**A RESILIENCY MODEL FOR RENEWABLE ENERGY SYSTEMS AGAINST EXTREME NETWORK GRID STRESS: THE 2020 COVID-19 PANDEMIC IN MINDANAO**

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**Abstract**

The COVID-19 pandemic has highlighted critical vulnerabilities in global power systems, particularly in regions like Mindanao, Philippines. This study aims to develop a comprehensive resiliency model for renewable energy (RE) systems by leveraging existing power system metrics in Mindanao. The model is structured into four profiles: energy balance, energy mix, cost, and reliability, each representing various aspects of the power system's performance before and during the pandemic. The findings reveal that the energy balance and energy mix profiles experienced slight impacts due to reduced demand and pre-pandemic planning, achieving resiliency scores of 16.33/18 and 13.5/18, respectively. The cost profile remained unaffected with a perfect resiliency score of 6/6, attributed to pre-pandemic power purchase agreements, while the reliability profile showed minimal disruption with a score of 4.67/6. Overall, the study achieved an aggregate resiliency score of 40.5/48, indicating that the Mindanao power system maintained stable operations during the pandemic. The research successfully incorporated RE performance into the resiliency model, though it acknowledges the model's limitations and suggests the inclusion of additional metrics for further refinement. This study contributes valuable insights into enhancing power system resilience, particularly in developing regions, amid unprecedented global challenges.

**Keywords**: Power System Resilience, Renewable Energy, COVID-19 Pandemic, Mindanao Energy Grid, Resiliency Metrics

1. **INTRODUCTION**

The power sector is a cornerstone of modern economies, providing essential energy to industries, services, and households. Its role becomes even more critical during crises, such as the COVID-19 pandemic, which underscored the need for a reliable and resilient power infrastructure. The pandemic accelerated existing trends, reshaping both business and societal interactions while revealing vulnerabilities in the Philippines' power market [1]. The Department of Energy (DOE) reported significant reductions in electricity demand across the country during the pandemic—30% in Luzon, 17% in Visayas, and 25% in Mindanao—reflecting the impact of lockdown measures on industrial and commercial activities, contrasted with increased residential consumption [2]. These fluctuations in electricity demand are illustrated in Figure 1, which shows the demand-supply situation in Mindanao during the pandemic.

Figure 1 Mindanao Demand-Supply Situation Timeline

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However, the challenges presented by the pandemic extend beyond demand fluctuations. The necessity for flexible power systems that can adapt to sudden changes in demand and supply has become increasingly apparent. Traditional power systems, designed for stability under predictable conditions, struggled to cope with the sudden shifts caused by lockdowns and other pandemic-related disruptions [3]. Flexibility in power generation, transmission, and distribution is essential to mitigate these challenges and to ensure continuous power delivery across varying timescales [4], [5]. The types of power interruptions and their causes during the pandemic period, such as system failures and transient faults, are depicted in Figure 2, highlighting the range of issues that the current infrastructure needs to address.

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Figure 2 Mindanao Power Interruptions (March 18 - July 31, 2020)

The need for a resilient power system in Mindanao is particularly pressing. The region has faced numerous power interruptions, with causes ranging from system failures and transient faults to external factors such as vegetation and wildlife [6]. These interruptions underscore the importance of developing a robust resilience model that can account for such disruptions and ensure reliable power supply under both normal and crisis conditions.

*Problem Statement*

The COVID-19 pandemic has exposed significant weaknesses in the power systems of many regions, including Mindanao. The increased demand for electricity, driven by factors such as urbanization, industrialization, and the automation of production processes, combined with the growing importance of uninterrupted power for digital communication, highlights the need for a resilient and adaptable power system. The current power infrastructure, however, is not fully equipped to handle such disruptions, leading to productivity losses and long-term economic consequences [2], [6]. Figure 3 provides an overview of the types of losses incurred by end-users during power outages, emphasizing the broader economic impact.

A diagram of a power supply system

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Figure 3 Types of Losses Incurred During Power Outages by End-User

*Literature Review and Proposed Solution*

The concept of power system resilience is relatively nascent, emerging from the recognition that traditional reliability metrics do not fully capture the impacts of low-frequency, high-impact events such as those seen during the COVID-19 pandemic [12], [10]. Resilience, distinct from reliability, is defined as the ability of the power system to recover from such significant disruptions. As outlined by Raoufi et al., resilience models should be comprehensive, considering spatial-temporal effects, decision-making utility, and the differentiation between operational and infrastructural resilience [10]. However, the application of these models in the context of developing regions like Mindanao, particularly during an unprecedented global health crisis, remains underexplored.

