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Energy recovery from exhaust air of textile industry

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Abstract: A system to recover part of the energy of exhaust air from an axial fan of 75kW using a Horizontal Axis Wind Turbine is discussed in this paper. The actual air data at the fan outlet are collected from central air conditioning station of a composite textile mill (Kombolcha Textile Share Company) using log-Tchebycheff method. Since the air flow type determines the steps in progress the air flow type is arithmetically found to be fully turbulent. A duct is designed to correct the air turbulence and transport the exhaust air from the fan to the turbine. The enclosure duct design is developed in consideration of the actual situation of the company to attain a fully developed region where the air speed attains a uniform velocity profile and create a venturi effect (to increase the air speed) for better energy output and guide the air before it interacts with the wind turbine blades. By turning what was exhausted to useable form 5.7kW of electric power can be harvested. As there are vast application areas of industrial air system, utilizing the exhaust from such air systems as energy resource could be helpful and used as supplementary power for industry production floor lighting and little power supply requiring auxiliary processes.

Keywords: Exhaust Air, Wind Turbine, Energy Recovery, Clean Energy

1. Introduction

Currently alternative energy supply is becoming a pressing issue due to the exponential rise of energy price. Power regenerating plant implementation seems to be the compulsory solutions to cover the growing demand of electricity; furthermore the trend of increasing environmental concern regarding energy related emissions is also becoming one of the driving force for power regenerating plant implementation and with this regard some decades has passed since trials on invention and improvement of air operated power units begun. Interest in waste recovery for energy generation can be traced back to the 1970's energy crisis when there was an external pressure, especially in certain sectors of industry to reduce energy costs as the price of oil rose significantly due to the energy crisis of 1973 [1]. 40 years on, there is renewed interest in the capture of waste energy for reuse. In this era of manmade climate change, the spirit of peak oil and concerns surrounding security of energy supply, the need for maximizing the amount of energy utilized per cents spent is considered more pressing than ever. Regarding power generation, approximately 95% of Ethiopia's current electrical energy supply is generated from hydropower, with the rest 5% supplied by temporary diesel generators. Although Ethiopia is said to have a national hydro power potential of 45,000 MW; in times of drought and during pick demand, hydro power is unable to supply enough electricity to users. Additionally, recent energy demand studies show that under the current economic development Ethiopia will need a 38-fold electricity supply increase by 2030 [2]. Facing this domestic but also the growing export demand shortfall the Government of Ethiopia (GoE) has recognized the need for diversification of power generation. A feed-in tariff bill is also currently discussed in order to offer an attractive environment for independent power producers and private investors [3].

Despite regulatory, planning and energy cost considerations, waste energy recovery is not yet uniformly implemented globally or across all industrial sectors.

The main business model for recovering energy from waste is to reduce the energy consumption that a business incurs directly. By using the available energy inside the business to reduce expenditure on energy from external sources and thereby increase the overall energy efficiency of the business.

Energy usage in the industrial sector in Ethiopia today represents about 40% of the installed potential and a substantial part of that is related to support processes such as heating, ventilation and cooling systems. These systems especially in textile industries are vital as they are directly related both to indoor production floor climate management and to the health of the occupant workers and as well as energy cost. The ventilation and cooling processes are highly related to utilization of constant volume machines (fans) which move the same volumetric flow rate of air irrespective of the air density. From the different classes of fans the axial type high volume industrial fan only is considered for this work.

Small scale wind turbine categories with rated capacity of less than 100 KW and rotor diameters between 0.58m and 6.4m for a typical household application of average annual electricity demand of about 10,000KWh on a site with an average wind speed of about 5.5m/s has been short listed for better performance and identified for application.

Generally this paper deals with case study of utilizing the exhaust air from Kombolcha textile industry for driving a small wind turbine. The specific approaches that have been used to perform this work are:

Firstly, the actual air speed data at the fan outlet are collected using log-Tchebycheff method developed by Cooling Tower Institute (CTI), and the calculated average speed value, volume flow rate, and flow type are identified.

Secondly, with the identified flow type and air velocity profile duct size design is developed and with this duct orientation the possible best fitting small size wind turbine is set and the expected power output is calculated. And finally solidwork software has been used to analyse the air flow pressure contour in the pipe.

