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Ventilator Turbine Model Application to the Mosque Tower's Dome as Electricity Generator

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Abstract. Dome of the mosque tower with an altitude of over 40 meters above the ground surface is getting strong winds, and it is commonly and widely applied to the mosque in Indonesia. The wind can be used to rotate the dome of the mosque tower as turbine ventilator. This paper develops a turbine ventilator model for mosque tower's domes that eventually can generate electricity. Dome tower constructed as turbine model, by the size of a ventilator, 1250 mm and a stator shaft shaped solid and hollow. These two shafts are connected to the bearing, while turbine blades are connected to the hollow. The speed of the turbine ventilator model of the mosque tower's domes is caused by the wind that rotates the turbine blade. The test is done by using a wind tunnel equipped with an axial fan at its end. When the turbine rotates, the hollow which is paired with a gear at its end has a ratio of 4:1, and is accelerated the rotation of the DC generator shaft. At a wind speed of 3m/s, it produces a turbine rotation of 720 rpm, and the generator shaft rotation is 2880 rpm. The output current is 98 A. When the wind speed is increased to 5m/s, the turbine rotation increases to 1300 rpm, the rotation on the DC generator shaft increases to 5200 rpm. The output voltage and current are 42 Volt and 130 A, respectively. Both the output voltage and current are adequately generating electricity for several lightings in the mosque.

Keywords: *Turbine ventilator, mosque tower's dome, DC generator, electricity.*

1. Introduction

Indonesia is a country located in the tropics, Indonesia only has 2 seasons, with an average length of 6 months per season. The dry season generally takes place around May-October. In this season, the air temperature tends to be quite hot, which is around 28°-34°C during the day, for the Aceh region where the research is carried out the temperature can reach 30°-35°C. While at night, the air temperature will drop around 21°-25°C. In this season, the wind can blow at speeds of 2-11.12 m/s [1]. Because of the increase in temperature this season, many factories and housing are applying turbine ventilators to reduce the temperature in the room [Figure 1 and 2], the use of a turbine ventilator as a tool to reduce indoor temperatures can save electricity costs because it does not use electricity as the driver.

Wind energy is an indirect form of solar energy because wind is affected by uneven heating from the earth's crust by the sun. This energy is renewable energy and can be adopted for various uses such as for pumping water, moving sailing vessels, and generating electricity. The use of wind energy as a non-



conventional alternative energy source, especially in developed countries has been widely applied both to produce electricity and mechanical energy. In Germany for example, throughout 2003, 18,500 GWh of energy derived from the wind had been utilized. Wind energy is an environmentally friendly energy source that does not produce exhaust emissions of carbon dioxide emissions. For this moment In Indonesia, wind energy has been used to generate electricity by building a 72 MW windmill power plant in Janeponto, Sulawesi [2].



Figure 1. Rooftop turbine ventilators



Figure 2. Single turbine ventilator

2. Turbine Ventilator

One application of wind energy conversion system is used in turbine ventilators. Basically, turbine ventilator serves to flow hot air from a room to the surrounding environment. Havens modelled turbine ventilators combined with backward curved centrifugal fans and windmills. The rationale is the fact that turbine ventilators capture and use wind power as a wind turbine. This model shows that the ventilator rotation speed as a function of wind speed, then turbine ventilator is made to pump air out of the room.

With inner vane- the experimental study by [3] on the impact of installing inner vane inside the frame of turbine ventilator has confirmed that the added element can help the device to exhaust better. However, the study concluded that the availability of inner vanes inside the turbine ventilator sized 20" (500mm) and 14" (360mm) do not mark significant differences in the ventilation rate induced. According to [3], structural factors in the flow and the imperfect shapes of the inner rotating vanes could be the major factors limiting its performance, which should be taken into consideration when designing a new model of the turbine ventilator [3]. Figure 3 shows a typical configuration of turbine ventilator, while Figure 3(a) is with the inner vane, and Figure 3(b) is without the inner vane.



