IJECBE (2024), **2**, **2**, 204–217
Received (4 June 2024) / Revised (25 June 2024)
Accepted (27 June 2024) / Published (30 June 2024)
https://doi.org/10.62146/ijecbe.v2i2.61
https://ijecbe.ui.ac.id
ISSN 3026-5258

International Journal of Electrical, Computer and Biomedical Engineering

RESEARCH ARTICLE

Blackout Recovery Scenario in Combined-Cycle Power Plant via Line Charging and Internal Cross-Supply: A Techno-Economic Comparative Analysis

Gamal Fiqih Handono Warih, Fauzan Hanif Jufri, Muhammad Gillfran Samual, and Chairul Hudaya*

Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
*Corresponding author. Email: c.hudaya@eng.ui.ac.id

Abstract

The readiness of fast response power plants, such as Combined-Cycle Power Plant (CCCP), following a blackout in the power system shall be maintained to preserve the availability of the supply. Hence, blackout recovery scenario is usually prepared and considered as one of the measures to achieve the system readiness after blackout. This study presents a techno-economic comparative analysis between two blackout recovery methods, namely via line charging and internal cross-supply, in Priok CCCP, Indonesia. It analyzes the historical data of the relationship of the active power contribution to the frequency, and then obtains the appropriate settings for the power plant parameters. From the technical perspective, the gain value or participation factor of this plant is 49 MW/Hz with 6% droop setting and 0.029 Hz of deadband frequency. It is found that a load set point lower than 2.49 MW can lead to grid synchronization failure since there are self-consumption loads on each gas turbine. Moreover, to prevent the risk of reverse power and to achieve a successful internal cross-supply scenario, the minimum load setting shall be adjusted to 3 MW. Meanwhile, from an economic perspective, the results show that a successful internal cross-supply method may save up to IDR 2.7 billion compared with line charging method.

Keywords: Blackout, Internal Cross-Supply, Line Charging, Combined Cycle Power Plant, Minimum Load Set Point

1. Introduction

Blackout phenomenon has happened in Indonesia's grid systems, one of which was Jawa, Madura, and Bali (JAMALI) power systems. One of the major blackout events happened in August 2019 that caused several areas in Jakarta, Banten, West Java, and parts of Central Java and surrounding areas to experience power outages, which affected around 21 million customers. Since the incident, all generators in JAMALI grid systems are required to prepare the blackout recovery procedures. Hence, every operating thermal power plant is requested to provide an internal cross-supply mechanism for internal cross-supply power requirements. Besides, the power plants are also requested to reconfigure the settings for the deadband frequency, governor, and Automatic Generation Control (AGC). A regulation issued by the Ministry of Energy and Mineral Resources of the Republic of Indonesia requires that every operating CCPP should fulfill the deadband frequency activation requirement of 0.033 Hz, and to operate with AGC and governor as primary control. The law also requires the CCPPs to implement internal cross-supply and line charging scenarios [1].

A study by Ravikumar et al. explains in detail about generator control with automatic speed governors and voltage regulators. One of the main requirements for the stability of an electric power system in islanded mode is the ability to monitor and control all generators to maintain voltage and frequency. Generation control systems (GCS) typically perform rebalancing actions at slow and high speeds. The key to load sharing between generators is to implement the same type of controller [2]. A laboratory-scale study has shown difficulties in synchronization between the incoming generator and the network system when using automatic mode. Therefore, operator supervision is required to observe the governor's response, leading to related simplifications of the synchronization circuit that can reduce costs and increase reliability [3]. Another study focuses on frequency matching and phase differences between generation-side and network-side values, which are key issues in synchronization procedures [4].

Another study demonstrated simulations involving control tuning for islanding schemes, underfrequency load shedding, and transfer capability limits. The way forward to ensure reliability in highly dynamic power grids is to incorporate DSA tools to visualize system states to detect fast-paced events that require early response. An adaptive and comprehensive islanding scheme needs to be developed considering future growth in renewable energy loads and generation [5]. The issue that this paper aims to answer is how to optimize the ability of gas turbines to synchronize with the grid when using anti-blackout strategies such as internal cross-supply and line charging from the aspect of governor control, and its influence on the self-use load and the specified minimum load reference value (minimum load set point).

