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Analysis of the Performance Evaluation Study of Generator Excitation Unit in Atik Bakery Factory

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Article Info	ABSTRACT
Keywords: Generator excitation, performance evaluation, and voltage stability	Atik Bakery uses a power generation system to meet its operational energy needs, one of which comes from a generator unit that plays an important role in maintaining a stable power supply. One of the key components in generator operation is the excitation system that functions to regulate the generator output voltage. This study aims to evaluate the performance of the generator unit excitation system at Atik Bakery, by analyzing efficiency, voltage stability, and response to changes in load. The methods used include measuring the generator output voltage at various load conditions, as well as monitoring the parameters of the excitation system using measuring devices and data analysis. The results of the study indicate that the generator unit excitation system can maintain a stable output voltage under normal load conditions, but there is a decrease in performance at higher loads, which can affect the quality of power supply to the factory. This evaluation provides a basis for efforts to improve and enhance the performance of the excitation system to improve operational efficiency and stability at Atik Bakery.
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INTRODUCTION

Power plants in the manufacturing industry, including bakeries, play an important role in ensuring smooth operations. One of the resources used to meet the electricity needs at the Atik Bakery Factory is a generator unit. This generator not only functions to generate electricity, but also to ensure the stability of the electricity supply needed by production machines, baking tools, and other systems. The generator excitation system is one of the vital components in regulating the generator output voltage. Excitation functions to regulate the exciter current flowing to the generator rotor, which in turn determines the output voltage. Good excitation system performance greatly affects the stability of the output voltage and the operational efficiency of the generator. If the excitation system does not function optimally, voltage fluctuations can occur that interfere with machine performance, and can even damage electronic equipment in the factory.

Atik Bakery uses generators to ensure continuity of power supply for their production process. However, the performance of the excitation system on the generator unit used in this factory has not been thoroughly evaluated, so that potential disturbances in the excitation system or suboptimal generator performance may not be detected. Therefore, evaluating the performance of the excitation system is important to ensure that the generator functions efficiently and stably, and can support the smooth operation of the factory. This study aims to evaluate the performance of the generator unit excitation system at the Atik Bakery, with a focus on efficiency, voltage stability, and response to load changes. It is expected that the results of this study can provide recommendations for improving and increasing the performance of the excitation system in order to maintain power stability in the factory, which will ultimately support increased productivity and overall operational efficiency of the factory.

Theoretical Basis

Electric Power System

In general, the purpose of an electricity company is to maintain continuity of electricity service, so that the power distributed can reach customers continuously without interruption. The electric power system starts from the generation, transmission, and distribution systems. As shown in Figure 2.2.

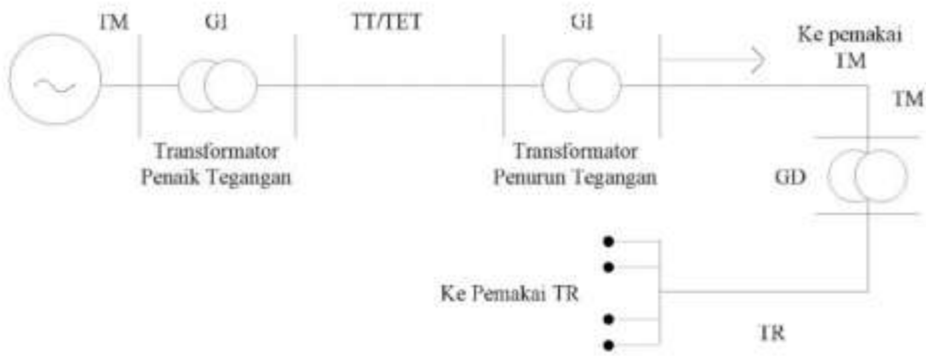

Figure 1. Single line diagram of electric power system

P : Generator
TM : Medium Voltage
TT : High VoltageTET : Extra High Voltage
GI : Main Substation
GD : Distribution Substation

