2012 and has undergone several developments to date. then the development of the prototype of the sultan wind turbine v.2 in 2014, and the development of the prototype of the sultan wind turbine v.3 in 2015, and finally the development of the prototype of the sultan wind turbine v.4 in 2017 with several changes including the seat frame, changing the shaft, and adding fin. However, because there are still shortcomings in the sultan wind turbine v.4 prototype, it is necessary to develop it into a sultan wind turbine v.5 prototypes with a lighter mount frame but does not reduce the strength of the sultan wind turbine holder.

The process of making the underframe must go through a series of tests using an application so that the desired results are appropriate and at the simulation stage it can also be known how to optimize the frame of the Sultan Wind Turbine v5.0, because the Sultan Wind Turbine works all the time, so a frame that can withstand dynamic loads is needed. The latest design of the Sultan Wind Turbine frame is expected to have a better shape, stronger and more efficient frame structure. The holder frame on the prototype of the sultan wind turbine is a part of the turbine construction that functions to transmit the load transmitted from the upper structure to the subgrade layer. This mounting frame can support the static turbine load (the weight of the turbine and other components) (Egi, 2017). The seat framework that will be designed in this study is an improvement from the previous seat framework, which is expected to produce a simpler design (Egi, 2017). The design of this mount framework includes determining the design, calculating the safety factor, and analyzing it using computer-aided design (CAD) software (Egi, 2017). In previous research on the sultan wind turbine v4.5, the framework design used a design based on structural rules and material determination using conventional materials. Determining the choice of method in computer-aided design (CAD) design is to get a more optimal design in the use of materials but not reduce the strength of the structure (Perry et al.,

2020). One example of developments in the world of structural design is using topological optimization methods, methods that use gradient-based mathematical programming techniques such as the optimality criteria algorithm and the asymptote moving method ,or non-gradient-based algorithms such as genetic algorithms. The emergence of manufacturing additives makes design complexity no longer a problem and only a matter of the number of materials to carry out the production process (Siva Rama Krishna et al., 2017). it is a very useful method for engineers and scientists to create innovative and high-performance conceptual designs (Herrero-Pérez et al., 2022)

Making the prototype of the sultan wind turbine, there have been many developments, starting from the manufacture of the prototype of the sultan wind turbine v.1 which was made in 2012 ,and continued in the manufacture of the prototype of the sultan wind turbine v.2 in 2014. Thus the prototype of the sultan wind turbine is developed again. in 2015 became the prototype of the sultan wind turbine v.3. In the testing phase for the prototype of the sultan wind turbine v.3, there are several that must be developed to become the prototype of the sultan wind turbine v.4, including changes to the seat frame, changes to the shaft, and the addition of fins as a determinant of wind direction. In Cilegon where this research was conducted, not many have tried to capture the potential of wind energy, to be used as alternative renewable energy, which incidentally is close to the offshore Cilegon which has good wind potential to be used as an alternative energy source. So that in practice a blade that has superior performance is needed in capturing wind energy that is by the characteristics of the city of Cilegon. As for the characteristics of the wind, namely, wind that changes frequently, frequent occurrence of turbulence, and speed increases with altitude (energy is proportional to the power of three multiples), the actual potential is determined by the distribution of wind speed (topography) of the location. Meanwhile, the wind speed in the Cilegon area is 2 m/s – 4 m/s (Sippa, 2019). The wind turbine which is now located on the top floor of the Sultan Ageng Tirtayasa University Rectorate Building can still be developed further and find solutions to the problems that exist in the sultan wind turbine v4, including the framework that has begun to be corrosive and a lighter frame is needed based on previous research (Egi, 2017). The purpose of this study was to design the underframe of the Sultan Wind Turbine V5.0 to obtain a more stable and durable frame design and a stronger and lighter pedestal.

1.1 Topology Optimization

Generative design is a term that encompasses the various types of technologies involved in modeling these progressive types of products. These technologies include topology optimization, biomimicry, experimental design methods ,and lattice structure creation. Biomimicry imitates patterns or processes from nature which are then applied in the industry (Pollak et al., 2020). Three main parts in optimization are topology optimization, size optimization, and shape optimization(Pilagatti et al., 2021). The combination of topology optimization and additive manufacturing provides more creative space for the design and manufacture of various components(Kang et al., 2021).The development of the optimization topology was initially shown for 2D problems, then gradually it can be used for 3D integrated with CAD (Cuillière et al., 2018) Compared to conventional manufacturing, process topology optimization gives users the freedom to produce very complex geometries and material compositions(Wang et al., 2021). The optimization topology shows the effectiveness of the proposed optimization algorithm to get a structure with maximum damping or stiffness(Huang et al., 2015). Conventional manufacturing strategies have evolved to realize design goals for a wide variety of applications, but topology optimization is and will continue to have a major impact on design and manufacturing(Blakey-Milner et al., 2021). Little by little, topology optimization, which is a high-cost and difficult-to-obtain method, has developed and is available in the form of applications for research fields, such as structure optimization.(Roque et al., 2021)

