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PID Controller System Analysis on Automatic Voltage Regulator (AVR) for Regulating Excitation Voltage of a 3-Phase Synchronous Generator

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Article Info	ABSTRACT
Keywords: PID controller, Automatic Voltage Regulator(AVR)	In power generation, voltage stability is a very important thing to consider because it can affect the electrical system. Changes in the output voltage of a generator are influenced by various factors including dynamic load and magnetic amplifier voltage (excitation voltage). In this final project, a 3-phase synchronous generator excitation voltage control system is created to maintain the stability of the generator voltage according to its rating of 380 volts. By implementing a PID controller, the size of the excitation voltage can be adjusted by changing the duty cycle of the PWM for switching the IGBT in the DC-DC converter power circuit of the buck-boost converter type. With the PID controller parameters Kp = 3, Ki-0.001, Kd = 0.001 and the excitation voltage that can be provided by the power circuit up to 130 volts dc, the system can be stable when there is a change in load. The recovery time to reach steady state is 1.3 seconds when loaded and 1.1 seconds when the load is removed.
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INTRODUCTION

The main problem of power generation is the generator output voltage that changes due to changes in the load on the generator. In large-scale interconnection systems, manual voltage stabilizers are never used and instead an automatic voltage stabilizer called an Automatic Voltage Regulator (AVR) is installed on each generator. The use of an Automatic Voltage Regulator (AVR) is inseparable from its advantages in terms of reliability in addition to ease of design and implementation..

Based on these conditions, in this study, an automatic generator voltage regulation system (AVR) with PID control referring to a three-phase system will be analyzed to regulate the excitation voltage that will be injected into the field coil. If the load on the generator output terminal is increased, the generator output terminal voltage will decrease. With the decrease in the generator output terminal voltage, the Automatic Voltage

Regulator(AVR) will automatically and quickly increase the excitation voltage which will then be injected into the field coil with the aim of increasing the generator output terminal voltage with the aim of making the output voltage stable to match the setting point voltage.

Literature Review

Pid Controller

PID controller is a combined control system between Proportional integrator and differential controller. The block diagram of PID controller can be seen in the following figure:

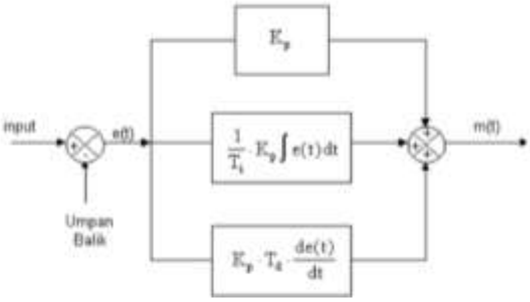

Figure 1. PID Controller Block Diagram

In continuous time, the output signal of the PID controller is formulated as follows:

$$u(t) = K_p e(t) + \frac{K_p}{T_1}\int_0^1 e(t)dt + K_p T_d \frac{de(t)}{dt} \text{..........} \quad (1)$$

Where:
u(t) =PID controller output signal
Kp =proportional constant
You =integral time
Ki =integral constant
Kd =differential constant
e(t) =error signal

So, the transfer function of the PID controller (in domain s) can be expressed as follows:

$$\frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i(s)} + T_d s\right) = K_p + \frac{K_i}{s} + K_d s \text{..........} \quad (2)$$

Buck Boost Converter

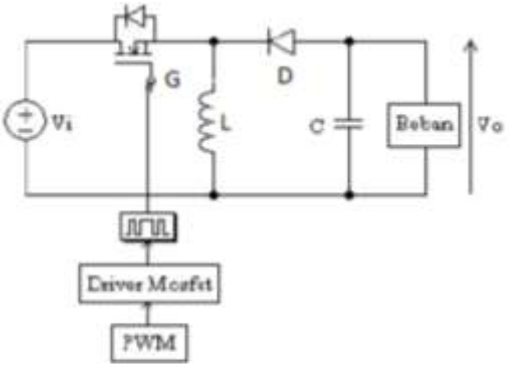

Figure 2. Buck-boost converter circuit

This Buck-Boost Converter circuit is a power circuit used to provide excitation voltage that will be injected into the generator field coil. The working principle of this buck-boost is divided into 2 parts, namely:

a. When the switch (S) is turned ON at t = 0 the diode will be reverse biased (open) and the incoming current will increase through the inductor (L) and the switch (S). Because the voltage on the capacitor is still 0 (zero) so the load does not receive a voltage supply when the switch (S) is first turned ON

