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Modelling Back Pressure Power Plant to Increase Reliability and Decrease Self Power Consumption by Utilizing Residual Main Steam*

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Abstrak

Jumlah uap yang terbuang di PLTP Kamojang dalam 4 tahun terakhir cukup besar, memiliki potensi energi sebesar 7 MW (110 ton/jam) akibat rendahnya unit loading dispatch, perubahan ini tidak diimbangi dengan konsumsi energi listrik dari peralatan unit *auxiliary* sehingga persentase performa pemakaian sendiri (%PS) meningkat. Ditambah lagi dengan permasalahan bahwa beban listrik perkantoran dan pembangkitan esensial masih disuplai oleh grid (PLN) yang ditagih setiap bulannya sebagai pelanggan industri, hal ini berakibat pada ketidakmampuan untuk melakukan *houseload* karena katup ventilasi kompressor disuplai oleh tegangan grid. Untuk itu dilakukan penelitian pemodelan desain sumber listrik yang memanfaatkan besarnya uap yang terbuang di PLTP Kamojang dari *vent valve* berupa PLTP tipe back pressure yang disalurkan ke sistem *self-service* 6,3 kV unit PLTP Kamojang. Desain PLTP dimodelkan dengan menggunakan cycle tempo untuk mendapatkan daya (MW) turbin generator, menggunakan Homer untuk analisis finansial PLTP back pressure dan menggunakan ETAP untuk mensimulasikan aliran beban PLTP *back pressure* terhadap sistem swakelola PLTP 6,3 kV Kamojang. Berdasarkan simulasi *cycle tempo* dan dengan beberapa asumsi bahwa back pressure PLTP membutuhkan aliran uap sebesar 76 ton/jam atau 5 MW, dan berdasarkan simulasi ketika terjadi black out beban pemakaian sendiri, PLTP Kamojang masih beroperasi secara normal, yang berarti unit mampu melakukan houseload dan siap untuk melakukan sinkronisasi kembali dengan lebih cepat apabila dibutuhkan. Selama 4 tahun terakhir PLTP Kamojang telah kehilangan kesempatan untuk menurunkan nilai %PS sebesar 3,34% selama, dan realisasi back pressure PLTP membutuhkan dana sebesar $6.325 dan akan kembali investasi selama sekitar 1 tahun dengan asumsi beban esensial ditanggung sepenuhnya sepanjang tahun oleh back pressure PLTP.

Kata Kunci: Siklus Tempo, ETAP, Beban Rumah Tangga, Tekanan Balik PLTP, Uap Panas Bumi

Abstract

The amount of steam wasted at the Kamojang PLTP in the last 4 years is quite large, having an energy potential of 7 MW (110 tons / hour) due to low unit loading dispatch, this change is not offset by the electrical energy consumption of auxiliary unit equipment so that the percentage of self-use performance (%PS) increases. In addition to the problem that office electricity loads and essential generation are still supplied by the grid (PLN) which is charged every month as an industrial customer, this results in the inability to houseload because the comporessor vent valve is supplied by grid voltage. For this reason, modeling research on the design of electricity sources was carried out that utilized the large amount of steam wasted in the Kamojang PLTP from the vent valve in the form of a back pressure type PLTP which was distributed to the 6.3 kV self-use system of the Kamojang PLTP unit. The PLTP design is modeled using cycle tempo to get power (MW) turbine generator, using Homer for financial analysis of PLTP back pressure and using ETAP to simulate the load flow of PLTP back pressure against the 6.3 kV Kamojang PLTP self-use system. Based on cycle tempo simulations and with some assumptions that the back pressure PLTP requires a steam flow of 76 tons / hour or 5 MW, and based on simulations when there is a black out of its own usage load, the Kamojang PLTP is still operating normally, which means that the unit is able to houseload and is ready to sync again faster if needed. Over the past 4 years PLTP Kamojang has lost the opportunity to reduce the %PS value by 3.34% during, and the realization of PLTP back pressure requires funds of $ 6,325 and will return on investment for about 1 year assuming the essential burden is fully borne throughout the year by PLTP back pressure.

Keywords : Cycle Tempo, ETAP, Houseload, PLTP Back Pressure, Geothermal Steam

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1. INTRODUCTION

PLTP is one of the electricity centers that has been operating for a long time and one of the sources of EBT (New Renewable Energy) which has an energy mix that is prioritized in the next few years even until 2038 is targeted to reach 28% of the total generating capacity in Indonesia. So that now and in the next few years learning activities, geothermal deepening, geothermal energy conversion and geothermal resource exploration will continue to be carried out in order to meet the Indonesian government's target in energy security [1]. One of the largest and first PLTP in Indonesia is the Kamojang PLTP managed by PLN Indonesia Power with a capacity of 540 MW including PLTP Kamojang, Darajat, Gunung Salak, Ulubelu , Lahendong and Ulumbu. Different units, of course, different systems used, some are direct dry steam type or some are separated / double single flash type depending on the needs and quality of the steam [2]. Kamojang PLTP has flash steam technology where the steam is a vapour dominated type with a working pressure of 6.5 bar which is then fed into the turbine to be converted into mechanical energy and electrical energy. In maintaining the working pressure of steam entering the turbine, equipment is used on the steam reciving header, namely the vent valve to pour steam which operates automatically with set point of main vapor pressure value.