Topology optimization is a mathematical method that optimizes the layout of materials within a given design space, for a set of loads, boundary conditions, and constraints with the aim of maximizing system performance. The optimization topology method is directly extended to a robust formulation to achieve an eroded, intermediate, and widened design topology so that the design is resistant to possible manufacturing errors (Huang & Li, 2022). Topology optimization is also a shape optimization method that determines the

optimal structure in the design domain for high structural efficiency (Kim, 2020). Topology optimization differs from shape optimization and size optimization in the sense that the design can achieve any shape within the design space, instead of handling predefined configurations. The conventional optimization topology formulation uses the finite element method (FEM) to evaluate the design performance. The design is optimized using gradient-based mathematical programming techniques such as optimality criteria algorithms and asymptote moving methods or non-gradient-based algorithms such as genetic algorithms (Perry et al., 2020). In this case, structural optimization is an application of topology optimization with the to aim the optimal distribution of materials according to the demands of a structure (Kalantre et al., 2018).



Figure 1. Topology result

The optimization method used in topology optimization uses Optistruct Altair software. The topology optimization of the underframe design is carried out because the shape is a structure and topology optimization results in a large enough mass reduction (Suryo et al., 2021). Altair Inspire's topology optimization technology makes it possible to get the exact shape of the product according to the specified load and constraints. However, due to the specifications of the optimization algorithm, it may be necessary to manually increase the amount of material in the part to make the optimized assembly more technologically advanced (Dolmatov & Kolesnikov, 2020). Process flow for topology in Altair Inspire: (Nandanwar et al., 2021)

The first step is to develop a CAD model from the required parts and generate an sldprt format file, then open Altair Inspire and import the Solidworks file in it, dividing the model into 2 parts design space and non-design space, for simulation, such as support, force, pressure or moments , etc. Material properties are also selected for the section, after all the above steps are completed the icon for topology optimization is selected. Now there are 2 goals of minimizing weight or maximizing stiffness (for the selected weight percentage, for the underframe, the maximum stiffness is chosen for a certain percentage of the weight, after the simulation is complete, presented with a rough surface optimized for the topology, finally making the results smoother using the features called *polynurbs* which smoothen the surface to improve mechanical properties and make it manufacturable. Topological optimization finds initial structural configurations that meet predetermined criteria based on finite element analysis (FEA) and sometimes provide completely new and innovative designs. (Yan et al., 2022) With the structure already integrated, production exhibits optimal mechanical strength and encourages design unification.(Meena et al., 2021)

1.2 Factor of Safety

The factor of safety is obtained using the thumb method, the factor of safety can be quickly estimated using a variation of five measures (Ullman, 2017). The Factor of Safety (FoS) is how much the system can withstand more than the expected or actual load. The Factor of Safety also known as a factor of safety is often calculated using the ratio of the ultimate load to the allowable load for a model or structural design in constructions such as bridges and buildings. The factor of safety is basically used to ensure the structural design does not occur unexpected failure or deformation or defects. The smaller the Safety Factor, the higher the chance for the design to fail. Resulting in uneconomical and non-functional designs. As for the higher Safety Factor, the components will be much more expensive resulting in higher design costs (Maria, 2016).

FS=(Fs material)(Fs stress)(Fs geometry)(Fs analysisfailure)(Fs reliability) (1)

Estimated Contribution to Material, FS material

• FS = 1.0 if material properties are known. Experimentally obtained from specimen testing.

• FS = 1.1 if material properties are known from manuals or fabrication values.

• FS = 1.2 – 1.4 if the material property is not known.

Estimated contribution of stress due to overload, FS stress

• FS = 1.0 – 1.1 if the load is limited to static or fluctuating loads. If an overload or shock load and if using accurate analytical methods.

• FS = 1.2 – 1.3 if the normal force is limited to a certain condition with an increase of 20%-50% and the stress analysis method may produce an error below 50%.