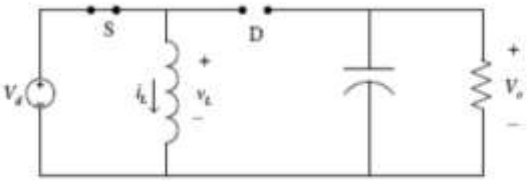

Figure 3. Equivalent circuit of mode I

$$\Delta i_L closed = \frac{VdDT}{L} \qquad (3)$$

b. Starting when the switch (S) is turned OFF, the diode becomes forward biased (closed) to conduct current. Current flows from the inductor to the capacitor, the load. The energy stored in the inductor will be distributed to the load. And the current in the inductor will decrease until the switch (S) is turned ON again for the next cycle.

$$\Delta i_L Opened = \frac{Vo(1-D)T}{L} \qquad (4)$$

The average output voltage is:

$$\Delta i_L closed + \Delta i Opened = 0$$
$$\frac{VdDT}{L} + \frac{Vo(1-D)T}{L} = 0$$
$$Vo = -Vd\left(\frac{D}{1-D}\right)$$

RESEARCH METHODS

To get a system response that matches the given setpoint, a controller is needed. There are various types of controllers and various methods of approach to get the value of the controller parameters. The choice of control method is influenced by the type of plant to be controlled. In this final project, the controller used is the PID (Proportional-Integral-Derivative) type. The following is a block diagram of the PID type control.

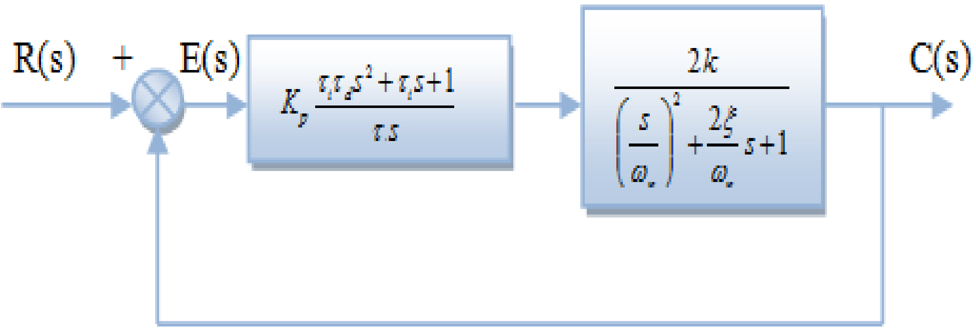

Figure 4. PID Control Block Diagram

Specification:

a. Ts(±5%) = 1 second
b. Without overshoot

The mathematical model of the plant used is when the plant is without load, namely:

$$TF = H(s) = \frac{1{,}141}{0{,}0826s^2 + 0{,}4591s + 1}$$

The parameters that need to be searched from this PID controller include Kp, τi, τd. By using the analytical method, the values of Kp, τi, τd will be calculated as follows:

With$\tau_i\tau_d = \frac{1}{\omega_n^2}$So:

a. Integral time

$$\frac{2\xi}{\omega_n} = \tau_i$$
$$\frac{2(0{,}7988}{3{,}48} = \tau_i$$
$$\tau_i = 0{,}46$$

b. System result time constant

$$t_s{}^* = 5\tau^*$$
$$1 = 5\tau^*$$
$$\tau^* = 0{,}2Detik$$

c. Differential time

$$\tau_i\tau_d = \frac{1}{\omega_n{}^2}$$
$$0{,}46\tau_d = \frac{1}{3{,}48^2}$$
$$\tau_d = 0{,}18$$

d. Proportional reinforcement

$$Kp = \frac{\tau_i}{\tau^* k}$$
$$Kp = \frac{0{,}46}{0{,}2(1{,}141)}$$
$$Kp = 2{,}016$$