During 2019 – 2022 the steam wasted from the steam reciving header averaged around 110 ton/h, quite a lot of steam was wasted because the dispatch loading of the Kamojang PLTP was 75% of the maximum load. This will make the PS (Self-Use) performance index high and the efficiency of the generating unit low because the production produced decreases while the power consumption of the generating equipment remains. The potential of wasted steam to be reused so that the efficiency of the generating unit increases, it is necessary to design modeling the utilization of this residual steam to reduce power consumption PS and improve efficiency and reliability at PLTP Kamojang. Many researchers have conducted research related to residual steam or exhaust vapor from the steam reciving header of the Kamojang PLTP both in terms of efficiency and in terms of safety, as did I.A. Pratama (2017) which studied the exhaust steam of the Kamojang PLTP is used as the main fuel to heat ammonia which varies in mass fraction so that the power generated by turbines is different. The results of the study did not determine how much the output power of the turbine so that the load fluctuated and its usefulness. There is also research related to the efficiency of turbine generator by M.I. Hajar (2019) which decreased when the load was 55.5MW the efficiency reached 95% while when the load was 54MW the efficiency 91% assuming COSPHI 0.98% where the efficiency value is used as a reference whether maintenance is carried out or not. Another concept of ideas related to PLTP back pressure isa back pressure type PLTP that uses Direct Dry Steam technology and has been successfully operated with capacity 2x 2.5MW incoming on 70 kV medium voltage network.

Seeing the problems that still occur and various suggestions or references , in this study an analysis and modeling of how to produce electricity of 5MW with steam that wasted from the steam reciving header of the Kamojang PLTP and designing, calculating, analyzing and simulating PLTP Back pressure using cycle tempo 5.0 software which is directly used to become a power supply PS (self-use) equipment in Units 1, 2 and 3 through ETAP software simulation. In addition, a financial analysis of the break event point of the PLTP back pressure will also be carried out and calculate the PS saving opportunities and their effect on the output power of the Kamojang PLTP Generator Units 1, 2 and 3. That way this research will be clearer in providing recommendations and lessons for making PLTP Back pressure that supports government programs related to the use of EBT in Indonesia and as an effort to be able to implement the CDM (Clean Development Mechanism) program in order to get Certified Emissions Reductions (CERs).

2. RESEARCH METHODOLOGY

2.1. Research Flowchart

In a systematic research endeavor, it is essential to create a flowchart to ensure that the process is carried out in a step- by-step manner to achieve its objectives. The following is the flowchart for this research:

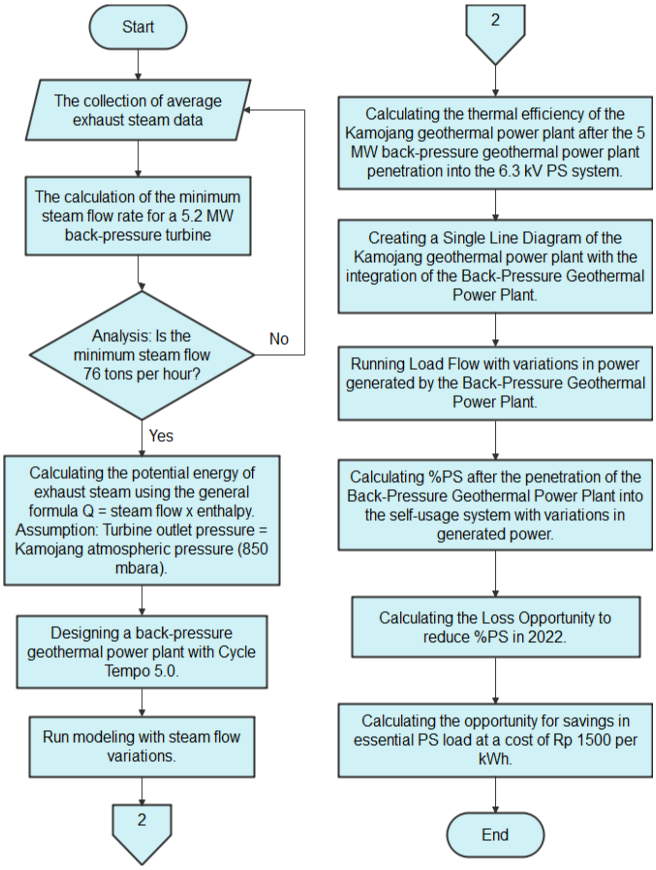

Figure 1. Flowchart of Kamojang Back Pressure Geothermal Power Plant (PLTP) Research

From the above flowchart, this research can proceed when the minimum calculated flow rate of wasted steam from the receiving header reaches 76 tons/hour to generate approximately 5MW of power. Additionally, this includes calculating the potential heat energy from the wasted steam using Cycle Tempo software. The research will then advance to the next phase until the opportunity for PS savings is identified, along with an assessment of the reliability of the Kamojang power generation facility.

2.2. Considerations for Adapting the Ulumbu Unit 1 and Unit 2 Back-Pressure Geothermal Power Plant (PLTP) System

The adaptation of the Ulumbu Unit 1 and Unit 2 PLTP systems is considered due to their similar parameters, which align with the Kamojang PLTP, making it highly feasible to construct them with the same power generation system. The following parameters are taken into account:

Table 1. Reference Parameters Common between Ulumbu PLTP and Modeled Back-Pressure PLTP

No	Parameter	keterangan
1	Sumber Energi	panas bumi
2	Fluida kerja	H2O
3	Beban	< 10 MW
4	Primeover	steam turbine
5	Generator	sinkron 3 fasa
6	Operasi Tegangan	masuk tegangan menengah

In the Ulumbu PLTP system, steam from the well is directly introduced into a separator to separate it from heavy particles such as gravel or condensed gases. Afterward, the steam enters the steam turbine system with a pressure of 9 barA and a temperature of 186°C. Excess steam is released into the atmosphere through the vent valve system of the Ulumbu PLTP. The generator's output power is 2.5 MW, which is smaller than the proposed 5.2 MW in this design. The Ulumbu Unit 1 and 2 PLTP systems are relatively straightforward, requiring only a separator, valves, a steam turbine, and a generator. Therefore, these existing units can serve as a reference for this research.