This paper compares the reasoning whether to apply the line charging or internal cross-supply for blackout recovery purpose. The decision is defined based on the technical and economics perspective. First, the significance of the relationship between generator speed and active power during the synchronization process, particularly during internal cross-supply and line charging, are investigated. Then, the effect of minimum load set point reduction if the Priok CCPP operates in internal cross-supply or in line charging mode are explored to obtain the synchronization process simplification. Additionally, this paper addresses the economic impact of internal cross-supply and line charging application in CCPP Priok.

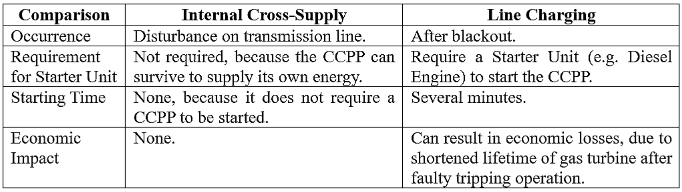
The novelty provided by this paper is the optimization of the internal cross-supply conditions, to help the CCPP to be synchronized automatically with the grid, without the help of manual addition of set point speed. Thus, this process can then be applied to similar power plants that have the same synchronization problem, which also have a higher minimum load set point compared to the actual load. The remaining of this paper is organized as follows: Section 2 describes the technical and economic perspective of the blackout recovery, Section 4 discusses the research results, and the research is concluded in Section 5.

2. Economic Objective for Blackout Recovery

A blackout is a condition of losing the power generation in the power system due to various faults occurring in the system and causes the customers to experience power outages a couple of times. Causes of systems experiencing blackouts include overloaded transmission lines, failure to operate control and protection systems, lightning strikes on electrical power system equipment, poor maintenance, human error, voltage drops, equipment failure, cyber-attacks, rapid frequency drops, etc. [6]. To resolve these issues, blackout recovery scenarios, such as internal cross-supply or line charging are often implemented. Internal cross-supply means that the generator's internal cross-supply used to withstand network disruptions is supplied by the other generator from the same power plant [7]. Meanwhile, line charging is a scenario carried out in a blackout situation, which is generally carried out by diesel or hydro type generators which aims to supply other generators such as thermal generators so that they can absorb power from the network to turn on the auxiliary system to restore the generator [8].

A comparison between internal cross-supply and line charging is given in Table 1.

Table 1. A Comparison between Internal Cross-Supply and Line Charging



Comparison	Internal Cross-Supply	Line Charging
Occurrence	Disturbance on transmission line.	After blackout.
Requirement for Starter Unit	Not required, because the CCPP can survive to supply its own energy.	Require a Starter Unit (e.g. Diesel Engine) to start the CCPP.
Starting Time	None, because it does not require a CCPP to be started.	Several minutes.
Economic Impact	None.	Can result in economic losses, due to shortened lifetime of gas turbine after faulty tripping operation.

The decision to implement the internal cross-supply or the line charging is obtained through techno-economic analysis. The technical aspect considers aspects of governor control system. Whereas the economic aspect considers the impact of losses between internal cross-supply and line charging scenarios. In overall, the flow of decision making is presented in Fig. 1.