However, on the one hand, the electrical equipment in the generation, transmission, and distribution systems will experience basic problems such as disturbances, maintenance, and aging which result in equipment replacement. Although maintenance has the same impact as disturbances and aging resulting in the cessation of electrical equipment from working, maintenance aims to improve the reliability of electrical equipment. Therefore, well-scheduled maintenance is highly expected. Transformers are important components in the electric power system. Disturbances in power transformers result in the interruption of the power flow distributed by the power transformer, decreased reliability of the power transformer, and the most noticeable impact is economic losses to the electricity company. Power transformer disturbances are divided into 2, external disturbances and internal disturbances. Power transformers are equipped with several protection relays that work together with PMT (Circuit Breaker). The protection relay functions to protect the power transformer from external and internal disturbances. So the performance of the protection relay works very well, so that no damage occurs to the power transformer.

Transformer

Transformer is an electrical device consisting of an iron core and a coil wrapped around the iron core. The basic principle of a transformer is based on Lorenz's law and Faraday's law. When the primary coil is given an alternating voltage, a primary current will appear in the primary coil. According to Lorenz's law, if current flows through an iron core, a magnetic field will arise around the surface of the iron core. The primary current will generate Flux, flux is the number of magnetic lines that pass through an iron core. Flux changes occur because the magnetic lines of force that pass through the surface of the iron core are not always perpendicular to the surface of the iron core. According to Faraday's law, if there is a change in flux through a coil with N number of turns, an induced EMF will arise[1].

$$e_1 = N_1 \frac{d\emptyset}{d}$$

$$\emptyset = \emptyset\, m \quad S$$

$$\frac{d\emptyset}{d} = \omega\, \emptyset m \quad C$$

$$e_1 = N_1\, \omega\, \emptyset m \quad C$$

Where:

dØ = Change in magnetic lines of force in weber units

dt = Change in time in seconds

e1 = EMF on the primary side

N1 = Number of turns of primary winding

The flux flowing through the iron core will induce the secondary coil and just like the primary coil, there will be a change in flux in the secondary coil, so that an induced EMF will arise in the secondary coil.

Electric Power System

An electric power system consists of three main parts, namely the power plant center, transmission lines and distribution system. In general, the good or bad of the electric power transmission and distribution system is mainly reviewed from the quality of power received by consumers. Good power quality includes adequate power capacity and constant voltage at nominal voltage. Voltage must always be kept constant, especially at voltage losses that occur at the end of the line. Unstable voltage can cause damage to equipment that is sensitive to voltage changes (especially electronic devices). Voltage that is too low will cause electrical equipment to not operate properly. Likewise, voltage that is too high can potentially damage electrical equipment, including changes in frequency values that will be greatly felt by electricity users whose use is related to/depends on frequency stability.

Consumers in this group are usually industrial/factory consumers who use automatic machines using time/frequency settings such as motor equipment. Therefore, frequency and voltage stability must always be controlled to avoid possible risks so that damage to system failure can be avoided (Jefri Arianto, 2015).

Definition of Generator

A generator is a tool used to produce electrical energy by converting mechanical energy into electrical energy using electromagnetic induction. The mechanical energy in question is used to rotate the coil of conducting wire in a magnetic field or vice versa to rotate the magnet between the coil of conducting wire. Faraday's law explains the principle of the generator is that the magnetic field flowing in the iron will cause electromotive force. While the 3 phase generator is an alternating current generating system with 3 outputs with a phase difference of 1200.

A generator is an electrical device that functions to produce a source of electric current. In this study, the source of current produced by the generator is 3-phase AC electric current. The electricity produced can function to activate electrical devices that require 3-phase AC electric current such as electric motors, home electricity, crane motors, etc.

