SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Mechanics

Journal homepage: https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Load Switching Scada-Based on Three-Phase 15 MW and 20 MW Synchronous Generators

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ARTICLE INFO

Article history:
Received 7 May 2024
Received in revised form 2 July 2024
Accepted 15 July 2024
Available online 30 July 2024

Keywords:
Generator; SCADA; Load; Voltage

ABSTRACT

PT. Pupuk Iskandar Muda (PT. PIM) generates electricity from two main gas turbine generators (GTGs), one with a capacity of 15 MW and 20 MW respectively. The generator's performance can only be at its best if its operation remains stable, even when it exceeds capacity or faces potential damage from its outdated engine. When the electrical load increases and reaches its maximum capacity, load transfer is commonly accomplished through synchronous generator operation. However, the synchronisation may lead to generator failure. This study focuses on (1) examining the PT's load transfer process of Iskandar Muda fertiliser, operated based on Supervisory Control and Data Acquisition (SCADA), and (2) evaluating the influence of voltage and frequency on this process. This study utilised qualitative methods by directly observing field data at PT PIM. The results obtained indicated that the load transfer process at PT PIM is carried out on two simultaneously operating gas turbine generators using SCADA-based technology. The load transfer process employs two methods, namely fast load transfer and slow load transfer. Changes in the decrease in power in GTG 1 and the increase in power in GTG 2 can cause the generator's rotational speed and the governor's setting point to change, resulting in changes in the voltage and frequency characteristics. The load transfer is performed regularly in stages of 200 kW to maintain the stability of the generator condition. However, a transfer of 1 MW is executed during the final stage to avoid overloading and a potential burden on one of the generators. GTG 1 experiences a voltage increase of 0.018% and a frequency increase of 0.0059% due to load changes in the two generators, whereas GTG 2 has a voltage increase of 0.018% and a frequency increase of 0.0019% when the load shifts from 1 MW to 9 MW.

1. Introduction

PT. Pupuk Iskandar Muda (PT. PIM) operates five power plants, including gas turbine generators (GTG 1 and GTG 2, generating a power of 15 MW and 20 MW, respectively), which operate at a voltage of 13.8 KV. The plant is currently operational and ready to supply power. The gas turbine generator has a capacity of 1.5 MW and operates at a voltage of 2.4 KV, while the diesel engine

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https://doi.org/10.37934/aram.122.1.175185

generator (DEG) has a capacity of 350 KW and operates at a voltage of 480 V. In the event of a main generator failure, the standby generator will initiate automatically, according to the manual for backup electrical power distribution by PT PIM. In the past, DEG was exclusively utilised for short-term emergencies before activating the GTG standby and for less than 10 seconds following a blackout at the primary generator. It also serves as a backup for electric motors capable of handling 480 V voltage capacity. Energy will be transmitted and distributed through transmission and distribution channels to end-use installations such as utilities, urea, ammonia, offices, housing complexes, and workshops [1]. The operation of the synchronous generator is an excellent solution for managing the escalating electricity or load requirements. Parallel generator operation is thought to be more cost-effective in terms of power plant continuity and output. If a generator is subjected to a load that exceeds its capacity, it may cease functioning or even be damaged due to the engine's age. Therefore, it can be run and combined with other generators operated simultaneously with those previously working on the same electricity network.

Disturbances or load transfers in the system must be muted and aligned within a certain time frame to be considered stable. Transient stability is one of the factors that influence stability. It is necessary to conduct research to determine how to transfer the load using an online system to synchronise two generators and the power factor at PT. PIM. The subjects to be investigated comprise the voltage, phase angle, frequency, phase angle, and power, as well as the steps for selecting cases under specific conditions. This study aims to determine how the SCADA-based load transfer process works and assess the effect of voltage and frequency due to load transfer on the generator.