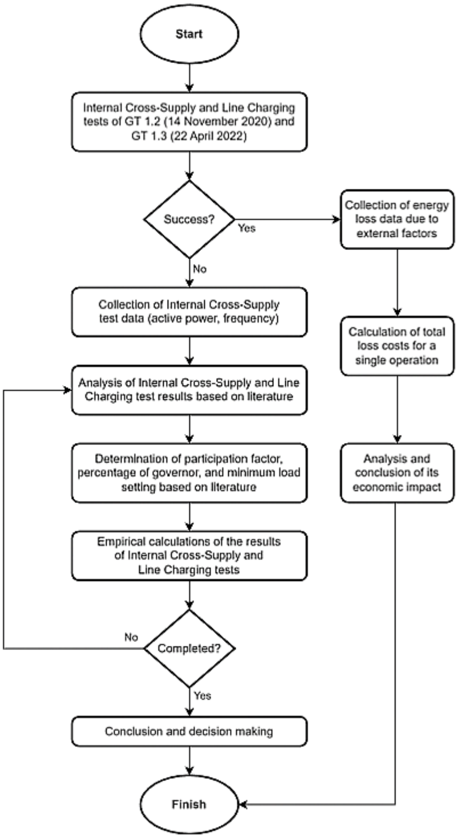


Figure 1. Decision Making Flowchart

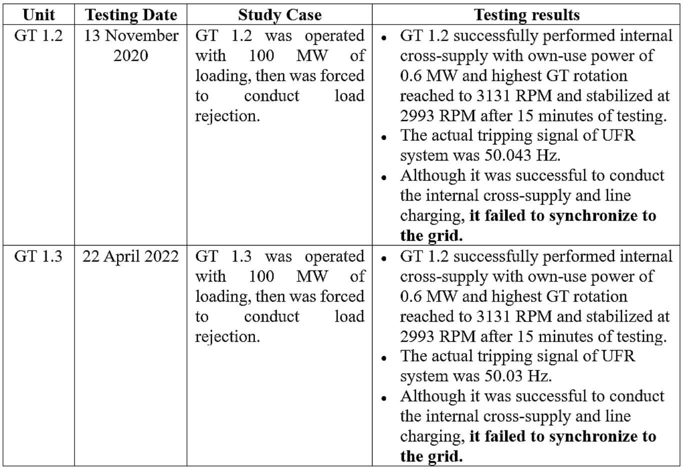
2.1 Internal Cross-Supply and Line Charging Test

According to the document containing standard internal cross-supply testing procedures of Priok CCPP, the steps of internal cross-supply and line charging testing in the case study on the Priok CCPP Gas Turbine (GT) Unit 1.2 (which is applicable to all identical GT) are as follows:

1. Prior to the internal cross-supply mode, the Under-Frequency Relay (UFR) should be set to be 47.5 - 50.1 Hz. Meanwhile, the actual grid frequency is set to be 50.20 Hz for a maximum of 2 minutes.
2. The subsystem area dispatcher coordinates with area dispatcher and Priok CCPP operator regarding the operation pattern arrangement, including line grid testing for internal cross-supply and line charging.
3. Once the line grid is clearly declared, the dispatcher will inform the internal cross-supply testing team to start the test.
4. Internal cross-supply and line charging testing were carried out with a fixed 50.10 Hz under frequency method by selecting display priority stop at GT 1.2.

Using this procedure, the internal cross-supply and line charging tests were carried out. However, these results to failures in synchronization process to the grid, as explained in Table 2.

Table 2. The Experiment of Internal cross-supply and Line Charging Testing



Unit	Testing Date	Study Case	Testing results
GT 1.2	13 November 2020	GT 1.2 was operated with 100 MW of loading, then was forced to conduct load rejection.	• GT 1.2 successfully performed internal cross-supply with own-use power of 0.6 MW and highest GT rotation reached to 3131 RPM and stabilized at 2993 RPM after 15 minutes of testing. • The actual tripping signal of UFR system was 50.043 Hz. • Although it was successful to conduct the internal cross-supply and line charging, **it failed to synchronize to the grid.**
GT 1.3	22 April 2022	GT 1.3 was operated with 100 MW of loading, then was forced to conduct load rejection.	• GT 1.2 successfully performed internal cross-supply with own-use power of 0.6 MW and highest GT rotation reached to 3131 RPM and stabilized at 2993 RPM after 15 minutes of testing. • The actual tripping signal of UFR system was 50.03 Hz. • Although it was successful to conduct the internal cross-supply and line charging, **it failed to synchronize to the grid.**

2.2 The Effect of Internal Cross-Supply and Line Charging to Equivalent Operating Hours

The failure to synchronize using internal cross-supply and line charging mechanisms will result in energy losses. This covers the loss of energy production from the generator and the accelerated overhaul duration with an additional 300 Equivalent Operating Hours (EOH). The 300 EOH addition can occur if the GT temperature exceeds 970 °C, with the main breaker and/or generator breaker open [9], [10]. Figure 2 represents the logic of EOH counter system in which the overhaul of GT was conducted for every 4,000, 8,000, 12,000, and 16,000 hours, respectively [11].

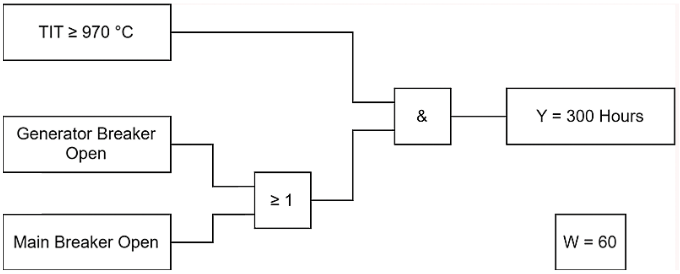


Figure 2. Logic Counter Equivalent Outage Hours (EOH) of the Gas Turbine Type 13E1