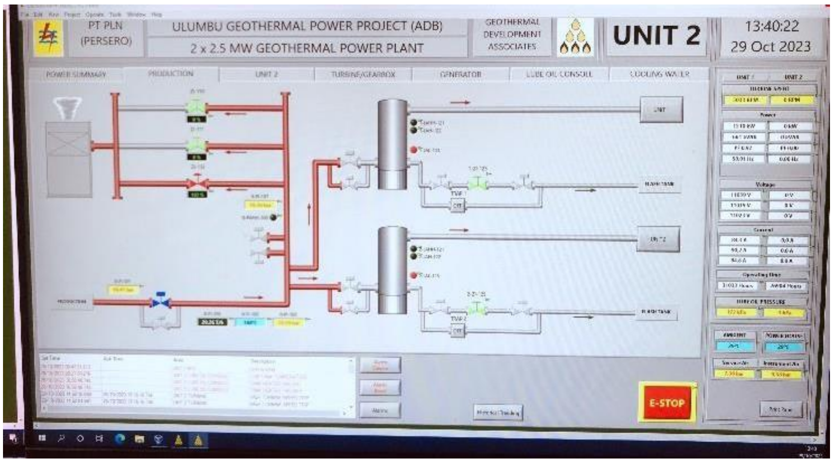

Figure 2. Steam System of Ulumbu Unit 1 PLTP

The design of the 5 MW Back-Pressure PLTP cycle proposed here is quite straightforward, as it lacks auxiliary equipment such as a condenser, cooling tower, and additional cooling systems. Inlet steam is also taken from the discharge of the Kamojang PLTP receiving header, maintaining the same pressure and temperature as the Kamojang PLTP unit.

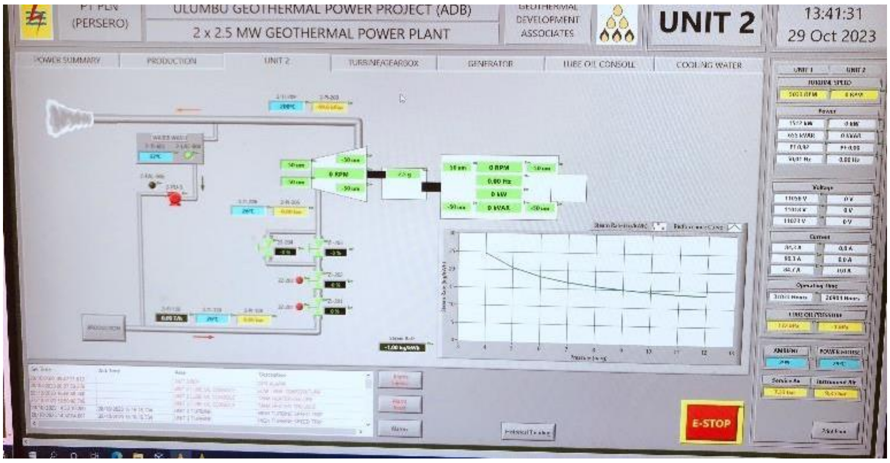

Figure 3. Turbine and Generator of Ulumbu Unit 1 PLTP

2.3. Data Collection

1. Average Wasted Steam Data

   The average wasted steam data for the Kamojang PLTP was collected from January 2019 to May 2023, obtained from operation reports routinely submitted by the Indonesian Power Operator to Pertamina Geothermal Energy (PGE). The following trend illustrates the data:

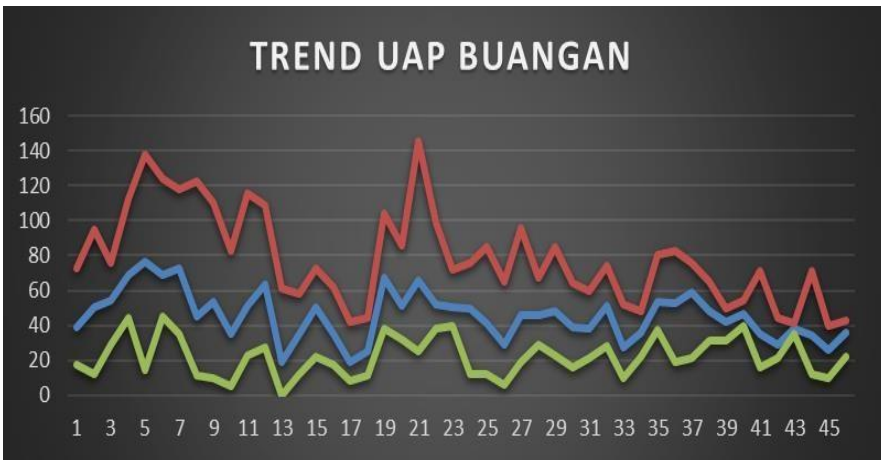

Figure 4. Trend of Wasted Steam from the Receiving Header 2019-2023

From the above trend, it is observed that the average wasted steam released into the atmosphere from January 2019 to May 2023 is 45% (112 tons/hour), with a minimum average of 18% (43 tons/hour) and a maximum of 78% (195 tons/hour).

2. Self-Consumption Load Data for Kamojang PLTP Self-Consumption Load (PS) at Kamojang is connected to 380 VAC and 6.3 kVAC voltage busbars supplied by the respective unit generators before being distributed to the 150 kV network. Equipment included in the PS load comprises the main cooling water pump, primary and secondary cooling pumps, and other devices. The following table presents the PS load data for Kamojang:

Table 2. PS Load Data for Kamojang PLTP

No	Unit	Active Power (kW)	Reactiv P
1	PLTP 1		
2	PLTP 2		
3	PL		
4			

The total self-consumption load for Kamojang PLTP is 5058 kW and 3640 kVAR. Therefore, a 6 MW capacity turbine generator can support all the self- consumption loads of Kamojang PLTP units. Based on dispatch from the load regulator in the 150 kV network from 2019 to 2023, the units are often dispatched at 75% load with a fixed PS power value. This results in an increase in the PS performance percentage, as observed on January 15, 2023, when Unit 1 had a PS percentage of 4.5%, Unit 2 had 4.6%, and Unit 3 had 4.7%, totaling 4.58%. This increase in PS percentage leads to a decrease in unit performance and efficiency indices.

