LCA For Diffuser Augmented Wind Turbine (DAWT)

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LCA for DAWT

Abstract

As the global carbon emissions are rising, there is increase demand in renewable energy as it is cheaper and environment friendly. Due to rise in carbon footprints and in order to meet the energy requirements it is necessary to switch to renewable energy. There is huge demand for renewable energy as it is cheaper and easy to make. Wind turbines are great source of renewable energy but in some areas wind speed can be an issue, and due to less wind speed wind turbines can not function properly. Therefore by increasing wind speed through a diffuser can be helpful by mounting it on top of wind turbine which can further increase the speed of wind thus generating more power. In this paper I have defined two alternatives for wind energy which are CWT (conventional wind turbine) and DAWT (diffuser augmented wind turbine) which are (*figure 3* and *figure 2)* respectively. I have analysed DAWT, proved that inlet velocity increases in a DAWT through Ansys Fluent and made a comparison using *MCDA* (Multi criterion decision analysis) to point out which turbine has more advantage in power production , emission reductions , noise cancelation , manufacturing cost, maintenance cost etc, and overall which is more sustainable. . This paper illustrates the life cycle of diffuser augmented wind turbine (DAWT). By using a diffuser on a wind turbine we can increase the wind velocity hitting the blades , reduce noise , decrease vortexes (air leaving through sideways) and generate more electricity per cost , and at last , generate better Power Coefficient (*Cp*) than a regular wind turbine. There can be lot of further improvements in DAWT (diffuser augmented wind turbine) by changing its materials to recyclable materials which helps in reuse of the wind turbines materials from a decommissioned wind turbine. We can even put Solar panels on diffuser to make it hybrid model of electricity generation as both solar and wind can be used in such a model.

Introduction

Operation of DAWT is similar to wind turbine but it has diffuser which creates a region of high and low pressure. This difference is because of two vacuums are created. There are two vacuum one in front of inlet face of DAWT and Vacuum 2 is at exit (outlet), *P1* is the high pressure region in *figure* 1 and *P2* is the low pressure region by Momentum theory and due to this pressure difference it creates it creates a vacuum which makes the air flow from high to low pressure area which increases the wind speed *V1*, which in turn gives more wind flux hitting per blade. It increases power generated by rotor as $P \propto V$^3 for a wind turbine where *p* is Power and *v* is velocity, so it generates more wind speed which gives more power. There have been many studies which proves that ducted wind turbine generates more power. "The analysis results showed that enclosing this turbine in a duct increases power 2-3 times of unducted turbine" (wang et al., 2013) and many other research papers proves this theory. To prove this theory *DAWT design in Figure 2* has been designed. Many simulations were carried out in ansys which are explained in *Project Alternative* and data was collected to determine which turbine can generate more power Further more their advantages and disadvantages are discussed and *MCDA* is used to find best alternative. In methodology Life Cycle assessment and sustainability optimization are performed for DAWT. It prevents air leaking from sideways which generate noise and heat and it uses that energy to increase wind speed where as in normal wind turbine these vortex produces air leakage which results in noise and loss of energy. There are numerous designs and CFD simulations which proves that diffuser can increase inlet velocity due to low pressure region created by it. .

Project Alternatives

Conventional wind turbine (CWT) Vs Diffuser augmented wind turbine (DAWT)

Figure 2 was used in Ansys to determine if the diffuser can increase inlet velocity hitting the blade , so that power generated is enhanced as $P \propto V^3$.

For reference , inlet velocity was taken as 8 Km/h which is 2.2 m/s and pressure 1 atm. To determine velocity hitting the blade Ansys Fluent was used. First design was created in solid works and it was meshed in Ansys fluent. Boundary conditions were for pressure was 1 atm . we can see that diffuser increased the inlet velocity to 4.4 m/s in *figure 5.*

So for *Alternative 1* (CWT)

V=2.2 m/s (no increment)

$P \propto (2.2v)^3$ which is equal to $p \propto 10.6v^3$

For *Alternative 2* (DAWT)

Initial velocity (Vo)= 2.2 m/s

Increment velocity = 4.4 m/s from *figure 5*

$P \propto (4.4)^3$ *which is equal to* $P \propto 85.1v^3$ Which can be interpreted as power is increased by 8 times in this particular case. This shows that diffuser can increase inlet velocity and it can be installed at regions with low wind speed. Although this gives us insight of how a velocity can have impact on turbine and further more advantages and disadvantages for both the alternatives are discussed.