2.3 Calculation of Governor Control in Priok CCPP

The type of governor system used in this plant is a hydraulic electric governor system. The system consists of electronic parts that get input from the rotation rate signal and electric load. The output of this electronic part is a voltage signal which is then converted into hydraulic pressure by an Electro-Hydraulic Converter (EHC). Furthermore, the pressurized hydraulic fluid will drive the high-pressure servo control valve. The governor will act to withstand frequency changes [12]. This governor rotation rate sensor can be in a flyball assembly or frequency transducer. The output of the EHC is then used to regulate rotation rate (in RPM) and loading (in MW). The primary regulation parameter used is in the form of speed droop setting, which is used to enable each generator to contribute in order to meet grid demand when there is a change in frequency. This parameter be expressed mathematically using equation (1) [13]–[14]:

$$\Delta P = -K\Delta F \tag{1}$$

Where:
ΔP = Load Variation (MW)
K = Controller Gain (MW/Hz)
ΔF = Frequency Variation (F-50 Hz)
And the value can be obtained using equation (2):

$$K = \frac{P_0}{F_0 R} \tag{2}$$

Where:
P_0 = Nominal Load (MW)
F_0 = Nominal Frequency (Hz)
R = Speed Droop

The system calculation to obtain the control gain value or the power participation factor gain constant as for the speed regulator model used in the Priok CCPP is described in Figure 3 [15], [16].

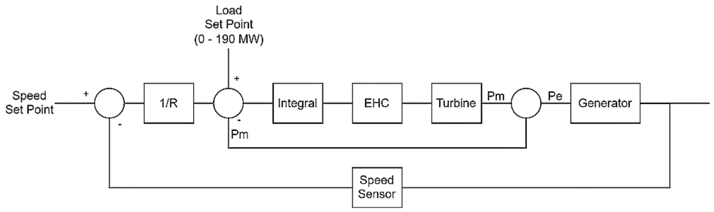


Figure 3. Reduction of Speed and Power Regulation Block Diagram of Priok CCPP

Figure 3 is a part of the block diagram of Priok CCPP Blocks 1 and 2 which has a reference set point of 3000 RPM, where there is a speed or frequency sensor as feedback to compare the actual speed (RPM) or frequency (Hz) with the reference set point. The output of the compared value is then multiplied by the speed droop constant gain, which is expressed by the block diagram 1/R. The result of the multiplication is then compared with the load set point and the actual mechanical load (P_m). The output then enters the integral constant and triggers the EHC system which will then move the turbine, which outputs the mechanical power Pm, and convert it into the active electric power (P_e). The electric power is sensed with the power on the grid which is expressed as frequency (Hz) and will be compared again with the set point speed (RPM) as feedback [11], [16]. Table 3 shows the data obtained from the setting value in the logic diagram and measurement system [17].

Table 3. Specifications for Active Speed and Power Measurement

Variables	Value/Range	Unit
Measurement Speed	0-3000	RPM
Setting Speed	2850-3450	RPM
Base Active Power	147	MW
Measured Active Power	190	MW

From the measurement results given in Table 2, the gain value of the participation factor in the CCPP control system (K_1) can be calculated using equation (3):

$$K_1 = \frac{DifferenceofMeasurementSpeedRange}{Difference\ of\ Setting\ Speed\ Range}$$

Which gives : (3)

$$K_1 = \frac{3000-0}{3450-2850} = 5$$

The voltage gain value (K_2) can be calculated using equation (4):

$$K_2 = \frac{Measured\ Active\ Power}{Base\ Active\ Power}$$

Which gives : (4)

$$K_2 = \frac{190}{147} = 1.2925$$

The proportional gain value (K_p) is obtained using design parameters provided by the GT controller manufacturer. The values of K_p will vary according to the operational status of the GT unit. The operational status considered in this paper is the condition when the GT is starting up, and the condition when the GT is running at full speed with loading (on-grid). Since the grid-code regulation require CCPPs to run with a deadband frequency requirement of 0.033 Hz [1], the value of GT at on-grid status should be modified to meet the required grid-code.

The values of K_p for every unit status considered in this paper are based on values from the logic gain control of speed addition from gas turbine 13E1, which is provided in Figure 4. The logic diagram describes the gain control scheme for each addition or change in speed of the gas turbine. The K_p values are summarized in Table 3.

