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Utilization of Flywheel Generators with Inertial Loads To Produce Optimal Power

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ABSTRACT

The increasing need for electrical energy encourages the development of more efficient alternative energy sources. This study aims to analyze the utilization of flywheel-based electric generators with inertial loads to produce optimal output power. The research method used is an experiment, by testing a flywheel-based electric generator with variations in flywheel mass, namely 26 kg, 28 kg, and 54 kg. Testing is carried out by measuring the rotational speed of the shaft, torque, and output power produced under various operational conditions. The results of the study showed that the use of a flywheel contributed to maintaining the stability of the generator rotation speed, so that the output power produced was more consistent. From the test results, a flywheel with a mass of 26 kg produced an optimal output power of 367.6 W compared to other flywheels. The flywheel is also able to store mechanical energy and release it as needed, increasing system efficiency. The conclusion of this study is that a flywheel-based generator with an inertial load can be a potential solution in the development of more efficient and sustainable alternative power plants.

Keywords: *electric generator, flywheel, inertial load, output power, optimization*

1. INTRODUCTION

The need for energy in the current era is very large due to the rapid development of technology in all fields. Electrical energy can be generated from power generating machines, one of which is the use of electric generators which are now being intensified. New and renewable energy sources in the future will increasingly have a very important role in life. Especially in remote areas that researchers have visited where electrical energy sources are still very minimal, which finally researchers took this research to utilize existing generators. The working principle of the generator is to convert mechanical energy into electrical energy. The generator consists of two main parts, namely the rotor and the stator. The rotor is the part that moves and produces a magnetic field. The stator is the part that is still and receives magnetic flux. Electric generating machines require an electrical system as a producer of electric current, namely by using an electric dynamo as a generator. Electric dynamos often experience many problems that can reduce their work efficiency in a power plant.

The objectives to be achieved in this research are to improve the flywheel-based electrical energy system by utilizing an electric generator, study the utilization of electrical energy by using a flywheel-based electrical generator and identify the parameters and performance of the flywheel-based electrical generator system in utilizing electrical energy.

This research has important significance because it has the potential to overcome challenges in the efficiency and sustainability of electrical energy utilization using flywheel technology. By analyzing the utilization of electric generators using flywheels through inertial loads generated from the rotation of the flywheel, this study aims to improve our understanding of flywheel efficiency and performance compared to conventional energy storage methods. The results of this study are expected to provide practical solutions that can be applied to improve the stability and reliability of electric power systems, reduce environmental impacts, and support the transition to a more sustainable energy system. Thus, this research can make a significant contribution to the innovation of electric generator technology and support global efforts to achieve energy sustainability.

2. METHODOLOGY

2.1 Research methods

The research method used is the experimental method, which is a method to find a causal relationship between problems that have been determined by research with those that affect the output power of the electric generator. The experimental method used is to analyze the utilization of flywheel-based electric generators with inertial loads to increase the efficiency of the electrical energy system.

2.2 *Research Variables*

In this study there are two types of variables, including:

2.2.1 *Independent variable*

Independent variables are conditions that affect the emergence of a symptom. In this study, the independent variables are the use of flywheel masses of 26 kg, 28 kg and 54 kg.

2.2.2 *Dependent variable*

The dependent variable is a variable that is influenced by the independent variable. This variable is the result of the treatment given by the independent variable. In this study, the variables affected by the independent variable are to produce optimal rotation, torque and output power.

2.3 *Data analysis techniques*

Record all measurement and analysis results to determine the characteristics of the flywheel-based electric generator you created.

2.3.1 *Moment of inertia*

The moment of inertia is calculated using the equation (1):

$$\boldsymbol{I = \frac{1}{2} m r^2} \qquad (1)$$

Where, I is moment of inertia, m is flywheel mass, and r is flywheel spokes.

2.3.2 *Torque*

Torque is calculated using the equation (2):

$$\boldsymbol{T = F r} \qquad (2)$$

Where, T is torque, F is force, and R is radius of flywheel.

Torque is obtained by multiplying the force by the radius of the flywheel. To find the value of the force, can be used the equation (3):

$$\boldsymbol{F = m\alpha} \qquad (3)$$

Where, F is the force that working on object (N), m is flywheel mass (kg), and $\boldsymbol{\alpha}$ is acceleration of an object subjected to force (m/s^{-2}).

