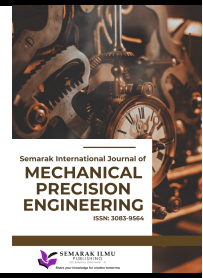




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Case Study of Increasing Excitation on Generator Output Performance at Bawean PLTMG

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ARTICLE INFO	ABSTRACT
Article history: Received 29 March 2026 Received in revised form 30 May 2025 Accepted 10 September 2026 Available online 1 October 2026 Keywords: Excitation; synchronous generator; PLTMG; voltage; reactive power; generator performance	This study aims to analyze the effect of increased excitation on generator output performance at Bawean PLTMG. This generating system uses a synchronous generator with a brushless excitation system that functions to maintain voltage stability by regulating the rotor field current. The research was conducted using a quantitative descriptive method by collecting generator operation data every three hours. The parameters analyzed included active power, voltage current, reactive power, power factor, and excitation voltage. The results showed that the increase in excitation had an effect on the increase in power and current of the generator, but did not cause significant changes. The excitation system also plays a role in regulating the reactive power and power factor to keep it optimal. Therefore, the excitation system in the Bawean PLTMG generator works optimally in maintaining voltage stability and generator performance against load changes.

1. Introduction

Synchronous generators are the main components in the power generation system that function to convert mechanical energy into electrical energy through the principle of electromagnetic induction. In a power system, the generator cannot be separated from the excitation system which plays a role in forming a magnetic field on the rotor so as to generate voltage. The excitation system is an important part to determine the generator's ability to produce electrical energy optimally [1]. Excitation regulation is carried out using an Automatic Voltage Regulator (AVR) which works automatically to adjust the output voltage in the generator to keep it stable according to the needs. The AVR will adjust the excitation condition based on the change in terminal voltage, so that the voltage can be used as an indicator to determine the performance of the excitation system in the generator [2].

The change in the voltage of the generator terminals is closely related to the excitation conditions. When excitation increases, the voltage of the generator tends to increase, on the other hand, if the excitation decreases then the voltage will also decrease. Voltage changes also affect the

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reactive power generated, so voltage can be used as the main parameter in analyzing generator performance. When current data is not available [3]. An increase in voltage that indicates increased excitation does not necessarily have a positive impact on the performance of the generator. Too high voltage can cause the generator to produce excessive reactive power, which can reduce system efficiency and increase the generator's workload. This condition also has the potential to cause system instability and accelerate damage to electrical equipment [4].

In an Electric power system, the change in load will also affect the voltage of the generator. When a load fluctuation occurs, the AVR will work to adjust the excitation so that the voltage remains within normal limits [5]. In the daily monitoring data at the Bawean PLTMG, the parameters used are voltage, reactive power and power factor without excitation current data. Nonetheless, voltage can be used as an indicator to analyze changes in excitation. Therefore, this study is focused on analyzing the effect of increased excitation as an illustration of the increase in excitation on generator performance, especially on the reactive power and power factor produced.

Table 1

Summary of previous research on the effect of increased excitation on generator performance

Simulation Model	Method	Main Finding	Result	Reference
Generator + AVR	Experimental and simulation-based approach	Load affects excitation	Voltage remains stable with AVR	[6]
PID AVR Model	Control system simulation using PID optimization	PID improves stability	Reduced overshoot	[7]
AC Excitation Model	Dynamic system simulation and control analysis	Excitation system improves stability	Faster system response	[8]
Static Excitation System	System modeling and diagnostic analysis	Excitation affects the performance of the generator	The system is more stable when controlled	[9]
Voltage Control Model	Simulation-based voltage control analysis	Excitation reduces fluctuations	More stable voltage	[10]
Brushless Excitation	Experimental evaluation of excitation system performance	More efficient brushless system	Improved generator performance	[12]
Generator System	Case study analysis based on operational data	Excitation affects reactive power	Over excitation lowers efficiency	[13]
Synchronous Generator Excitation System	Literature review and analytical study	The excitation system greatly affects the voltage stability and performance of the generator	Excitation control improves system stability	[14]

Most previous research on synchronous generator performance has focused on mathematical modeling, the development of excitation control systems, and voltage stability simulations assuming that the increase in excitation will be directly proportional to the increase in generator performance. However, empirical analysis based on actual load fluctuations is still very limited. This study aims to analyze the relationship between the increase in excitation indicated through voltage changes to the performance of the generator at the Bawean PLTMG under fluctuating and stable operating

conditions. By utilizing daily monitoring data in the form of voltage, active power, reactive power and power factor, this study uses a direct analysis approach to evaluate generator operations. The results of this study are expected to provide an empirical study of the phenomenon of declining generator performance due to the dominance of reactive power under high excitation conditions, which has been limited to being discussed in generator performance studies based on field data.