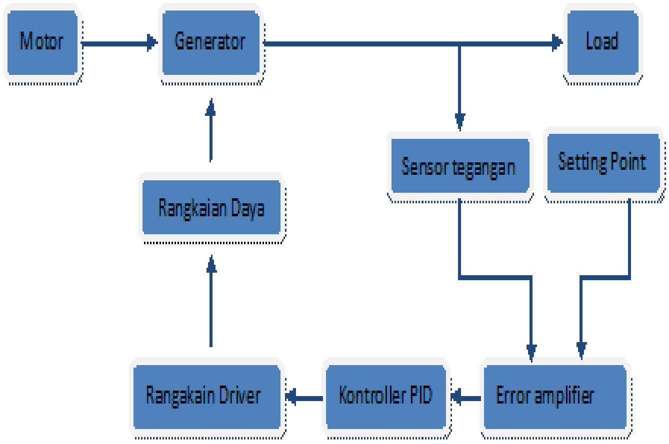

Figure 5. System Block Diagram

The block diagram above shows the basic configuration of an AVR control with a PID controller and a voltage divider circuit as a voltage sensor with a buck-boost DCDC converter power circuit as an actuator to inject excitation voltage into the generator field coil.

The plant used is a 3-phase AC generator with a prime mover, namely a 3-phase synchronous motor with the following specifications:

3 phase synchronous motor

a. Power: 2.2 kW
b. Voltage: 380 V
c. Frequency: 50 Hz o Current: 4.6 A
d. Rotation: 1500 rpm
e. Number of Poles: 4 poles

3 phase AC generator

a. Power: 2 kVA
b. Voltage: 380 volts
c. Current : 3.1 A
d. Frequency : 50 Hz
e. Rotation: 1500 rpm
f. Number of poles: 4 poles

RESULTS AND ANALYSIS

Result Test

This test is to determine the output voltage and current that can be produced from the buck-boost converter because later the output voltage and current of the buck-boost converter will be the source of excitation of the synchronous generator field amplifier. So that the output voltage and current of the buck-boost converter become parameters of efficiency and the ability of the power actuator in supplying excitation voltage. In this buck-boost converter test, the output side of the circuit is given a load of two lamps with a power capacity of 400 W with an input dc voltage from the rectification of 64 volt AC voltage to

87 volt dc and a switching frequency of 40kHz. By changing the amount of duty cycle, it will produce different output voltages and currents of the buck-boost converter along with changes in the duty cycle.

Table 1. Buck-Boost Converter Efficiency Test Results

Wine(volt)	Iin(amperes)	Vout(volt)	Iout(amperes)	Efficiency
86.4	0.3	28.4	0.8	87.6%
86	0.4	39	0.83	94.1%
85.3	0.6	48	0.94	88.2%
84.8	0.72	54	1	88.4%
83.5	1	62.7	1.12	84.1%
83.1	1.2	73.9	1.2	88.9%
83	1.6	85.7	1.26	81.3%
82.9	2	94	1.4	79.4%
82.4	3	116	1.52	71.3%
82	3.6	130	1.6	70.5%

$$Efisiensi = \left(\frac{P_{Out}}{P_{In}}\right) x100\%$$

Where:
Pout = Output power (Vout x Iout)
Pin = Input power (Vin x Iin)

From the test results table above, it is obtained that the output voltage and current of the buck-boost converter circuit can withstand a voltage of 130 volts and a current of 1.6 amps. In this condition, the inductor begins to saturate and begins to vibrate, causing noise in the inductor. In addition, the output voltage and current of the buck-boost converter begin to be unstable. Thus, the buck-boost converter circuit is only able to provide an excitation voltage supply for the generator field amplifier up to that limit. Meanwhile, its efficiency is on average above 70% and decreases along with the increase in duty cycle and output voltage. This is likely due to the inductor starting to saturate and make noise. The inductor that saturates and makes noise is possible because the inductor design is not good, for example, the air gap is not large enough and tight enough, and the inductor wire winding is not tight enough so that there is still space. With a switching frequency of 40kHz, the inductor will vibrate and saturate, causing many losses that make efficiency low.