1.1 Main Gas Turbine Generator (GTG)

A gas power plant is a type of power plant that uses gas to turn a turbine, thereby driving a generator. Its main components are the turbine and the generator. As a result, if the turbine rotates, the generator will also rotate. So, as the generator rotates, a potential difference in its magnetic field will be created, generating electrical energy. Theoretically, a gas power plant is similar to a steam power plant. It is just that the steam has been replaced by gas. Due to the notable difference between steam and gas properties, there will be some fundamental differences between steam and gas. Furthermore, the gas used in a Gas Power Plant is arguably easier to prepare than steam. Therefore, a Gas Power Plant can be more cost-effective. In addition, a Gas Power Plant can start producing from a "cold" state in minutes, say about 10 minutes to 30 minutes, much faster than what can be done by a Steam Power Plant [1]. The PT PIM's GTG 1 and GTG 2 are illustrated in Figure 1 and Figure 2, respectively.

Fig. 1. GTG 1 (PT PIM, 2021)

Fig. 2. GTG 2 (PT PIM, 2021)

1.2 Load Sharing

The term load sharing describes the process of dividing the power supplied by multiple generators operating in parallel proportionally, considering both reactive power (KVAR) and active power (KW). Load sharing is very important to prevent overload on a generator and maintain network stability and continuity of electrical power supply to the load.

In short, load sharing is a system in the operation of the generator, namely the sharing of the load jointly by several generators or more, while the purpose of this load sharing system is to maintain the continuity (smoothness) of electric power and act as protection for the security of the generator itself in the event of a decrease or increase load [2].

1.3 Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) is a system that collects information or data from the field before sending it to a central computer that will manage and control the data. SCADA systems are used in industrial processes such as steel plants [3], the generation and distribution of electric power (conventional and nuclear), and chemical plants, as well as in some experimental facilities such as nuclear fusion. From the SCADA point of view, the size of the plant or process system ranges from 1,000 to 10,000 I/O (output/input), but currently, SCADA systems can handle up to hundreds of thousands of I/O.

A gas power plant is a type of power plant that uses gas to turn a turbine, which then drives a generator. Two shaft objects are the turbine and the generator. As a result, if the turbine rotates, the generator will also rotate. So, as the generator rotates, it creates a potential difference in its magnetic field, which generates electrical energy. Theoretically, a gas power plant is similar to a steam power plant. It is just that the steam has been replaced by gas. Because the properties of steam and gas differ in general, there will be some fundamental differences between steam turbines and gas turbines. Furthermore, the gas used in a Gas Power Plant is arguably easier to prepare than steam. Therefore, a Gas Power Plant can be more cost-effective [1].

1.4 Power Factor

The power factor, also known as cos φ, is defined as the ratio of active power (kW) to apparent power (kVA). It compares the current in a circuit that can produce work to the total current that enters the circuit [4,5]. A flowing load causes a power factor value in an AC voltage system, and its value is determined by the characteristics of the load, as shown in Eq. (1).

$$\cos \phi = \frac{P(w)}{S(VA)} \quad (1)$$

where, P = active power (Watt) and S = apparent power (Volt Ampere)

The power factor can also be defined as a number that indicates how efficiently the network distributes available power. A low power factor is also harmful because it increases the load current. In Eqs. (2) and (3), apparent power is defined as the total power of the generator's maximum power capacity or as the sum of active and reactive power.

$$S = V \times I \text{ (VA)} \quad (2)$$

$$S = \sqrt{P^2 + Q^2} \quad (3)$$

Active power, also known as real power, has a unit of watts, representing the power used to carry out actual energy. The phase calculation can be seen in Eq. 4. Meanwhile, reactive power has the unit of VAR, denoting the power supplied by reactive components. It is also called the amount of power required for forming a magnetic field, and it can be mathematically expressed in Eq. (5) [4,5].

$$P = V.I.\cos Q.\sqrt{3} \quad (4)$$

$$Q = V.I.\sin Q.\sqrt{3} \quad (5)$$

1.5 Voltage and Frequency Against Load

Voltage, measured in volts, is the electric potential difference between two points in an electrical circuit. In this case, the potential energy of an electric field that causes an electric current to flow in an electric conductor is measured. The resistance/load is the parameter which signifies a voltage drop between its two channels when current flows through it, calculated using the derivatives of Eq. (6).

$$V = \frac{P}{\mathrm{IL} \times (\mathrm{Cos}\ \phi) \times \sqrt{3}} \quad (6)$$

where, V= voltage generator, P= active power, IL= load current.