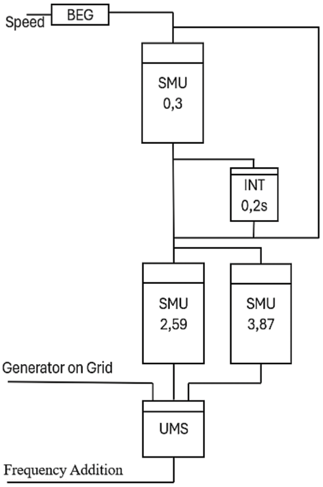


Figure 4. Logic Gain Control of Speed Addition from Gas Turbine 13E1

Table 4. Proportional Gain Values for Each Unit Status

GT Unit Status	K_P
Start-Up	2,00
On-Grid (Before Grid-Code)	3,87
On-Grid (Modified as per Grid-Code)	2,59

The value of the speed droop constant gain (R) can be calculated from the measurement range of speed, active power, and K_p , where the product of the three values is inversely proportional to the value of R. Then, the value of R is also validated when there is a disturbance on the network, that has an impact on the contributing power participation of the operating generators. Thus, by referring to the governor regulation implemented in each generator, the values of K_1, K_2, K_3 and can be determined, each of which is calculated using equations (3), (4), and the data given in Table 3. Therefore, R can be calculated using equation (5):

$$K = \frac{1}{K_1 K_2 K_p}$$

The calculation of R values for each on – grid status are as follows : (5)

$$R_{original} = \frac{1}{(5)(1.2925)(3.87)} = \frac{1}{24.9615} = 0,03998 \approx 4\%$$

$$R_{modified} = \frac{1}{(5)(1.2925)(2.59)} = \frac{1}{16,055} = 0,05974 \approx 6\%$$

2.4 *Active Power Set Point Range*

The active power set point range is used as the first reference point for synchronization of the GT to the grid. The setting values of the active power set point range are given in Table 5, according to the GT control manufacturer design. The minimum load value is 5 MW, and the maximum is 190 MW. During start-up, the CCPP has a self-consumption load of 2.49 MW, which must be fulfilled by the GT.

Table 5. Active Power Set Point Range Setting Value

Power Active Set Points	Controller Gain	Rated Value
Minimum	2,6 %	5 MW
Maximum	100 %	190 MW

2.5 *Economic Methodology*

The economic methodology used in this research is the calculation of the number of disturbances that occur in the 150 kV/500 kV transmission network, which have an impact on Priok CCPP production failures. This is done by calculating the total costs required for one production (start-up), including gas consumption, own consumption (kWh) and the calculation of losses resulting from accelerated addition of EOH. Table 6 describes the variables included in the calculation of loss costs due to internal cross-supply and line charging failures [18], [19].

Table 6. Variables to Calculate Economic Cost

Variable	Unit	Value
Fuel Cost of CCPP	**IDR**	**18,157,135**
Gas Consumption in One Start-Up	MMBTU/sec	0.19676
Duration Required by GT for One Start-Up	Second (sec)	1,080
Fuel Cost of Diesel Engine (High-Speed Diesel)	**IDR**	**31,397,511**
Duration Required by Diesel Engine for One Start-Up	Second (sec)	60
Total Cost of Fuel	**IDR**	**49,554,646**
Auxiliary System Cost of CCPP	**IDR**	**6147.586**
Cost of Acceleration of EOH	**IDR**	**5,333,333,333**

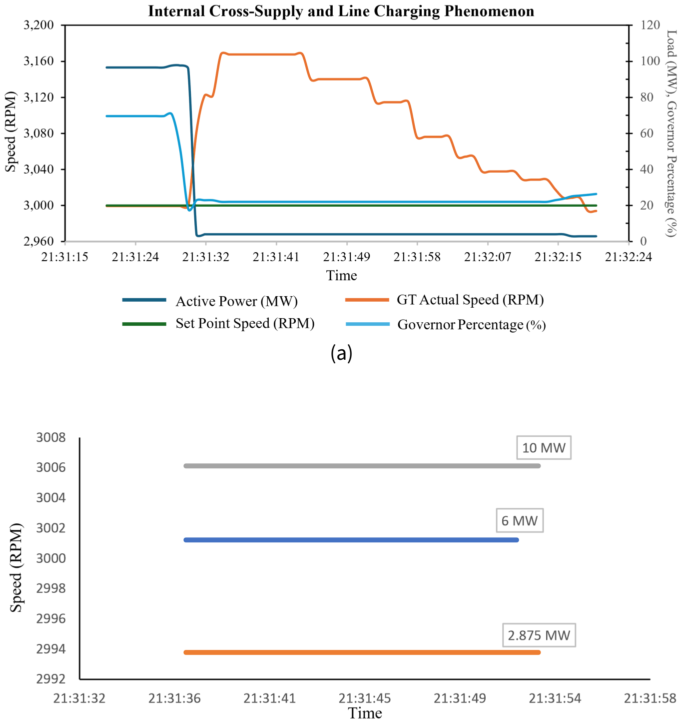
The calculation formula can be described mathematically using equation (6) (in Indonesian Rupiah, IDR):

$$\text{Total Production Losses} = \text{Cost of Auxiliary System} + \text{Cost of Fuel} + \text{Cost of Accelerating EOH} \tag{6}$$