Generator Parts

The generator consists of two main parts, namely:

a. Stator (stationary part)
   1. The stator frame is a housing (frame) that supports the generator anchor core.
   2. The stator core, made of special magnetic steel or iron alloy laminations attached to the stator frame.
   3. The grooves (slots) and teeth are where the stator coils are placed. There are three forms of stator grooves, namely open, half-open and closed.
   4. The stator coil (anchor coil) is usually made of copper. This coil is where the induction electromotive force (EMF) arises.

b. Rotor (rotating part)
   1. Slip ring is a metal ring that encircles the rotor shaft but is separated by a certain insulation. The rotor coil terminals are attached to this slip ring and then connected to a direct current source via brushes that are attached to the slip ring.
   2. The rotor coil (field coil) is an element that plays a major role in producing a magnetic field. This coil receives direct current from a specific excitation source.
   3. The rotor shaft is where the rotor coil is placed, where slots have been formed parallel to the rotor shaft.

RESEARCH METHODS

The methodology of the final project is a systematic sequence of stages of this research work carried out from the start of the work to the end. The writing of this article is a combination of design and experimentation so that supporting data is needed to support the implementation of the research. The methodology used by the author in conducting this research generally begins with literature studies, data collection, determining and compiling test equipment, conducting tests, data collection, calculating, validating test result data, conducting analysis and ending with drawing conclusions and suggestions. In the first stage, learning is carried out on theories that support the research and will be discussed in writing the final project. The theory in question is related to how the generator works, the nature of the generator stator coil material, how to test generator performance. Sources used as references can come from books, journals, papers and the internet. Next is data collection aimed at obtaining information related to the problems that will be discussed in writing this final project so that several supporting devices are needed in data collection. The types of data that will be collected at this stage include:

a. Technical Specifications of Feedback GeneratorTechnical Specifications of DC Motor as the main driver
b. Optimal working environment temperature of generator
c. Generator Stator Coil Material Types
d. Types of Tests used

Next is the preparation starting from determining to compiling the test equipment into a series of tests that can produce good test results. The types of data that will be collected at this stage include:

a. Generator
b. DC Motor
c. Voltmeter
d. Ammeter
e. Megger
f. Ohmmeter
g. Burden

Continued generator performance testing The generator is tested with several types of tests, these tests include:

a. No-load testing
b. Load testing

At this stage, data collection is also carried out for each test carried out at each level of environmental temperature. So that for each type of test, data such as voltage, current, and generator rotation speed are obtained and the generator output power and losses that occur in each test (without load and loaded) are calculated. After the analysis and discussion, the results obtained are validated, against changes in the characteristics of the stator coil material due to temperature variations. Are there still results that do not match the initial problem formulation and are the results obtained in accordance with the theory used. Validation is carried out not only on the data obtained but also a comprehensive evaluation related to the method and stages of implementation. After the analysis and discussion process is carried out, the next step is to draw conclusions from the research results. Conclusions are based on the results of data analysis and discussions that have been carried out. The next step is to provide suggestions that are given as input and consideration for related parties to carry out further analysis.

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Figure 2. System Flowchart

This research is expected to provide the following benefits:

1. Practical Benefits for Atik Bakery
   The results of the evaluation of the excitation system performance on the generator unit are expected to help factory management in identifying potential problems in the excitation system and determining appropriate corrective measures. Thus, the factory can improve energy efficiency and ensure the stability of electricity supply, which is very important for smooth production.
2. Contribution to the Development of Generator Excitation Technology
   This research can provide new insights into the effect of excitation performance on voltage stability in generators in production environments. This can be a reference for generator manufacturers or related parties in developing and refining more reliable and efficient excitation technology.
3. References for Further Research.
   This study can be a reference for further research that wants to study the excitation performance of generators in various industrial sectors. In addition, the results of this study can also be the basis for the development of a more comprehensive excitation performance evaluation method.
4. Academic Benefits.
   This research can enrich the literature in the field of electrical engineering, especially in terms of generator excitation performance studies and their implementation in industry. This can be an additional reference for students or academics who are

interested in conducting similar research in the field of power generation systems and energy management. These benefits are designed to provide a positive impact, both practically and theoretically, so that the results of this study can be widely applied.

