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Analyzing the Role of Automatic Voltage Regulator towards Excited Synchronous Generators on the Sultan Hasanuddin Training Ship

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***Abstract*— Voltage instability in a synchronous generator can lead to system instability, affecting the quality and ability to transfer power to consumers. The worst-case scenario is load-shedding. To prevent this, the Automatic Voltage Regulator (AVR) is used to control the voltage stability of the synchronous generator. However, the AVR is often damaged, which prompted us to investigate its role in stabilizing the output voltage of the synchronous generator. This study was conducted on the Sultan Hasanuddin Training Ship owned by the Marine Science Polytechnic (PIP) Makassar using experimental research methods. Data collection techniques included observation, measurement, and documentation, and quantitative descriptive methods were used for analysis. Results indicated that the role of the AVR on the Sultan Hasanuddin Training Ship was insignificant since changes in generator load did not result in high fluctuations. The excitation current on the voltage amplifier or the output voltage of the synchronous generator remained within the working limit. This was proven by the generator's rotation speed, which ranged from 1470 to 1500 rpm, and a generator load of 36 to 38 kW.**

Keywords—AVR; excitation current; rotational speed

I. Introduction

Electricity has become an essential requirement in modern life, and the electric voltage generator plays a vital role in fulfilling the needs of industry, offices, and the community. Any disruption at the generator can cause significant disruption to all related activities. The power plant comprises various primary equipment, and one such equipment is the synchronous generator [1]. Synchronous generators are crucial in generating large-scale electrical energy, which is used by consumers for their daily needs. Typically, the synchronous generator's working principle is when the rotor is rotated by the prime mover and the stator is excited simultaneously at the same speed [2, 3]. However, synchronous generators are susceptible to voltage instability, which can cause instability of the entire system, affecting the system's quality and ability to transfer power from the generator to the consumer [4,5].

The Automatic Voltage Regulator (AVR) is a crucial device used to regulate voltage in synchronous generators and stabilize their output voltage. The AVR is essential in controlling the terminal voltage of the generator and compensating for any voltage fluctuations resulting from changes in the load. This is achieved by monitoring the excitation current in the voltage amplifier (exciter). The voltage regulation value can be used to determine the percentage of voltage drop between the generator's generated voltage and the output voltage. The AVR plays a crucial role in controlling and regulating the voltage of a synchronous generator.

The main goals of this research problem were: firstly, to investigate the impact of AVR on addressing voltage instability issues when the generator load changed on the Sutan Hasanuddin Training Ship; secondly, to explore the Excitation Current Control on the voltage amplifier (Exciter) when there was an increase or decrease in the output voltage of the Synchronous Generator on the Sultan Hasanuddin Training Ship.

II. Automatic Voltage Regulator (AVR)

AVR is a voltage regulator device used in synchronous generators to stabilize the output voltage [6]. The output voltage of a synchronous generator is generally unstable so a device is needed that can control the generator output voltage without being influenced by external interference (without the help of human power). This AVR equipment generally consists of several components, such as:

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regulator, firing, Power, Equipment Base Adjuster 70E, Voltage Adjuster Equipment (90R), and balance Meter (BM).

Construction of Automatic Voltage Regulator (AVR) is divided into two main parts [7], namely:

1. The rectifier section which functions to convert AC energy into the required DC by a synchronous generator in the process of excitation. In this section, the priority is the control signal which is used to turn on the transistor.
2. The part of the voltage regulator that functions as a DC voltage controller for the synchronous generator. Voltage regulator is the most important part in the excitation process in a synchronous generator. In this section there is a PI control that functions to regulate the DC voltage to be injected into the synchronous generator field. The input from the voltage regulator is a DC voltage from the rectifier and the desired reference voltage with the PI control used, the output is an excitation voltage which is the input to the synchronous generator.

III. Research Methodology

A. Location

The research was conducted on the Sultan Hasanuddin Training Ship belonging to the Makassar Marine Science Polytechnic. This research started from May 2021 to November 2021.