Existing literature highlights several gaps in resilience research, particularly in the integration of renewable energy sources into resilience models. Denholm and Hand, as well as Cochran et al., emphasize the importance of flexibility in power systems, which includes the ability to respond to changes in net load, incorporating renewable energy, and adjusting to unforeseen conditions [10], [9]. However, many existing models do not adequately address the unique challenges posed by renewable energy variability and the specific socio-economic conditions of regions like Mindanao [8], [11]. Furthermore, traditional reliability metrics such as SAIFI, SAIDI, and MAIFI, though useful, fall short in capturing the full scope of resilience needed for modern power systems [7], [13].

This study proposes developing a power system resilience model specifically tailored to the Mindanao electricity grid. By integrating resilience metrics with an emphasis on renewable energy performance, the model seeks to enhance the flexibility and robustness of the region's power infrastructure. This approach fills the gap in existing literature and provides a practical framework for addressing the unique challenges faced by the power sector in Mindanao during crises such as the COVID-19 pandemic.

*Innovation and New Value of Research*

The research introduces a novel resilience model that incorporates both traditional reliability metrics and new resilience metrics tailored to the specific conditions and challenges of the Mindanao power sector. Unlike existing models, which primarily focus on developed regions with more stable power infrastructures, this model is designed to address the complexities of a developing region with a high reliance on renewable energy sources. The model’s novelty lies in its comprehensive approach, which includes the integration of spatial-temporal resilience metrics, considering renewable energy variability, and applying these metrics in real-time decision-making processes during crises.

This model provides critical insights for policymakers and industry stakeholders, offering a framework for improving power system resilience in Mindanao and other regions facing similar challenges. The findings will contribute to the broader field of power systems engineering by offering practical solutions that address the vulnerabilities exposed by the pandemic, ultimately enhancing the reliability and sustainability of power systems in the Philippines and beyond.

1. **METHOD**

**2.1 Conceptual Framework**

The conceptual framework guiding the development of the resiliency model is depicted in Figure 3.1. The primary inputs for the resiliency model were derived from reports maintained by the Department of Energy (DOE), National Grid Corporation of the Philippines (NGCP), and Energy Regulatory Commission (ERC). Expert consultations were also conducted to gain additional insights. The outputs of the resiliency model include the following profiles: energy balance, energy mix, cost, and reliability. These components are integral to the resiliency model, acknowledging that the concept of resiliency is relatively new in the power system. Therefore, the model heavily relies on existing power system metrics [10].

A diagram of a resilience model

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Figure 4 Conceptual framework of the study.

**2.2 Information Sources**

The study relies on data sourced from the Department of Energy (DOE), National Grid Corporation of the Philippines (NGCP), and the Energy Regulatory Commission (ERC). These sources provided key metrics including:

1. Energy Delivery: Total electric energy consumed (MWh).
2. Peak Demand: Highest demand periods (MW).
3. Power Supply-Demand Scenario: Rated and available capacity, peak demand, and reserves (MW).
4. Generation per Fuel Type: MWh generated by coal, oil, geothermal, hydroelectric, solar, and biomass.
5. Conventional-vs-Renewable Generation: Comparative data on conventional and renewable energy.
6. Capacity per Fuel Type: Rated capacity for different energy sources (MW).
7. Average Distribution Rates: Cost of electricity across regions (₱/kWh).
8. Reliability Indices: SAIFI, SAIDI, and MAIFI metrics for distribution utilities.

Table 1 summarizes these information sources, emphasizing their relevance to developing a resiliency model.

|  |  |
| --- | --- |
| Information | Source |
| Energy Delivery | NGCP Operations (open-source data) |
| Peak Demand | NGCP Operations (open-source data) |
| Power Supply-Demand Scenario | Department of Energy |
| Generation per Fuel Type | Department of Energy |
| Conventional-vs-Renewable Generation | Department of Energy |
| Capacity per Fuel Type | Department of Energy |
| Average Distribution Rates | Mindanao Rates (DOE) |
| Reliability Indices | Mindanao Reliability Indices Summary (ERC) |

Due to time and scope limitations, not all data could be obtained. However, requests were made through the Freedom of Information (FOI) zx in **Table 3.2**.