Advantages and disadvantages for both the alternatives

Alternative 1

Conventional wind turbine (CWT)

Advantages

1. CWT uses less manufacturing material than DAWT because of diffuser.

2. It has less maintenance cost because it does not have diffuser.
3. It's installation process is cheaper than DAWT.
4. It uses less space in a wind farm rather than DAWT.
5. It uses less material in electroplating or galvanization to prevent corrosion as it does not have diffuser.

Disadvantages

1. CWT has less power factor than DAWT as explained by Wood et al., (2018) " The DAWT power was a factor between 2 and 5 larger than that of a bare wind turbine with the same blade diameter and wind speed."
2. CWT produces less electricity per cost because of power generated is less than DAWT as $P \propto V^3$.
3. It produces noise because of vortices, "A turbine will have a sound pressure level of 43 decibels." (General Electrics, 2013). Due to this it can a negative impact on its surroundings and it will affect local residents.
4. It has more flickering ratio than DAWT because of open profile of blades.

Alternative 2

Diffuser augmented wind turbine (DAWT)

Advantages

1. "The DAWT power was a factor between 2 and 5 larger than that of a bare wind turbine with the same blade diameter and wind speed" (Wood et al., (2018)). This is the only main advantage over CWT because DAWT produces more electricity per cost because of this enhanced velocity flow.

2. DAWT produces less noise as it traps vortices. It reduces tip vortex because of physical barrier of diffuser.It prevents air leaking from sideways due to physical barrier. So it has less negative impact than CWT on it's surroundings and better societal acceptance.
3. It has less flickering ratio than CWT because of close geometry so it has better societal impact.
4. "The ducted turbine's blade had a higher axial force than the conventional at the same V and the same λ" (Ramayee et al., (2021)). It is because of pressure gradient which is generated by vacuum at both inlet and outlet as explained in *figure 1*

Disadvantages

1. Because of Diffuser, It increases raw materials which are required for manufacturing and it become economically difficult to afford DAWT because of specific raw materials required for diffuser specifically which is made up of glass, steel and plastic.
2. It requires more maintenance cost because of diffuser.
3. It has a very expensive installation process because of diffuser.
4. It requires more space in a wind farm because of its parameter which is larger than CWT
5. It uses more material in electroplating to prevent corrosion and dislocations inside the blade and diffuser element. To prevent dislocations and corrosion more galvanization is required on surface area which is economically not affordable.

MCDA (Multi criterion decision analysis) For Both the alternatives

It is performed on both alternatives to find which one is best in terms of every indicator which are defined in *MCDA matrix* in *Table 1*. Preference scores are given for each indicator for both of the alternatives out of 5. Preference score determines which indicators are better in each category for example raw materials are needed less in CWT so it has more preference score than DAWT because it is more preferred than other alternative, similar to this process other indicators are defined in *Table 1* and their preference scores are defined. Manufacturing cost, transportation cost, maintenance cost and installation cost for a DAWT increases because of diffuser due to this it's preference score decreases in every category. Finally index (∑ of all the preference scores) is calculated for all the preference scores for both alternatives and it is found that Alternative 1 (CWT) has more index than Alternative 2 (DAWT). Alternative 1 (CWT) has index of 32 and Alternative 2 (DAWT) has index of 27.