B. Tools

Some tools were using this research in order to get data as follows:

- AVR (Automatic Voltage Regulator) was used to regulate the generator terminal voltage by controlling the amount of excitation current supplied generator field winding.
- Synchronous generator is an electrical machine that is used to convert mechanical energy (movement energy) into electrical energy through the process of electromagnetic induction.
- Multi-meter was used to measure voltage, resistance and current.
- Watt meter was used to measure active power.
- VA Reactive was used to measure Reactive Power.

IV. Results and Discussion

A. Results

The Sultan Hasanuddin training ship is owned by the Ministry of Transportation and is operated by the Makassar Shipping Science Polytechnic, which is a part of the Transportation Human Resources Development Agency. According to the ship's particulars document, all data related to the training vessel has been finalized. The ship was built in 2018 by Steadfast Shipyard and has a length of 63 meters, width of 12 meters, and draft of 2.8 meters. Its capacity is 1200 Gross Tonnage and is powered by two main engines with a total output of 2 x 759 KW, capable of reaching a maximum speed of 12 knots.

The Sultan Hasanuddin training ship has various rooms including space for 20 crew members, 10 instructor rooms, 4 guest rooms (VVIP), 60 cadets space, 20 cadets space, and can accommodate 100 passengers and cargo up to 50 tons. It is equipped with navigation equipment such as two radars, GPS, GPS plotter with map, MFA-IF Radio, two VHF Radios, Inmarsat C, Navtex Receiver, AIS, Magnetic Compass and Giro Compass, Autopilot, Echo Sounder, Doppler Speed log, Wheater fax, barometer, thermometer, Hygrometer, and Anemometer. Additionally, it is equipped with safety equipment, such as 10 units of inflatable life craft with a capacity of 25 people, two units of life boats with a capacity of 45 people, four units of lifebuoy completed with self-lighting and eight units with line, four units of EPIRB, four units of SART, 12 units of red hand flame, 12 units of smoke signal, 12 units of rocket parachute signal, four units of line throwing apparatus and four units of MOB light smoke signal. Since its operation, the Sultan Hasanuddin training ship has sailed to several port cities in Indonesia, including Pontianak, Makassar, Surabaya, Kendari, Selayar, Pare-Pare, and the nearest islands around South Sulawesi [8].

The construction of the training ship serves as a means to support practical activities for adequate training participants with the aim of improving their competence, particularly those from PIP Makassar, in producing reliable and professional personnel in the field of water transportation, in accordance with the mandate of law number 17 of 2008 and the implementation of IMO regulations on the STCW Convention 78 amendments to 2010. It is hoped that after completing their education and working in the maritime industry, they will support the government in providing more effective, efficient, and affordable inter-regional connectivity through sea

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transportation services. The Sultan Hasanuddin Training Ship has been utilized for basic marine engineering and practical learning for PIP Makassar cadets and student officers, as well as for improvement training. Thus, it is crucial to maintain and ensure the generator's performance to prolong the training ship's usability.

The data obtained on the Sultan Hasanuddin Ship, especially related to Generator data to analyze the effect of AVR on the Synchronous Generator voltage, are as follows:

Table 1. Main Generator Data

Brand	Mecc Alte
Output	280 KW
Rotation	1500 rpm
Frequency	50 Hz
Voltage 1 Phase	221
Voltage 3 Phase	380 Volt
Excitation Voltage	35 V
Excitation Curent	3.6 A
Phase	3 Phase
Pole	4 Pole
Power Factor	0.83
Field Ampere	7 ,3 Ampere
Data Year	04-2016