3. Kamojang Geothermal Power Plant Operation Data

Table 3. Data for 75% Load

Parameter	PLTP 1	PLTP 2	PLTP 3	unit	Vent Valve Open	Esensial
Active Power	25.2	42	42.5	MW	68%	
Steam Flow	219	370	350	ton/h		
Pin	6.23	5.9	6.26	barA		
Tin	161	166	169	degC		
Pout	126	98	110	mbarA		
Tout	51	50.5	51.6	degC		
PS	1081	1961	1875	kW		115

Table 4. Data for Full Load Operation

Parameter	PLTP 1	PLTP 2	PLTP 3	unit	VentValve Open	Esensial
Active Power	30.6	53.9	54	MW	12.9% (29 ton/h)	
Steam Flow	240	430	440	ton/h		
Pin	6.26	6	6.1	barA		
Tin	170	163	167.5	degC		
Pout	155	90	56.5	mbarA		
Tout	55	53	110	degC		
PS	1071	2080	1900	kW		100

From Table 3 reveals that at 75% load (109 MW), the opening of the vent valve (located in the receiving header) reaches 68%, equivalent to 150 tons/hour, and the total self-consumption load (PS) is 5032 kW. Consequently, the potential energy from this wasted steam amounts to 10.6 MW (assuming the steam pressure exiting the turbine is 850 mbara). Thus, this potential data exceeds the planned design of 5.2 MW. Table 4 indicates that the steam discharge during full load operation is 12%. However, this study utilizes the lowest data point, as required by the Back-Pressure PLTP, to avoid reverse power, where the minimum generator power is 5% of 6 MW, equivalent to 300 kW. Based on this table, the minimum steam discharge at the vent valve exceeds the minimum requirement of 2%, allowing the Back-Pressure PLTP to remain operational, with an estimated minimum power of 300 kW. In other words, if the vent valve's steam discharge falls below 2%, the Back-Pressure PLTP unit cannot operate, while the total PS load requirement is 5151 kW. Data from the operation also provides information about essential electrical power still receiving supply voltage from the 150 kV network, as seen in Figure 3. One of the essential pieces of equipment that significantly affects the reliability of the Kamojang PLTP unit is the Vent Valve, which regulates the main steam pressure entering the turbine by venting steam in the steam receiving header. In the event of a blackout in the 150 kV network system, the Kamojang PLTP unit cannot house the load because there is no control of the main steam pressure, namely, the vent valve in the steam receiving header, as it does not receive a supply of voltage, causing overpressure in the turbine. Therefore, in this Back-Pressure PLTP modeling, load flow related to the 6.3 kV voltage system, including essential equipment, will also be simulated. The figure below illustrates the connection of essential equipment in the Kamojang PLTP.

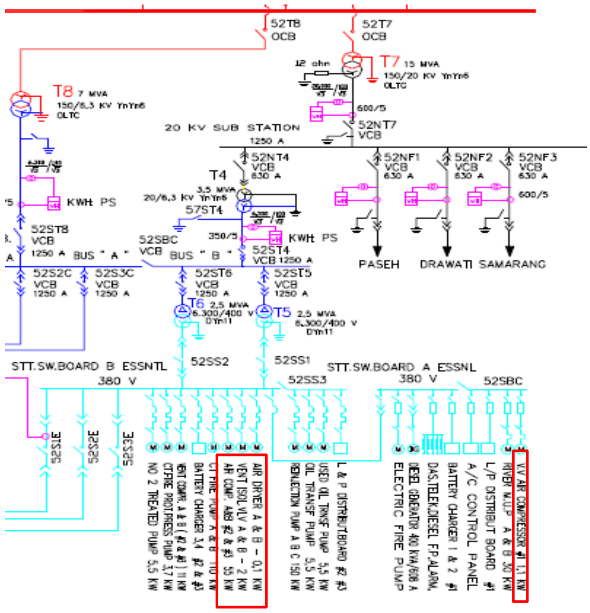

Figure 5. Single Line Diagram of Essential Equipment

2.4. Back Pressure PLTP Design with Cycle Tempo

A successful simulation can be conducted and accurate data can be obtained when the sequence of processes or steps is correct. Therefore, a flowchart has been created to guide the design and simulation process, as follows:

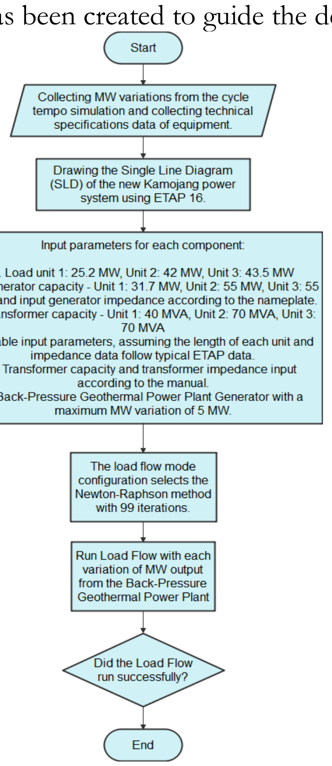

Figure 6. Flowchart of CycleTempo 5.0 Design

The most important aspect of the Back-Pressure PLTP simulation design is to experiment with different steam flow values, which can be controlled through a valve. The range of flow values tested ranges from the minimum flow of 9 tons/hour (wasted steam during maximum load at the Kamojang PLTP) to 76.5 tons/hour (at 75% load). The next step involves displaying a T-s (Temperature-Entropy) diagram to determine the working area of the turbine and recording the resulting power values for each steam flow variation until reaching 5.2 MW.

