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Electricity Supply for Hydrogen Plant through Power Swap Based Reliability and Risk Case Study Pertamina Power's Electrolyzer in Sumatra

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ABSTRACT: This research investigates the integration of renewable energy sources into hydrogen production in Sumatra, with a focus on the utilization of power swap mechanisms to ensure energy reliability and effectively manage risks. This study is in line with the ongoing collaboration between PT. Pertamina, Chevron New Energies International Pte Ltd, and Keppel Infrastructure, which aims to develop hydrogen production facilities using renewable energy through electrolysis.

The main objective is to assess the reliability and risk management in renewable energy-powered hydrogen production, with a focus on the operational reliability of geothermal and solar power plants and the effectiveness of the power swap system.
The methodology combines theoretical and empirical approaches Reliability Evaluation using metrics such as power balance, load flow analysis and Monte Carlo Simulation to analyze the variability and risks in the power generation and swapping system, improving the understanding of system behavior under various scenarios, and Data Analysis through statistical analysis of data collected from ETAP simulations to see patterns. This study hypothesizes that high reliability of renewable energy sources and an effectively managed power swap system can significantly improve the stability and sustainability of hydrogen production. It is expected that the implementation of strategic power exchange can reduce the risks associated with renewable energy variability, thereby strengthening the overall stability of energy supply for hydrogen production.

This study aims to provide insights and actionable recommendations to improve system efficiency and reliability, providing valuable perspectives for the discourse on renewable energy utilization and hydrogen production in Indonesia.

KEYWORDS: Energy Reliability, Power Swap Mechanism, Renewable Energy integration, Risk Management.

INTRODUCTION

Sumatra, as one of Indonesia's largest islands, is endowed with significant potential for generating energy from renewable sources. This island boasts access to abundant natural resources including hydro, solar, wind, and geothermal energy, which have not yet been fully exploited. Sumatra's strategic geographical position, combined with its wealth of renewable energy sources, provides a tremendous opportunity to support national and global efforts towards transitioning to cleaner and more sustainable energy. Sumatra is at the forefront of green energy initiatives in Indonesia, with the potential to revolutionize the way energy is produced and utilized in the region.

Currently the need for sustainable energy solutions is increasing, Pertamina has launched an ambitious plan to strengthen renewable energy capacity in Sumatra through partnerships with Chevron New Energies International Pte Ltd and Keppel Infrastructure. This collaboration aims to utilize electrolysis technology to produce hydrogen, a step that will not only enhance energy diversification but also has the potential to increase the country's foreign exchange earnings through exports. The hydrogen production process will rely on energy sourced from Renewable Energy Power Plants using a power swap system connected to the PLN grid in Jambi Province to Kuala Tungkal. The implementation of this strategy supports government initiatives to reduce carbon emissions and develop clean energy.

Pertamina owns pipeline assets previously used to transport natural gas from Jambi to Singapore, which are now planned to be utilized for hydrogen transportation. The hydrogen plant with a production capacity of 40,000 tons of hydrogen per year to be built in Kuala Tungkal will not only serve as a production point but also as an export hub, using the existing natural gas pipeline to send hydrogen to Singapore. This plan reflects Pertamina's effort to modernize existing energy infrastructure and repurpose it to support renewable energy production.

An electrolyzer operates by using electrical energy to split water into hydrogen and oxygen through a process known as electrolysis. When connected to a 400MW power source, the electrolyzer can leverage this substantial energy input to generate

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hydrogen gas. In the electrolyzer, water molecules are broken down at the anode, releasing oxygen gas and protons. These protons travel through an electrolyte to the cathode, where they combine with electrons to form hydrogen gas. With an efficiency range of approximately 60% to 80%, a 400MW electrolyzer can produce a significant amount of hydrogen. For instance, at 70% efficiency, it can generate roughly 7,112 kg of hydrogen per hour. This hydrogen can be stored and utilized as a clean energy source for various applications, including fuel cells for transportation, industrial processes, and energy storage solutions. The integration of such high-capacity electrolyzers is crucial for advancing renewable energy technologies and reducing carbon emissions.

Hydrogen products will be transported using the existing natural gas pipeline from the TGI Station in Kuala Tungkal to Singapore. This plan also includes the redirection of gas supply from Grissik in South Sumatra to Java Island and North Sumatra through the Special Economic Zone (SEZ), indicating a strategic reorientation in energy resource management in Indonesia.