2. Literature Review

2.1 Generator Sinkron

2.2.1 Definition of synchronous generator

Synchronous generator is a type of electrical generator that functions to convert mechanical energy into electrical energy with the principle of electromagnetic induction, where there is a cut in an electronic field in the strator by the rotation of the rotor coil which then produces electrical energy [12]. It is said that a synchronous generator because it has the number of rotations of the rotor equal to the number of rotations of the magnetic field on the strator. The field coil on a synchronous generator is located on the rotor while the anchor coil is located on the stator. The electromagnetic induction that occurs in a generator is a real application of Faraday's law which states: "The magnitude of the induced electric motion force (GGL) in an electrical circuit is proportional to the rate of change of the magnetic flux passing through that circuit". The faster the change in the magnetic field or the stronger the magnetic field occurs, the greater the electrical voltage produced [13].

2.2.2 Synchronous generator components

Synchronous generators consist of stators, rotors, and air gaps that work together to generate electrical energy. The stator is the part of the generator that does not rotate / stand still while the rotor is the part that rotates and becomes the place for the field coil supplied by the direct current from the exittor. The air gap is the space between the stator and the rotor [14].

1. Rotor

Rotor Is the rotating part of an Electrical machine, which functions to generate a magnetic field that interacts directly with the magnetic field of the stator to generate voltage and Electrical current. The generator has two types of rotors, namely:

- Salient pole rotor This rotor has poles that protrude somewhat out of the rotor surface.
- The cylindrical rotor is cylindrical in shape with coils embedded in the grooves on the rotor surface.

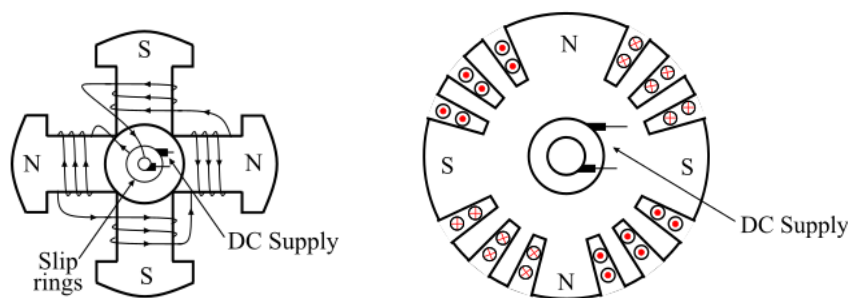


Fig. 1. a) salient pole rotor [14] b) cylindrical rotor [14]

2. Stator

Stator Is a part of an Electric motor that is stationary (static) as a container where a magnetic field interacts with the coil to generate the movement of electric current in the generator. As the rotor (which carries the magnetic field) rotates inside the stator's Center hole, its magnetic force lines will cut through the copper wire coil on the stator. According to Faraday's law, this process is called "cutting" of the magnetic field which produces electrons or currents on the wire which are then transmitted to the electrical grid [20].

The stator is made silent because in the generator the current produced is very high (thousands of amperes). It would be very dangerous to channel large currents through rotating connections such as carbon brushes. Therefore, the part that produces high power is always kept silent [21].

2.2 Working Principle of Synchronous Generator

The working principle of synchronous generators is based on the law of electromagnetic induction, Faraday's Law states that if a conductor cuts the lines of magnetic force, or if there is a change in the magnetic flux that surrounds a coil, then at the ends of the conductor it will produce an Electric Motion Force (GGL) or induction voltage [17]. This process starts at the rotor, which serves as a magnetic field giver. In order for the rotor to become magnetic, the coil wrapped around it must be supplied with a direct electric current (DC). The DC current converts the iron core on the rotator into an electromagnetic one that holds the north and south poles constant. When the rotor is rotated by the main drive, the magnetic field will rotate at the same speed as the shaft [18].