The force is obtained by multiplying the mass of the flywheel by the radius of the flywheel. To find the acceleration value of an object can be used the equation (4):

$$\boldsymbol{\alpha = \frac{\Delta\omega}{\Delta t}} \qquad (4)$$

Where, α is acceleration of an object that is given force (m/s^{-2}), Δω is rotational speed (rad/s), and Δt is time (s). To find the change in rotational speed, use the equation (5):

$$\boldsymbol{\omega = 2\pi f} \qquad (5)$$

Where, ω is rotational speed (rad/s) and ƒ is rotation frequency (Hz).

The rotation frequency (rpm) is calculated with the equation (6):

$$\boldsymbol{f = \frac{rpm}{60}} \qquad (6)$$

Then to find the moment of force can be used the equation (7):

$$\boldsymbol{\tau = I\alpha} \qquad (7)$$

Where, τ is moment of force, I is moment of inertia, and α is rotational acceleration.

2.3.3 *The relationship between input and output power through efficiency.*

Electrical power is calculated using the equation (8):

$$\boldsymbol{\eta = \frac{P_{out}}{P_{in}} \, x \, 100\%} \qquad (8)$$

Where, η is efficiency (%), P_{out} is output power (Watt), and P_{in} is power input (Watt).

3. RESULTS AND DISCUSSION

3.1 Results

Analysis of the use of flywheel-based electric generators to determine efficient output for several loads. In this study, the loads used were GMC 80W pedestal fan, MF-65G 260W water fan, and JY1A-4 0.37 kW single phase motor. This research and testing were carried out using a 220V/2800rpm AC electric motor as the main driver sourced from PLN electricity. The output used was a Matsumoto ST-3 1 phase generator.

3.1.1 Calculation of the moment of inertia, torque and power of the flywheel

The mass of flywheel is m = 26 kg and r = 0.42 m, the moment of inertia is:

$$I = \frac{1}{2}mr^2 = \frac{1}{2}(26)(0.42)^2 = 2.293\ kgm^2$$

The rotation speed f = 551,4 rpm (9.1 Hz) and time is 60s, the angular speed is:

$$\boldsymbol{\omega = 2\pi f = 2(180)(9.1) = 3.276\frac{rad}{s}}$$

The rotational acceleration is:

$$\boldsymbol{\alpha = \frac{\Delta\omega}{\Delta t} = \frac{3.276}{60} = 54.6\ rad/s^2}$$

Force moment is:

$$\boldsymbol{\tau = I\alpha = 2.293(54.6) = 125.19\ N}$$

Table 1. Electric motor input with a flywheel mass of 26 kg

Burden	n1 (electric motor pulley rpm)	n2 (flywheel pulley rpm)	n (rpm pulley generator)	P_{in} (Watt)
Fan	2901	551.4	1703	895.3
Blower	2882	547.5	1684	1014
Electric motor	2837	537.2	1654	1254
Fan + Blower	2859	542.7	1674	1105
Fan + Electric Motor	2808	531.5	1635	1331
Blower + Electric Motor	2773	523.1	1609	1469
Fan + Blower + Electric Motor	2743	518.1	1587	1561

Table 2. Output of electric generator with flywheel mass 26 kg

Burden	n1 (electric motor pulley rpm)	n1 (flywheel pulley rpm)	n1 (rpm pulley generator)	P_{out} (Watt)
Fan	2901	550.9	1702	81.3
Blower	1874	545.6	1684	193.6
Electric motor	1823	535.0	1649	205.9
Fan + Blower	2853	541.3	1669	272.1
Fan + Electric Motor	2802	530.2	1632	273.4
Blower + Electric Motor	2764	522.3	1604	367.6
Fan + Blower + Electric Motor	2733	515.9	1582	425.7

3.1.2 Calculation of the moment of inertia, torque and power of the flywheel mass 28 kg.

The mass of flywheel is m = 28 kg and r = 0.42 m, the moment of inertia is:

$$I = \frac{1}{2}mr^2 = \frac{1}{2}(28)(0.42)^2 = 2.469\ kgm^2$$

The rotation speed f = 545,5 rpm (9.0 Hz) and time is 60s, the angular speed is:

$$\boldsymbol{\omega = 2\pi f = 2(180)(9.0) = 3.240\frac{rad}{s}}$$

The rotational acceleration is:

$$\boldsymbol{\alpha = \frac{\Delta\omega}{\Delta t} = \frac{3.240}{60} = 54\ rad/s^2}$$

Force moment is:

$$\boldsymbol{\tau = I\alpha = 2.2469(54) = 133.32\ N}$$

Table 3. Electric motor input with a flywheel mass of 28 kg

Burden	n1 (electric motor pulley rpm)	n2 (flywheel pulley rpm)	n3 (rpm pulley generator)	P_{in} (Watt)
Fan	2893	548.6	1700	876.9
Blower	2871	543.4	1684	976.4
Electric motor	2816	529.8	1636	1236
Fan + Blower	2834	535.7	1662	1174
Fan + Electric Motor	2761	522.2	1619	1413
Blower + Electric Motor	2708	510.0	1579	1558
Fan + Blower + Electric Motor	2644	5694	1538	1698