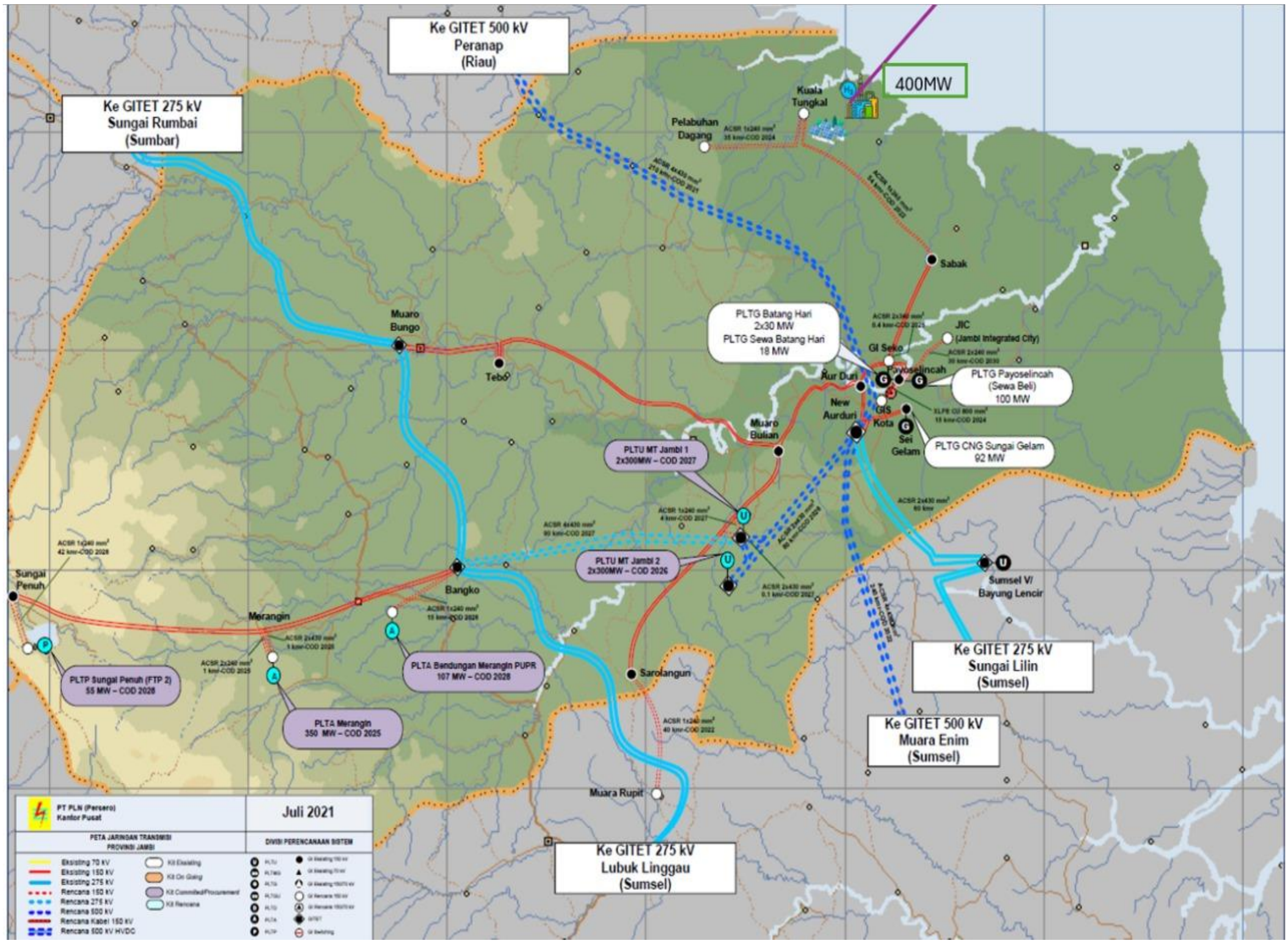

Figure 1 Jambi Province Electricity Transmission

This research aims to analyze the reliability and risk associated with renewable energy power generation integrated into hydrogen production. This analysis will include an evaluation of the performance of existing energy infrastructure, potential operational risks, and the impacts of integrating the power swap system. This study is expected to provide insights into the optimization of infrastructure and technology needed to support a sustainable energy transition in Indonesia, as well as recommendations to mitigate potential risks. This analysis includes geographical and environmental considerations specific to the island. Meanwhile, the night peak load in Jambi Province will be reach 1085 MW on 2030, while the supply capacity reaches 1158 MW

A. Situation and Problem Identification

The problem formulation covers aspects of reliability and risk in the context of renewable energy operations in Sumatra, with a particular focus on the integration and sustainability of hydrogen production. The operational reliability of the Power Plant from renewable energy in Jambi Province in 2030 based on the 2021-2030 RUPTL planned to be connected to the PLN grid in Kuala Tungkal is evaluated to understand its impact on the capacity and stability of hydrogen production. Furthermore, the risks associated with the implementation of the power exchange system in Jambi Province are analyzed, especially in terms of how this system affects the overall reliability of energy supply for the electrolysis process in the hydrogen plant.