For a three-phase synchronous generator, three coils are used that are placed in the strator and arranged in a certain shape, so that the arrangement of coils that have been made can produce an induction voltage in the three coils that are the same size but the phase 120° is different from each other. After that, the coil terminals are ready to be operated to generate Electrical energy.

2.3 Excitation System

What is meant by an excitation system is a system that creates magnetism in the rotor. Since synchronous generators work on the principle of electromagnetic induction it requires a magnetic field with a strong current to cut the stationary coils on the stator. The excitation current flowed to the rotor coil will turn the iron core of the rotor into a magnet with a large current [18]. When the rotor is rotated by the main drive, this magnetic field rotates and induces alternating Electrical (AC) voltage on the stator coil. Based on the main method used to channel direct current on the rotor of a synchronous generator, this excitation system consists of two types, namely the excitation system using a brush (brush excitation) which consists of a convertible excitation system and static excitation and for the excitation system without using a brush (brushless excitation), which is using a permanent magnet generator system [20].

1.3.1 System with brush

In this system, the current used to generate a magnetic field comes from the battery which is then used to supply the generator's booster rotor, through the sliding rings and brushes of the excitation system. This system works for the reinforcement of the magnetic field present in the winding of the generator field.

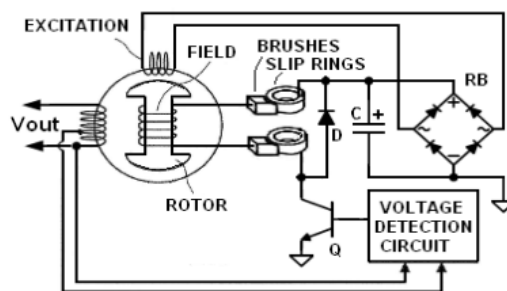


Fig. 2. Series of excitation systems with brushes [21]

The excitation system with a brush has advantages and disadvantages. The advantages of this system are easier in terms of repairs in the event of a breakdown and the maintenance price for this system is relatively cheap. As for the disadvantage of this system, namely unstable tension in every load change that occurs due to friction that occurs continuously so that the brush begins to thin out, therefore it is necessary to replace the brush periodically [8]. The force generated by the winding of the field is not large enough to generate voltage, so it needs regular maintenance.

1.3.2 Brushless system

This system is often used in generators that have large capacities. The amplifier of this system is a small generator where the circuit of terrain is located on the rotor. The three-phase output of this generator is directed by the rectifier to obtain direct current that will be used to supply current to the synchronous generator. By regulating the magnitude of this amplifier current, it is set for the field current on the synchronous generator without slips and brushes.

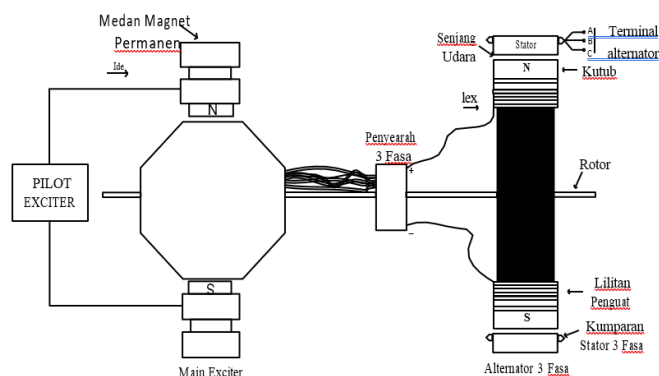


Fig. 3. Brushless system [2]

Because there is no direct mechanical contact, then this brushless reinforcement requires less maintenance compared to those that use slip rings and brushes [16]. To get complete generator amplification and not depend on external power sources, this system is equipped with a small pilot exciter to control the field current in the generator. If this amplifier is equipped with a synchronous generator shaft then no more external power sources are needed at the time the generator is operating.