ANALYSIS AND RESULTS

In this paper, there are several stages of the results of testing three-phase synchronous generators before using an isolation room and after using an isolation room, respectively, with discussions according to the testing steps explained in the previous chapter.The generator used in Atik Bakery Factory is a 3-phase synchronous type with a capacity of 250 kVA, operating at a voltage of 400 V, and a frequency of 50 Hz. The excitation system uses an automatic voltage regulator (AVR) with a brushless excitation system method. Data collection is carried out when the generator is operating under the following conditions:

a. Minimum load (30% capacity)
b. Full load (≥90% capacity)

Minimum Load Characteristics Test Results.

The following table shows the test results of a three-phase synchronous generator under open circuit or minimum load open circuit conditions:

Table 1. Minimum load characteristics test results

Current Excitation	DC Volt meters	Minimum Load RO	SO	TO	RS	ST	TR	Freq	Motor rpm range	Torque Nm
0.1	40	117	116	117	200	200	200	50	2999 - 3002	0.18
0.2	100	230	229	230	398	398	398	50	3000 - 3006	0.19
0.3	150	321	320	321	560	560	560	50	3000 - 3006	0.21
0.4	200	402	400	401	695	695	695	50	3001 - 3006	0.23
0.5	250	442	441	442	770	770	770	50	3002 - 3007	0.24
0.6	300	486	485	486	841	841	841	50	3004 - 3008	0.26
0.7	350	528	528	528	896	896	896	50	3004 - 3008	0.28

In Table 1, a graph can be made of the generator characteristics of the Atik Bakery bread factory.

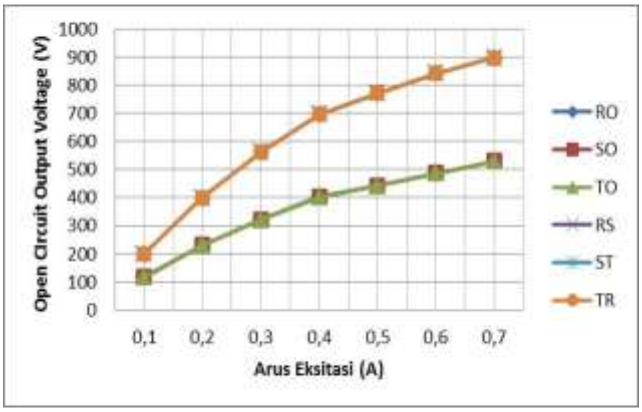

Figure 3. Characteristic Graph of Open Circuit Voltage Against Excitation Current

Basically, the minimum load generator is a condition where the anchor current (Ia) does not flow in the stator, so that the flux is only produced by the field current (If) because it is not affected by the anchor reaction. From figure 1, it can be seen that the output voltage increases in proportion to the addition of excitation current, the addition of excitation current means that the flux value increases which has an impact on the torque required by the driving motor. This is in accordance with the equation Eo = cnΦ, where Φ = BIL, the voltage is directly proportional to the magnetic flux and current, so that the greater the excitation current given, the greater the flux, causing the output voltage to also increase.

Test Results of Open Circuit Characteristics with Full Load.

Testing was carried out at full load by varying the temperature from 34˚C, 41˚C, 49˚C, 57˚C, and 65˚C. The following table shows the test results of a three-phase synchronous generator in open circuit conditions or open circuit with factory space:

Table 2. Test Results of Open Circuit Characteristics with Isolation Room at Temperature 34˚C