In addition, the effect of fluctuations in energy production from renewable sources such as geothermal and solar power on the reliability of energy supply for electrolysis is also assessed. The impact of the integration of the power exchange system with the local PLN grid in Kuala Tungkal is also studied, especially regarding its effect on the stability and reliability of the electricity grid in handling variations in load and energy sources.

This comprehensive problem formulation aims to explore how generator reliability and risks associated with the power exchange system can be managed to support the implementation and operation of effective and sustainable hydrogen power plants in Sumatra.

B. Objectives and Scope

This research considers following assumptions

1. Evaluate the operational reliability of geothermal and solar power plants connected to the PLN grid in Kuala Tungkal, focusing on their capacity to support hydrogen production consistently.
2. Identify and analyze the potential risks linked with the power swap system, particularly its impact on the stability and reliability of the energy supply for hydrogen electrolysis in Sumatra.
3. Investigate the Effects of Energy Source Fluctuations by study the impact of fluctuations in renewable energy production (geothermal and solar) on the energy supply's reliability for the electrolysis process.

Therefore, the research concentrates on :

1. The study is centered on the renewable energy systems connected to the PLN grid in Kuala Tungkal, Sumatra.
2. Methodological Approach :
   i. Gather data from geothermal and solar power plants, and the power swap system covering operational performance and energy outputs.
   ii. Use statistical methods and models to assess the reliability of each power source, focusing on failure rates and operational consistency for reliability analysis.
   iii. Simulate various scenarios to predict the impact of renewable energy fluctuations and power swap dynamics on overall system reliability and power supply stability using Monte Carlo Simulation.
   iv. Analyze the collected data and simulation outcomes using tools like Excel and Matlab to identify patterns, correlations, and insights.
3. Examine how renewable energy sources like geothermal and solar can be integrated with hydrogen production processes through power swap systems, assessing the overall sustainability and efficiency of these integrations.
4. Focus on managing the risks and enhancing the reliability of the power systems involved in hydrogen production.

BASIC CONCEPT

A. Section Headings

This chapter provides an in-depth examination of the theoretical foundations and recent advancements in the field of power system reliability and risk assessment, with a special focus on renewable energy contributions to hydrogen production facilities. Utilizing seminal methodologies from Roy Billinton's ‘Reliability Evaluation of Power Systems’, the chapter discusses the integration of these methods with modern tools such as Monte Carlo simulations and software like Excel and MATLAB. This synthesis aims to capture the nuances of energy system dynamics.

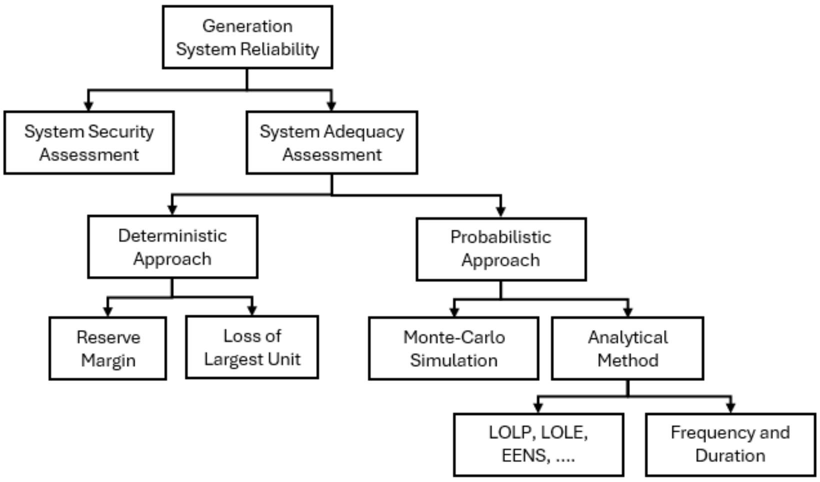

Figure 2 Reliability Assessment Category

B. Load and Supply Curve Analysis

Load and supply curves are essential for understanding the dynamics of power systems, especially in regions with significant contributions from renewable sources. These curves represent the relationship between power demand and supply over time, illustrating the periods of potential energy shortfall or surplus.

Mathematical Considerations:

- The load curve L(t) measured in watts (W) can be expressed as:

$$L(t) = \sum_{i=1}^{n} P_i(t)$$

Where $P_i(t)$ is the power consumption of the i-t sector at time t.

- The supply curve S(t) for renewable sources measured in watts (W), especially variable ones like solar and wind, can be modeled as:

$$S(t) = \alpha(t) \cdot C$$

where α(t) represents the availability coefficient of the resource at time t, and C is the installed capacity.