2. Measured Data Values and Analysis

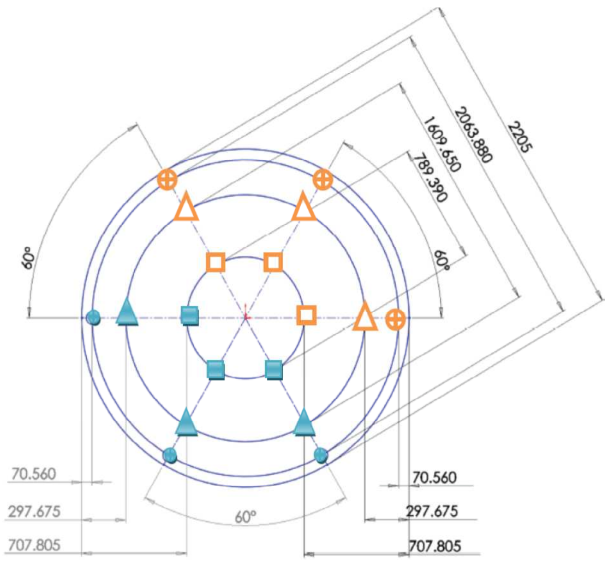

Figure 1. Location of measuring points when traversing a round duct. (Dimensions in mm)

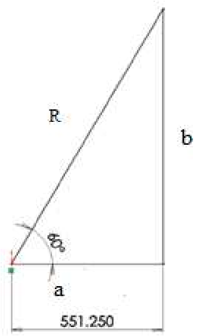

Figure 2. Traverse line marking angle

The air speed V_{outlet} was calculated by averaging 6 velocities taken over a diameter oriented at 60 degrees interval around the circle. In this paper the circular duct is divided into 3 concentric parts of equal area, 18 points has been measured using vane anemometer as shown in Fig. 1.

Based on the log-Tchebycheff method [4] the traverse lines at which the air speed measured are find by the geometry made over the outlet of the fan as shown in Fig. 2 below. In dividing the fan outlet in to 6 sectors of 60^0 each a measure of a right angle triangle with legs ‘a’ and ‘b’ and a hypotenuse ‘R’ are marked considering the horizontal traversing line as a reference over which leg ‘a’ lie on.

2.1. Air Speed Analysis

The natural wind speed is constantly changing and it is influenced by so many factors that make it complicated to model exactly. The annual average wind speed gives an indication about the potential power that can be developed from a particular site, on a shorter time basis, the distribution of wind speeds around the mean is extremely important [5].

Unlike natural wind speed distribution calculated as a Weibull probability density function [6],the fan exhaust air speed distribution observed over the exit duct diameter is calculated as an average as per the method which was developed and seen earlier. Reading data at those points was taken in two rounds with 30 seconds duration over a single point, totally 36 times and the difference observed between the values at each point was insignificant and is summarized in to one as shown below in Table 1.Based on the data in the table below average attainable air speed at the fan exit is 15.719m/s. Data and Plots of the wind speed distribution over the fan exit diameter are shown in Table 1 and Fig.3 respectively.

2.2. System Description

Achieving the corrected velocity profile at the fan exit have an impact both for power regenerating device and on fan performance itself; hence correcting the velocity profile is very crucial in air moving & operating machines.

Table 1. *Wind data over fan exit diameter*

Location along the diameter measured from the inner wall	Air Speed (m/s)			
	North West- south East	North East-South West	East-West	Average
70.56 (0.032D)	24.05	36.53	37.985	32.9
297.675 (0.135D)	20.49	25.495	15.455	20.5
707.805 (0.321D)	2.825	2.845	1.92	2.5
1497.195 (0.679D)	1.82	3.27	2.27	2.5
1907.325 (0.865D)	14.87	10.795	13.61	13.1
2134.44 (0.968D)	25.335	23.81	19.57	22.9
Overall Average Air speed (m/s)				15.719

As per Air Movement and Control Association of American Standard Association (AMCA) the 100 percent-effective duct length (a straight duct length on the discharge side of a fan) in order to achieve a uniform velocity profile basically is a function of the fan exit diameter and the average air velocity[7].

$$E_l = D_d(3094.29/1000) \quad (1)$$

Where: E_l is effective duct length and D_d is discharge diameter

As shown in fig.3below the cylindrical part of the duct is 6.8m and the constricted part of the duct before it reach the fresh air inlet fan is 0.7m, hence for this total length of 7.5m duct is required to let the air reach the turbine.