3. Results and Discussion

3.1 *Technical Analysis*

This graph was obtained from Distributed Control System (DCS) Symphony Plus data, where the data was collected during the internal cross-supply and line charging testing process on 14 November 2020, which is given in Figure 5.



(a)

(b)

Figure 5. (a) Dynamic Response During Test on GT Unit 1.2 (b) Approximate Response when Self-Discharging Load is Increased

As illustrated in Figure 5(a), the scenario involves the release of load from 100 MW to 3.9 MW, and steadies at 2.6 MW. This is followed by a change in the percentage of GT control valve, which is linear with the load condition. During the load release, the speed rises to 3,181 RPM due to inertial force on the GT, compared to the nominal set point speed of 3,000 RPM. From the phenomenon that occurs when testing the GT in internal cross-supply mode, the response of the servo valve to regulate the fuel flow rate is linear with the changes in load, and the speed conditions tend to rise when load release is carried out, due to mechanical and inertial forces of the GT.

Furthermore, Figure 5(b) illustrated the relationship between self-consumption load of the GT and the resulting GT speed. At a load of 5 MW, the resulting GT speed is 3000 RPM, which is its nominal value. When we increase the load to 6 MW, which is a 1 MW increase from the nominal value of 5 MW, the speed increases to 3001.22 RPM. This shows the linear characteristic between self-consumption load/auxiliary load and the generator speed. To modify the minimum load set point to the value of self-consumption load of CCPP during start-up (2.49 MW), the nearest logical set point which can fulfill this is 3 MW (rounded up), which gives an actual speed of 2997.55 RPM. This value is important to make sure that the synchronization process between the GT and the grid can be carried out successfully.

It is found that the greater the difference in active power between the generator and the self-consumption load, the difference in speed set points with speed on the grid will be higher. This condition is validated by the results on the start and stop data when we synchronize the generator to the grid, which is given in Table 7. The phenomenon is visualized in Figure 6.

Table 7. Data Start Period CCPP

Start Up Date and Time	Online Date and Time	Status Start	Fuels
04 April 2024 - 12:39	04 April 2024 - 12:54	Success	Liquid Natural Gas
05 April 2024 - 09:42	05 April 2024 - 09:56	Success	Liquid Natural Gas
22 April 2024 - 07:38	22 April 2024 - 07:50	Success	Liquid Natural Gas