(a)



(b)

Figure 3. A typical configuration of turbine ventilator (a) with inner vane (b) without inner vane

With Extractor Fan – In ensuring the reliability of the turbine ventilator operation in low-wind velocity condition, one of the most strategies that seem promising is by combining a wind-driven turbine ventilator and solar-powered extractor fan, as shown in Figure 4(a). The prototype 20" (500mm) hybrid solar-wind turbine ventilator developed by [4] by replacing the existing inner vane with 16" (400mm)

PV powered DC inner fan showed that it succeeded to increase the ventilation rate (m^3/s), especially with a rated rotation speed of 1500rpm and at low outdoor wind speed of up to 5m/s. However, in high outdoor wind speed condition, the study showed that the evaluation indicator (inner fan enhancement) was negative; meaning that raising the inner fan rotational could reduce the ventilation fraction. The study also suggested that for the best performance of the device in Taiwan building and factory, the optimum power of PV panels should be 74.76W, charge controller is 3.2A (24V), 10.35 Ah at 24 batteries for one-day storage and at least one dc/ac inverter [4].



Figure 4. Hybrid PV-Wind Powered Turbine Ventilator (a) Illustrative diagram of the prototype device developed in [3], (b) Full-scale model developed in [5]

On the other hand, [5] also developed a hybrid PV-wind turbine ventilator but the main intention is to maximize free flow of air in the absence of sunlight by placing the motor-fan at the upper part of the turbine (Figure 5(b)). In line with [4] result, this study revealed that such combination showed better performance compared to the conventional wind driven turbine ventilator, especially at zero to low wind speeds [6].

In India, [6]. Developing rooftop turbine ventilator (RTV) consist of the stationary part and rotational part. The stationary part is composed of a base and fixed shaft and rotational part are composed of fan blades and bush put on the fixed shaft on the stationary part. The AC generator is connected to the ventilated ball and also connects to an external battery charger to supply the electric current for Light Emitting Diode (LED) lamp [5]. The main component of the system is the auxiliary current generator is showed in Figure 5. It will convert the kinetic energy from the wind to the electricity for use. The generated electricity will go into the AC-DC rectifier to convert it to direct current (DC) voltage.



Figure 5. The main components of system electric power generation by RTV

2.1. The efficiency of Turbine Ventilator, η

The efficiency of turbine ventilator is the comparison between the power produced by turbine ventilator and the total power of wind flow that enters the turbine ventilator. The power of it is calculated using the following equation;

$$P = V \times I \quad (1)$$

Where V is the voltage generated by turbine ventilator (volts), i is the electric current generated by turbine ventilator (Ampere), so the efficiency of turbine ventilator can be calculated using the following equation:

$$\eta = \frac{P}{\rho D^2 U_\infty^3} \quad (2)$$

when p is the power that been distributed by the turbine ventilator (Watt), ρ is air density, (kg/m^3), and D is the diameter of the chimney pipe turbine ventilator (m), and U_∞ is the velocity of air freestream (m/s).

2.2. Strouhal, St Number

In this experiment, the *Strouhal* number is used to represent the angular velocity of the rotation produced by a turbine ventilator. The magnitude of angular velocity can be calculated using the following equation;

$$\omega = \frac{2\pi n}{60} \quad (3)$$

where n is rotation of turbine ventilator (rpm), So that the magnitude of the *Strouhal* numbers is:

$$St = \frac{\omega D}{U_\infty} \quad (4)$$

when ω angular velocity for turbine ventilator (rps), D is the diameter of the chimney pipe turbine ventilator (m), and U_∞ is the velocity of air freestream (m/s).