3. Methodology

3.1 Research Flow Diagram

This research was carried out using a descriptive research method with a quantitative approach with operational data of the actual generator of the Bawean PLTMG. This approach is used to analyze the relationship between the excitation increase presented through the generator's performance voltage under real operating conditions. The data used was obtained from the daily monitoring system of the Bawean PLTMG. A quantitative approach is used because the data analyzed includes numerical data such as voltage, reactive power and power factor. Descriptive analysis was used to describe the relationship between the variables studied, especially the relationship between voltage as an indicator of excitation to reactive power and power factor.

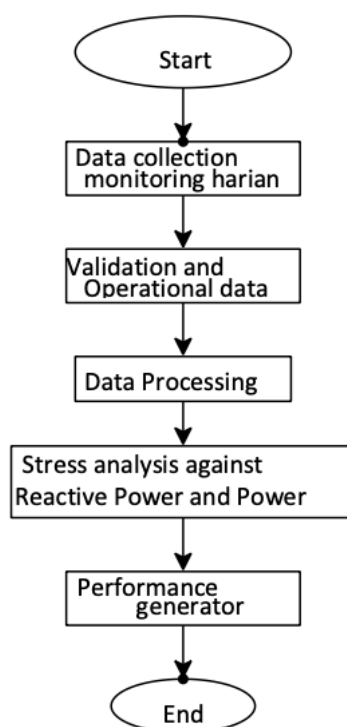


Fig. 4. Research flow diagram

The research stage begins from the process of collecting daily monitoring data of the generator which includes voltage parameters, reactive power, and power factors. The data obtained is then selected to ensure that the data used is complete data and is in normal operating conditions. After the data is declared valid, the data will be processed in the form of tables and graphs to facilitate the analysis process. It aims to look at the pattern of voltage changes and their relationship with reactive power and power factors. Next is the analysis of the relationship between voltage to reactive power and power factor. In this study, voltage is used as an excitation indicator because there is no excitation current available. The increase in voltage can be assumed to be an increase in excitation which can affect the reactive power and power factor. Then the results of the analysis are used to evaluate the performance of the generator to see the voltage stability, reactive power changes, and the value of the power factor produced.

3.2 Research Objective

The objective of this study is a synchronous generator used in the Bawean PLTMG Power Plant unit, especially in the generator excitation system. Generators are the main components in electricity generation which play a role in converting mechanical energy from the driving engine into electricity through the electromagnetic induction process. The generator used at the Bawean PLTMG is a three-phase synchronous generator equipped with an excitation system to produce field current on the rotor. This excitation system has a function in maintaining the stability of the generator voltage as well as measuring the reactive power generated by the generator. This study is focused on the analysis of the effect of the excitation system on the output performance of the generator based on the operation data obtained from the generator monitoring system.

3.3 Generator Specifications

The generator specifications can be known through the generator nameplate attached to the generator. The generator nameplate contains information regarding the capacity and operating parameters of the generator set by the factory.

Table 2

Generator specifications

No.	parameter	Specifications
1	Types of equipment	Generating Set
2	Standards	ISO 8528
3	Manufacturer	GE Jenbacher Gas Engine
4	type	JGS 320 GS-N
5	Serial number	1076331
6	year of manufacture	2013
7	nominal power	1017 kW
8	Power Factor	1
9	Maximum installation height	500 m
10	maximum ambient temperature	40 °C
11	Nominal frequency	50 Hz
12	nominal voltage	400 V
13	nominal current	1540 A
14	Mass	11000 Kg
15	performance class	G2

3.4 Safety Device Generator PLTMG BAWEAN

The safety device generator functions as a safety system that functions to keep the equipment operating within safe limits. In the excitation system, the safety device functions to prevent the occurrence of over excitation which can cause overheating which can interfere with voltage stability.