C. Advances in Renewable Energy Reliability Metrics

Recent advancements in renewable energy technologies have necessitated a refinement of traditional reliability metrics. As the share of renewable energy in power grids increases, researchers and engineers are exploring new metrics to better capture the stochastic nature of sources like wind and solar.

Enhanced Metrics for Renewable Energy:

- Capacity Credit (CC) is measured in watts (W): This metric is used to measure the effective capacity that a renewable energy source adds to the system, considering its variability and availability. The mathematical formulation is:

$$CC = P_{gen} \times CF$$

where P_{gen} is the installed capacity and CF is the capacity factor, which varies over time due to environmental conditions.

- Reserve Margin (RM): The reserve margin is enhanced to account for the unpredictability of renewable outputs, defined as:

$$RM = \frac{Total\ Capacity - Peak\ Demand}{Peak\ Demand} \times 100\%$$

This metric helps in planning the additional capacity required to ensure reliability during peak demand periods under renewable variability.

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D. Integration of Excel in Data Analysis and Visualization

While ETAP in complex simulations, Excel remains a favored tool for simpler analyses and visualization due to its accessibility and widespread use among professionals.

Capabilities and Uses:

- Data Sorting and Filtering: Excel's intuitive interface allows for easy manipulation of large datasets, which is crucial when dealing with hourly or minute-level data from renewable energy sources.
- Graphical Tools: Excel's charting tools enable quick visualization of trends and patterns in energy production and consumption, facilitating immediate insights into system performance.

In sum, this chapter outlines a robust framework for understanding and enhancing the reliability and risk assessment of renewable energy systems, particularly in the context of hydrogen production. By leveraging both theoretical advancements and practical tools like ETAP and Excel, the methodologies discussed provide a comprehensive approach to managing the complexities introduced by renewable energy integration. The subsequent application of these methodologies to real-world scenarios in Sumatra will illuminate their efficacy and adaptability, providing valuable insights for future energy systems planning and development.

METHODOLOGY SCENARIO

The primary energy sources for the hydrogen plant are >90% from renewable energy in Jambi Province, selected due to their prevalence and renewable nature in Jambi. The model assumes:

- High Renewable Integration: The system is designed to maximize the use of renewable energy, assuming that these sources can reliably meet most of the hydrogen plant's energy demands.
- Advanced Power Swap Capabilities: It is assumed that a sophisticated power swap system is in place, allowing for real-time energy exchange between the hydrogen plant and the local grid to manage excess production or supply shortfalls.
- Continuous Operation: The hydrogen plant operates continuously, requiring a stable and uninterrupted power supply to maintain optimal production levels.