Table 4. Output of electric generator with flywheel mass of 28 kg

Burden	n1 (electric motor pulley rpm)	n2 (flywheel pulley rpm)	n3 (rpm pulley generator)	P_{out} (Watt)
Fan	2880	545.5	1692	81.6
Blower	2852	540.2	1676	190.2
Electric motor	2782	527.4	1633	203.9
Fan + Blower	2826	535.4	1658	267.3
Fan + Electric Motor	2754	520.6	1612	269.1
Blower + Electric Motor	2695	509.7	1579	357.2
Fan + Blower + Electric Motor	2647	498.1	1541	408.0

3.1.3 Calculation of the moment of inertia, torque and power of the flywheel mass 54 kg.

The mass of flywheel is m = 54 kg and r = 0.42 m, the moment of inertia is:

$$I = \frac{1}{2}mr^2 = \frac{1}{2}(54)(0.42)^2 = 2.762\ kgm^2$$

The rotation speed f = 550,1 rpm (9.1 Hz) and time is 60s, the angular speed is:

$$\boldsymbol{\omega = 2\pi f = 2(180)(9.1) = 3.276\frac{rad}{s}}$$

The rotational acceleration is:

$$\boldsymbol{\alpha = \frac{\Delta\omega}{\Delta t} = \frac{3.276}{60} = 54.6\ rad/s^2}$$

Force moment is:

$$\boldsymbol{\tau = I\alpha = 2.762(54.6) = 150.80\ N}$$

Table 5. Electric motor input with a flywheel mass of 54 kg.

Burden	n1 (electric motor pulley rpm)	n2 (flywheel pulley rpm)	n3 (rpm pulley generator)	P_{in} (Watt)
Fan	2905	551.4	1704	904.5
Blower	2880	546.4	1687	1018
Electric motor	2835	535.3	1651	1256
Fan + Blower	2859	541.2	1671	1107
Fan + Electric Motor	2801	529.5	1634	1343
Blower + Electric Motor	2772	521.9	1602	1479
Fan + Blower + Electric Motor	2743	428.8	1584	1582

Table 6. Output of electric generator with flywheel mass of 54 kg.

Burden	n 1 (electric motor pulley rpm)	n 2 (flywheel pulley rpm)	n 3 (rpm pulley generator)	P_{out} (Watt)
Fan	2889	550.1	1700	80.8
Blower	2874	544.8	1681	194.4
Electric motor	2817	532.9	1644	203.9
Fan + Blower	2851	540.0	1666	272.8
Fan + Electric Motor	2795	527.9	1627	272.8
Blower + Electric Motor	2760	520.1	1607	366.0
Fan + Blower + Electric Motor	2723	512.3	1577	424.0

From the calculation results of the table above, it can be seen that the 26 Kg flywheel is efficient with a result of 0.27%. While the flywheel with a mass of 28 Kg produces 0.24% and 54 kg produces 0.26%.

3.1.4 The relationship between input and output power through efficiency

Table 7. Effect of flywheel on output power

Burden	Flywheel 26 Kg		Flywheel 28 Kg		Flywheel 54 Kg	
	P_{in}	P_{out}	P_{in}	P_{out}	P_{in}	P_{out}
Fan	895.3	81.3	876.9	81.6	904.5	80.8
Blower	1014	193.6	976.4	190.2	1018	194.4
Electric motor	1254	205.9	1236	203.9	1256	203.9
Fan + Blower	1105	272.1	1174	267.3	1107	272.8
Fan + Electric Motor	1331	273.4	1413	269.1	1343	272.8
Blower + Electric Motor	1469	367.6	1558	357.2	1479	366.0
Fan + Blower + Electric Motor	1561	425.7	1698	408.0	1582	424.0
η%(efficiency)	0.27		0.24		0.26	

The calculations are then analyzed, as illustrated in Figure 1.