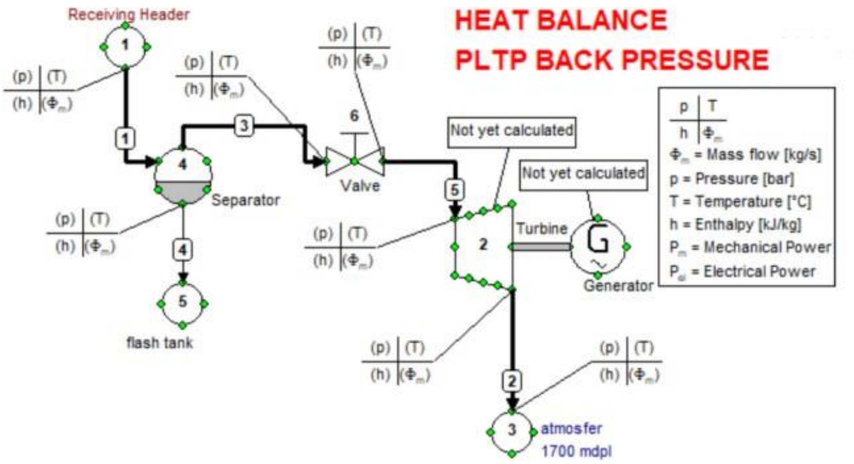

Figure 7. Results of Back-Pressure PLTP Simulation with Cycle Tempo

After obtaining data from the simulation, the next step is to create a block diagram of the Back-Pressure PLTP system to determine the new unit's configuration.

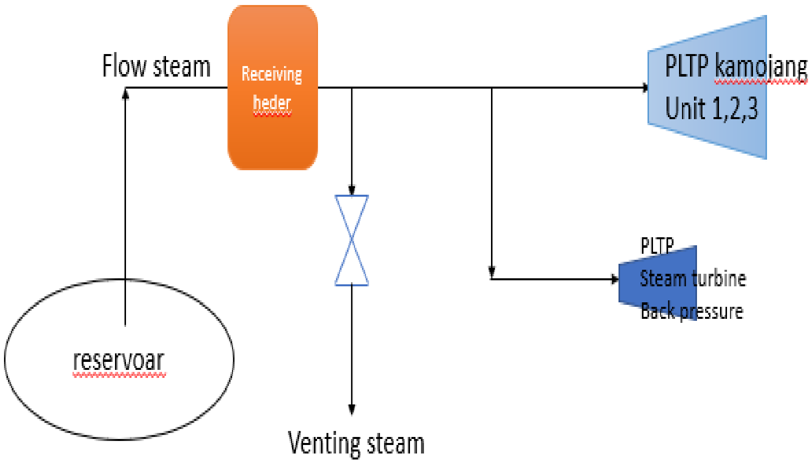

Figure 8. Concept of Adding Back-Pressure PLTP Unit

The use of Back-Pressure turbines means that the steam pressure at the turbine outlet is equal to atmospheric pressure, aiming for operational simplicity to support the reliability of the electrical power system. The reservoir is where geothermal steam is produced by utilizing the magma heat flow from within the Earth to heat groundwater. This heated water is then collected in the receiving header, as the input is not from a single well but from multiple wells (65 geothermal wells). Excess steam is released into the atmosphere through the venting system to maintain stable steam well pressure and comply with the PJBU contract.

2.5. Electrical System Design for Back-Pressure PLTP

The design of the 5 MW Back-Pressure PLTP generator is integrated into the self-consumption electrical system of the Kamojang PLTP unit and is depicted in the diagram using ETAP 16. The Back-Pressure PLTP generator has an output voltage of 6.3 kV, and there is a breaker separating the self- consumption busbar and the Back-Pressure PLTP generator busbar, serving as a circuit breaker or PMT and a unit safety actuator. The following diagram shows the electrical wiring using ETAP 16

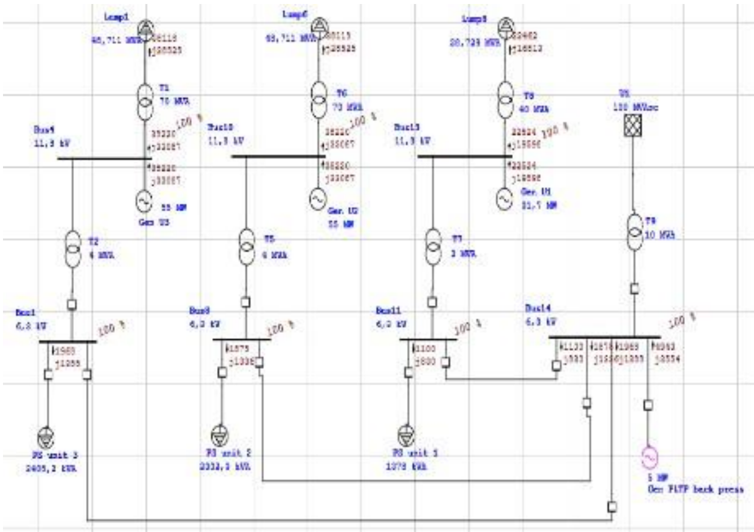

Figure 9. Electrical Wiring When Back-Pressure PLTP Enters

3. RESULTS AND DISCUSSION

At Kamojang PLTP, there is a main steam control system in the form of a vent valve to maintain the steam's entry pressure into the turbine at a stable 6.5 barA. This is due to the fluctuating steam flow from the Earth and varying pressures in different wells, compounded by activities (maneuvers and maintenance of well valves) performed by the geothermal steam supplier (PT Pertamina Geothermal). These fluctuations affect both pressure and flow. Data on wasted steam during the period from 2019 to 2023 was substantial, averaging around 100 tons/hour. This was primarily due to changes in the daily operational load plan dispatch for Kamojang PLTP, which reduced to 75% of full load. As a result, the steam discharge increased. This increase was not accompanied by a corresponding increase in self-consumption load, leading to a rise in the percentage of self-consumption load (PS) performance. To facilitate the discussion, some design assumptions were made using Cycle Tempo:

1. Generator efficiency was assumed to be 98% (a common assumption with a power factor of 0.8).
2. The isentropic efficiency of the steam turbine was assumed to be 75% (taking the lowest value).
3. The Back-Pressure PLTP cycle was in steady-state conditions (not connected to the 150KV network).
4. Energy losses due to kinetic and potential energy were neglected, as were losses in the pipes (as these losses were relatively small).