Table 2. BuckBoost Converter Circuit Error Test Results

Dutycycle e	Wine(Volt)	Vout_ R (volts)	Vout_ T (volts)	V_error
23%	86.4	28.4	25.8	10%
28%	86	39	33.4	16%
35%	85.3	48	45.93	4%
40%	84.8	54	56.5	4%
46.5%	83.5	62.7	69.9	10%
52%	83.1	73.9	90	17%

Dutycycle e	Wine(Volt)	Vout_ R (volts)	Vout_ T (volts)	V_error
58%	83	85.7	114.6	25%
64%	82.9	94	147.4	36%
69.7%	82.4	116	189.5	38%
75.5%	82	130	252.7	48%

$$V - Error = \left|\frac{Vout\_T - Vout\_R}{Vout\_T}\right| x100\%$$

Where:
V_error : Voltage error
Vout_T: Output voltage calculation
Vout_R : Measurement output voltage

Open Loop System Testing

In this open loop system test, the buck-boost converter actuator is run to provide excitation voltage up to 380 volts. Then the generator output is given a resistive load. The following is a table of the results of the open loop system test using the buck-boost converter actuator.

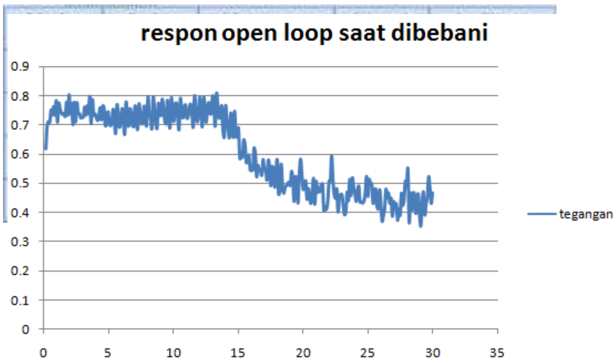

Figure 6. Generator Output Voltage Response When Open Loop

From the test results table and generator output voltage graph when the system is open loop, the generator voltage does not change when not loaded. When starting to be loaded with a load current of 0.4 A, the generator voltage drops by 1.05%. And when the load current reaches 1.23 A, the generator voltage drops by 5.26% from the nominal voltage. The decrease in generator voltage is followed by a decrease in excitation voltage and excitation current. For the excitation voltage from the buck-boost converter output when partial testing is carried out, there is a change when it is inserted into the generator field amplifier. During the partial test to produce a current of 1.3 A, the buck-boost converter voltage is 86 volts. While when inserted into the field amplifier to produce a current of 1.3 A (so that the nominal generator output voltage is 380 volts) the buck-boost converter voltage drops to 55 volts. This is because during the partial test the buck-boost converter is loaded with an incandescent lamp where the incandescent lamp load is resistive. While when loaded with a field amplifier that is not only resistive but also has an inductive element because the field amplifier is a coil. So when it is inserted into the buck-boost converter voltage generator field amplifier, it drops 36% from the partial test.

Close Loop System Testing

After the design and manufacturing process is carried out, the next step is direct implementation to the 3-phase synchronous generator plant through the configuration between the ADAM 5000 series and the hardware that has been created. In this closed system integration test, all parts of the tested block diagrams are combined into one which includes the controller, buck-boost converter, and voltage sensor.