Frequency is defined as the number of vibrations occurring within one second or the number of waves or electrical vibrations produced every second [6,7]. The relations between the frequency and load can be shown in Eq. (7).

$$F = \frac{N \times P}{120} \quad (7)$$

where, F = mains frequency (Hz), N = rotor rotational speed = magnetic field speed (rpm), and P = number of magnetic poles.

2. Methodology

2.1 Field Data Collection

Research data is obtained from daily log sheet observations of documents, manual books, data records, generator data, and single-line diagrams. Load variations, voltage values, frequencies, load transfer diagrams, and generator specifications under study are also included. Research data of 15 and 20 MW gas turbine generators was collected on the 22nd and 24th of February 2022 at PT Iskandar Muda in Krueng Geukuh, North Aceh [11].

Table 1
Specification of Generator 20 MW

Data Generator	
Merk	General Electric
Generator	20 MW
Serial Number	IM-3006-3123
Made In	Indonesia
Rated Power (ONAN/ONAF)	15/20 MW
Rated Voltage	
Speed (rpm)	5100
Trip Over speed (rpm)	5610
Connection	-
Temperature Rise	
1.Oil	50 C
2.Winding	55 C
Frequency	50 Hz
Voltage Regulation	11 Kv
Power Factor	0,8
Standard	SOM 61042
Phase	3
Flow	Axial

2.2 Data Processing

The purpose of this method is to analyze field data and gather power value specification data for optimizing the generator's output power when switching loads:

i) The observation method is to review the existing data on the load transfer system process on the generator at PT. PIM.
ii) The library method collects reference data for each case.
iii) Consultation and discussion with other competent parties, particularly in some special cases.
iv) The test method assesses the available system by conducting targeted experiments that align with its objectives and gathering experimental data for analysis.

2.3 Data Analysing

The data analysis involves the following attributes:

i) Analysing the performance of the 20 MW GTG at PT. PIM and the load transfer on the generator by synchronising two generators.
ii) Examining the effect of load transfer on power, voltage, and frequency at PT. PIM.

A more detailed representation of the research method is shown in Figure 3 as follows.

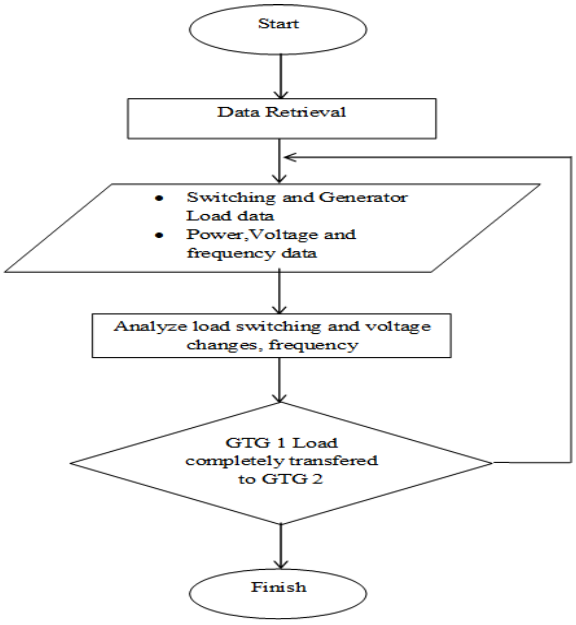

Fig. 3. Research flowchart

3. Results

3.1 Scada-Based Load Transfer Process on Generators at PT. PIM

The block diagram presented in Figure 4 illustrates the electrical system at PT. Pupuk Iskandar Muda. This system is responsible for managing several priority loads supplied by gas turbine generator units 1 and 2. The allocation and prioritization of these loads are documented in Table 2 for the PIM 1 and PIM 2 plants.