2.3. Pressure difference coefficient, K_p

The pressure difference coefficient is a representation of the amount of pressure flowing in the inlet and outlet of the chimney turbine ventilator pipe. The greater the pressure difference in the inlet and outlet of the chimney ventilator chimney pipe, the greater the suction-discharge flowing through the chimney pipe of the turbine ventilator. To calculate the difference in static pressure in the turbine ventilator chimney pipe, the static pressure at the chimney inlet and the outlet pipe are calculated first. Static pressure on the chimney pipe turbine ventilator inlet, p_i :

$$p_i = SG_{\text{redoil}} \times \rho_{\text{air}} \times g (h_2 - h_1) \times 2 \times \sin \alpha \quad (5)$$

$$p_o = SG_{\text{redoil}} \times \rho_{\text{air}} \times g (h_2 - h_1) \times 2 \times \sin \alpha \quad (6)$$

when SG_{redoi} is specific gravity from red oil (0,804), ρ_{air} is water density (kg/m^3), g is gravity acceleration (m/s^2), h_1 and h_2 are initial and final reading from Manometer (m), and α is tilt angle of the manometer (m).

So that the difference in static pressure between the inlet and outlet of the turbine ventilator chimney pipe is:

$$\Delta p = p_o - p \quad (7)$$

when P_o is static pressure at the chimney of pipe inlet N/m^2 , the static pressure is at the chimney of pipe outlet (N / m^2). So that the coefficient of pressure difference is calculated using the following equation;

$$K_p = \frac{\Delta p}{\rho U_{\infty}^2} \quad (8)$$

when Δp is the pressure difference between the inlet and outlet of the chimney pipe (N/m^3), ρ is the density of air, (kg / m^3). And U_{∞} is the velocity of air free stream (m/s),

3. Method

3.1. Development of turbine ventilator model dome tower of a mosque

Turbine ventilator used in this study is a turbine dome model of a mosque tower with a diameter of 1500 mm which will be paired at the top of the mosque tower's dome, turbine ventilator works based on the principle of wind speed that hit the blade of the turbine. When the wind hits the blade of the turbine blade, the turbine ventilator will rotate, this it rotation will flow hot air from inside the tower out through the blade of the turbine blade, the turbine rotation other than due to the wind flow that hit the blade of the turbine blade is also due to the difference in indoor temperature outside the room, the turbine rotation will rotate the driving shaft, where at the end of the drive shaft has been paired with pulleys. Pulleys on the drive shaft are connected with pulleys on the electric motor shaft with the help of belt conveyors, the ratio of drive pulleys with pulleys driven is 8:2. The comparison is made to speed up the rotation on the generator shaft. In this paper, the wind speed is generated by a blower placed in a wind tunnel, the wind speed can be adjusted to the settings of the blower.

Figure 6 shows the turbine ventilator model used in this study, this turbine then be placed at the top of the mosque which has a height above 35 meters from the surface of the ground with a wind speed at the top of the tower of at least 3 m / s, turbine ventilator this model has two parts the main one is;

- Turbine ventilator model of the minaret dome as a driving motor
- Motor DC that is driven.

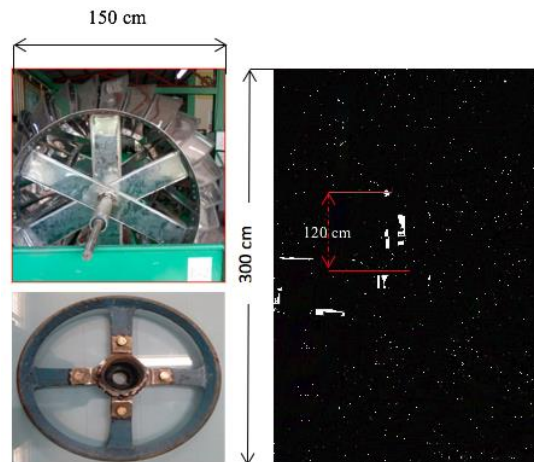


Figure 6. Construction of turbine ventilator model of mosque's dome

There is two rotating principle of a ventilator. the first principle is hydromechanics that can air flow high-temperature area to low-temperature area to motivates blade to rotate. In that time when the turbine is rotating the high-temperature air will be discharged so that the air density in the room can be reduced, then the outdoor cold air enters in the room to achieve the goal. The second principle is the air it relies on the breeze to rotate its blades [7].