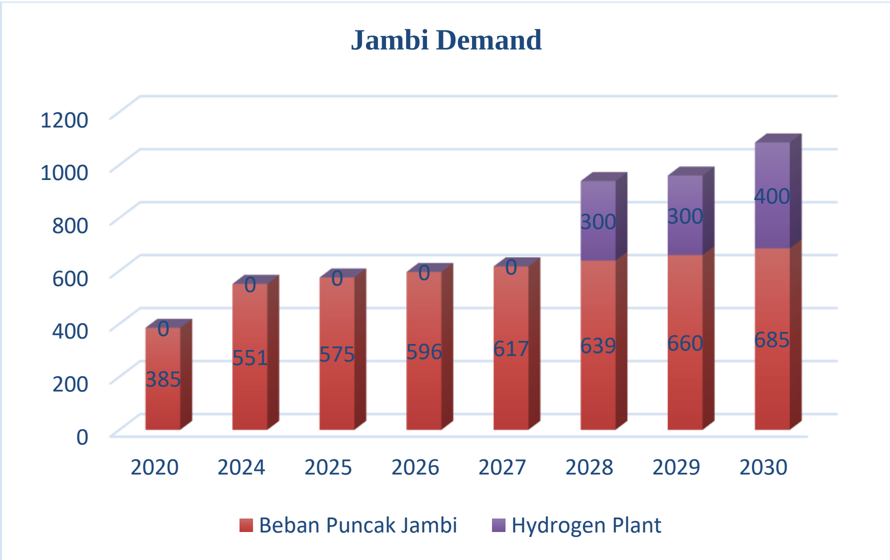

Figure 3 Jambi Province Electricity Demand

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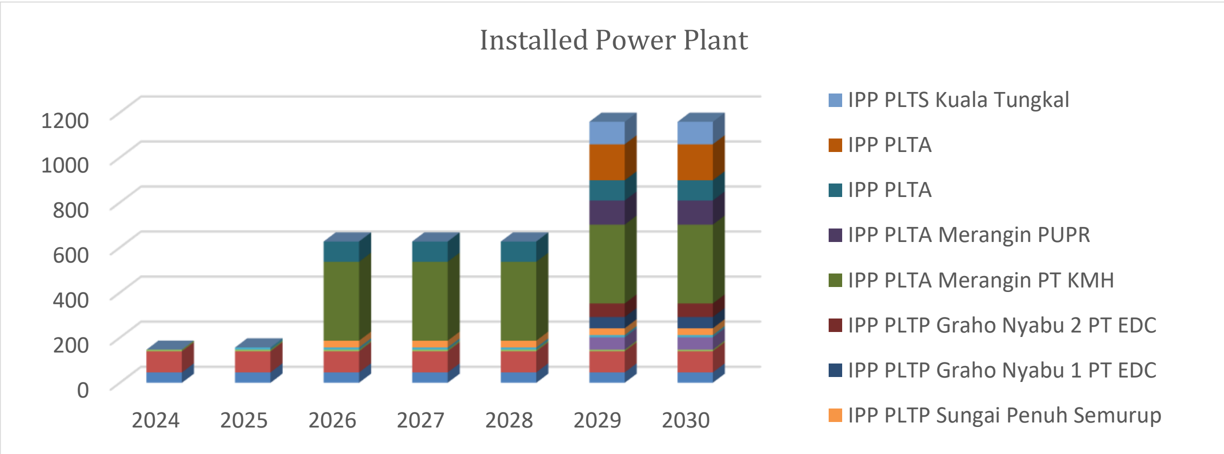

Figure 3 Jambi Province Power Plants

System Limitations:

- Intermittency and Variability: The primary limitation is the intermittency of solar power and the somewhat less variable, but still unpredictable, geothermal power output.
- Infrastructure Adequacy: Existing infrastructure for power transmission may not be fully equipped to handle the high loads and rapid fluctuations associated with renewable energy sources without upgrades.

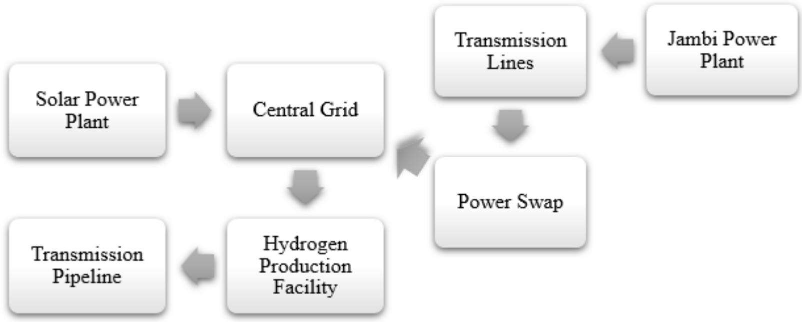

Figure 4 Propose System Diagram

Subsystem Descriptions:

1. Energy Generation Subsystem:
   - Components: Consists of geothermal wells and solar panel arrays.
   - Functionality: Captures and converts natural resources into electrical energy.
   - Output Variability: Outputs are subject to environmental conditions, requiring robust forecasting and management tools.
2. Energy Transmission Subsystem:
   - Components: Includes transmission lines, substations, and transformers.
   - Functionality: Transports electricity from generation sites to the hydrogen plant and into the local grid.
   - Challenges: Must handle variable energy flows without significant losses.
3. Hydrogen Production Subsystem:
   - Components: Comprises electrolyzers that split water into hydrogen and oxygen.
   - Functionality: Consumes significant amounts of electricity; efficiency is critical to overall sustainability.
   - Energy Demand: Designed to adjust operation rates based on energy availability from renewable sources.
4. Power Swap Management Subsystem:
   - Components: Involves smart grid technologies and software for managing energy credits and real-time energy exchange.

- Functionality: Balances energy supply and demand between the grid and the hydrogen plant, smoothing out intermittencies.
- Strategy: Uses predictive analytics to anticipate energy surpluses or deficits.

RESULT AND DISCUSSION

A. Results

The reliability assessment of the hydrogen plant's power supply system, integrating geothermal and solar energy sources with a power swap mechanism, demonstrated high operational stability under modeled scenarios. The simulations revealed:

1. The probability of failure for geothermal power generation was consistently low due to the stable nature of geothermal energy. The capacity factor was observed at an average of 85%, with minimal fluctuations.
2. Solar power generation showed higher variability due to weather-dependent factors. The daily Global Horizontal Irradiance (GHI) averaged 4.56 kWh/m², which supports an average operational efficiency of 20.3% for photovoltaic modules. However, peak-hour performance ensured sufficient energy production to balance the grid during daytime operations.