3.1. Results of Back-Pressure PLTP Simulation

The initial step involved calculating the potential energy values of the wasted steam under two conditions: when the venting was at its minimum and when it was at the average operational level.

Table 5. Potential Energy of Wasted Steam

Items	Min	Average
mass flow (ton/h)	43	112
Pin (barA)	6.5	6.5
Tin (degC)	169	169
Hin (kj/kg)	2759	2759
Pout (barA)	0.85	0.85
Hout (kj.kg)	2501	2501
eff isentropic	75%	75%
Q (MW)	2.79	7.9
P generator	2.7342	7.742

Based on manual calculations, the data in Table 5 indicates that at the minimum venting condition, the generated power is 2.73 MW, while at the average venting condition, the turbine generator produces 7.7 MW. The steam entering the turbine is slightly superheated due to the mechanical process in the separator. After input data was run and experiments were conducted with various steam flows, ranging from the minimum to reach a turbine output of 5.2 MW.

Table 6. Steam Flow Variations with Power Output

No	Flow Uap (ton/h)	Power of Backpressure Power Plant (MW)
1	0	0
2	3.816	0.26
3	18	1.2
4	25.2	1.74
5	46.8	3.2
6	57.6	3.98
7	72.72	5.02
8	76.5	5.2

According to the table, the minimum flow of steam required to meet the self-consumption load of all units is 76.5 tons/hour, or when venting is at a minimum of 33%. Steam flow variations were tested through the valve, ranging from 0 tons/hour to 76.5 tons/hour. Testing the variations in steam flow was based on the minimum electrical power requirement to meet the self-consumption load of each unit. Unit 1 required a minimum PS power of 1.1 MW, Unit 2 required 2.975 MW, and Unit 3 required 4.955 MW. Therefore, the minimum power that the Back-Pressure PLTP needed to generate was 5.07 MW to support the essential equipment. The following are the results of Cycle Tempo modeling for the Back- Pressure PLTP.

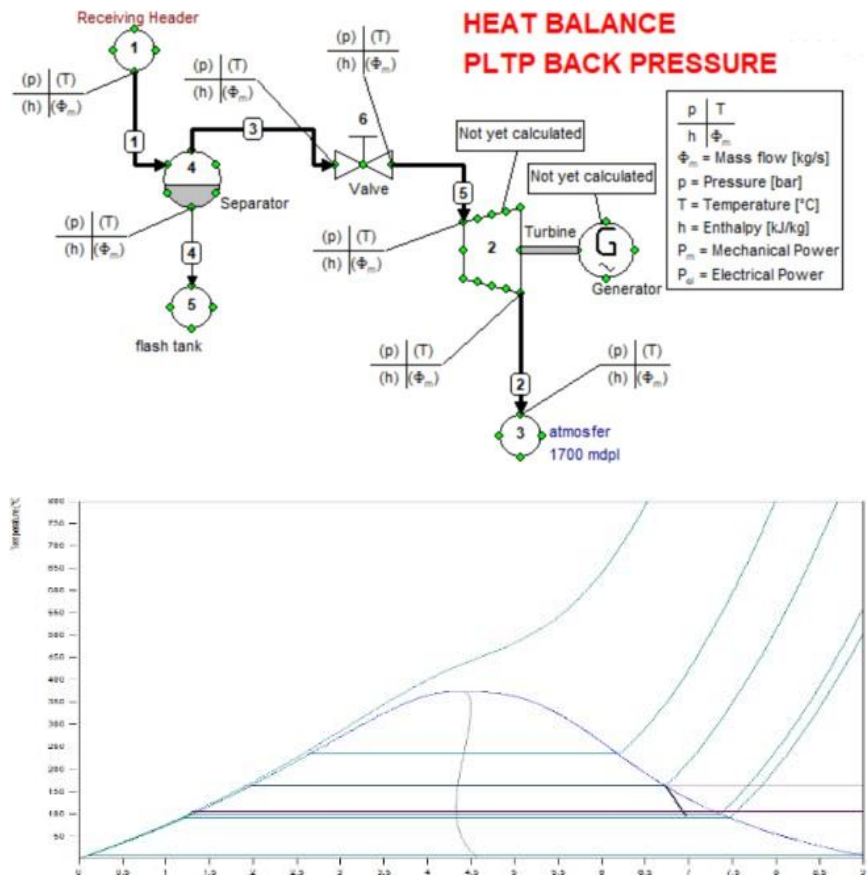

Figure. 10. Heat Balance Simulation Results of Back- Pressure PLTP

The simulation results show that the Back-Pressure turbine is capable of generating 5.2 MW of power when the minimum steam flow is 21 kg/s. Consequently, the Back-Pressure PLTP can meet the self-consumption load for all Kamojang PLTP units, including essential equipment. The diagram indicates that the working area of the Back-Pressure turbine is on the vapor-saturate line, slightly superheated. This is due to the pressure drop experienced by the steam, intentionally done to prevent the fluid phase from reaching saturation or forming water droplets in the fluid, which could damage the turbine blades, especially those at the first stage of the turbine. The steam leaving the turbine is in a mixed state, with an entropy of around 7 kJ/kgK, and it undergoes a temperature decrease to 95°C.

