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Original Article

Utilization of an Electrical Transient Analyzer Program (ETAP) in Calculating Power Optimization for Fuel Cost Efficiency

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Abstract - *Efforts to optimize power distribution to the load are becoming increasingly crucial in minimizing fuel costs and active power losses while maintaining system voltage quality. The optimal power flow method minimizes generation costs while meeting load balance. This study applies the Optimal Power Flow (OPF) method using the Electrical Transient Analyzer Program (ETAP) in the electricity system of northern Sumatra. The findings show that the implementation of power flow optimization significantly reduced fuel costs during peak load hours by US$ 3,569,794.11, resulting in a cost efficiency of 59.97%. The method proved to be satisfactory for optimizing the northern Sumatra electricity system. Furthermore, the study reveals a remarkable reduction in electricity generation costs from US$ 5,953,077.18 to US$ 2,383,283.06 after optimization. These findings highlight the potential of the OPF method, mainly when used with ETAP simulation, in achieving cost-effective and efficient power distribution. This study offers a valuable contribution to the field of electricity optimization, particularly in the northern Sumatra region.*

Keywords - *Electrical transient analyzer program, ETAP simulation, Generation cost efficiency, Optimal power flow, Power distribution optimization.*

1. Introduction

Electricity has become a necessity for modern life as it powers the majority of machines and instruments used in various fields. The rapid expansion of Indonesia's population and industrial development has resulted in a corresponding increase in the demand for electrical energy each year [1]. In order to meet this demand, electrical energy must be transmitted and distributed through the electric power system, which includes a generation facility, transmission lines, and distribution lines.

The distribution process involves transporting energy from the generation center through a vast network to reach customers. As the number of consumers connected to Indonesia's state power plant network continues to increase with the country's economic development, the installed electricity network must become more durable to support this growth [2]. Hence, it is imperative to enhance the effectiveness and dependability of the electrical grid to guarantee continuous and cost-effective availability of electricity to everyone [3].

Power flow analysis is a crucial technique for ensuring the safety and reliability of electric power systems, making it essential for future system planning and evaluation of existing systems [4]. This analysis provides insight into the steady-state performance and power flow, including real and reactive power, under specific conditions. In addition, power flow calculations serve as initial data for system disturbance analysis and stability analysis [5].

The key objectives of a power system study are to determine the magnitude of voltage, angle/voltage vector, active and reactive power flow, and power losses that occur within the system. A thorough power flow analysis can optimize the system for improved efficiency, reduced costs, and increased reliability [6].

Efforts to optimize power distribution are becoming increasingly crucial in minimizing fuel costs and active power losses while preserving voltage quality [7]. This Optimal Power Flow (OPF) study focuses on the latter. OPF was introduced in the early 1960s as an extension of Economic Dispatch (ED) to determine the optimal configuration of control variables while adhering to constraints [8], [9]. OPF addresses a variety of interrelated network optimization issues.

Despite frequent oversupply, the amount of electricity generated by the state power plant is always less than the quantity sold to customers [10]. As a result, the plant has been forced to purchase electricity from third parties to meet the demand. This information is available in the Indonesian state power plant's statistics summary for 2021, which reports that the plant generated 182,970 GWh of its own electricity and purchased an additional 106,490 GWh from external sources. Despite this, the state power plant's total electricity supply for the year was only 289,470 GWh, with only 257,630 GWh being sold to customers. This indicates a significant difference in oversupply, estimated at approximately 31,800 GWh by the end of the year. This oversupply is not necessarily due to insufficient consumer demand but rather the plant's excessive electricity purchases from third parties. This suggests the need for further investigation into the state power plant's electricity generation and purchasing processes and the potential for optimization to improve efficiency and cost-effectiveness [11].