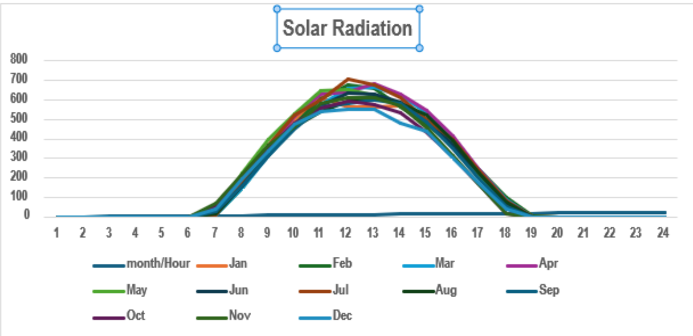

Figure 5 Solar Radiation in Kuala Tungkal

$$Capacity = \frac{\text{Eo}}{\text{PSH x } \eta\text{mod x Cf x } \eta\text{sm}}$$

$$Capacity = \frac{2472\ MWh/day}{4{,}56 \text{ x } 0{,}203 \text{ x } 0{,}93 \text{ x } 0{,}85}$$
$$= 3378{,}2MW \sim 3379MW$$

Solar PV Plants need 3379 MW

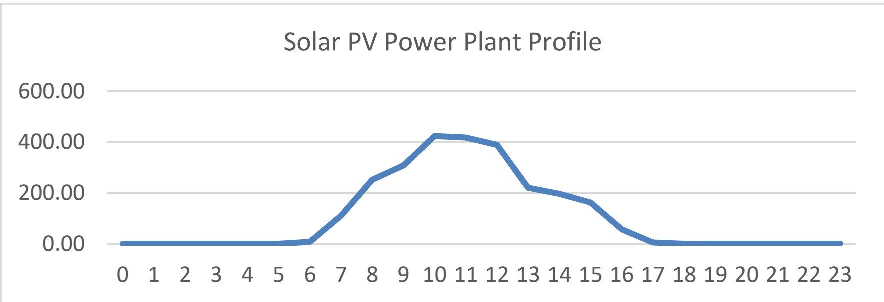

Figure 6 Solar PV Production Profile in Kuala Tungkal

3. The power swap system effectively mitigated energy supply gaps during peak demand periods, particularly at night when solar power was unavailable. By utilizing grid-based power from PLN during these times, the system maintained a balanced energy flow.

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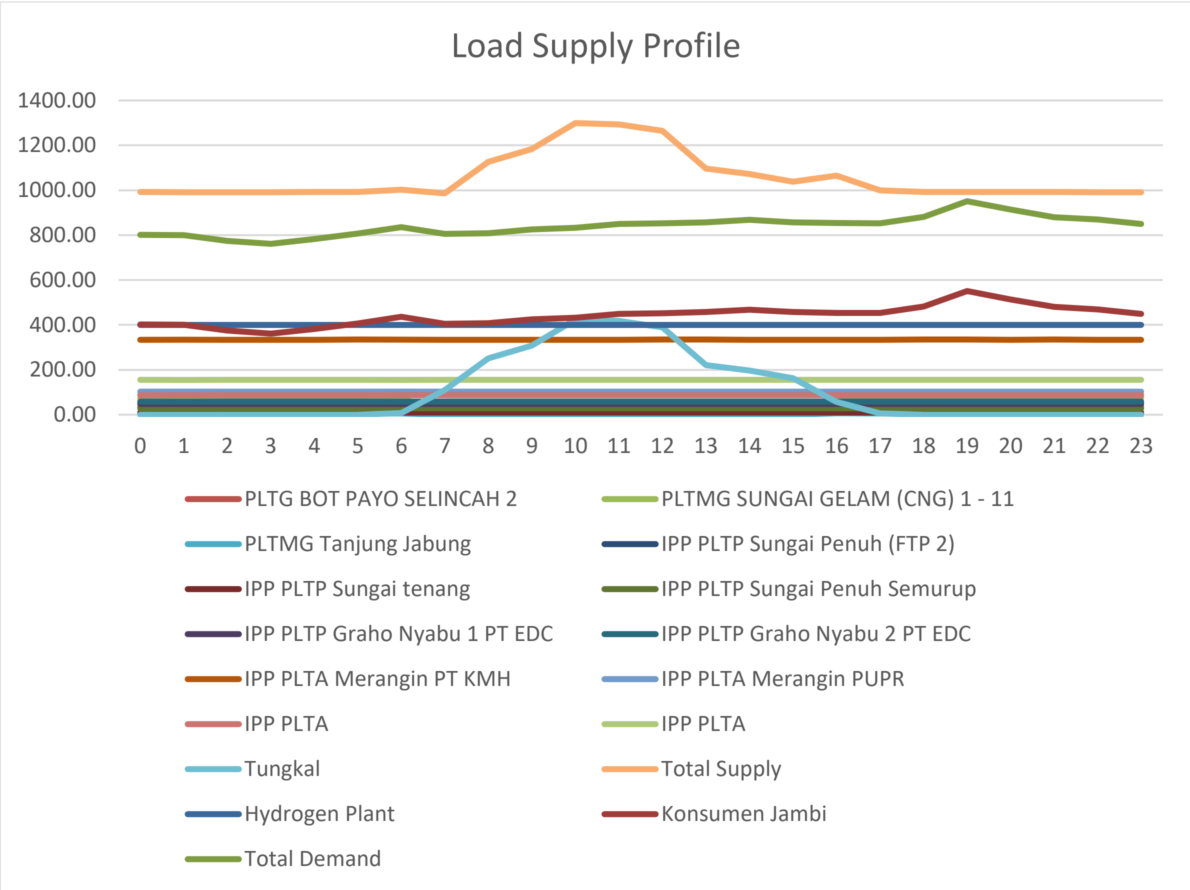