Current Excitation	DC Volt meters	Open Circuit Output Voltage						Freq	Motor rpm range	Torque Nm
		RO	SO	TO	RS	ST	TR			
0.1	40	115	113	114	195	195	195	50	2999 - 3002	0.18
0.2	100	227	226	227	395	382	382	50	3000 - 3006	0.19
0.3	150	318	317	318	541	539	541	50	3000 - 3006	0.21
0.4	200	396	395	395	673	666	666	50	3001 - 3006	0.23
0.5	250	438	439	438	768	768	768	50	3002 - 3007	0.24
0.6	300	482	483	484	840	840	840	50	3004 - 3008	0.26
0.7	350	525	524	525	892	892	892	50	3004 - 3008	0.28

Table 3. Test Results of Open Circuit Characteristics with Isolation Room at a Temperature of 41°C

Current Excitation	DC Volt meters	Open Circuit Output Voltage						Freq	Motor rpm range	Torque Nm
		RO	SO	TO	RS	ST	TR			
0.1	40	113	112	113	192	192	192	50	2999 - 3002	0.18
0.2	100	225	225	225	383	383	383	50	3000 - 3005	0.19
0.3	150	315	314	314	536	534	534	50	3001 - 3005	0.21
0.4	200	390	389	390	663	661	663	50	3002 - 3006	0.23
0.5	250	435	434	435	764	764	764	50	3002 - 3006	0.24
0.6	300	478	479	479	838	838	838	50	3004 - 3007	0.26
0.7	350	520	520	520	889	889	889	50	3005 - 3008	0.28

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Table 4. Test Results of Open Circuit Characteristics with Isolation Room at Temperature 49˚C

Current Excitation	DC Volt meters	Open Circuit Output Voltage RO	SO	TO	RS	ST	TR	Freq	Motor rpm range	Torque Nm
0.1	40	109	108	109	188	188	188	50	2999 - 3002	0.18
0.2	100	221	220	221	376	374	376	50	3000 - 3005	0.19
0.3	150	311	310	311	529	527	529	50	3001 - 3005	0.21
0.4	200	383	383	383	654	654	654	50	3002 - 3006	0.23
0.5	250	429	430	429	760	760	760	50	3002 - 3006	0.24
0.6	300	472	471	472	834	834	834	50	3004 - 3007	0.26
0.7	350	512	511	512	885	885	885	50	3005 - 3008	0.28

Table 5. Test Results of Open Circuit Characteristics with Isolation Room at a Temperature of 57°C

Current Excitation	DC Volt meters	Open Circuit Output Voltage RO	SO	TO	RS	ST	TR	Freq	Motor rpm range	Torque Nm
0.1	40	106	105	106	185	185	185	50	2999 - 3002	0.18
0.2	100	217	215	216	370	370	370	50	3000 - 3005	0.19
0.3	150	307	306	305	524	524	524	50	3001 - 3005	0.21
0.4	200	376	376	376	642	642	642	50	3002 - 3006	0.23
0.5	250	422	421	422	754	754	754	50	3002 - 3006	0.24
0.6	300	464	463	464	832	832	832	50	3004 - 3007	0.26
0.7	350	504	503	504	882	882	882	50	3005 - 3008	0.28

Table 6. Test Results of Open Circuit Characteristics with Isolation Room at a Temperature of 65°C

Current Excitation	DC Volt meters	Open Circuit Output Voltage RO	SO	TO	RS	ST	TR	Freq	Motor rpm range	Torque Nm
0.1	40	104	104	104	183	183	183	50	2999 - 3002	0.18
0.2	100	213	211	212	368	368	368	50	3000 - 3005	0.19
0.3	150	303	302	303	520	520	520	50	3001 - 3005	0.21
0.4	200	373	373	373	638	638	638	50	3002 - 3006	0.23
0.5	250	418	419	418	750	750	750	50	3002 - 3006	0.24
0.6	300	459	460	469	830	830	830	50	3004 - 3007	0.26
0.7	350	490	489	490	879	879	879	50	3005 - 3007	0.28

Based on the data in tables 2 to 6, a graph is obtained as shown in the following image:

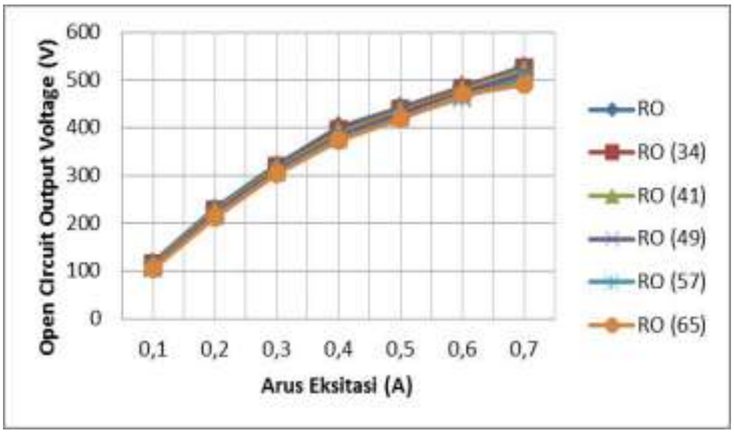

Figure 4. Characteristics of Output Voltage Against Excitation Current With Isolation Space

From figure 3. it can be seen that the output voltage increases in proportion to the addition of excitation current, the addition of excitation current means that the flux value increases which results in the torque required by the driving motor getting higher. This is in accordance with the equation Eo = cnΦ, where Φ = BIL which voltage is directly proportional to magnetic flux and current, so that the greater the excitation current given, the greater the flux, causing the output voltage to also increase. However, if we look at the data and graphs above, there is a decrease in voltage value at each increase in temperature. This proves that the increase in room temperature affects the performance of the generator.

Meanwhile, the results of measuring the insulation resistance and coil resistance after being given an isolation room as a replacement for the machine room can be seen in Table 7.

Table 7. Results of Insulation Resistance and Coil Resistance Measurements of Open Circuit Characteristics with Isolation Space

No	Temperature (°C)	Generator	Mark Prisoner Isolation	Mark Standard IEEE	Generator	Mark Prisoner Coil	Information
1	34	U-Body	480 MΩ	100 MΩ	U1-W2	8 MΩ	Good
		V-Body	480 MΩ	100 MΩ	V1-U2	8 MΩ	
		W - Body	480 MΩ	100 MΩ	W1- V2	8 MΩ	
2	41	U-Body	460 MΩ	100 MΩ	U1-W2	7 MΩ	Good
		V-Body	460 MΩ	100 MΩ	V1-U2	7 MΩ	
		W - Body	460 MΩ	100 MΩ	W1- V2	7 MΩ	
3	49	U-Body	430 MΩ	100 MΩ	U1-W2	6 MΩ	Good
		V-Body	430 MΩ	100 MΩ	V1-U2	6 MΩ	
		W - Body	430 MΩ	100 MΩ	W1- V2	6 MΩ	
4	57	U-Body	400 MΩ	100 MΩ	U1-W2	5 MΩ	Good
		V-Body	400 MΩ	100 MΩ	V1-U2	5 MΩ	
		W - Body	400 MΩ	100 MΩ	W1- V2	5 MΩ	
5	65	U-Body	350 MΩ	100 MΩ	U1-W2	4 MΩ	Good
		V-Body	350 MΩ	100 MΩ	V1-U2	4 MΩ	
		W - Body	350 MΩ	100 MΩ	W1- V2	4 MΩ	

Based on table 7. the results of the insulation resistance measurements on the U-Body, V-Body, W-Body each experienced an average decrease in value of 30 MΩ and the coil resistance each experienced an average decrease in value of 1 MΩ. From the observation results and referring to the IEEE minimum standard, the generator is good for use even though the insulation resistance and coil resistance have decreased.