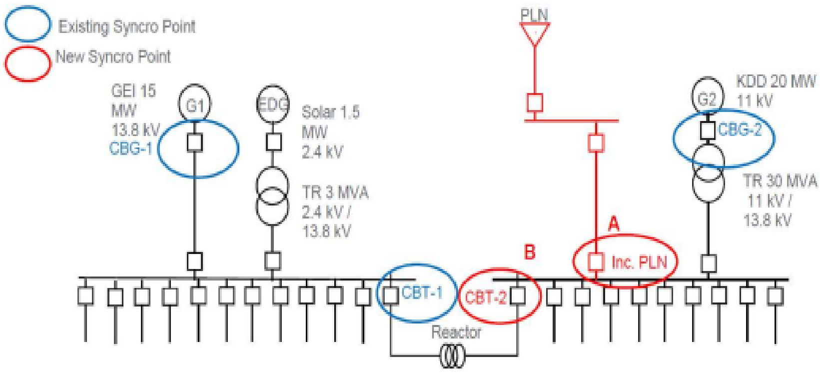

Fig. 4. Diagram block

Table 2
Load Priority Data

No	Item	Name	Load	Priority
1	NG 1102	Main& Utilities	1.26	1
2	SG-411-7	Utility/Offsite 2.4 kVMCC-321	4.29	2
3	SG-411-8	Utility/Offsite 480 V MCC-331	3.24	3
4	SG-411-3	Ammonia 2.4 kV MCC-121	4.13	4
5	SG-411-4	Ammonia 480 V MCC-231	1.92	5
6	NG 1103	Ammonia Unit No.1	2.64	6
7	NG 1104	Ammonia Unit No. 2	1.30	7
8	NG 1106	Bagging Unit/PPU Urea 1	0.11	8
9	NG 1105	Urea Unit No. 1	3.40	9
10	SG-411-5	Urea 2.4 kV MCC-221	1.57	10
11	SG-411-6	Urea 480 V MCC-231	2.67	11
12	NG 1112	Additional Air Compressor	1.60	12
13	SG-411-9	Urea Bulk Storage and Bagging Facilities 480 V	0.14	13
14	NG 1112	Feeder for Maintenance Shop	0.17	14
15	NG 1107	Administration Building	0.14	15
16	NG 1108	Housing Colony	0.97	16
17	NG 1111	Eks AAF	2.64	17
18	NG 1109	Eks Pim-2 Construction	1.30	18
19		Empty Spare (NPK Outgoing)	0.11	19
20		Incoming Feeder (NEW)	3.40	20

The process of transferring the load from generator unit 1 to generator unit 2 is as follows:

i) Check that the breaker on the generator to be paralleled is open or that the system has secured the condition of the incoming generator.
ii) AVR (Automatic Voltage Regulator) in "automatic" mode
iii) Start the prime mover or prime mover until it reaches full speed with no load.
iv) The frequency in the high position is one-tenth of the system frequency set and controlled by the governor.
v) Set the voltage on the AVR in the generator position to equal or exceed the system height.
vi) Using the syncroscope on the incoming generator, slowly rotate the frequency setting in the "fast" position close to 0.
vii) Close the incoming generator breaker 1 to 2 degrees before position 0 on the synchroscope, assuming the breaker has an inert mass, closing the breaker exactly at 0 on the synchroscope.
viii) Deactivate the synchroscope system.
ix) Use governor control to gradually and continuously transfer the load to the incoming generator.
x) If the power factor read between two or more parallel generators is not the same, adjust the AVR of each generator until the power factor of each generator is close to the same.