Table 3. Results of PID Parameter Calculations Using Analytical Methods

PID Method/Parameters	Desired Response	Kp	Ki	Kd
No burden	1 Second	2	3	0.3

The PID controller parameters calculated above are not accurate when applied to the controller. Therefore, a tuning process is needed to find the controller parameters until the system response is as expected. After performing the controller parameter tuning process and observing the system response, a fairly good PID controller parameter is obtained. The following is a table of controller parameters resulting from the tuning process.

Table 4. Results of PID Parameter Calculations Using Analytical Methods

PID Method/Parameters	System Response	Kp	Ki	Kd
Resistive Load	1.3s and 1.4s	3	0.001	0.001

Plant testing with pure resistive load on each phase. The given setting point is 4.17 volts dc and sampling time 0.001s.

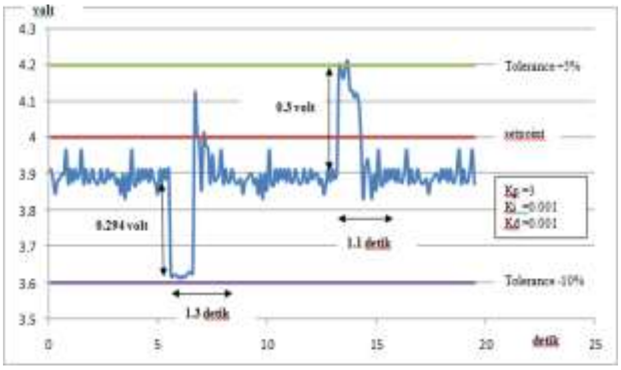

Figure 7. Transient Response of Resistive Loaded Plant

From Figure 7 above, it can be seen that the disturbance to the plant occurred at second 6 when the load began to be inserted. When the generator began to be loaded, the output voltage dropped suddenly to -9.5% of the generator's nominal voltage. This occurs because the current flowing to the load is getting bigger so that there is a very large voltage drop in the impedance in the generator. The controller's time to return the voltage to the setting point is 1.3 seconds. While at second 13 when the load is removed, the generator's output voltage increases to 5.2% of the generator's nominal voltage. This is because the load current suddenly decreases so that the voltage drop in the impedance in the generator decreases and the generator's output voltage increases. And the controller's time to return the voltage to the setting point is 1.1 seconds. With the increase and decrease of the generator voltage, the controller will provide its control action, namely by increasing and decreasing the control voltage until the smallest error condition is reached.

CONCLUSION

Based on the data obtained from all the tests that have been carried out, it can be concluded that: PID controller can be implemented in generator excitation voltage regulation to stabilize the generator output voltage when the load changes. The generator output voltage is disturbed when the generator load is suddenly inserted and removed. When the load is inserted, the generator output voltage drops due to a voltage drop in the impedance in the generator. The appropriate controller parameters to obtain the expected system response are with values of Kp=3, Ki=0.001 and Kd=0.001. The transient condition of the plant requires a time of 1.3 seconds to reach steady state when the generator is loaded and 1.1 seconds to reach steady state when the load on the generator is removed. The overshoot and undershoot of the generator response still meet the voltage tolerance standards of -10% and +5%. When loaded, the voltage drops by 9.5% and when the load is removed, the voltage rises by 5.2% of the generator's nominal voltage.

REFERENCE

B. Satria, Rahmaniar, R., & Dalimunthe, M. E. (2024). An Implementation Iot Weather Station Based On ESP 32. *Jurnal Scientia*, *13*(04), 1453-1460.

B. Satria et al (2025) A Development IOT Based Real-Time Weather Monitoring System Using NodeMCU ESP32 and BMP280-DHT11 Sensor. *INFOKUM*, *13*(03), 698-710.

Dalimunthe M.E (2024) ANALISIS KINERJA MODIFIKASI ALAT PENGUKUR DAN PEMBATAS SATU PHASE DIPELANGGAN YANG MENYEBABKAN SUSUT NONTEKNIS DI PT. PLN ULP MEULABOH. *Jurnal Informatika dan Teknik Elektro Terapan*, *12*(3).