Table 1 Data request log from ERC.

|  |  |  |
| --- | --- | --- |
| Data Requested | Date | Tracking Code |
| Quarterly Reliability Report of DUs in Mindanao | 08/04/2020 | #ERC-544467777343 |
| Mindanao Distribution Utilities Reliability Indices for 2020 | 02/25/2021 | #ERC-196965514224 |
| Tolerable Ranges for SAIFI, SAIDI & MAIFI | 02/26/2021 | #ERC-511850592506 |

### 2.3 General Data Handling Procedure

This study utilizes IEEE 1366 standards to measure power system reliability, focusing on SAIFI, SAIDI, and MAIFI indices. These indices assess outage duration and frequency, complemented by data on power interruptions, demand, electricity rates, and generation mix. Secondary data was obtained through interactions with DOE and NGCP management, aimed at enhancing understanding and direct evaluation of the Mindanao Grid's performance.

Data were analyzed quantitatively to characterize trends and summarize key metrics. These were presented through tables, figures, and summary statistics, with year-to-year comparisons before and during the pandemic. The key data points include:

1. Energy Delivery (2015-2020): Trends in energy consumption.
2. Peak Demand (2013-2020): Yearly peak demand analysis.
3. Power Supply-Demand Scenario (2019-2020): Daily granulation to compare pre- and post-pandemic periods.
4. Generation per Fuel Type (2018-2020): Monthly performance analysis by energy source.
5. Conventional vs. Renewable Generation (2018-2020): Comparison of generation sources.
6. Average Distribution Rates (2016-2020): Regional distribution rates with confidentiality preserved.
7. Reliability Indices: Analysis by Distribution Utility (DU), considering unique circumstances affecting reliability.

### 2.4 Key Informant Interview

### A consultation with ASec. Redentor Delola from the Department of Energy centered on the rationale for using existing reliability metrics within the resiliency model. It was noted that reliability metrics such as Loss of Load Expectation (LOLE), Loss of Load Frequency (LOLF), and Loss of Load Probability (LOLP) are seldom employed in the Philippines, necessitating reliance on SAIFI, SAIDI, and MAIFI indices. These indices are maintained by the National Grid Corporation of the Philippines (NGCP) and provide a whole-system perspective crucial for reliability evaluations. Additionally, reliability performance in the Philippines is evaluated through a system of incentives, which raises some transparency issues in reporting. This consultation emphasized the utility of existing metrics for capturing the reliability of the power system, reinforcing their role as essential components of the resiliency model in the Mindanao power grid.

### 2.5 Drafting the Resiliency Model

The development of the resiliency model focused on ensuring that resiliency metrics are measurable, comparable, and replicable using real-world power system data. The model must facilitate comparisons between different systems and within a system before and after resilience enhancement to demonstrate the effectiveness of such strategies. The data sources were categorized into four profiles: Energy Balance, Energy Mix, Cost, and Reliability. These profiles encompass key parameters such as energy delivery, peak demand, generation per fuel type, and reliability indices. Each parameter was assessed using predefined tolerance levels as shown in table 3.3 to determine how the power system's performance during the pandemic deviated from pre-pandemic norms. The overall resiliency score was calculated based on these assessments, providing a practical and replicable framework for evaluating resiliency in future scenarios and similar power systems.

Table 2 Measure of resiliency as a function of percent tolerance.

|  |  |
| --- | --- |
| Tolerance Levels | Resiliency Points |
| ± 1-5% | 6 |
| ± 6-10% | 5 |
| ± 11-15% | 4 |
| ± 16-20% | 3 |
| ± 21-25% | 2 |
| ± 26-30% | 1 |
| > ± 30% | 0 |

1. **RESULTS AND DISCUSSION**

**3.1 RE Resiliency Model**

The resiliency model for renewable energy systems in Mindanao was developed to address the core objectives of the study: assessing how energy balance, energy mix, cost, and reliability performed under the stress of the COVID-19 pandemic (Figure 5). These profiles provide a comprehensive view of the system’s ability to absorb, adapt, and recover from disruptions. By focusing on key system performance metrics, the model fills a critical gap in understanding how renewable energy systems respond to extreme events, especially when compared to conventional energy systems.