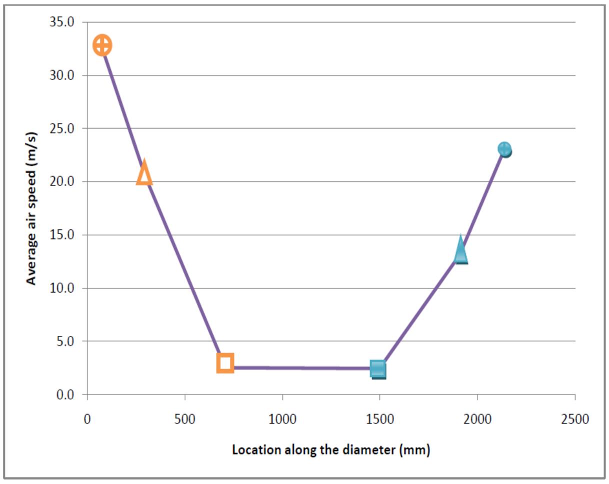

Figure 3. *Wind speed distribution over fan exit diameter*

For proper functioning and less system effect, fan installation manuals [8] allow a gap at least equal to one fan diameter between the fan intake and nearby obstructions. So the design was developed in consideration for better power output and the proper functioning of the next step (fresh air inlet). The gap between end of the outlet duct and the fresh air inlet fan in this system design is 1.186m.

3. Working Principles

This innovative system design of an energy recovery system is to reuse the released air from an exhaust fan outlet to produce electricity. It is done by installing horizontal axis wind turbine (HAWT) that is integrated with an enclosure in front of the outlet of an exhaust air fan. Fig.4 depicts the arrangement of the designed system. In order to capture the wind blowing from the axial fan (whose axis horizontally lying fan), the turbine is installed over a vertical tower in front of an axial fan the exhaust air from fan is led to flow through a circular duct of fan outlet diameter size. The duct arrangement and shape is in particular designed to guide, correct the velocity profile and make a venture effect to increase the air speed for better output. For these purposes the duct is aimed to be cylindrical on the first part just at the fan outlet and partly conical downstream along the flow direction for the venturi effect. Various types of HAWTs that are available from the market can be used in this system.

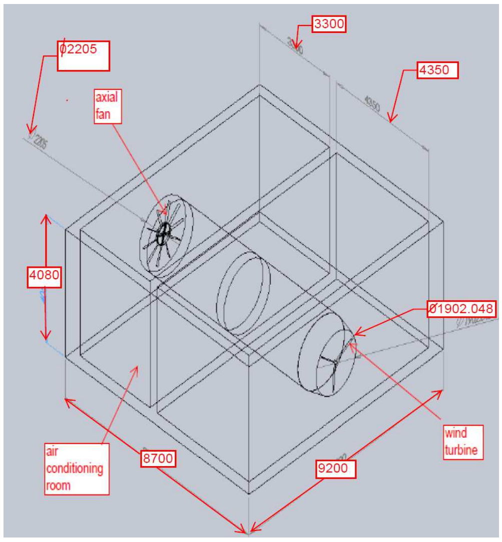

Figure 4. *System assemblies for energy generation in front of the exhaust air fan (Dimensions in mm)*

Any type of HAWT to be selected going to be positioned at a predefined orientation in front of the corrected exhaust air outlet to ensure zero or minimum negative impact on the performance of an exhaust air system (fan) while capturing maximum air flow. The effective duct length (a straight duct length on the discharge side of a fan in order to achieve a uniform velocity profile) as calculated by using (1) becomes 6.8m. Basically it is a function of the fan exit diameter and the average air velocity.

Once the uniform velocity profile is achieved considering the flowing air to have a constant density from continuity equation (2) of fluid flow the velocity values can be calculated at any flowing diameter in the duct, especially

$$A_1V_1 = A_2V_2 \quad (2)$$

when the duct diameter gets decreased the velocity increased which in turn lets the power output to be raised to the velocity increment exponent of three as shown in fig.5.