Yoel Wesly Dirney Lumbantoruan, Parlin Siagian, Haris Gunawan, 2025 "Analysis of Electrical Energy Consumption of Circulation Pump Cooling Tower P21C Using Inverter at PT Unilever Oleochemical Indonesia" Serambi Engineering Journal Volume X, No. 2, April 2025, p-ISSN: 2528-3561 e-ISSN: 2541-1934

HaryonO, Iskak, et al. Evaluation of Generator Performance After Maintenance of Building 21. EBN Research Results 2018, 2018, 251-258.

Fathudin, Asep, Saud Maruli Tua, and Haris Gunawan. "EVALUATION OF ELECTRICAL VOLTAGE FLUCTUATION IN RADIOMETALLURGY FACILITIES." EBN Research Results 2018 (2018): 223-233.

M. Munawar Sajali Tanjung, Zulkarnain, Mhd Erpandi Dalimunthe, Yuliarman Saragih, 2025 "Analysis of Generator Set (Genset) Reliability as Emergency Power Supply Application in Campus 3 Unpab Electrical System"Journal HomepageVolume 7 Issue 1 p-ISSN: 2686-0139 e-ISSN: 2685-9556

Fakhrul Razi Anjas, Muhammad Erpandi Dalimunthe, 2025 “Design of Single Phase Voltage Loss Relay System on Three Phase Motors at Blang Pidie Substation” INFOKUM Volume 13, Number 02, 2025, DOI 10.58471/infokum.v13i02ESSN 2722-4635 (Online)

Irham Amando Lubis, Dino Erivianto, Zuraidah Tharo, 2024 "Analysis of Power Distribution System Reliability Using System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) On Feeder KR04" nternational Journal of Economic, Technology and Social Sciencesurl Volume 5Number 2 page211-223 e-ISSN 2775-2976:https://jurnal.ceredindonesia.or.id/index.php/injects

Liliana, Benedicto F, Bandri S, 2021 “Performance Analysis of Automatic Voltage Regulator (Avr) as a Controller of Excitation Voltage Supply of 3 Phase Ac Generator” IJEERE: Indonesian Journal of Electrical Engineering and Renewable Energy Vol. 1 Iss. 1 June 2021, pp: 37-44 P-ISSN: 2797-1155 E-ISSN: 2797-0868 Journal Homepage:https://journal.irpi.or.id/index.php/ijeere

Abdul Muis Prasetia, Linda Sartika, Abdul Saad 2023 “AVR Optimization on Synchronous Generator Using Adaptive Neuro Fuzzy Inference System (ANFIS) Method” Media Elektrika, Vol.16, No.2, December 2023 (p-ISSN: 1979-7451, e-ISSN: 2579-972X)

Al Ma'ruf, 2021 "Use of PID on Automatic Voltage Regulator (AVR) for Stability of Terminal Voltage of 3 Phase Synchronous Generator" Department of Electrical Engineering, Faculty of Engineering, University of Borneo Tarakan 2021

Pamungkas, TD, Sutisna, U., & Fauzan, YR (2018). Application of Fuzzy Algorithm for PID Controller Optimization on AVR Generator Control System 3 Phase 480VA Based on ATMega16 Microcontroller. 2, 35–45

Muhammad, RD, & Faisal, F. (2019). Stability Study of Generator System of Sulselrabar. Journal of Electrical and Electronic Engineering, 3(1), 82-119.

Siagian, P., Hamdani, H., & Dalimunthe, M. E. Pengaruh Tabir Filter Film Terhadap Tegangan Output Solar Sel Jenis Polycrystalline. *SITEKIN: Jurnal Sains, Teknologi dan Industri*, *19*(2), 414-418.

Wibowo, P., Satria, B., Dalimunthe, M. E., & Muflih, A. (2024). Pengembangan Charging System Untuk Kendaraan Listrik. *Sinergi Multidisiplin Sosial Humaniora dan Sains Teknologi*, *1*(1), 101-109.