3.2. Modelling

Modelling is made using Matlab R2009a platform, with three degrees of freedom as shown in Figure 7. The DC motor data parameters used in this simulation are as follows;

$RA = 2 \text{ Ohm}$ $LA = 0.005 \text{ H}$ $VT = 56 \text{ V}$ $J = 0.5 \text{ Kg/m}^2$
 $K = 0.2388 \text{ V/(A rad/s)}$ $P = 1000 \text{ watt}$ $V \text{ wind} = 5 - 8 \text{ m/s}$
 $N = 300 \text{ Rpm}$

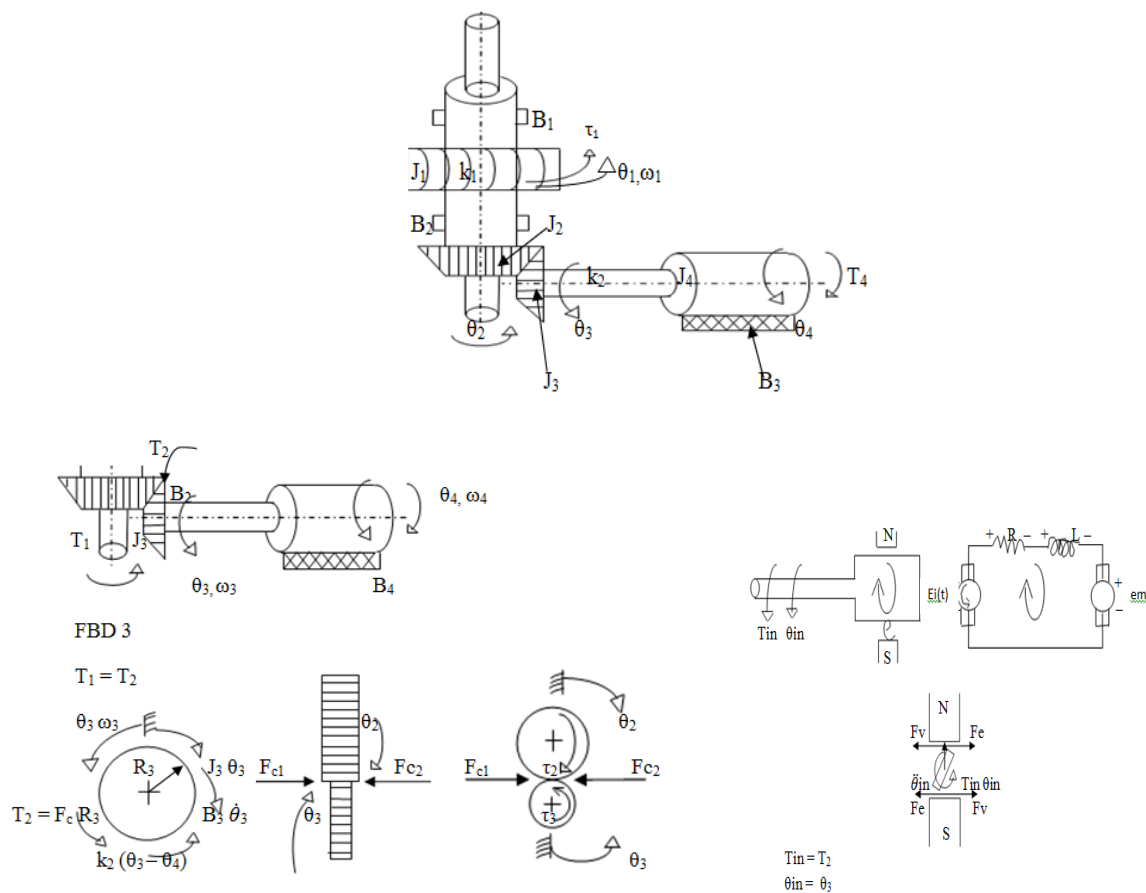


Figure 7. Physical modelling

Furthermore, physical modelling is made in mathematical modelling, so that mathematical equation are obtained in the form of state variable equation 9.