• FS = 1.4 – 1.7 if the load is unknown or the stress analysis method has uncertain accuracy.

Approximate contribution to geometry, FS geometry

• FS = 1.0 if the production tolerance is high and guaranteed.

• FS = 1.0 if the tolerance of the average production yield.

• FS = 1.1 – 1.2 if the product dimension is less important.

Estimated contribution to failure analysis FS failure analysis

• FS = 1.0 – 1.1 if the failure analysis comes from stress types such as uniaxial stress or multiaxial static stress or full multiaxial fatigue stress.

• FS = 1.2 if the stress analysis used is a simple theoretical area of multiaxial, full alternating stress, and uniaxial average stress.

• FS = 1.3 – 1.5 if the failure analysis is static or does not change as in a typical breakdown or multiaxial average stress.

Estimated contribution to reliability, FS reliability

• FS = 1.1 if a component does not require high the reliability.

• FS = 1.2 – 1.3 if the reliability at the average price is 92% - 98%.

• FS = 1.4 – 1.6 if the required high reliability is more than 99%.

To determine the value of the safety factor based on the maximum stress and working stress are: (Ullman, 2017)

$$SF = \max/\sigma work \quad (2)$$

Information :

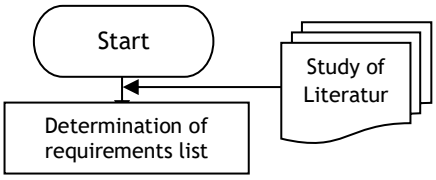
SF: Safety factor

max: Maximum stress (N/mm2)

work: Working Voltage (N/mm2)

2. METHODS

The following are the stages of the research used as shown in Figure 2. Flowchart of the optimization research under the sultan wind turbine v5 frame using an optimization topology method.



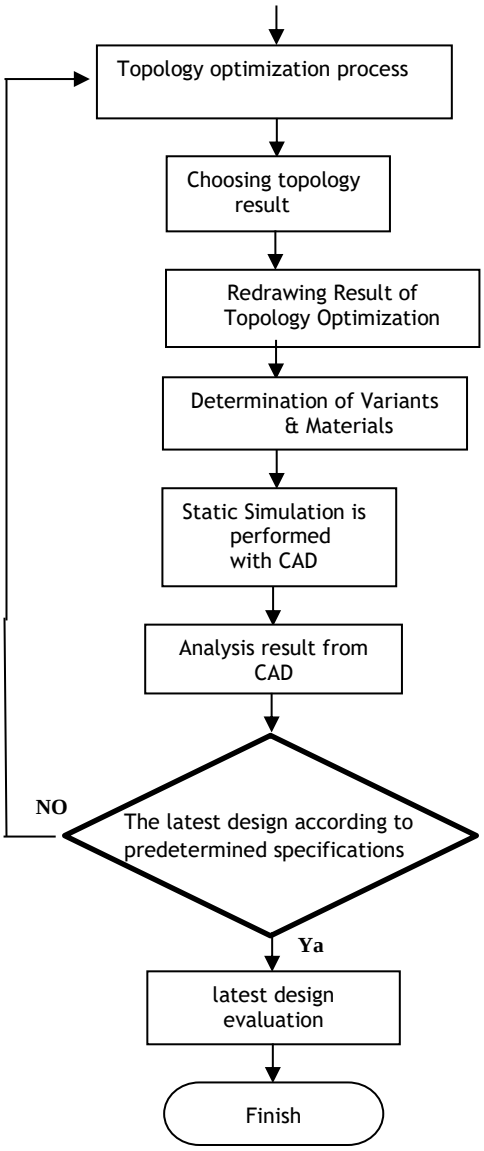


Figure 2. Research methods

The explanation of the research method so that the flow chart above can be easily understood.

1. Study of Literatur

The first stage of this research is collecting information sources, reading, and understanding them. The sources come from various journals, theses, and also articles on the internet. The manufacture of the prototype of the sultan wind turbine v.1 began in 2012 and has undergone several developments to date. then the development of the prototype of the sultan wind turbine v.2 in 2014, the development of the prototype of the sultan wind turbine v.3 in 2015, and finally the development of the prototype of the sultan wind turbine v.4 in 2017 with several changes including the seat frame, changing the shaft, and adding fin. However, because there are still shortcomings in the sultan wind turbine v.4 prototype, it is necessary to develop it into a sultan wind turbine v.5 prototype with a lighter mount frame but does not reduce the strength of the sultan wind turbine holder.