Table 4
Safety device generator PLTMG Bawean

No.	Description	Setting	Engine	Time delay
4	Generator	360 V	Shutdown	
4a	Generator Under Voltage Stage 1	320 V	Shutdown	
4b	Generator Under Voltage Stage 2	440 V	Shutdown	
4c	Generator Over Voltage Stage 1	460 V	Shutdown	
4d	Generator Over Voltage Stage 2	49 Hz	Shutdown	
4e 4f	Generator Under Frequency Stage 1	48,5 Hz	Shutdown	time delay 1 sec time delay 0,2 sec
4g	Generator Under Frequency Stage 2	52,5 Hz	Shutdown	time delay 0,3 sec time delay 0,2 sec
4h	Generator Over Frequency	4%	Shutdown	time delay 0,5 sec time delay 0,5 sec
4i 4j	Generator Voltage Assymetric	30%	Shutdown	time delay 0,2 sec time delay 3 sec
4k	Generator Neutral Current Maximum	105%	Shutdown	time delay 1 sec time delay 0,2 sec
4l	Thermal Overload Protection	3 Hz/ cycle	Shutdown	
	ROCOF	-145 Kw	Shutdown	
	Generator Reverse Power			
5	Synchronizer	400 V		
5a	Voltage Range 1 Generator	400 V		
5b	Voltage Range 2 (Busbar)	0,2 Hz		
5c	Maximal Positive Frequency Different	-0,2 Hz		
5d	Maximal Negative Frequency Different	3 V		GCB Closed at 400 V
5e 5f	Voltage Defferent Maxsimum	7 deg		
5g	Maximum Defferent Angle Pass	100 msec		
	Circuit Breaker Closing Time			

4. Results and Discussion

4.1 Data on the Operation of the PLTMG Generator Bawean

Based on the results of research conducted on the Bawean PLTMG generator, operating data was obtained from the results of monitoring the power plant system at the Bawean PLTMG. The data includes three engine units of Engine 1, Engine 2 and Engine 3 taken every hour for 24 hours, with key parameters including excitation voltage, reactive power (Q), active power (P), voltage (V), and frequency.

Table 5

Engine 1 daily monitoring data

Jam	Excitement (V)	P (kW)	Q (kVAr)	Tegangan (V)	Frequency (Hz)
02.00	24,8	800	300	392	50
08.00	24	770	275	391	50
11.00	23,9	770	275	391	50
14.00	24	750	276	391	50
17.00	25	800	296	392	50
20.00	26,0	850	315	393	50
23.00	25,9	850	322	392	50

Table 6

Engine 2 daily monitoring data

Jam	Excitement (V)	P (kW)	Q (kVAr)	Tegangan (V)	Frequency (Hz)
02.00	24,7	800	287	392	50
08.00	25,3	770	334	392	50
11.00	25,2	770	332	392	50
14.00	24,9	750	322	391	50
17.00	25,8	800	342	392	50
20.00	27,9	900	330	393	50
23.00	28,0	900	355	393	50

Table 7

Engine 3 daily monitoring data

Jam	Excitement (V)	P (kW)	Q (kVAr)	Tegangan (V)	Frequency (Hz)
02.00	39,1	850	314	392	50
08.00	40	800	320	392	50
11.00	39,8	800	318	392	50
14.00	39,5	780	310	391	50
17.00	40,5	850	330	392	50
20.00	41,1	900	343	393	50
23.00	40	870	295	392	50

From the daily monitoring table of the three engines, it can be seen that all generators operate at a stable frequency of 50Hz with a relatively constant voltage of 391-393 V. However, the difference can be seen in the excitation value of each engine. Engine 1 and engine 2 were in normal condition with maximum excitation values of 26 V and 28 V, while engine 3 showed much higher excitation values up to 41.1V. this indicates that engine 3 carries a much greater reactive load (kVAr) than the rest of the unit. This imbalance is called load distribution distribution, where the difference in the internal parameters of the set point generator on the AVR can force one unit to work harder to maintain grid voltage stability. If the given excitation current is too large, the generator will enter a state of over-excitation which has the potential to cause overheating of the insulation components [].

Based on the monitoring results in table 4.3, engine 3 is the most critical unit in this study because all excitation measurement points throughout the day are in the range of 82-89% of the warning limit. It is measured in the range of 37.7 V to 41.1 V, with an average of 38.84 V. These conditions are very different from engine 1 and engine 2.