$$\begin{aligned}\dot{\omega}_1 &= \frac{1}{J_1} [-B_1 \omega_1 - k_1 (\theta_1 - \theta_2) + \tau_1(t)] \\ &= \frac{1}{J_1} [-B_1 \omega_1 - k_1 \theta_1 + k_1 \theta_2 + \tau_1(t)] \\ \dot{\omega}_3 &= \frac{1}{J_{3eq}} [-B_{eq} \omega_3 - k_{3eq} \theta_3 + N_1 k_1 \theta_1 + k_2 \theta_4] \\ \dot{\omega}_4 &= -\frac{k_2}{J_4} \theta_3 - \left(\frac{B_4}{J_4} + \frac{\alpha^2}{J_4 R}\right) \omega_3 + \frac{\alpha}{J_4 R} \text{eit}\end{aligned}\quad (9)$$

Based on the equation of the variable state, it can be made in the form of a matrix as follows;

$$\dot{\theta} = 0.\theta_1 + 1.\omega_1 + 0.\dot{\theta}_3 + 0.\dot{\omega}_3 + 0.\dot{\theta}_4 + 0.\omega_4$$

$$\begin{Bmatrix} \dot{\theta}_1 \\ \dot{\omega}_1 \\ \dot{\theta}_3 \\ \dot{\omega}_3 \\ \dot{\theta}_4 \\ \dot{\omega}_4 \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ \frac{-k1}{J1} & \frac{-B1}{w1} & \frac{Nk1}{J1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ \frac{N1K1}{J3eq} & 0 & \frac{K3eq}{J3eq} & 0 & \frac{K2}{J3eq} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & \frac{-K2}{J4} & \left(\frac{B4}{J4} + \frac{\alpha^2}{J4R}\right) & 0 & 0 \end{bmatrix} + \begin{Bmatrix} 0 \\ \tau_1(t) \\ 0 \\ 0 \\ 0 \\ \ell_1(t) \end{Bmatrix}$$

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & \frac{\alpha}{J4R} \end{bmatrix} \quad (10)$$

From the matrix equation above it is changed in the form of block Simulink diagrams shown in Figure 8. Based on the parameters of the DC electric motor parameters and the wind speed notated above are included in the Simulink diagram block.