The state power plants in several locations risk facing another coal supply crisis, as coal suppliers are increasingly reluctant to do business with them. Suppliers lack interest in extending or signing new contracts for coal supply, as stated in the records of the state power plant. This situation will likely diminish the coal reserves of the state power plant and exacerbate the existing energy crisis [12]. In other words, there is a potential coal supply crisis faced by state power plants. The reluctance of coal suppliers to extend or sign new contracts for coal supply poses a risk to the power plants, leading to a depletion of coal reserves and exacerbating the existing energy crisis.

To address this issue, the present study aims to optimize the system power flow, with the ultimate goal of minimizing generation costs while maintaining load balance. Kumolo [13] conducted research using Electrical Transient Analyzer Program (ETAP) in the KSO Pertamina EP-Geo Cepu Indonesia, which revealed that the simulation results conducted under 100% load operation showed significant voltage drops in several buses and considerable power losses.

In a study conducted by Widiarto and Suprihartini [28], it was found that the power flow and losses within the electric power system at an aviation college building remained unchanged even in the presence of a disruption in one of the electricity distribution networks. Additionally, Putro et al. [15] investigated the voltage drop in the electrical distribution system of Pelalawan, finding it to be 41% in the mid-voltage range and 30% in the low-voltage range. The common problem identified in those studies is the occurrence of voltage drops and power losses in electrical power systems.

The research gap in this context is the lack of studies or solutions addressing state power plants' looming coal supply crisis. While previous research has examined various aspects of power generation and optimization techniques, there is a notable absence of specific investigations into the coal supply issue.

This study brings novelty compared to previous research by focusing on the electricity system of northern Sumatra, which has unique characteristics and challenges. It utilizes the OPF method in combination with ETAP for power flow optimization. Additionally, the research highlights the economic benefits of optimizing power flow, particularly in reducing fuel costs. By doing so, this study offers a potential solution to the looming coal supply crisis while simultaneously contributing to the broader goal of achieving efficient and cost-effective power generation.

2. Methods

2.1. Analysis Process

This study discussed optimizing power flow during peak load hours (5 PM to 10 PM) in the northern Sumatra electrical system with 17 substations. A calculation method was used in fuel cost analysis. Meanwhile, analysis to optimize power flow was carried out using the OPF analyzer method with the simulations on ETAP software. Figure 1 shows the simulation flowchart.

The simulation process was initiated by making a one-line diagram with 17 substations and eight generations of power plants from the electricity system of northern Sumatra. Parameters were inputted in each component. Then, the Load Flow (LF) and OPF were determined to view the power flow and the optimal power flow on ETAP [16], [17]. The cost and fuel efficiency in normal conditions and after optimization using ETAP were measured [18], [29].

2.2. Network Model

ETAP provides a complete representation of the electrical equipment or components used in the simulation, especially in studying power flow. The models of the channels and equipment used are as follows:

- The transmission line is modeled as a frequency-dependent lumped parameter, while the input data is from the line conductor.
- The source is modeled with a power supply and swing, which present the ETAP standard. The load connected on the medium voltage side of the 20 kV transformer is expressed in MVA or lumped load. Load modeling is performed by ETAP standard by converting its value into P and Q.

- The transformer is modeled at an impedance value of Z%, while voltage and typical X/R standard ETAP are presented as IEC.
- The values of components such as R, X, and Y are entered according to the respective values of the data specified in the ETAP.

Tables 1, 2, 3, and 4 provide data used in the analysis process using ETAP. Table 1 shows the generator rating on eight power plants used in the simulation process. Tables 2 and 3 display electrical load data at peak load hours and rating data from 17 substations. Meanwhile, Table 4 shows the substation channels' transmission line length, impedance, and admittance data.