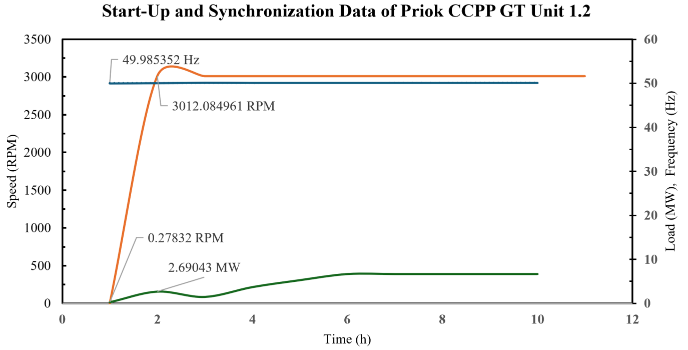


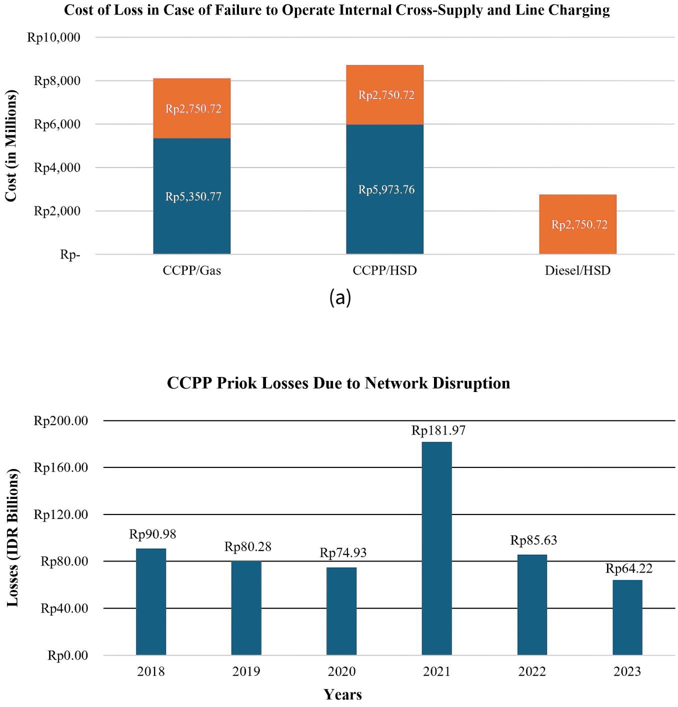
Figure 6. Start-Up Condition of GT at Full Speed No Load During Grid Synchronization

Based on the start data in Figure 6, the deviation between the gas turbine speed of 3012.08 RPM compared to the grid frequency of 49.98 Hz, which is equivalent to 2998 RPM, is around 14 RPM or equivalent to 0.233 Hz. This positive deviation is necessary for the synchronization process of GT to grid, which means that the speed or frequency of the GT should be higher than the frequency of the grid, to enable the synchronization process.

3.2 Financial Analysis

From the study, a financial analysis was carried out by looking at the cost factor of the energy price of auxiliary system cost, fuel cost (both gas and High-Speed Diesel (HSD)), and investment costs for one overhaul. The results are visualized in Figure 7. In Figure 7(a), for one start, CCPP using gas tends to be cheaper than HSD, where line charging costs more than IDR 8 billion. This cost is taken from the variables described above. When the internal cross-supply scenario is successfully implemented, there is no need for an implementation of line charging using diesel, which could save cost up to IDR 2.7 billion.

Figure 7(b) outlines the annual cumulative loss of GT energy due to network disruptions. The year 2021 gives the highest amount of loss, where there are 4 blackouts occurred in the Priok subsystem. The blackouts are caused by failure in implementing internal cross-supply scenario, where the result is a loss of up to IDR 181.97 billion.



(a)

(b)

Figure 7. (a) Daily Loss when GT Start Using Internal Cross-Supply and Line Charging Methods, (b) Annual Cumulative Loss of Energy of GT (kWh)

4. Conclusion

Blackout phenomenon has happened in Indonesia's grid systems, which has affected millions of customers. Blackouts often require line charging using diesel engines to help in the starting up of the affected GT. However, line charging is expensive to be implemented, thus another scenario, i.e. internal cross-supply is considered. From the scenario studied in this paper, it is found that the characteristics of the GT have a participation factor value of 49 MW/Hz or equivalent to 0.816 MW/RPM. The power used by the GT itself is 2.49 MW during start-up, and the current minimum load set point value is 5 MW. When GT is synchronized, the difference between the grid frequency and the GT frequency is around 14 RPM or equivalent to 0.233 Hz. To get the optimal setting for grid synchronization, the minimum load set point that is close to self-consumption at start-up is 3 MW.

The speed set point of GT must be higher than the frequency of the grid network. The internal cross-supply problem can be resolved by changing/reducing the set point near the load of each self-consumption auxiliary system of the GT, from 5 MW to 3

MW. If the value is smaller than 3 MW, it will increase the risk of reverse power. From an economic perspective, the success of internal cross-supply scenario without line charging results in savings of IDR 2.750.721.933, compared to the implementation with the line charging scenario.

Acknowledgement

We would like to thank the General Manager of PT PLN Indonesia Power Priok PGU Mr. Igan Subawa Putra, and Senior Manager Mr. Romadhoni Sigit, for allowing us to access the data for research purposes.

References

[1] The Ministry of Energy and Mineral Resources of the Republic of Indonesia. *Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 20 Year 2020 regarding Codes of Electricity Power System Network (Grid Code).* Indonesia. 2020.

[2] K. G. Ravikumar et al. "Isochronous load sharing principles for an islanded system with steam and gas turbine generators". In: *2017 Petroleum and Chemical Industry Technical Conference (PCIC).* IEEE. Sept. 2017, pp. 405–412. DOI: 10.1109/PCICON.2017.8188761.