3.2 Slow Load Switching

The process of transferring the load from generator unit 1 to generator unit 2 using the slow load switching method is as follows:

i) Choose a priority level for each load that has been determined at PT. PIM is included in the load-shedding scheme. Each load group must be known and approved by the circuit breaker position.
ii) Then, the load release begins slowly and gradually according to the provisions after the generator is overloaded.
iii) The step (next load) was validated by an overloaded generator, which is still present after the time delay.
iv) Each step in the load has an associated delay. This value will be set during testing or commissioning.
v) Load shedding will stop after the overload condition of the generator has disappeared. In other words, it is finished.
vi) The overload generator will be determined by the connected engine hardwired to the PLC input, which is triggered by the signal of the installed protection device.

3.3 Fast Load Switching

The process of transferring the load from generator unit 1 to generator unit 2 using the fast load switching method is as follows:

i) Selection of the load priority level that has been determined at PT. The operator will enter PIM from the shedding feeder through the SCADA system.
ii) Then, the PLC will calculate the load shedding based on the power plant and the resulting load power.
iii) When the PLC has calculated the shedding load before the generator overload occurs
iv) A shed flag will be displayed on SCADA. PLC does the calculation of fast load shedding before load shedding occurs.

The calculation considers the balance of supply (engine maximum and reserve capacity) and demand (total load of each feeder). The maximum capacity of the engine is the amount of power it can supply. The maximum reserve capacity is the amount of power available if one of the engines fails. SCADA can be used to set the maximum capacity of each generator.

3.4 Effect of Load Switching on GTG 1 and GTG 2 on Voltage and Frequency

Normal loading data on generator units 1 and 2 and voltage, current, and frequency values collected by research and the data collection process on GTG unit 1 and GTG unit 2 at PT. PIM are shown in Tables 3 and 4, respectively.

Table 3
Normal loading at GTG 1

Load (MW)	Voltage (KV)	Current (A)	Frequency (HZ)
9.7	13.8	665	50.18
9.8	13.8	666	50.18
9.8	13.8	667	50.18
9.9	13.8	669	50.18
9.9	13.8	668	50.18

Table 4
Normal loading at GTG 2

Load (MW)	Voltage (KV)	Current (A)	Frequency (HZ)
9.8	13.8	665	50.18
9.9	13.8	669	50.18
9.8	13.8	666	50.18
9.7	13.8	662	50.18
10	13.8	673	50.18

The load transfer carried out on GTG 1 and GTG 2 affects the value of voltage, frequency, and current caused by periodic load switching. Load switching is carried out gradually from the initial value of GTG unit 1, with a total load of 9 MW being transferred gradually, as much as 200 KW and 1 MW, until the load is completely transferred. The gas turbine generator (GTG) unit 1 operates with a load that PT bears. Pupuk Iskandar Muda of 9 MW, unit 2 gas turbine generator (GTG) has been operated on standby at full speed with no load (FSNL) position to be ready to accept the load from GTG 1, which will be transferred. GTG unit 1 will perform a SCADA-based load transfer by transferring a load of 200 Kw in stages. The initial condition of GTG 1 has a voltage parameter of 11.04 KV and an initial frequency of 50.18 HZ, and GTG 2 has a voltage of 11.04 KV and a frequency of 50.18 HZ [11].

When GTG 1 continues to reduce its load from 7.8 MW to 7.2 MW, and GTG 2 continues to experience additional load continuously, the load will be gradually shifted, which will continue to affect the voltage and frequency of the generator. However, it does not change significantly due to speed regulation and Automatic Voltage. Regulator (AVR) frequency of 50.17 HZ. At a load of 2.4 MW, GTG 2 has a voltage parameter of 11.05 KV, and the frequency drops two points to 50.16 HZ. GTG 1, with a load of 6.8 MW, has a voltage of 11.05 KV with the highest frequency increase of 50.21 HZ. GTG 1 has a capacity of 6.8 MW and a voltage of 11.05 KV with a temporary frequency value of 50.21 HZ at its setting point, whereas GTG 2 has a voltage of 11.05 KV and a relatively low frequency of 50.16 HZ. After continuously switching the load, GTG 1 is already in the load position of 6.6 MW, with a voltage of 11.04 KV and a setting point and frequency of 50.18 HZ. GTG 2 has a voltage of 11.04 KV and the same frequency as GTG 1. The load is transferred at 200 KW, and GTG 1 has a load of 6.4 MW, maintaining the voltage and frequency at 11.04 KV and 50.18 HZ. A similar case goes to GTG 2. Both generators are in position with the same parameters.