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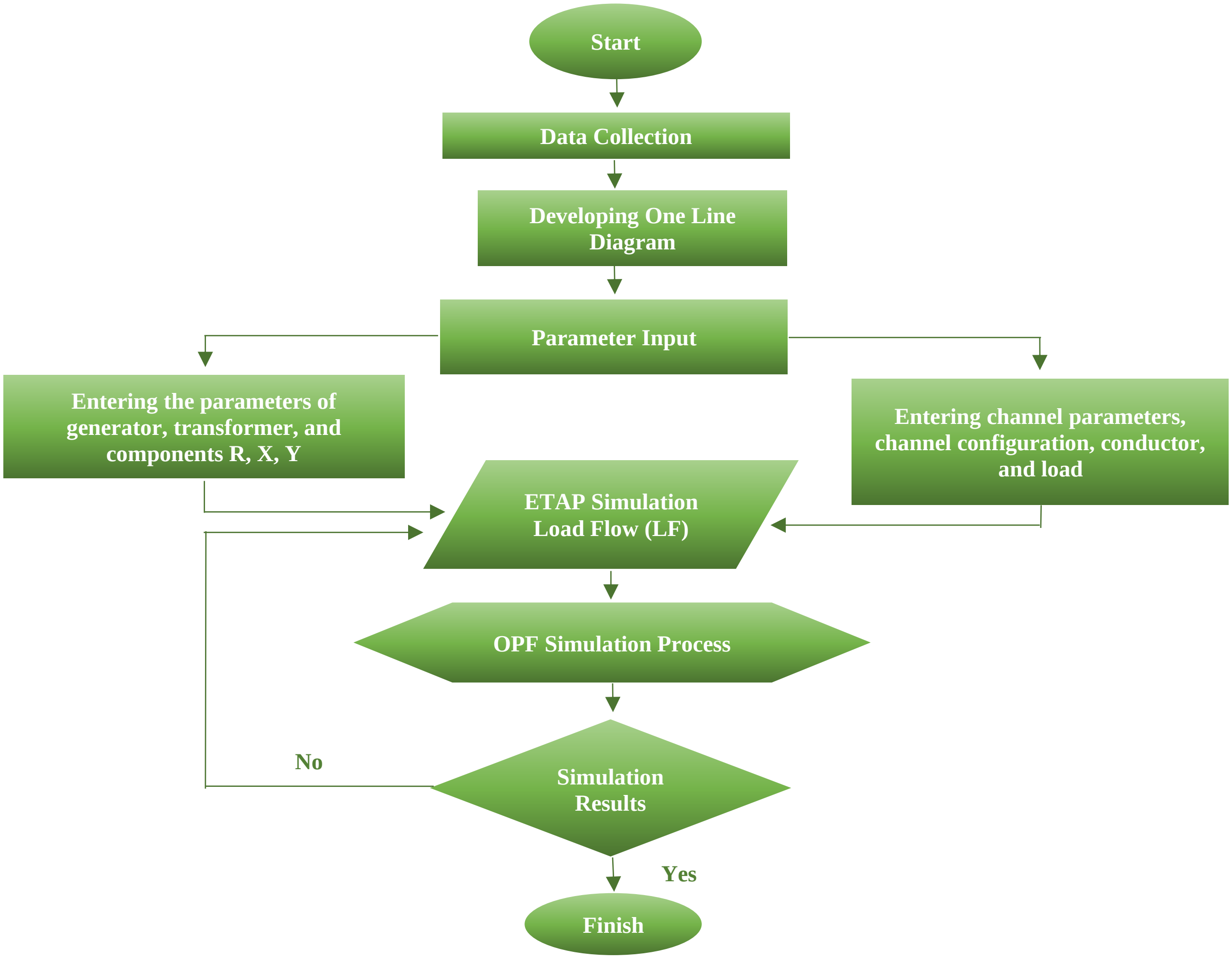

Fig. 1 ETAP Simulation flowchart

Table 1. Generation Data on Power Plants

Power Plants	**Generator Rating**		
	MW	**kV**	**Cos ϕ**
PLTU Belawan[a]	260	11/150	0.85
PLTGU Belawan[b]	1067.3	11/150	0.85
PLTG Paya Pasir[c]	90	11/150	0.85
PLTU Pangkalan Susu[a]	220	11/150	0.85
PLTU Inalum[a]	90	11/150	0.85
PLTD Paya Pasir[d]	90	11/20	0.85
PLTD Titi Kuning[d]	124.84	11/150	0.85
PLTD Glugur[d]	150	11/150	0.85
Total	2.092.14		