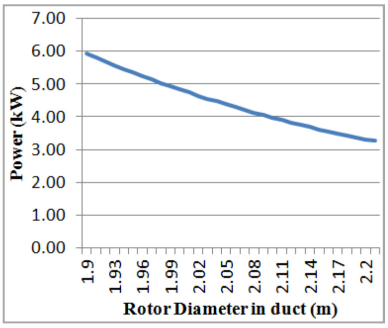

Figure 5. *Actual power output values of the constricted duct part*

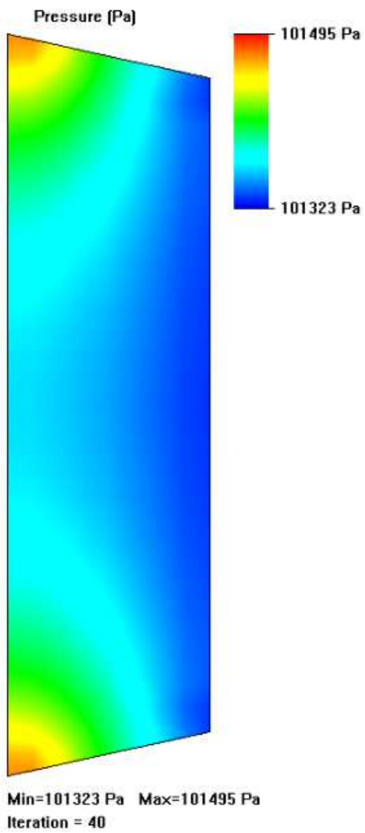

Figure 6. *Pressure contour of the flowing air in the constricted part of the duct*

The analysis was carried out on a solid work software fluid flow analysis work bench. Using the 0.7m long constricted part of the duct and the attained pressure contour shown in fig. 6 indicates that the pressure distribution on the outlet of the duct is uniformly distributed and hence the stress on the turbine blades would be uniform.

4. Results and Discussion

The proposed design is to recover part of the energy available in the exhaust air of the fan without causing negative impact on the performance of the exhaust fan.

Based on the initial set-up the air speed at the outlet of the fan was only 15.719 m/s but with the duct mounted at the outlet the exiting air speed reaches 20.7m/s which would raise the extracted ideal power from 5.04 to 9.15kW. For practical wind turbine, the maximum C_p value is in the range of 0.2 to 0.45[9]. With an average power coefficient value of turbines with this diameter available on the market estimated up to 37.5% and hence the attainable mechanical wind power (P_w) goes to

P_w= Theoretical wind power at 59.3% * (available turbine power coefficient/Ideal efficiency)

$$P_w = 5.8\text{kW}$$

The electric power output from the wind turbine can be obtained as:

$$P_e = C_p \eta_g P_w \quad (3)$$

Where:-$P_w = {}^1\!/_2\, C_p\, \rho\, A\, V^3$ and

η_g is the generator efficiency

Based on the estimated electrical generator efficiency of 98% the electric power output [10] the electrical power output will be then:

$$P_e = \eta_g\left({}^1\!/_2\, C_p \rho\, A\, V^3\right) \quad (4)$$

$$P_e = 5.7\text{kW}$$

4.1. Yearly Energy Yield from the Fan

$$Energytobesavedbyregeneration = N_d N_h P \quad (5)$$

$$E = [N_d - ((M_h * N_w)/N_h)] * N_h * P_w$$

Where:-

Nd= No. Of Working days per year = 360

N_h= No. Of Working hours per day = 24

M_h= weekly maintenance hours =3

N_w= No. of weeks per year =52

P_w = Wind power at Cp value of 37.5%

E = Yearly generated energy

$$E = \left[360 - \left(\frac{3 \text{ X } 52}{24}\right)\right] \text{ X } 24 \text{ X } 5.7\text{kW}$$

E = 48358.8kWh

E = 48.36MWh

Data found from the company in consideration to the weaving section shows that the overall loss due to electricity and electrical parts failure is 7.2%; out of this a 1% estimate is electrical down time due to power cut which could make the fan not to operate and the calculated value yearly generated energy from the fan using (4) goes to 47.88MWh.