[3] M. J. Thompson. "Fundamentals and advancements in generator synchronizing systems". In: *2012 65th Annual Conference for Protective Relay Engineers.* IEEE. Apr. 2012, pp. 203–214. DOI: 10.1109/CPRE.2012.6201234.

[4] A. Mazloomzadeh, V. Salehi, and O. Mohammed. "Soft synchronization of dispersed generators to micro grids for smart grid applications". In: *2012 IEEE PES Innovative Smart Grid Technologies (ISGT).* IEEE. Jan. 2012, pp. 1–7. DOI: 10.1109/ISGT.2012.6175812.

[5] A. Pandey et al. "Dynamic Modeling and Cascade Failure Analysis of the Mumbai Grid Incident of October 12, 2020". In: *IEEE Access* 10 (2022), pp. 43598–43610. DOI: 10.1109/ACCESS.2022.3160740.

[6] H. Haes Alhelou et al. "A Survey on Power System Blackout and Cascading Events: Research Motivations and Challenges". In: *Energies* 12.4 (Feb. 2019), p. 682. DOI: 10.3390/en12040682.

[7] P. Mahat, Z. Chen, and B. Bak-Jensen. "Control strategies for gas turbine generators for grid connected and islanding operations". In: *IEEE PES TD 2010.* IEEE. 2010, pp. 1–8. DOI: 10.1109/TDC.2010.5484471.

[8] A. Asheibi and S. Shuaib. "A Case Study on Black Start Capability Assessment". In: *2019 International Conference on Electrical Engineering Research & Practice (ICEERP).* IEEE. Nov. 2019, pp. 1–5. DOI: 10.1109/ICEERP49088.2019.8956978.

[9] H. Gajjar, S. Jain, and A. Modi. "Gas Turbine Life Extension: A 655 MW Combined Cycle Power Plant User's Experience". In: *Volume 2: Turbo Expo 2003.* ASMEDC. Jan. 2003, pp. 795–801. DOI: 10.1115/GT2003-38420.

[10] D.-J. Kim et al. "Impact of a Heavy-Duty Gas Turbine Operating Under Temperature Control on System Stability". In: *IEEE Transactions on Power Systems* 33.4 (July 2018), pp. 4543–4552. DOI: 10.1109/TPWRS.2017.2781239.

[11] ABB. *Inspection Recommendation Service Intervals and Maintenance of Gas Turbine TYPE 13E.* Technical report.

[12] P. Kundur. *Power system stability and control.* New York, NY: McGraw-Hill Professional, 1994.

[13] M. Beus and H. Pandžić. "Application of an adaptive model predictive control algorithm on the Pelton turbine governor control". In: *IET Renewable Power Generation* 14.10 (July 2020), pp. 1720–1727. DOI: 10.1049/iet-rpg.2019.1291.

[14] K. G. Ravikumar et al. "Generation Control System: Using Isochronous Load-Sharing Principles With Gas and Steam Turbine Generators". In: *IEEE Industry Applications Magazine* 25.2 (Mar. 2019), pp. 36–44. DOI: 10.1109/MIAS.2018.2875127.

[15] ABB. *Functional Description Tanjung Priok FG GT-Controller*. 1994.

[16] L. C. Saikia and S. K. Sahu. "Automatic generation control of a combined cycle gas turbine plant with classical controllers using Firefly Algorithm". In: *International Journal of Electrical Power & Energy Systems* 53 (Dec. 2013), pp. 27–33. DOI: 10.1016/j.ijepes.2013.04.007.

[17] I. Indrawanto and H. Cahyono. "PEMODELAN DAN SIMULASI SISTEM PEMBANGKIT TURBIN GAS PLTGU TANJUNG PRIOK". In: *Mesin* 24.2 (2017). [Online]. Available: https://journals.itb.ac.id/index.php/jtms/article/view/4997, pp. 182–202.

[18] G. F. H. Warih and I. M. Arief. "Inlet Guide Vane Control System Modification to Improve the Reliability of Gas Turbine". In: *2023 4th International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*. IEEE. Aug. 2023, pp. 374–378. DOI: 10.1109/ICHVEPS58902.2023.10257377.

[19] S. Nurkholiq et al. "Redesign Integrated Control System GTG and HRSG to Reduce Loss of Electrical Production at Combined Cycle Power Plant Muara Karang". In: *IOP Conference Series: Materials Science and Engineering* 1096.1 (Mar. 2021), p. 012087. DOI: 10.1088/1757-899X/1096/1/012087.