This illustrate that alternative 1 is better than alternative 2. Despite having better Velocity profile in *figure 5*, DAWT fails in achieving best alternative in *MCDA Matrix.*

Methodology

Although DAWT failed to achieve better index than CWT in table 1, we can make modifications to DAWT so it have better index than CWT in *MCDA matrix*. To do this we need to increase the preference scores for *DAWT* which are in *table 1*. A diagram for *LCA* has been purposed in *figure 4.* Main focus of the LCA is to increase the preference scores for each indicator in MCDA matrix. It should have more recyclable materials with glass, steel and plastic so they can be reused from a decommissioned wind turbine, making it beneficial for industry and environment because it will cut down use of raw materials which can not be reused and they result in landfills of wind turbine blades. Although it needs more materials because of diffuser but using recycle material can will increase preference score. Indicator 2 which is design effectiveness, it means that enhancing the design of a diffuser can lead to better results than CWT in *Table.* There are many studies which defines the area of inlet and outlet of a diffuser and it's length are key factor in increasing inlet velocity. "The numerical result showed that locating the step at the outlet of duct increased wind velocity more than other positions"(Alqu et al., (2019)). It shows that changing the design of a diffuser can have more impact rather than changing geometry for *CWT.* To decrease manufacturing cost in *table* 1 we need to do create manufacturing optimizations as defined in LCA diagram in *figure 4*. Like these we need to increase the preference scores for each indicator defined in *table 1*. We need to decrease transportation cost. We can do it by using installation on site, by transporting sub parts for *DAWT* including diffuser we can cut down costs for installation and transport thus we can increase preference scores for these indicators. Finally we need to make sure that every step in *figure 5* is followed in contrast with socio, economical and environment concerns. To maintain sustainability , we need to make sure these three (triple bottom line) are recognized at every step of a process in LCA. This can help us in achieving sustainability from selection of raw materials to decommissioning of a turbine. Thus it has potential to become better alternative than *CWT* if all the indicators have better preference score in *table 1.*

Conclusion

From the discussion above we can analyze that DAWT is not a good alternative as compared to CWT because it is not economically feasible to manufacture such a wind turbine but if the preference scores are increased for every indicator in *Table* 1 for DAWT by using Life cycle assessment tool, it can be better alternative to CWT. We need to make sure socio, eco and environmental aspects are covered throughout entire life cycle of the DAWT. By doing this it can have better index in MCDA matrix in *table 1* . Thus there are many areas which needs to be researched like selection of raw materials which are recyclable and how to cut down costs for manufacturing and other process. Diffuser design can be changed so it have better inlet velocity profile. We can even install solar panels on diffuser to make it a hybrid model for a renewable energy.