Notes: [a] = Steam-electric power station; [b] = Combined cycle gas turbine plant; [c] = Gas turbine power plant; [d] = Diesel power station

Table 2. Load data used at peak load hours

Substation Name	Electrical Load	
	MW	MVAR
Labuhan	21.1	8.1
Lamhotma	6.84	2.16
Paya Pasir	2.1	1.1
Mabar	26.55	3.83
Paya Geli	107.81	28.58
Glugur	79.69	23.56
Namorambe	47.2	13.3
GIS Listrik	74.41	26.62
Titi Kuning	102. 34	31.8
Sei Rotan	61	10.8
KIM	29.26	7.04
Denai	51.98	18.17
Tamora	35.3	13
Kuala Namu	12.4	1.6
Binjai	80.34	22.86
Perbaungan	37.12	12.72
Pangkalan Brandan	26.9	7.75
Total	802.34	233.22

Table 3. Rating data of substation mounted transformer

Substation Name	Total	Capacity (MVA)	Ratio (kV)
Labuhan	2	31.5 + 60	150/20
Lamhotma	2	2 x 20	150/20
Paya Pasir	2	2 x 60	150/20
Mabar	3	(2 x 60.5) + 87.5	150/20
Paya Geli	3	3 x 60	150/20
Glugur	3	3 x 60	150/20
Namorambe	2	2 x 60	150/20
GIS Listrik	3	3 x 60	150/20
Titi Kuning	3	3 x 60	150/20
Sei Rotan	3	(2 x 60) + 31.5	150/20
KIM	3	3 x 60	150/20
Denai	2	2 x 60	150/20
Tamora	2	2 x 60	150/20
Kuala Namu	2	2 x 30	150/20
Binjai	3	3 x 60	150/20
Perbaungan	3	(2 x 31.5) + 60	150/20
Pangkalan Brandan	2	2 x 30	150/20
Total	43	2.294.5	

Table 4. Transmission Line Length, Impedance, and Admittance Data

Segment	Length (km)	Impedance				Admittance (Y)
		Z1 (Ω/km)		Z1 (Ω/km)		
		R1	jX1	R0	jX0	
Belawan – Labuhan	2.95	0.04	0.319	0.453	1.735	1.303
Belawan – Lamhotma	6.14	0.127	0.408	0.521	1.615	1.171
Belawan – Paya Pasir	6.2	0.039	0.313	0.481	1.773	1.303
Belawan – Sei Rotan	26.39	0.02	0.256	0.477	1.571	1.722
Belawan – Binjai	34.47	0.129	0.421	0.33	1.276	1.513
Lamhotma – Labuhan	3.2	0.129	0.421	0.33	1.276	1.513
Sei Rotan – Paya Pasir	23.72	0.103	0.428	0.544	1.883	1.176
Sei Rotan – Tamora	7.76	0,129	0.328	0.489	1.761	1.197
Sei Rotan – Denai	11.44	0.129	0.328	0.489	1.761	1.197
Sei Rotan – Titi Kuning	17.2	0.103	0.433	0.545	1.893	1.151
Denai – Tamora	11.15	0.129	0.328	0.489	1.761	1.197
Tamora – Kuala Namu	28.2	0.129	0.328	0.489	1.761	1.197
Glugur – Paya Geli	11.92	0.103	0.428	0.506	1.781	1.176
Mabar – Paya Pasir	5.93	0.103	0.433	0.545	1.893	1.151
Titi Kuning – GIS Listrik	7.93	0.103	0.433	0.545	1.893	1.151
Paya Geli – Namorambe	18.49	0.103	0.428	0.544	1.883	1.176
Titi Kuning Namoramber	12.44	0.103	0.428	0.544	1.883	1.176
Sei Rotan – KIM	20.74	0.129	0.328	0.489	1.761	1.288
Paya Geli – Paya Pasir	21.27	0.103	0.428	0.544	1.883	1.176
Sei Rotan – Perbaungan	36.51	0.129	0.407	0.558	1.87	1.168
P. Brandan – Binjai	50.81	0.129	0.44	0.571	1.9	1.054
Total Length of Channels	364.86 km					