Figure 7 Load and Supply Profile in Jambi Province

The integration of renewable energy sources presented specific risks, including:

- Solar energy's dependency on weather conditions created challenges in maintaining a continuous energy supply. Probabilistic models indicated a 15% chance of energy shortfalls during periods of prolonged cloud cover.
- Existing power transmission infrastructure required upgrades to handle increased loads and fluctuations. Simulation data highlighted a 10% probability of transmission losses exceeding 5% under peak load conditions.
- The failure probability for critical components, such as inverters and transformers, was modeled at 7% annually, emphasizing the need for robust maintenance protocols.

Energy Production Metrics

Using Panasonic N340 photovoltaic modules, the solar power plant (PLTS) achieved a peak capacity of 3,379 MWp. The daily energy output was calculated as:

- Total Daily Energy Production: 2,472 MWh.
- Land Area Required: 1,660 hectares for module installation.

Geothermal power production consistently supplied 297 MW to the grid, covering a significant portion of the hydrogen plant's 300 MW demand.

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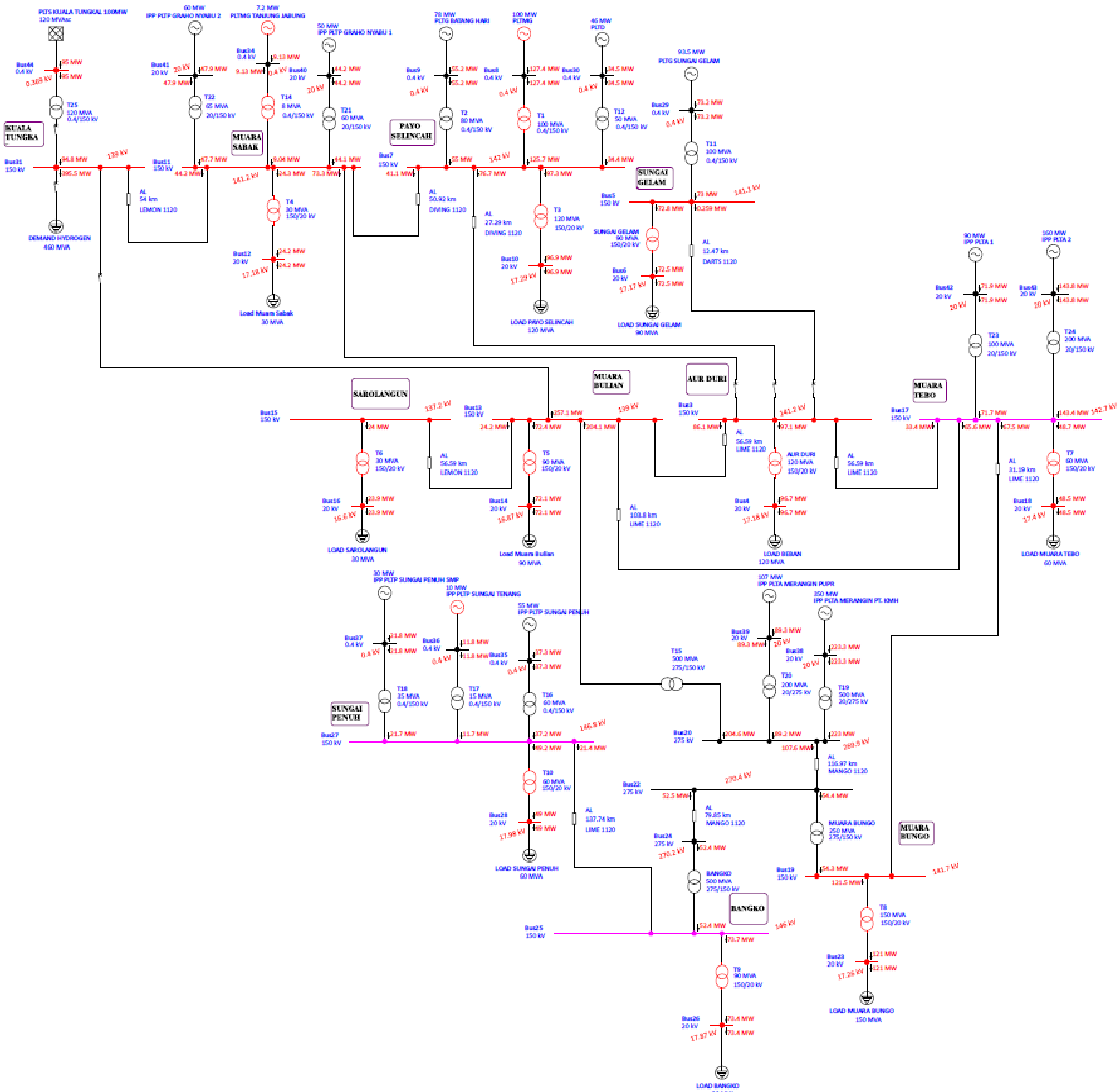