Figure 1

Air Flow through a diffuser

V0 = initial velocity

V1= velocity hitting the blades

V2= exit velocity

Po = atmospheric pressure

P1 = pressure at blades

P2= pressure at oulet

P3= pressure at exit

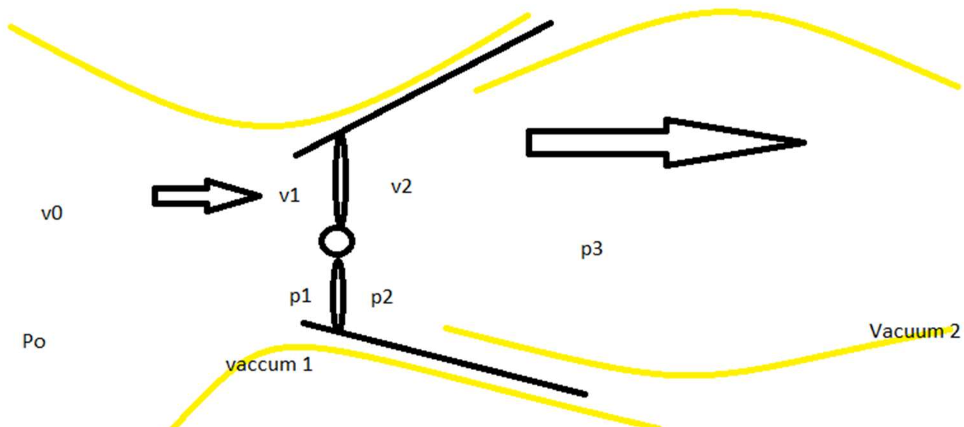

Figure 2

Diffuser augmented wind turbine (DAWT) design

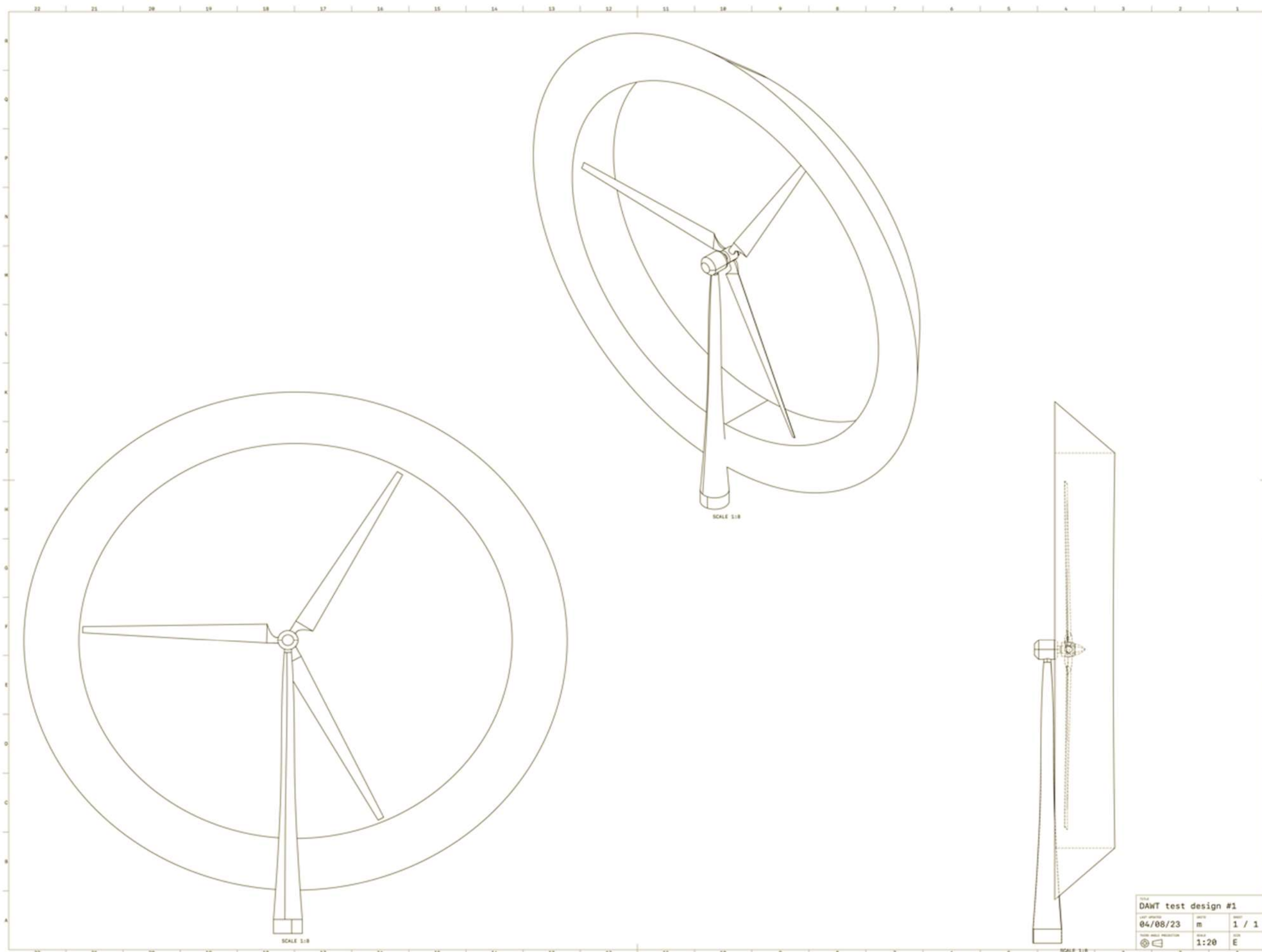

Figure 3

Conventional wind turbine

Figure 4

LIFE CYCLE ASSESSMENT for DAWT

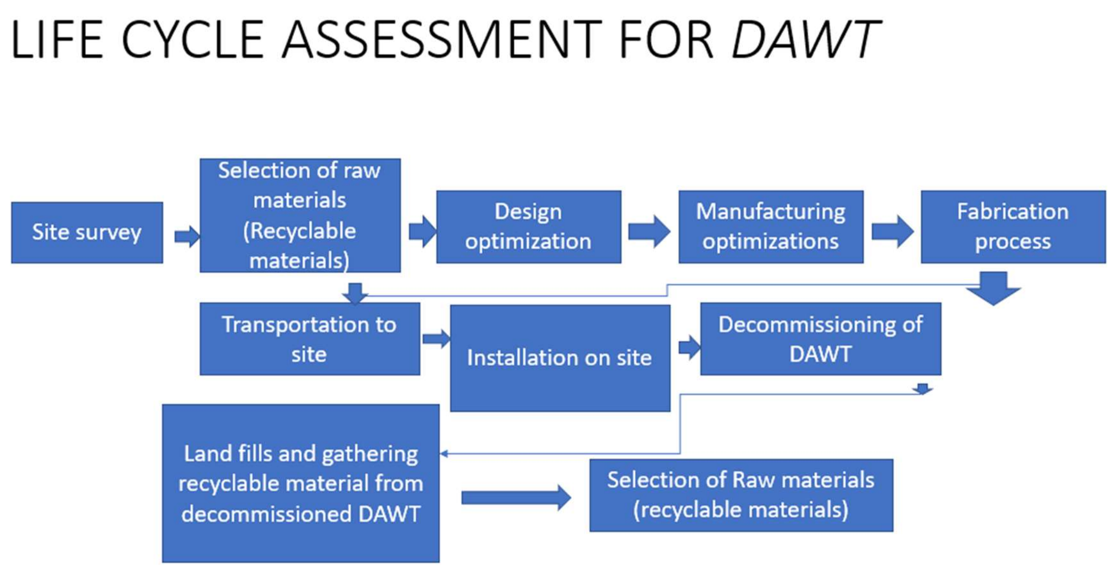

Figure 5