3. Results and Discussion

3.1. Fuel Cost Calculation

The energy production is consequential in one hour at peak load hours with the amount of energy production at the time of normal circumstances. Table 5 presents the fuel types and fuel consumption data for one-hour production of the power plants. The fuel used in power plant production consists of Marine Fuel Oil (MFO) and High-Speed Diesel (HSD). In this section, the example of fuel cost calculation was conducted using data from PLTU Belawan based on Table 5.

The following is the calculation of the generation cost using MFO for PLTU Belawan. Prior to the calculation, the fuel average usage must be determined.

Fuel Average Usage $= \frac{\text{Fuel Consumption}}{\text{Energy Production}} = \frac{3348\ L}{260\ MWh} = 12.9\ L/MWh$

Production Costs = Fuel Average Usage x Fuel Price = 12.9 L/MWh x Rp6,300/L = Rp81,125/MWh

Production Costs in a Month = Fuel Consumption x Fuel Price x 24 hours x 30 days = 3348 L x Rp6,300/L x 24 hours x 30 days = Rp15,186,528,000

Table 5. Fuel consumption data for one hour

Power Plants	Energy Production (MWh)	Fuel Types	Fuel Consumption (Liter)	Fuel Price in Region I (per Liter)
PLTU Belawan[a]	260	MFO	3348	Rp6,300
PLTGU Belawan[b]	1067.3	HSD	6567	Rp8,700
PLTG Paya Pasir[c]	90	HSD	554	Rp8,700
PLTU Pangkalan Susu[a]	220	MFO	2833	Rp6,300
PLTU Inalum[a]	90	MFO	1159	Rp6,300
PLTD Paya Pasir[d]	90	HSD	554	Rp8,700
PLTD Titi Kuning[d]	124.84	HSD	768	Rp8,700
PLTD Glugur[d]	150	HSD	923	Rp8,700

Notes: **a =** Steam-electric power station; **b =** Combined cycle gas turbine plant; c = Gas turbine power plant; d = Diesel power station

Table 6. Production costs calculation results

Power Plants	Energy Production (MWh)	Fuel Types	Fuel Consumption (L)	Fuel Average Usage (L/MWh)	Production Costs	
					per MWh	Monthly
PLTU Belawan[a]	260	MFO	3348	12.9	Rp81,125 (US$ 5.25)	Rp15,186,528,000 (US$ 983,074.07)
PLTGU Belawan[b]	1067.3	HSD	6567	6.2	Rp53,534 (US$ 3.47)	Rp41,138,171,266 (US$ 2,663,009.58)
PLTG Paya Pasir[c]	90	HSD	554	6.2	Rp53,534 (US$ 3.47)	Rp3,468,973,498 (US$ 224,558.10)
PLTU Pangkalan Susu[a]	220	MFO	2833	12.9	Rp81,125 (US$ 5.25)	Rp12,850,139,077 (US$ 831,831.91)
PLTU Inalum[a]	90	MFO	1159	12.9	Rp81,125 (US$ 5.25)	Rp5,256,875,077 (US$ 340,294.87)
PLTD Paya Pasir[d]	90	HSD	554	6.2	Rp53,534 (US$ 3.47)	Rp3,468,973,498 (US$ 224,558.10)
PLTD Titi Kuning[d]	124.84	HSD	768	6.2	Rp53,534 (US$ 3.47)	Rp4,811,851,683 (US$ 311,487.04)
PLTD Glugur[d]	150	HSD	923	6.2	Rp53,534 (US$ 3.47)	Rp5,781,622,496 (US$ 374,263.50)
						Rp91,963,134,593 (US$ 5,953,077.18)