Table 2. Main Generator Daily Load Data and Main

Time	Generator					
	f (Hz)	V (Volt)	I (Amp)	P (kW)	Q (VAR)	Cos ∅
01.00	49	220	79	37	2 ,5	0.82
02.00	50	220	79	37	2.5	0.83
03.00	50	220	79	37	2.5	0.83
04.00	49	220	79	37	2.5	0.82
05.00	50	220	79	37	2.5	0.83
06.00	50	220	78	37	2.5	0.83
07.00	50	221	79	37	2.5	0.82
08.00	49	220	79	36	2.5	0.83
09.00	49	221	78	37	2.5	0.83
10.00	49	222	80	38	2, 5	0.85
11.00	50	221	80	37	2.5	0.83
12.00	50	221	80	38	2.5	0.82
13.00	50	222	71	38	2.5	0.81
14.00	50	222	80	38	2.5	0.83
15.00	50	221	79	38	2.5	0.82
16.00	49	220	78	37	2.5	0.82
17.00	49	220	78	37	2.5	0.82
18.00	50	220	78	38	2.5	0.82
19.00	50	220	78	38	2.5	0.83
20.00	50	221	78	38	2.5	0.83
21.00	50	220	79	37	2.5	0.83
22.00	50	220	79	37	2.5	0.82
23. 00	50	220	80	37	2.5	0.82
24.00	50	221	78	37	2.5	0.82

B. Data Analysis

The speed can be determined by using the following equation [9]:

$$n = \frac{120\,f}{p} \qquad (1)$$

For example: f = 49 Hz, p = 4, thus:

$$n = \frac{120\ \ 49}{4} = 1470$$

The other result can be described in Table 3.

Table 3. Generator Speed Calculation Results

Time	n (rotation)	Time	n (rotation)
01.00	1470	13.00	1500
02.00	1500	14.00	1500
03.00	1500	15.00	1500
04.00	1470	16.00	1470
05.00	1500	17.00	1470
06.00	1500	18.00	1500
07.00	1500	19.00	1500
08.00	1470	20.00	1500
09.00	1470	21.00	1500
10.00	1470	22.00	1500
11.00	1500	23.00	1500
12.00	1500	24.00	1500

The excitation voltage in the Exciter can be determined by the following equation [10]:

$$Ef = n\,c\,\varnothing \qquad (2)$$

Where: $c\,\varnothing = \frac{Ef}{n} = \frac{35}{1500} = 0{,}0233$

For example : n = 1470, thus:

$$Ef = 1470\ x\ 0{,}0233 = 34{,}251\ V$$

The excitation current in the Exciter can be determined by the following equation [11]:

$$If = \frac{Ef}{Rf} \qquad (3)$$

Where: Exterior generator resistance value is :

$$Rf = \frac{Ef}{If} = \frac{35}{3{,}6} = 9{,}722\ \Omega$$

For example : Exciter voltage = 34,95 V, thus:

$$If = \frac{Ef}{Rf} = \frac{34{,}95}{9{,}722} = 3{,}59\ \text{Ampere}$$

Table 4. Calculation Results of Excitation of Voltage and Current

Time	Exciter	
	E_f (V)	I_f (A)
01.00	34.251	3.52
02.00	34.95	3.59
03.00	34.95	3.59
04.00	34.251	3.52
05.00	34.95	3.59
06.00	34.95	3.59
07.00	34.95	3.59
08.00	34.251	3.52
09.00	34.251	3.52

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10.00	34.251	3.52
11.00	34.95	3.59
12.00	34.95	3.59
13.00	34, 95	3.59
14.00	34.95	3.59
15.00	34.95	3.59
16.00	34.251	3.52
17.00	34,251	3.52
18.00	34.95	3.59
19.00	34.95	3.59
20.00	34.95	3.59
21.00	34.95	3.59
22.00	34.95	3.59
23.00	34.95	3.59
24.00	34.95	3.59

The Main Generator Constant Value is:

$$K = \frac{Eo}{\text{n If}} = \frac{380}{1500 \text{ x } 7{,}3} = 0{,}0347$$

The generator voltage without load every hour, can be determined by the formula equation [12]:

$$Eo = K\, n\, If \qquad (4)$$

For example: If = 3,59 A dan n = 1500, thus:

$$Eo = 0{,}0347x\ 1500x\ 3{,}59 = 186{,}8595\ V$$

The percentage of voltage without load every hour can be determined by using formula as follow:

$$\Delta V = \frac{Eo-V}{\text{V}}\ x\ 100\ \% \qquad (5)$$

For example:

$$\Delta V = \frac{179{,}55168-220}{220}\ x\ 100\ \% = -18{,}3856\ \%$$

Table 5. Calculation Results of Generator Voltage without Load and Percentage of Voltage Regulation