For writing this report, the sources are mentioned in the bibliography section.

2. Determination of Requirement List

At this stage, it will be explained what are the requirements for the design of the Sultan Wind Turbine underframe. This stage explains and defines tasks by describing tasks in a list of requirements

containing constraints in the form of requests and wishes. The requirement list used is the one from Alexander and Beus. Based on research conducted by Ljerka Beus-Dukic and Ian Alexander in 2008, this approach is more realistic and pragmatic for requirements lists by using a combination of requirements elements and discovery context. The results achieved from the research of Ljerka Beus-Dukic and Ian Alexander are positive that this approach will help turn an unclear problem into a clear problem such as Required Functionality (Use Case Diagram), Application domain information structure (Domain Model), and List of all requirements functional and Indicate its priority. The requirements list fulfills adequacy, correctness, coverage, readability, and consistency (Alexander & Beus-Dukic, 2008). Limitations of demand and desire themself are internal, i.e. limits are created by the author or external, namely restrictions obtained from users (consumers), so that some requirements cannot be calculated , or determined as a cost calculation. In short, Wish is a must-have consumer expectation that the design is worth the investment, while demand is something that a product must fulfill. otherwise, the status will be rejected.

Table 1. *Requirement List* (Alexander & Beus-Dukic, 2009)

Requirement List		Explanation	*Wish* = W Demand = D
Functional	Work System	Capable of withstanding the forces caused by the components above the wind turbine underframe	D
Geometry	Framework	Optimal and able to withstand static loads and has better strength than the previous version	D
Material	Framework Material	The type of material is easy to get	W
		Able to withstand a force of 886.0768 N and 1330.71 N	D
		Corrossion resistence	W
Maintenance	Maintenance	Easy maintenance	W
Output	Safety	Safe in simulation test (meet or greater than safety factor)	D

3. Topology Optimization Process

The topology process for optimizing the design of the subframe structure uses Altair 2019.4 Before performing topology optimization, several data must be prepared, namely Material properties, loading data, and Design space.Pemilihan Hasil Topologi. Selecting the optimization topology results from various experiments that have been carried out with the results of the analysis of the original shape of the optimization topology results using CAD static simulations in this case using Altair Inspire

4. Choosing Result of Topology Optimization
5. Redrawing Result of Topology Optimization

Redraw the results of the optimization topology because the results of the optimization topology are not in the form of blocks and have varied dimensions. Then the design will be made using a truss method. Truss is a framework that involves parts assembled into an object (Koirala et al., 2021). The ideal link between additive manufacturing and structural optimization is a key element in today's product development. On the one hand, models are manufactured with the addition of thousands of layers using additive manufacturing. It offers designers great geometric flexibility, at no extra cost, compared to traditional manufacturing. Additive manufacturing includes many technologies such as 3D printing, rapid prototyping, and direct digital manufacturing. On the other hand, structural optimization reduces material usage, shortens design cycles, and improves product quality. Structural optimization can be implemented. (Tyflopoulos et al., 2018)

6. Determination of Variants and Materials

Choose the best variant of the shape from the results of redrawing and the selection of materials that are stronger and easier to obtain.

7. Static Simulation with Software

The results of the selection of variants and materials are simulated using CAD

8. Analysis of Simulation Results on CAD
   Get results from static simulations in the form of voltage and safety factor data
9. Latest Design According to Specified Specifications
   Get results that match the specified requirements list
10. Evaluation of Latest Design Results
    Collect the data that has been obtained and define dimensions and material information

3. DISCUSSION

Topology Optimization Simulation

Topology optimization is a mathematical method that optimizes the layout of materials within a given design space, for a set of loads, boundary conditions, and constraints with the aim of maximizing system performance. The simulation is performed using computer-aided design (CAD) software which is capable of performing shape optimization and size optimization analysis in the sense that the design can achieve any shape within the design space, instead of handling predefined configurations. The application used to perform the topology optimization process using the Altair Inspire 2019.4.From the results obtained from the results of topology optimization with two loading directions. It is assumed that the solid results follow the existing shape, and the shape below is designed with the assumption that the load moves from all directions. And redrawing the design using an existing profile.