3.2. Load Flow Simulation with ETAP

Before conducting the load flow simulation, several parameters are established as follows:

1. The minimum power of the Back-Pressure PLTP generator is 300 kW (to prevent reverse power).
2. The load and operating conditions of the Kamojang PLTP are taken on June 6, 2023, during the 75% ROH load.
3. The length of the output cable of the Back-Pressure PLTP generator is 300 m, with typical impedance in ETAP.
4. The load flow simulation is run using the Newton- Raphson method with a maximum of 100 iterations.
5. The capacity of the Back-Pressure PLTP generator is 6 MW to avoid overloading.
6. The output power of the Back-Pressure PLTP is controlled by DCS technology to maintain power according to the set point.
7. The technical specifications of the bus duct and cables follow typical ETAP data with a field data approach, including XLPE insulation and aluminum alloy armor.

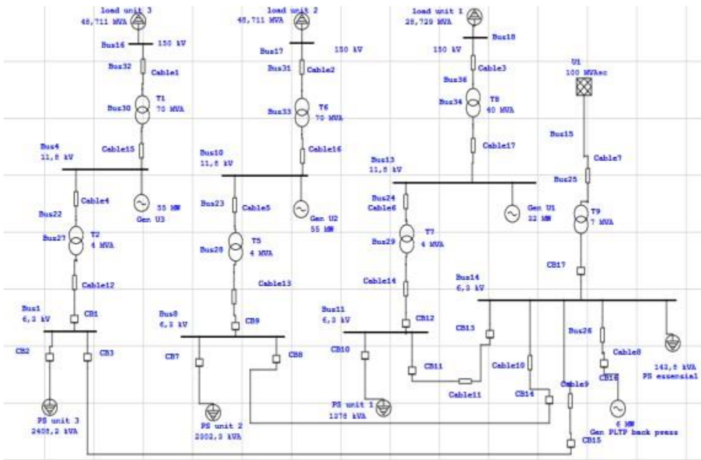

Figure 11. Load Flow Saat PLTP Bck Pressure Penetrasi The Back-Pressure PLTP enters the 6.3 kV voltage system

On the user side, and for each unit and essential equipment, it is connected with 3 breakers as protection and connectors. On one side are the units, and on the other side is the Back- Pressure PLTP of 5.2 MW. During Back-Pressure PLTP operation, all breakers remain closed because they are still operating above their reverse power limit (> 3000 kW), and the achievable power is taken during full-load operation. When the Back-Pressure PLTP penetrates the user's own system based on load flow using ETAP, the output power of Kamojang PLTP units 1, 2, and 3 decreases from 109.7 MW to 101 MW because the PS load has already been supplied by the Back-Pressure PLTP.

3.3. Influence of Output Power Variation on the Generator of Kamojang PLTP Unit

Table 7. Variation of Output Power of Kamojang PLTP Generator and PS Load

No	Geothermal Back Pressure (MW)	Generator Unit 1(MW)	Generator Unit 2 (MW)	Gnarator Unit 3 (MW)	Self-Use Unit 1	Self-Use Unit 2	Self-Use Unit 3	Self-Use Esential
1	0	24,17	40,98	41,07	1096 + j850	1862 + j1402	1954 +j1460	115 + j86
2	0,26	24,7	40,6	40,6	1680 + j116	1561 + j170	1561 + j170	115 + j86
3	1,1	24,4	40,4	40,4	1381 + j170	1289 + j191	1290 + j196	115 + j86
4	3	23,7	39,7	39,7	707 + j295	675 + j244	677 + j249	115 + j86
5	5	23	39,1	39,1	0,01 + j435	31 + j306	31 + j311	115 + j86
6	5,2	23	39	39	70 – j450	33 – j312	29 – j318	115 + j86

In the table, it can be observed that when there is no supply from the Back-Pressure PLTP for PS, the power still matches the initial data taken from each unit's generator. Then, when the Back-Pressure PLTP enters the self-consumption system with 0.26 MW of power, the power of unit 1 increases, but the PS power of units 2 and 3 decreases. This is because units 2 and 3 rely on unit 1. Subsequently, as the Back-Pressure PLTP's power increases to 1.1 MW, the power of unit 1 starts to decrease, followed by units 2 and 3. Finally, when the output power of the Back-Pressure PLTP reaches 5 MW, the generator's output power decreases further, initially at 106.22 MW, then to 101.2 MW, and finally to 101 MW.

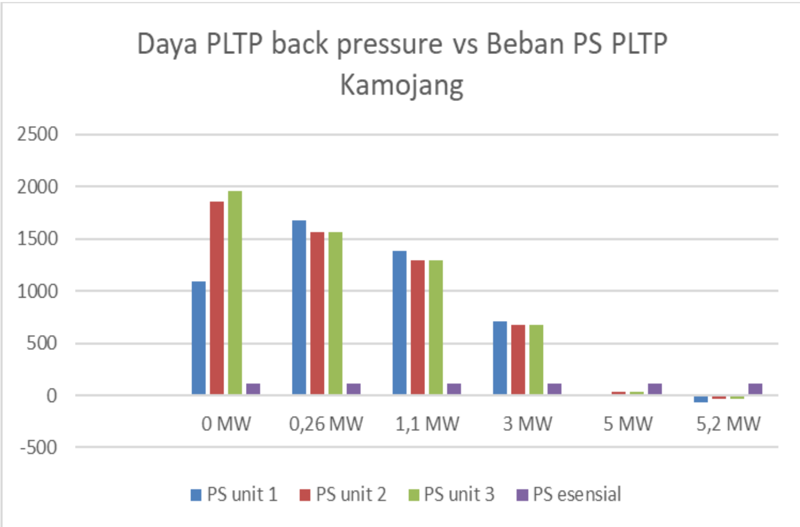

Figure 12. Trend of Back-Pressure PLTP Power and PS Load.