Measurement and Observation Results

Table 8. Observation Results

Load Condition	Output Voltage (V)	Excitation Current (A)	Excitation Voltage (V)	Frequency (Hz)
30%	403	2.1	52	50.1
90%	392	3.2	65	49.8

The output voltage is relatively stable at various load levels. However, there is a voltage drop when the load reaches 90%, from 403 V to 392 V (a decrease of about 2.7%). This is still within the operational tolerance limit of ±5%, but indicates that the excitation system begins to work harder to maintain voltage stability when approaching maximum load. The AVR shows an adaptive response by increasing the excitation current and voltage as the load increases. The increase in excitation current from 2.1 A to 3.2 A indicates that the excitation system is still working normally and proportionally to the magnetic field requirements on the rotor. The frequency remains close to 50 Hz with very small fluctuations (±0.2 Hz), indicating that the system governor is working well and there are no sudden loads that interfere with the generator rotation speed.

Evaluation of Excitation System Efficiency

The ratio between the excitation voltage and the output shows that the system does not experience overexcitation. The efficiency values are still in the range of 85-92% at each load level. This shows that the excitation system does not overload the generator. So we can take several important things including:

a. The excitation system works effectively and responsively to load changes.
b. The output voltage remains stable, with drops still within normal limits.
c. No anomalies were found in the operation of the AVR or the generator excitation as a whole.
d. For improved performance, regular maintenance of the AVR and periodic inspection of the brushless exciter are recommended to prevent wear.

Evaluation of the efficiency of the excitation system is done by comparing the excitation power consumed to the total output power of the generator. The excitation system in the generator functions to provide field current (excitation current) to create magnetic flux in the rotor. The more efficient the excitation system, the less power is needed to produce a stable output voltage.

Excitation System Efficiency Calculation

a. The efficiency of the excitation system (ηexcitationηexcitation) can be defined as:
b. ηexcitation=(1−PexcitationPoutput)×100%

$$\eta_{eksitasi} = \left(1 - \frac{P_{eksitasi}}{P_{output}}\right) \times 100\%$$

Information:

a. PeksitasiPeksitasi= Excitation voltage × Excitation current
b. PoutputPoutput= Output voltage × Output current × √3 × Cos φ

For example, at 90% load, if the power factor is assumed to be 0.85 and the output current is 360 A: An efficiency value approaching 100% indicates that the excitation system requires only a very small amount of power compared to the total generator output.

$$P_{eksitasi} = 65\,\mathrm{V} \times 3.2\,\mathrm{A} = 208\,\mathrm{W}$$

$$P_{output} = 392 \times 360 \times \sqrt{3} \times 0.85 = 207,242\,\mathrm{W} \approx 207.2\,\mathrm{kW}$$

$$\eta_{eksitasi} = \left(1 - \frac{208}{207242}\right) \times 100\% \approx 99.90\%$$

For example, at 90% load, if the power factor is assumed to be 0.85 and the output current is 360 A: An efficiency value approaching 100% indicates that the excitation system requires only a very small amount of power compared to the total generator output.

a. High efficiencyshows that the excitation system is working very well and does not significantly burden the system.
b. No indications of high losses or excessive excitation power consumption were found.
c. This performance is in line with the characteristics of brushless excitation which generally has high efficiency and low maintenance requirements.

CONCLUSION

Based on the results of the analysis and evaluation of the performance of the excitation system in the generator unit at the Atik Bakery Bread Factory, the following conclusions can be drawn: The excitation system works stably and responsivelyto changes in load, indicated by an increase in current and excitation voltage that is proportional to the generator's magnetic field requirements. The generator output voltage is within operational tolerance limits (±5%), although there is a voltage drop when the load reaches maximum conditions, this value is still considered normal and safe for factory equipment operations. The output frequency remains stable at around 50 Hz., indicating that the governor system and the generator drive motor speed controller are working properly. The efficiency of the excitation system is very high (approaching 99.9%), which means the power required for excitation is very small compared to the total output power of the generator. This reflects the excellent performance of the system. No indication of failure or work anomalies were found.on the Automatic Voltage Regulator (AVR) and the excitation system as a whole during the observation period.

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