4.2. Saving Over the Turbine Service Year

$$\text{Saving over the turbine service years} = (\text{existing power tariff} - \text{cost per kilowatthour})\ X$$

$$\text{generated power in the life span} = (0.569 - 0.194)$$
Birr/kWh X (20 X 353.5 X 24 X 5) kWh = 318,150 Birr over the life span

With this energy regeneration system the company would save its power payment every year by 15,059.1Birr, hence from the existing room lighting lamp distribution of weaving section
= (0.036kW/lamp X 378 lamps X 24hr X (353.5days/yr0.5691Br/kWh = 65,691.2Br/yr

Thus the overall economic analysis indicates that using this recovery system the electrical power cost the company paying for the weaving room lighting lamp distribution would be covered by 23%.

5. Conclusion

Industries are using air for different purposes and the used air is partially or completely removed from the working floor using exhaust fans. In Kombolcha Textile Share Company weaving section 216,000 m^3/hr of air is removed using axial fans. This paper is dealing to analyze the viability of recovering power from industrial exhaust fan. Based on the analysis 5.7kW of electricity could be produced from a single fan of 216,000m^3/hr capacity. Laten LT6.4 type horizontal axis wind turbine manufactured in China was chosen based on the 37% power coefficient value it has and least price and for it is a perfect wind turbine in domestic or light commercial applications, ideally suited to battery charging, grid supply and hybrid configuration.

The enclosure design is optimized to create a venturi effect and guide the air stream to interact with the wind turbine blades. The enclosure venturi effect significantly improves the air speed from 15.426 m/s to 20.776 m/s. Furthermore it could act as a protective cover to the entire system. Due to the simplicity of the design, this energy recovery system can be applicable to any exhaust air systems with minimum cost, minimum system effect on the fan and minimum noise impact.

The implementation of this energy recovery system is possible to conserve power consumption by the fan up to 7.6%. With this the company can attain a total of 318,150 Birr from a single exhaust fan over the life span of wind turbine. This energy recovery system has a fast payback period. As there are numerous usages of exhaust air system globally out puts from such air conditioning systems can directly be used as supplementary electric power for working floors or fed into the electric grid.

Unlike the conventional natural wind the air speed from such air moving machines/fans/ can be attained without fail as the fans are constant speed air devices and hence consideration of capacity coefficient to estimate the percentage of the time that the wind will be at the rated speed is not required. Further in utilizing exhaust air energy recovery for wind turbine driving there would be no need to have an over speed controller as only very small or no rotational speed fluctuation is experienced and this feature can increase the durability of the turbine due to less fatigue experienced and also minimize the turbine cost for there is no speed controller needed. The change in air speed with height would also be not an issue since a known constant air speed value from fan can be attained without dependence of the tower height and hence minimize the cost for tower and installation so an estimate for the small wind turbines cost will be minimized a lot. Furthermore the stability of the system is more secured due to its very short tower height.

Acknowledgments

Glory to the ALMIGHTY GOD!

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References

[1] Reay, D. 1979. Heat recovery systems –Adirectory of equipment and techniques.E&F N Spon Ltd.

[2] Solar and Wind Energy Utilization andProject Development ScenariosOctober 2007

[3] Federal Democratic Republic of EthiopiaMinistry of Water and Energy Scaling upRenewable Energy Program EthiopiaInvestment Plan, January 2012.

[4] TSI AIR FLOW Instruments Ltd.[online]. Available at: http://www.airflowinstruments.co.uk [accessed 21st April 2013]

[5] Chaniotakis, E. (2001), MSc. Thesis on Energy Systems and the Environment, Department of Mechanical Engineering University of Strathclyde

[6] A study on weibull distribution for estimating The parameters (Paritosh BHATTACHARYA CEM, Kolaghat, Midnapore, India)

[7] Johnson, G. L., 1986. Wind Energy Systems, Prentice – Hall Inc, New Jersey, USA. p1-3.

[8] Installation do's and dont's©FANTECH2008.

[9] Jagstorf B. Renewable Engineering and Development, Brochure toaccompany mobile exhibition on renewable engineering in Ethiopia, Factorfour Energy projects GmbH

[10] Agbeko, E.K, 2005. MSc thesis on Small Scale Wind Turbines, University of Strathclyde, Department of Mechanical Engineering.