Time	Eo (V)	VR (%)
01.00	186.8595	-18.8290
02.00	186.8595	-15.0638
03.00	186.8595	-15.0638
04.00	179.55168	-18.8356
05.00	186.8595	-15 ,0638
06.00	186.8595	-15.0638
07.00	186.8595	-15.4482
08.00	179.55168	-18.3856
09.00	179.55168	-18.7549
10.00	179.55168	-19.1209
11.00	186.8595	-15.4482
12.00	186.8595	-15.4482
13.00	186.8595	-15.4482
14.00	186.8595	-18.8290
15.00	186.8595	-15.4482
16.00	179.55168	-18.3856
17.00	179.55168	-18.3856
18.00	186.8595	-15.0638
19.00	186.8595	-15.0638
20.00	186.8595	-15.4482
21.00	186.8595	-15.0638
22.00	186.8595	-15.0638
23.00	186 ,8595	-15.0638
24.00	186.8595	-15.4482

The data of excitation current calculation reveals that the value of excitation current was influenced by several factors such as generator output voltage, number of generator turns, and generator load. As the rotation speed of the generator increased, the excitation voltage and current on the exciter generator also increased. For instance, when the rotation speed was 1500 rpm at 8:00, the output voltage was 220 V, and the load was 36 kW, the excitation current value was 3.52 A. Similarly, at 14:00 with the same rotation speed and an output voltage of 222 V and a load of 38 kW, the excitation current value was 3.59 A.

From the calculation data for the percentage value of the voltage regulation above, it is evident that several factors could affect the percentage of voltage regulation, including the excitation current value and generator frequency. Increasing the generator frequency also increases the generator speed, the excitation current value, and the no-load generator voltage. The terminal voltage also plays a role in determining the percentage of voltage regulation. When the no-load generator voltage is high, and the terminal voltage is low, the percentage of voltage regulation increases. Conversely, when the no-load generator voltage is low, and the terminal voltage is high, the percentage value decreases. For example, at 08:00 with a frequency of 49 Hz, an excitation current value of 3.52 A, a generator rotation speed of 1470 rpm, a no-load generator voltage of 179.55168 Volts, and a generator terminal voltage of 220 Volts, the percentage value of voltage regulation was -18.3856. Similarly, at 14:00 with a frequency of 50 Hz, an excitation current value of 3.59 A, a generator rotation speed of 1500 rpm, a no-load generator voltage of 186.8595 Volts, and a generator terminal voltage of 222 Volts, the percentage value of voltage regulation was -15.8290.

The value of the percentage regulation must not exceed the limit of the percentage value of the voltage regulation of ± 20%. By looking at the lowest value and the highest value and the percentage of generator voltage regulation on the Sultan Hasanuddin Training Ship owned by PIP Makassar, the regulation value did not exceed the percentage limit of the permitted generator voltage regulation. From the percentage value of the voltage regulation, meaning the *Automatic Voltage Regulator* (AVR) worked well and the *Automatic Voltage Regulator* (AVR) played a role in controlling the generator voltage on the Sultan Hasanuddin Training Ship owned by PIP Makassar.

The highest excitation current value occured at 14.00 with a speed of 1500 rpm, the output voltage was 222 volts and the load was 38 kW with an excitation current value of 3.59 A. The lowest excitation current value was at 08.00 with a rotation speed of 1470 rpm, the output voltage was 220 volts and a load of 36 kW with an excitation current value of 3.52 A.

V. Conclusion

From the results of the study to observe the effect of AVR on the output voltage of the synchronous generator, it can be concluded as follows:

1. The effect Automatic Voltage Regulator (AVR) on the Sultan Hasanuddin Training Ship has not been significant because from the data the changes in the generator load have not shown high fluctuations.

2. The management of the excitation current on the voltage amplifier or the reduction of the output voltage of the synchronous generator on the Sultan Hasanuddin Training Ship was still operating within the specified range. This was supported by the fact that the generator rotation speed ranges from 1470 to 1500 rpm, and the generator load was between 36 and 38 kW.

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