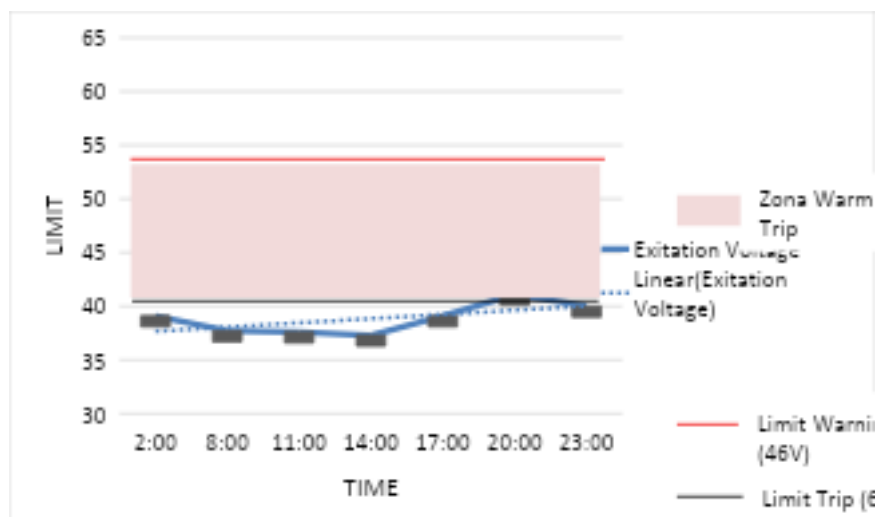


Fig. 5. Graph over excitation engine 3

From the graph, it can be seen that the excitation curve follows the daily loading pattern, decreasing during the day (11.00-14.00) and increasing again when there is a peak load at night (17.00-23.00). Based on daily monitoring data, engine 3 is already at 37.3V with the same load, this shows a decrease in performance in the generator, as seen from the high energy consumption of excitation to achieve power output equivalent to other units. Based on data at 20.00 WIB, engine 3 requires an excitation voltage of 41.1V to bear an active power load of 910 KW, while engines 1 and 2 are able to bear a similar load with an excitation value below 28V, this condition indicates an inefficiency in the process of forming a magnetic field in the generator. Where greater current is supplied into the rotor but does not result in an increase in output capacity, it actually causes greater power losses in the coil.

The generator's performance is said to be not optimal due to the low safety margin near the warning, with an operational value of 41.1V engine 3 only has a distance of 4.9V before touching the warning limit of 46V, thus limiting the generator's ability to respond to sudden reactive load fluctuations.

The subsequent impact of this decline in performance is related to the operational risk of the 60V trip limit. The data shows that the excitation value of engine 3 is always above 37V which can provide sustained thermal pressure to the rotor insulation even if it is not measured through a direct temperature sensor. The operational dependence on this high excitation level reaches 68.5% of the trip limit so that it proves that engine 3 operates outside its magnetic efficiency point, this suboptimal performance can increase the risk of automatic load termination when it occurs during peak load, so that it can trigger consecutive system failures and can threaten the continuity of electricity supply on Bawean island.

5. Conclusion

Based on the results of the analysis of operational data and discussions about the excitation system at the Bawean Power Plant, it can be concluded that there is a performance anomaly in engine 3 when compared to the other two units. The main findings in this study show that the engine operates at an average excitation voltage level of 38.84V far beyond engine 1 and engine 2. This condition reflects the use of the amplifier system capacity of up to 89% of the warning limit of 46V, which indicates the inefficiency of the magnetic megan formation process. As a result, there is an increase in the losses of copper dissipated as heat, thus accelerating the degradation of the rotor

insulation and the overall decrease in energy conversion efficiency as the system is forced to go the extra mile just to produce the same output as the normal unit. The most critical operational risk lies in the low safety margin remaining at only 4.9V before the alert alarm is activated, as well as the workload position that reaches 68.5% of the 60V trip limit. High excitation levels can eliminate the generator's flexibility in responding to sudden fluctuations in reactive loads, thus risking load disconnection/trip. If this failure occurs at peak load, then the electrical stability on Bawean island is threatened by the potential for cascading failure, which confirms that the current condition of engine 3 not only reduces engine performance but also reduces the reliability of the electric power system as a whole.

Advice

To restore the performance of the generator, it is recommended to immediately carry out a technical inspection of the internal components of engine 3, especially for field coil resistance testing and rectifier diode inspection to detect potential insulation damage or degradation. In addition, it is necessary to carry out load balancing between phases in the network to reduce high neutral currents and recalibrate the AVR system. For the integration of real-time excitation monitoring into the plant control system, it is highly recommended that similar anomalies can be detected and mitigated automatically before approaching operational critical limits.

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