Notes: **a =** Steam-electric power station; **b =** Combined cycle gas turbine plant; c = Gas turbine power plant; d = Diesel power station

Based on the results, PLTU Belawan requires the use of 12.9 L MFO fuel and costs of Rp81,125 (US$ 5.25) per MWh. In addition, the monthly production cost is Rp15,186,528,000 (US$ 983,074.07). Meanwhile, the results for all power plants are provided in Table 6.

3.2. Production Costs After Optimization

The simulation process using ETAP generated production data in Table 7. Therefore, the production costs after optimization are calculated using these data, and then, the results are compared to those obtained in Table 6 (normal condition). In this case, the following calculation uses an example of PLTU Belawan.

Production Costs in a Month (ETAP Optimization) = Energy Production x Production Costs per MWh x 24 hours x 30 days = 115 MWh x Rp81,125/MWh x 24 hours x 30 days = Rp6,717,118,154

The calculation results of production costs after ETAP optimization for all power plants are provided in Table 8. Meanwhile, Figure 3 compares production costs based on normal conditions (using field data) and after optimization with ETAP.

Table 7. Generation Data after Optimization using ETAP

Power Plants	Energy Production (MWh)
PLTU Belawan[a]	115
PLTGU Belawan[b]	214.4
PLTG Paya Pasir[c]	79.2
PLTU Pangkalan Susu[a]	97.5
PLTU Inalum[a]	75.8
PLTD Paya Pasir[d]	20.1
PLTD Titi Kuning[d]	109.5
PLTD Glugur[d]	95.1
Total	806.6

Notes: [a] = Steam-electric power station; [b] = Combined cycle gas turbine plant; [c] = Gas turbine power plant; [d] = Diesel power station

According to the ETAP simulation findings, the total monthly production costs are US$ 2,383,283.06, while in the normal condition are US$ 5,953,077.18, with potential savings of US$ 3,569,794.11 or 59.97%.

Comparison of active power generated during normal operation and optimization process makes generators with voltage bus lower their generated power during optimization. This effect occurs because the swing bus generator accommodates excessive loads interconnected with the nearest voltage bus generator [20]. The aim is also to maintain reliability and prolong the generator's life, which must work continuously during peak load times, especially since the swing bus generator still has a lot of energy capacity that can be generated. Thus, during peak load hours, the swing bus generator can be loaded more heavily, and the reliability process in the transmission network system is better and more stable [21].

Table 8. Production Costs Calculation Results after Optimization using ETAP

Power Plants	Energy Production (MWh)	Production Costs (Monthly)
PLTU Belawan[a]	115	Rp6,717,118,154 (US$ 434,821.22)
PLTGU Belawan[b]	214.4	Rp8,263,865,754 (US$ 534,947.30)
PLTG Paya Pasir[c]	79.2	Rp3,052,696,678 (US$ 197,611.13)
PLTU Pangkalan Susu[a]	97.5	Rp5,694,948,000 (US$ 368,652.78)
PLTU Inalum[a]	75.8	Rp4,427,457,009 (US$ 286,603.90)
PLTD Paya Pasir[d]	20.1	Rp774,737,414 (US$ 50,151.31)
PLTD Titi Kuning[d]	109.5	Rp4,220,584,422 (US$ 273,212.36)
PLTD Glugur[d]	95.1	Rp3,665,548,662 (US$ 237,283.06)
Total	806.6	Rp36,816,956,094 (US$ 2,383,283.06)

Notes: [a] = Steam-electric power station; [b] = Combined cycle gas turbine plant; [c] = Gas turbine power plant; [d] = Diesel power station