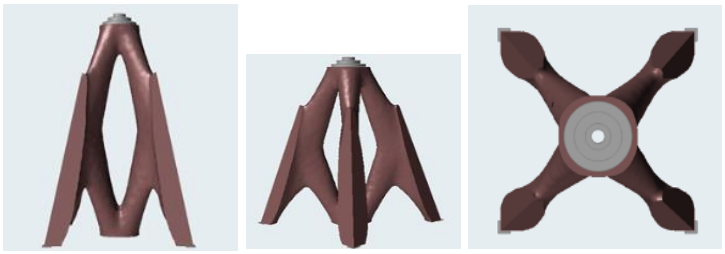
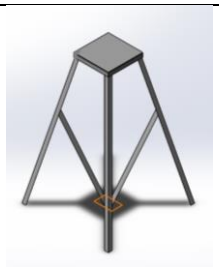
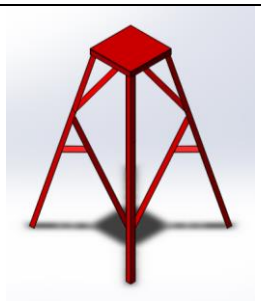


Figure 3. Topology Optimization result

From the simulation results and after redrawing, the results are similar to the shape of the simulation results. And added bracing to increase the strength of the frame structure.

Table2. Redrawing result

Model	Visualization	
Without Bracing		

With Bracing		

3.1 Under Framework Simulation

Under frame is a part of the construction that serves to transmit the load transmitted from the upper structure to the soil layer. The lower mount frame can to support the compressive force caused by the weight of the components above it and can to withstand the force caused by the wind. The following are some simulation results based on the materials used, which are shown in the image below. From the simulation results, the following results are obtained:

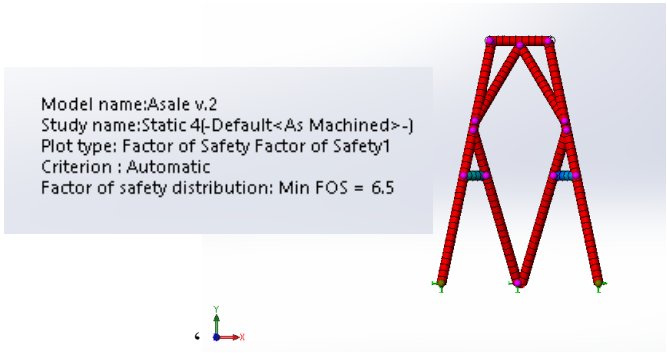


figure 4. Result Factor Of Safety

U To make the design more stable, from the results of redrawing the results of the optimization topology, braces are added to the design. And obtained the value of the safety factor of 16. Furthermore, the Contribution Estimated Analysis is carried out in terms of the aspects carried out in the simulation.

$$FS=(Fs_{material})(Fs_{stress})(Fs_{geometri})(Fs_{fatigueanalysis})(Fs_{reliability}) \quad (3)$$

so that,

1. Estimated contribution for Material, ie Fs Material = 1.1

Because the specified material properties are known from the manual and the fabrication value.

2. Approximate contribution to Stress, i.e. Stress Fs = 1.1

Because the loading carried out during the simulation is a static loading, it is also by the research scope or problem constraints.

3. Estimated contribution to Geometry, i.e. Geometry Fs = 1.0

Because, the tolerance given when designing the Frame Construction in Computer-Aided Design (CAD) Software is the average tolerance value, which is +- 0.01mm

4. Estimated contribution to failure analysis, ie Fs Failure Analysis = 1.2

Because the stresses applied during the simulation are on the theoretical area (surface) of a simple frame, such as axial stress, multiaxial stress, and uniaxial average stress.

5. Estimated contribution to reliability (the ability of the structure to withstand loads), i.e. Reliability Fs = 1.3

Because the reliability determined during the simulation ranges from an average value of 92-98% (according to the force values and equations used)

So, the minimum Factor of Safety that needs to be achieved is:

FS = (1,1).(1,1).(1,0).(1,2).(1,3)
FS = 1,8876

It can be concluded that, based on the simulation results in the simulation, the FS value is 2, where the minimum FS based on the above equation is 1.8876. It can be concluded :

FS simulation > FS manual = safe

Then, **6.5 > 1,8876 = safe**

4. CONCLUSION

Based on the research that has been done, it can be concluded that:

1. From the results obtained, the safety factor of 6.5 from the static simulation results on the CAD is greater than the Ullman equation which is 1.887, then the design of the Sultan Wind Turbine underframe is declared safe.
2. The selected topology results are with five force directions as shown in Figure 2.
3. For further research, it is better to use a more sophisticated CAD application to change the results of the optimization topology method into a design form that is commonly found in everyday life.

5. THANK-YOU NOTE

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