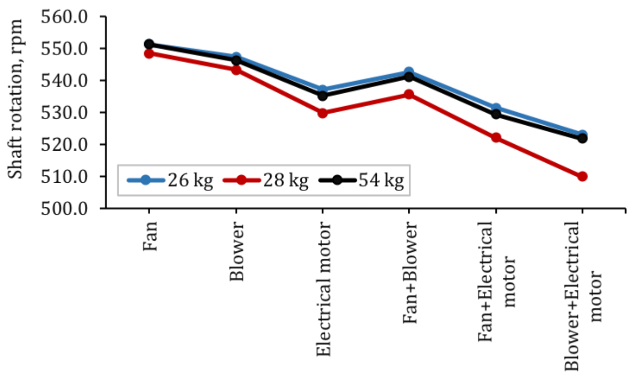

Figure 1. Graph of the relationship between flywheel weight and shaft rotation

From the graph above, it can be seen that the mass of the flywheel affects the rotation of the shaft, where it is known that the mass of the flywheel 26 kg and 54 kg is almost the same, namely at 523.1 and 521.9 rpm with a difference of 1.2 rpm, while the weight of the flywheel is 28 kg with a result of 510 rpm.

The influence of flywheel weight on the input of the electric motor is illustrated in Figure 2.

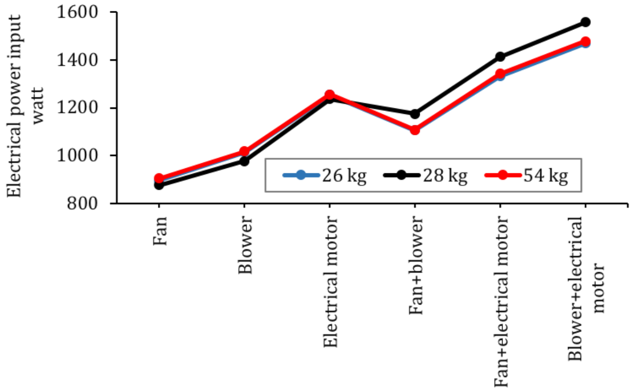

Figure 2. Effect of flywheel weight on electricity consumption

From the results of the graphic analysis above, it can be seen that the electric motor input at a flywheel weight of 26 kg reaches 1469 W, at a flywheel weight of 28 kg it increases to 1558 W and at a flywheel weight of 54 kg it decreases to 1479 W. This analysis is carried out to measure the power capacity of the electric motor with the addition of flywheel mass.

The analysis of the power output capability of an electric generator in relation to the load is illustrated in Figure 3.

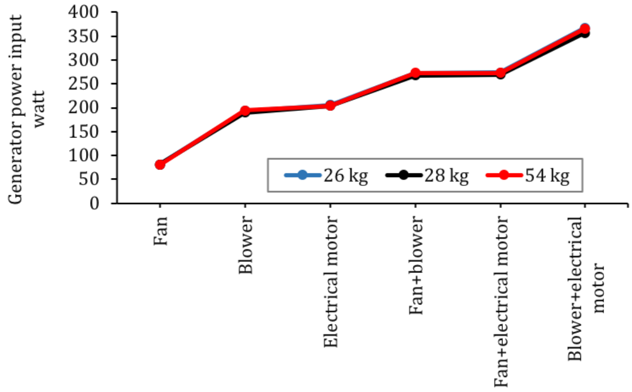

Figure 3. Effect of flywheel weight on electrical power output in generator

The test results and the accompanying graph indicate that the optimal output power is achieved with a flywheel weighing 26 kg, producing 367.6 W. In comparison, the 28 kg flywheel generates a power output of 357.2 W, while the 54 kg flywheel achieves 366 W. Therefore, the flywheel weighing 26 kg is identified as the optimal choice for power output.

Additionally, based on the analysis of the three graphs and the calculation results, the appropriate flywheel for the power generator engine is determined by considering the generator's requirements, such as high shaft rotation, the duration of shaft rotation, and the power generated by the shaft. It has been concluded that the 26 kg flywheel is the best option due to its capability to produce both high shaft rotation and optimal power output.

4. CONCLUSION

Based on the results of research and discussion regarding the utilization of flywheel-based electric generators with inertial loads to produce optimal output power, it can be concluded:

(1) The results of the design of the utilization of flywheel-based generators contain 3 series of components with the initial component for the electric motor then transmitted to the flywheel then transmitted to the electric generator. The use of a flywheel with a mass of 26 kg with a generator output power of 367.6 W, for a flywheel mass of 28 kg produces a generator output power of 357.2 W and for a flywheel mass of 54 kg produces an electric generator output power of 366 W, so it can be concluded that the optimal power in this study uses a flywheel mass of 26 kg.

(2) The function of the flywheel has a major influence on the rotation of the shaft. This study provides an overview of how load changes affect the performance of an electric motor in terms of rotational speed and power output where the Flywheel is used to store rotational energy and help maintain rotational stability. The generator is connected to convert mechanical energy into electrical energy.

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