Velocity contour for inlet in Ansys fluent

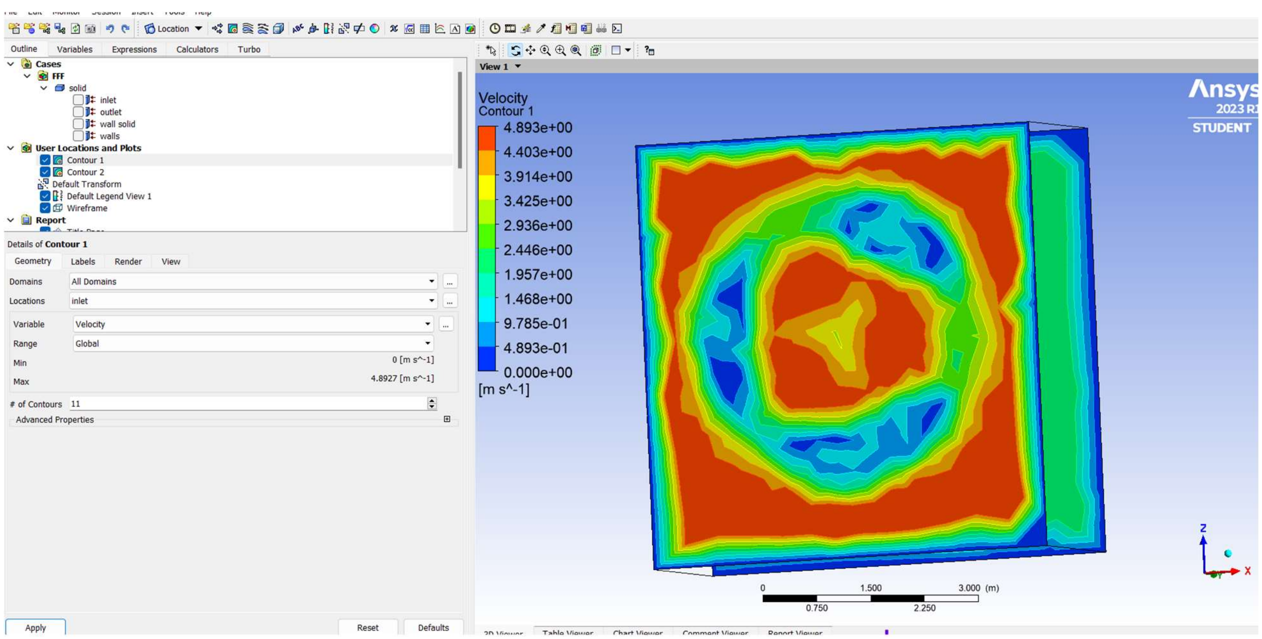

Figure 6

Velocity contour for outlet in Ansys fluent

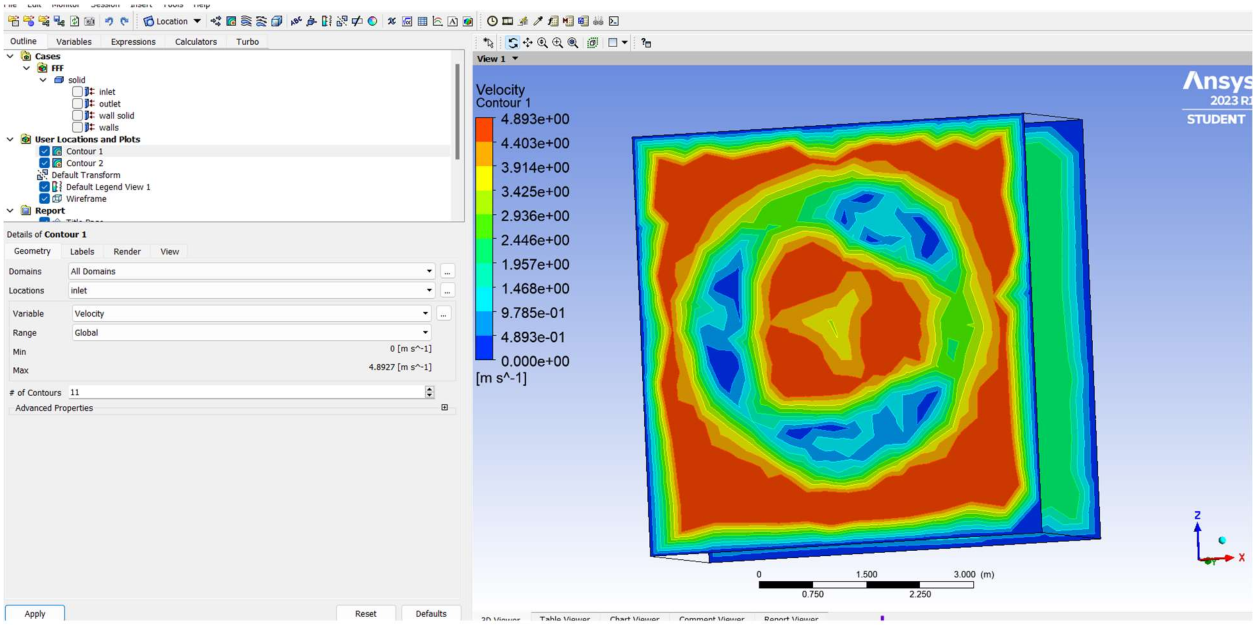

Table 1

MCDA (Multi criterion decision analysis)

Indicators	Alternative1 (*CWT*)	Alternative 2(*DAWT*)	Preference score out of 5 For Alternative 1 *CWT*	For Alternative 2 *DAWT*
Raw Materials	Less	More	4	2
Designs Optimization Effectivenss	Less	More	3	4
Manufacturing cost	Less	More	5	2
Transportation Cost	Less	More	3	2
Installation Cost	Less	More	3	1
Emissions from Manufacturing process	less	more	4	2
Society acceptance score Based on Flickering & noise	less	more	2	4
Maintainance cost	Less	More	3	2
Recyclable ablity	Less	More	2	3
Power Generation , Cp	Less	More	3	5
		∑ preference score (Index)	32	27

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Appendix

Softwires used for analysis and design

Design – Catia V5

Analysis- Ansys fluent

Equations

1. $Q=AV$ – Momentum theory