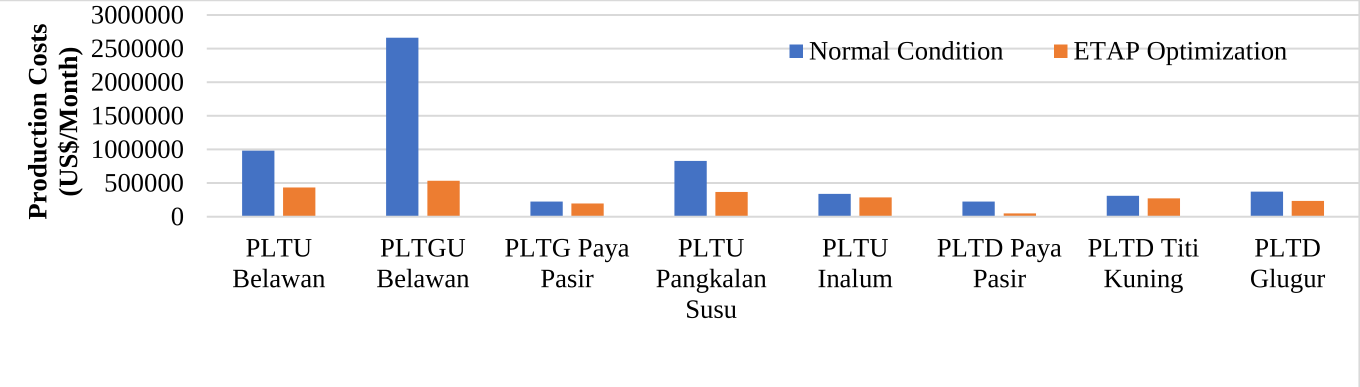

Fig. 2 Monthly production costs before and after ETAP optimization

This difference in production costs is likely due to the optimization and efficiency of the system achieved through the ETAP simulation [22]. The simulation can identify areas where the system can be improved and optimized to reduce costs, increase efficiency, and improve overall performance. Factors contributing to the difference in production costs include more efficient equipment, better load management, and more accurate modeling and analysis of the system [23]. Additionally, using real-time data and predictive analytics can help optimize the system further, leading to additional cost savings and performance improvements.

3.3. Efficiency and Losses in Generation

The total load during peak load hours of 602.53 MW per week using Load Flow (LF) is considered more static than the normal power flow. In addition, the amount of active power released by all power plants to be delivered to the load is 807.3 MW, with losses in the transmission network of 4.77 MW. Meanwhile, the optimal power flow with OPF obtained the amount of active power released by all plants to be delivered to a load of 806.2 MW and losses in the transmission network of 3.67 MW.

It indicates a decrease in active power at the time of optimization. This happens because the boundaries were adjusted during the OPF simulation. The adjustment was made to minimize generation costs and maintain load balance.

The computation of the difference between active power during normal power flow and optimal power flow is as follows:

LF active power: 807.3 MW
OPF active power: 806.2 MW
Power difference = LF-OPF
= 807.1 MW-806.2 MW
= 1.1 MW

$$\text{Power efficiency} = \frac{Power\ difference}{LF\ active\ power}\ x\ 100\%$$
$$= \frac{1.1\ MW}{807.3\ MW}\ x\ 100\%$$
$$= 0.14\ \%$$

Based on this calculation, the difference in active power decreased by 1.1 MW with a power efficiency of 0.14%. This can happen due to the optimization process performed on the studied system using ETAP simulation. In this optimization process, several factors allow for a reduction in active power differences and an increase in power efficiencies, such as more accurate system parameter adjustments, better load adjustments, and overall system capacity optimization [23]. By performing this optimization, the system can work more efficiently and stably and reduce the operational costs required to maintain the system running optimally.