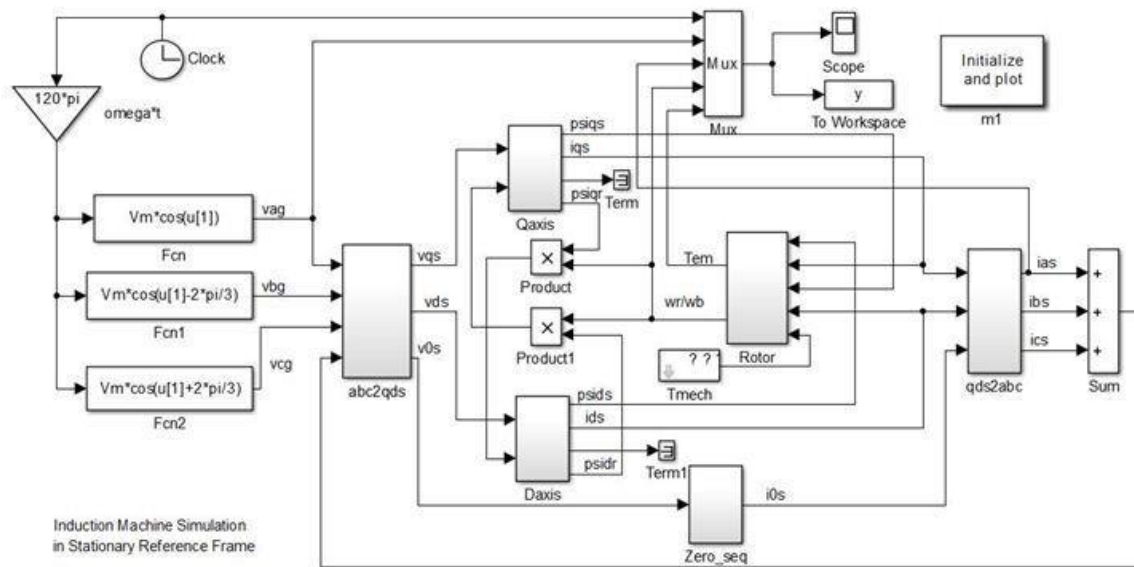


Figure 8. Simulink model of the system

4. Results and Discussion

The desired values, such as current, voltage and motor speed, torque and the resulting power can be monitored through an oscilloscope block or by storing the results of the simulation results into a worksheet and then plotted in the form of a time function graph. Drive simulations in the transient and steady state of the above system can be seen in the following figures. Figure 9 shows the drive response when given the initial step speed, with the motor without loading is 40 rad/s from the stationary state given at $t = 1$ second.

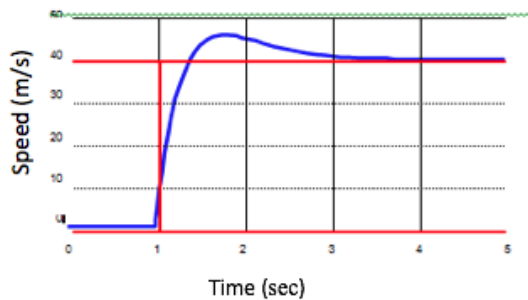


Figure 9. The transient response of the motor is derived from a state of rest

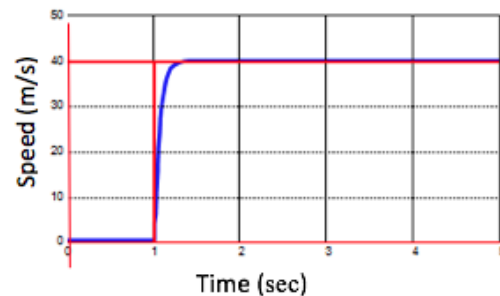


Figure 10. The transient response of the motor is derived from state of idle

The above response shows a bit of overshoot which indicates that the controller parameters can still be tuned to get a slightly better (underdamped) response. More responses are achieved after re-tuning and the results as shown in Figure 10. Based on the Simulink model that has been done in Figure 8, the relationship between wind speed, voltage and electric current is shown in Figure 11.

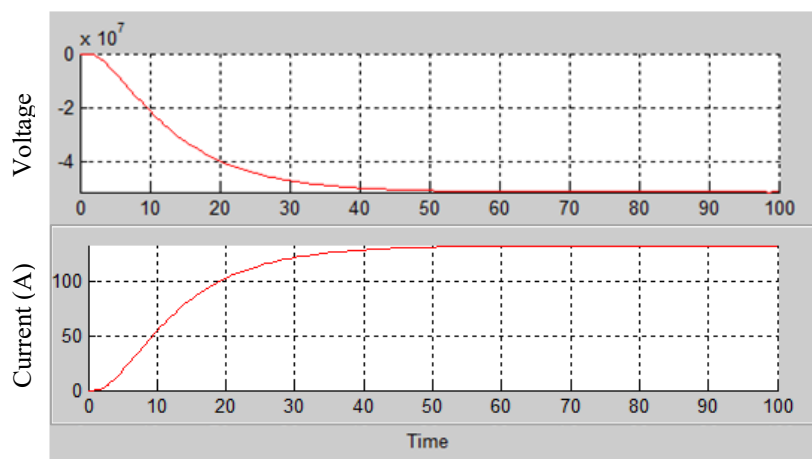


Figure 11. Voltage, Current and time graph

The graph of the relationship between the output voltage and the increase in current with time according to the characteristics of the Generator DC shunt is inversely proportional, the output voltage will decrease within 40 seconds along with the increase in load current at the same time. As a voltage source, the use of this generator is certainly not good, because a generator should have a constant output voltage, but this can be fixed by using a compound DC generator. From Figure 11 the increase in output current will be stable in 50 seconds, which is 130 Volt. The graph of the relationship between the rotation speed of a turbine, torque, and power versus time is shown in Figure 12.