GTG 1 has a capacity of 6.8 MW and a voltage of 11.05 KV with a temporary frequency value of 50.21 HZ at its setting point, whereas GTG 2 has a voltage of 11.05 KV and a relatively low frequency of 50.16 HZ. After continuously switching the load, GTG 1 is already in the load position of 6.6 MW, with a voltage of 11.04 KV and a setting point and frequency of 50.18 HZ. GTG 2 has a voltage of 11.04 KV and the same frequency as GTG 1. The load is transferred at 200 KW, and GTG 1 has a load of 6.4 MW with a stable frequency of 50.18 HZ.GTG 2 with a load of 6.4 MW, the voltage drops to 11.03 KV and again increases to 11.05 KV at a load of 6.6 MW as well as the frequency, which was originally decreased by 50.17 again increases to 50.18 HZ according to the load. The voltage condition on GTG 1 is normal at a load of 2.4 to 1.8 MW, which is 11.04 KV different, with a frequency that continues to increase as the load decreases to 50.20 HZ at a load of 2 MW. While the GTG 2 load increases from 6.8 MW to 7.4 MW, the voltage drops to 11.03 KV, and the frequency drops to 50.17 HZ. The burden carried by GTG 1 is only 1.6 MW, which will be transferred as much as 200 KW to a value of 1.2 MW, while the load for GTG 2 continues to rise to 7.6 MW to 8 MW, with both generators increasing in voltage and frequency, particularly in GTG 1. There is also a continuous and regular decrease in voltage and frequency in GTG 2, even though both generators will return to their respective initial setting points.

Because GTG 1's remaining load is only 1 MW, the burden will continue to be transferred directly to GTG 2 at 1 MW so that GTG 2 can bear the entire burden previously on GTG 1, which is 9 MW. If the amount is less than 200 KW at the end of the transfer process, it can cause GTG 1 to become a motor in the sense that GTG 1 becomes part of the dependent burden that must be carried by GTG 2, so the load transfer is carried out directly by 1 MW to anticipate these events, as well as other influences on GTG 2. Therefore, the load transfer is carried out directly by 1 MW to anticipate these events and other influences on the stable condition of generator performance. In this 1 MW load transfer condition, GTG 1 has a voltage of 11.05 KV with a frequency of 50.21 HZ, while the condition of GTG 2 has a normal voltage of 11.04 KV and a frequency of 50.18 HZ.

Figure 5 presents the effect of load switching on the voltage on GTG 1. During the load-switching process, the voltage condition has an initial setting point value of 11.04 kV. It continues to experience linear changes in voltage when power is transferred to 200 kW or 1 MW. The state of the voltage value and the relative increase is directly proportional to the frequency, with the increase in the highest voltage value being only at 11.06 kV while the lowest value is 11.03 kV. Figure 6 depicts the graphic results of the effect of changes in load on the frequency of GTG 1. The condition of the frequency parameters changes when the load on GTG 1 decreases. The change in frequency value is not significant but relatively increases even though the load continues to be transferred to GTG 2 regularly; the highest frequency value when switching the load is 50.21 HZ when the load is 6.8 MW also 1 MW and the lowest value is 50.17 Hz, the frequency has a setting point value of 50.18 Hz.