Furthermore, the calculation of the difference in losses during normal power flow and optimal power flow is as follows:

LF active power: 4.77 MW
OPF active power: 3.67 MW
Power Difference = Losses LF-Losses OPF
= 4.77 MW-3.67 MW
= 1.1 MW

$$\text{Power efficiency} = \frac{Power\ difference}{LF\ active\ power}\ x\ 100\%$$
$$= \frac{1.1\ MW}{4.77\ MW}\ x\ 100\%$$
$$= 23.4\ \%$$

Based on the computation, there is a 1.1 MW contrast in losses within the transmission network, operating at an efficiency of 23.4%. Several factors may affect the results obtained from the calculation, including environmental conditions such as temperature and humidity, which can affect the performance of electrical equipment. The quality of the equipment used in the transmission system, such as cables and transformers, can also affect power losses and system efficiency [30]. Operating conditions of the system, such as the load and electric current flowing, can also affect power losses and system efficiency. Furthermore, the system parameters used in the ETAP simulation, such as the electrical equipment models and environmental conditions set in the simulation, may also impact the calculation results [23].

The results of this study demonstrate the significant value it brings to electricity generation compared to previous research [13]–[15]. The focus on reducing losses in the transmission network highlights the importance of improving system efficiency. The implications of reducing losses extend beyond electricity savings, as it also contributes to positive environmental and economic outcomes. Furthermore, the cost savings for electricity providers contribute to economic benefits and alleviate the need for expensive infrastructure expansions to meet the growing electricity demand.

3.4. Cost Savings and Financial Implications

The remarkable reduction in electricity generation costs during peak load hours and the overall cost efficiency achieved through the ETAP optimization process has significant implications for the electricity generation industry. The process of ETAP optimization enables the analysis of an electrical system to enhance power utilization efficiency and reduce costs, specifically during periods of high demand. This is crucial because the cost charged by the utility during peak hours is significantly higher than during normal operating hours [25].

The substantial cost savings, exemplified by the decrease from an estimated US$ 5,953,077.18 to

US$ 2,383,283.06 in this study, present a valuable opportunity for the industry to enhance its financial performance. This reduction in generation costs translates to higher profit margins for businesses operating in the sector, fostering increased profitability and economic viability.

Furthermore, the cost savings attained through the ETAP optimization process can directly benefit electricity consumers. By reducing the cost of generating electricity, there is the potential for more affordable electricity prices, improving accessibility, and reducing financial burdens, particularly for households and businesses reliant on electricity. Other research studies have suggested applying innovative techniques such as optimal capacitor placement (OCP) to correct the power factor and enhance the system's performance. By implementing OCP, the goal is to maximize profits and improve the overall performance of the power distribution grid [26].

These financial implications extend beyond individual entities and encompass industry stakeholders such as regulators, policymakers, and investors. The reduced electricity generation costs bolster the industry's financial stability and attractiveness, stimulating investment and encouraging industry growth. Consequently, this can contribute to regional economic development.

Notably, the financial benefits of the ETAP optimization process have long-term sustainability implications for the electricity generation industry. By minimizing operational expenses associated with electricity generation, the industry becomes more resilient, better equipped to navigate future challenges, and poised for sustainable growth.

4. Conclusion

The findings of this research are promising and carry substantial implications for the power generation sector. The remarkable reduction in electricity generation costs during peak load hours cannot be overlooked. The cost of generating electricity during normal conditions was estimated at a staggering US$ 5,953,077.18 for one month. However, after implementing the ETAP optimization process, this cost dropped dramatically to US$ 2,383,283.06, leading to an incredible fuel cost savings of US$ 3,569,794.11. This optimization also resulted in a cost efficiency of 59.97%, indicating a significant improvement in the system's overall performance. These results demonstrate the immense potential of optimization processes, such as those using the ETAP simulation, to transform the electricity generation industry. Reducing costs and improved efficiency can lead to many benefits, including more affordable electricity for consumers, increased business profitability, and reduced environmental impact. Thus, this study is a valuable contribution to the field, providing a foundation for future research and practical application of optimization processes in the electricity generation industry.

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