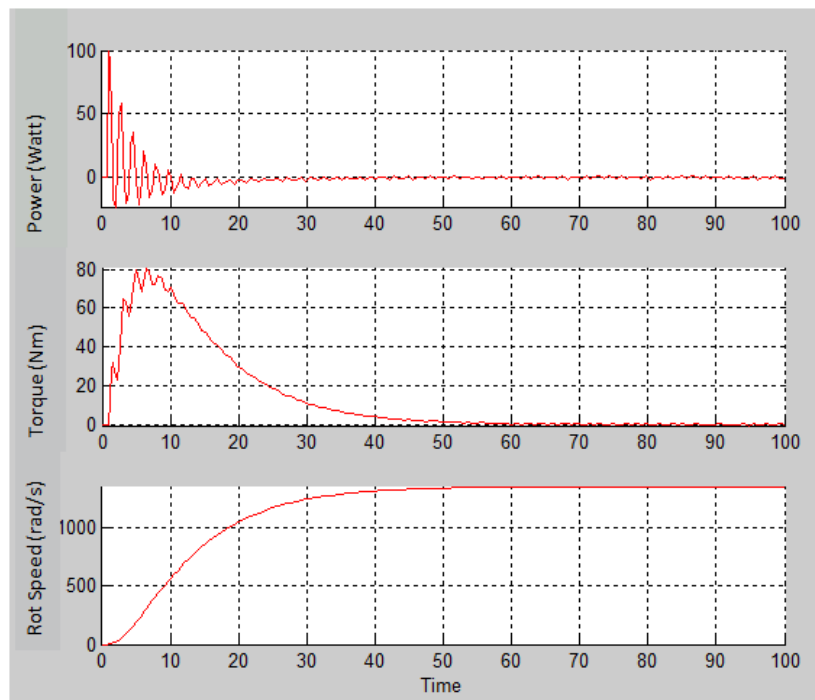


Figure 12. Speed, Torque and power versus time graph

By inputting the wind speed of 5 m/s in the Simulink model above, Figure 12 shows the relationship between power, torque and speed for DC motors versus time. From the graph, it can be seen that the torque is inversely proportional to the speed of rotation, in other words, there is a tradeoff between the torque produced by the motor and the motor rotation speed. DC motor speed will be constant at 1300 rpm in 50 seconds and this is in accordance with the practice. In fact, a constant DC motor speed does not depend on the load (up to a certain torque) after its speed decreases and is therefore suitable for commercial use with a low initial load. Speed can be controlled by installing prisoners in series with dynamo (decreasing speed) or by installing resistors in field currents (increasing speed).

Based on Figure 12, the generator power is directly proportional to the torque produced and inversely proportional to the rotation speed of the generator. The occurrence of a very sharp power surge at the beginning, because the motor requires a lot of power when starting. Then, the power stabilizes after 20 seconds.

5. Conclusion

Turbine ventilators with mosque tower dome models with a diameter of 1500 mm, at wind speeds of 4-5 m/s, capable of turning turbine ventilators up to 1300 rad/s within 50 seconds, and generate electric current up to 130 Ampere. While the biggest torque occurs in less than 10 seconds which is equal to 80 N.m. With a current of 130 Ampere can be used to turn on some lighting lights in the mosque room. Whereas to get the power, even greater voltage and current can be done by increasing the wind speed to 10 m/s. Furthermore, to test the results obtained in this study is valid, being experimentally carried out directly on the real turbine ventilator by entering parameter parameters as in the simulation.

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