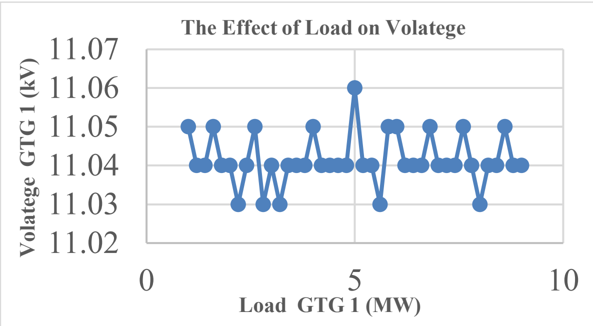

Fig. 5. The effect of load on voltage on GTG 1

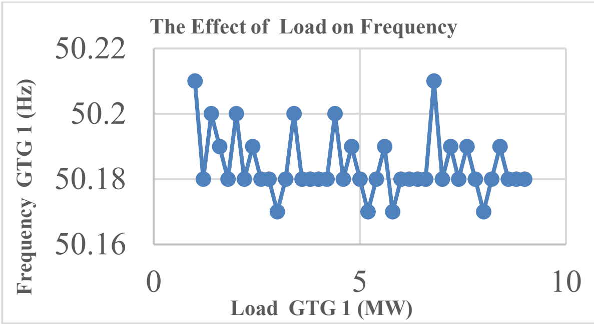

Fig. 6. The effect of load on frequency on GTG 1

Figure 7 depicts a graph of the effect of load changes on GTG 2 voltage. The load is transferred from GTG to GTG 2, which will gradually receive the load. Changes in increasing and decreasing voltage values and stable conditions occur due to increasing load, but overvoltage frequently results in a voltage drop. Figure 8 depicts a graph of the effect of load switching on the frequency of GTG 2. The load transfer process can cause the frequency to change following the increase in load received by GTG 2. As the load increases, GTG 2 decreases, returning to the initial setting point. The frequency with the highest value is when GTG 2 receives a load of 800 kW 1.6 MW and 5 MW at 50.19 Hz, while the frequency with the lowest value occurs several times with a value of 50.15 Hz.

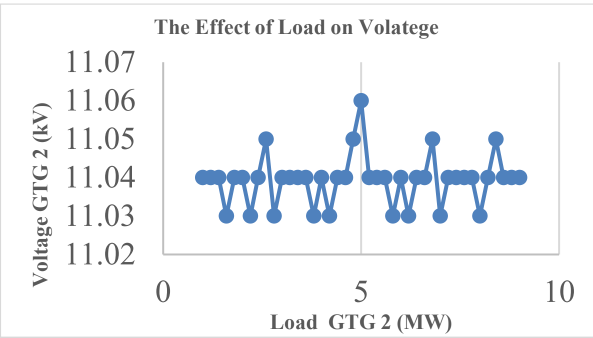

Fig. 7. The effect of load on voltage on GTG 2

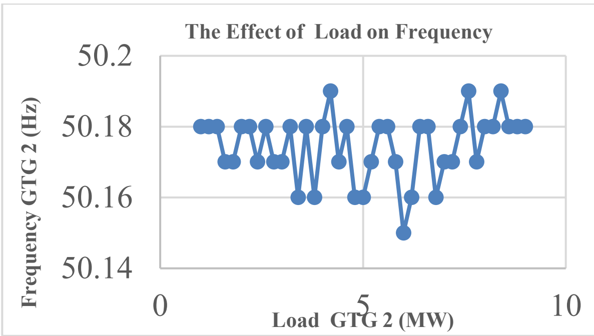

Fig. 8. The effect of load on frequency on GTG 2

4. Conclusions

The SCADA-based load transfer process at PT PIM involves two gas turbine generators operating simultaneously. This process employs two methods: *fast load transfer*, where PLC manages load shedding and priority levels before shedding, and *slow load transfer*, which directly manages load transfer during overload using a load shedding scheme that follows general transfer stages and load priority.

Changes in the decrease in power in GTG 1 and the increase in power in GTG 2 can cause the rotational speed of the generator and the governor point setting to change, resulting in changes in voltage and frequency characteristics. Nevertheless, in the last stage, a transfer of 1 MW is carried out to anticipate the occurrence of overload, which can cause one of the generators to become a burden. When switching from a load of 1 MW to 9 MW, the voltage has a percentage of 0.018% and the frequency has a percentage of 0.0019%.

Acknowledgement
This research was not funded by any grant.

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