The PS load of unit 1 had increased when the PLTP Back Pressure was 0.3 MW because the technical specifications of the generator unit 1 were different, then along with the increase in the power of the PLTP Back Pressure to 5.2 MW, the PS load of the PLTP Kamojang decreased even a surplus of 132 kW and was sent to the 150 kV network through the main transformer of the PLTP Kamojang.

3.4. Analysis of Kamojang PLTP PS Performance Percentage

The %PS calculation was taken during the dispatch of the Kamojang PLTP unit's load at 75%. It was simulated with variations in steam flow according to Table 5, resulting in the %PS from the total MW generated by Kamojang PLTP units 1, 2, and 3.

Table 8. Variation of Back-Pressure PLTP Steam and %PS

No	Flow Uap (ton/h)	Power of Backpressure Power Plant (MW)	%PS	MW PLTP Kamojang	Beban PS (MW)
1	0	0	4.482	109.7	4.917
2	3.816	0.26	4.187	109.7	4.917
3	18	1.2	3.388	109.7	4.917
4	25.2	1.74	2.896	109.7	4.917
5	46.8	3.2	1.565	109.7	4.917
6	57.6	3.98	0.854	109.7	4.917
7	72.72	5.02	-0.0938	109.7	4.917
8	76.5	5.2	-0.2579	109.7	4.917

When the Back-Pressure PLTP doesn't generate power, the estimated total %PS of the Kamojang PLTP is 4.48%. As the steam flow to the Back-Pressure PLTP increases to 76.5 tons/hour, the total %PS of the Kamojang PLTP units becomes 0%. The operation of the breaker connection from the Back-Pressure PLTP to the Kamojang PLTP's PS load begins to close when the Back-Pressure PLTP generates a minimum of 0.3 MW, which is the minimum power to avoid reverse power.

3.5. Analysis of Kamojang PLTP Loss Opportunity in 2022

In 2022, the Kamojang PLTP unit missed the opportunity to reduce %PS because the PS loads were only supplied by the PLTP unit itself. Here are the calculation results:

Table 9. Comparison of %PS If Back-Pressure PLTP Is Active

Month	Unit 1		Unit 2		Unit 3	
	Before	After	Before	After	Before	After
January	5.6	2.22	6.47	2.8	5.9	2.19
February	4.28	1.04	9.8	2.27	4.18	0.96
March	4.1	0.26	4.4	0.05	4.3	0.07
April	3.67	0.42	4.29	0.37	4.76	0.26
May	3.83	0.95	4.05	1.01	5.37	0.597
June	4.03	0.84	4.22	0.807	4.19	0.9
July	3.667	1.85	3.84	1.75	3.69	1.618
Augusts	4.03	0.128	4.33	0.002	4.19	0
September	3.78	0.737	3.94	0.704	4.06	0.68
October	3.72	2.26	3.84	0.104	7.31	0.3565
November	3.87	3.34	3.8	2.191	6.13	1.13
December	3.41	3.41	3.44	3.439	3.98	0.36
Average	3.998625	1.454583	4.700583	1.29147	4.839	0.760125

Unit 1 of the Kamojang PLTP missed the opportunity to reduce the %PS by 2.544%, Unit 2 missed it by 3.4%, and Unit 3 missed it by 4.07%. Missing the opportunity to reduce %PS keeps the PS performance value at 4.5% for all Kamojang PLTPs. Therefore, the performance rating for the Unit Performance Contract remains at 110%. However, if the Kamojang PLTP could utilize the Back-Pressure PLTP throughout 2022 to save/optimize %PS, the Unit Performance Contract achievement value would be 176% (the target value is 5%), as the Back-Pressure PLTP, based on the data of the steam released in 2022, could meet the needs of the 5 MW Back-Pressure PLTP.

3.6. Reliability and Savings Opportunity Analysis for BPP

In the ETAP simulation, which includes load flow modeling, the results show that when the Back-Pressure PLTP penetrates the 6.3 kV voltage system, the essential PS load is also supplied. This indicates that when the 150 kV network experiences a blackout, the Kamojang PLTP unit can serve as a house load because the power supply for the vent valve equipment is supported by the Back-Pressure PLTP. Examining the transient graph, when the Back-Pressure PLTP penetrates, it does not affect other units but enhances reliability by making the PS load redundant.

Savings for BPP can be achieved because the essential PS load for Kamojang POMU enters the industrial customer category. Based on the latest data, the cost per kWh is Rp. 997. Therefore, the cost savings opportunity when the PS load is supported by the Back-Pressure PLTP is as follows:

Cost = 115 kWh x 24 hours x 997 Rupiah/kWh

= Rp. 3,074,640 per day

Or in a month, it can save up to Rp. 82,551,600, meaning that the component C for generation costs is reduced, leading to a decrease in BPP.

4. CONCLUSION

To obtain 5.2 MW of turbine generator output through the Software Cycle 5.0 Tempo simulation, it requires a steam exhaust flow of 75.6 tons/hour. When dispatching a load of 75% and the Back-Pressure PLTP of 5 MW penetrates the units 1, 2, 3, and essential loads, the %PS becomes 0%. With the inclusion of the 5.2 MW Back-Pressure PLTP in the user's electrical system, the power supply to the unit and essential equipment becomes redundant, allowing the Kamojang PLTP units to house load during a blackout. When the Back- Pressure PLTP generates 5.2 MW of power, it can feed 123 kW of power into the grid through the user's transformer. The opportunity for savings on essential PS loads when the Back- Pressure PLTP penetrates is Rp. 82,551,600 per month, enabling a payback of the investment in 1 year. Throughout the year 2022, Kamojang PLTP missed the opportunity to reduce %PS by 3.34%.

It is hoped that this research will be developed as a solution for cogeneration in other similar power plants. This research is implemented in the Kamojang PLTP system to reduce noise and utilize wasted energy, thereby enabling participation in the Clean Development Mechanism (CDM) program to obtain Certified Emissions Reductions (CERs) or Verified Emissions Reductions (VERs) beyond kWh.

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