Figure 8 Load Flow Analysis

Hydrogen Production Efficiency

The electrolyzer's operation achieved an efficiency of 70%, translating to a hydrogen production rate of approximately 7,112 kg/hour under optimal conditions. This efficiency aligns with global standards for green hydrogen production and ensures minimal energy wastage.

Financial Feasibility

The cost analysis for integrating renewable energy sources and implementing a power swap system revealed:

- The use of renewable energy reduced reliance on fossil fuels, lowering operational costs by 15%.

- The projected ROI for the system, including infrastructure upgrades and renewable energy installations, was calculated at 8 years, based on current energy prices and demand forecasts.

B. Discussion

Integration Challenges

The findings underscore the technical and operational challenges of integrating intermittent renewable energy sources with continuous-demand systems like hydrogen production. While geothermal energy provided a stable baseline, the reliance on solar energy necessitated advanced predictive models and real-time grid management to mitigate variability.

Power Swap System as a Mitigation Strategy

The power swap mechanism proved effective in balancing energy supply and demand. By leveraging grid-based energy during low renewable output periods, the hydrogen plant avoided operational downtimes. However, the system's reliance on PLN grid stability highlights the need for strengthened grid infrastructure.

Sustainability Implications

The production of green hydrogen using renewable energy aligns with Indonesia’s carbon reduction goals. By repurposing existing gas pipeline infrastructure for hydrogen transport, the project also maximizes resource utilization, reducing the environmental footprint of new developments.

The research concludes that the integration of renewable energy sources, supported by a robust power swap system, presents a viable solution for sustainable hydrogen production in Indonesia. However, addressing infrastructure and variability challenges will be critical to realizing the full potential of this approach.

CONCLUSION AND RECOMMENDATION

E. Conclusion

This research has demonstrated that the integration of renewable energy sources, specifically geothermal and solar power, with a power swap mechanism is a feasible and effective solution for sustainable hydrogen production in Sumatra. Key findings include:

1. Geothermal energy’s stability and the strategic use of solar power during peak production hours ensure a consistent energy supply for hydrogen electrolysis.
2. The power swap mechanism effectively addresses the intermittency of renewable sources, maintaining operational stability and minimizing supply disruptions.
3. Renewable energy integration reduces reliance on fossil fuels, offering long-term cost savings and a favorable return on investment.
4. Green hydrogen production supports Indonesia’s carbon reduction goals and promotes the efficient use of existing infrastructure.

Despite these successes, challenges such as infrastructure limitations, renewable energy variability, and component failure risks remain critical areas for improvement.

F. Recommendations

1. Upgrade transmission and distribution systems to accommodate higher renewable energy loads and mitigate power losses.
2. Implement battery storage systems to store surplus solar energy for use during low production periods, ensuring a stable power supply.
3. Utilize advanced predictive analytics and IoT-based monitoring systems to anticipate energy fluctuations and manage maintenance proactively.
4. Work with government agencies to develop policies that incentivize renewable energy adoption and provide financial support for infrastructure upgrades.
5. Encourage collaboration between public institutions and private sectors to share resources, expertise, and investments in renewable energy projects.

By addressing these recommendations, Indonesia can optimize the potential of renewable energy for hydrogen production, enhancing both energy sustainability and economic growth in the region.

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