A diagram of a company's re resilience metrics

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Figure 5 Resiliency Model for Renewable Energy in Mindanao

**3.2 Energy Balance Profile**

One of the key objectives of the study is to evaluate how well Mindanao's energy system managed supply and demand under the pandemic. The energy balance profile plays a crucial role in this by examining energy delivery, peak demand, and the overall supply-demand scenario.

**3.2.1 Energy Delivery**

From 2015 to 2019, energy delivery steadily increased, indicating an expansion of energy consumption driven by economic growth. However, the dip in 2017 due to the Marawi Siege demonstrates the system's vulnerability to local conflicts (Figure 6). In 2020, the energy delivery became erratic due to the pandemic-induced lockdowns, most notably in April, when energy demand dropped sharply (Figure 7). As restrictions eased, energy demand began to recover by August, signaling an adaptive response by the energy system.

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Figure 6 Energy delivery for Mindanao from 2015 to present

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Figure 7 Energy delivery for Davao Region from 2015 to present

These results align with the objective of evaluating the system's performance during extreme events like the pandemic. The dip in energy demand during the lockdown underscores the system's exposure to sudden shocks, but the quick recovery highlights its resilience. This fills a knowledge gap in understanding how rapidly a power system reliant on both conventional and renewable sources can recover from such disruptions.

**3.2.2 Peak Demand**

Peak demand patterns typically reflect economic and seasonal activities. In 2020, an unusual peak was recorded in February, right before the lockdown, followed by a steep decline in demand during the quarantine period, with recovery by May (Table 5, Figure 8). This deviation from typical patterns illustrates the immediate economic impact of the pandemic on energy consumption.

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Table 5 Peak demand in Mindanao from 2013-2020.

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Figure 8 Peak demand trends in Mindanao from 2013-2020

The observed fluctuations in peak demand are significant in addressing the study's objective of understanding the resiliency of energy systems under stress. The sharp decline followed by recovery highlights both the vulnerabilities and strengths of the system. It demonstrates that while demand dropped, the infrastructure remained stable, ready to ramp up again once economic activities resumed. This insight addresses the gap in assessing how peak demand impacts resiliency during unprecedented events.

**3.2.3 Power Supply-Demand Scenario**

In 2020, despite the pandemic, Mindanao’s power supply remained stable, with sufficient capacity to meet demand (Figure 9). The dip in peak demand during the Enhanced Community Quarantine (ECQ) did not significantly affect the overall system performance, as gross reserves remained available.

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Figure 9 Power supply-demand scenario in Mindanao from 2019-2020

This scenario addresses the objective of assessing the system's ability to maintain equilibrium between supply and demand under extreme conditions. The stability of supply despite a drop in demand suggests that pre-pandemic regulations and protocols played a key role in sustaining system performance. This finding helps fill the gap in understanding the power system’s preparedness for maintaining service continuity in times of crisis.

**3.3 Energy Mix Profile**

Another core objective of the study is to analyze how Mindanao’s energy mix, particularly the balance between conventional and renewable sources, contributed to the system’s resiliency during the pandemic.

**3.3.1 Generation per Fuel Type**

Coal generation remained dominant from 2018 to 2020, increasing even during the pandemic. However, renewable sources such as geothermal and hydroelectric power declined, while solar and biomass showed modest gains (Figure 10).

A graph of energy consumption

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Figure 10 Generation per fuel type in Mindanao from 2018 to 2020

The continued dominance of coal suggests that Mindanao's energy system is heavily reliant on conventional energy, which may limit the system’s flexibility. The decrease in renewable energy generation during the pandemic underscores the challenges renewable sources face in scaling up during times of economic or supply disruptions. This finding addresses the gap in literature regarding the adaptability of renewable energy in times of crisis.

**3.3.2 Conventional vs. Renewable Generation**

The comparison between conventional and renewable energy sources reveals that while coal and oil-based generation remained stable, renewable energy struggled to maintain its pre-pandemic levels (Figure 11).

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Figure 11 Generation comparison between conventional and renewable energy sources in Mindanao from 2018-2020

This section addresses the objective of understanding how the energy mix impacts resiliency. The decline in renewable generation during the pandemic suggests that while renewable energy is a crucial component of the energy transition, it is still vulnerable to external shocks. These insights are critical for shaping future strategies aimed at increasing the resiliency of renewable energy systems.

**3.3.3 Capacity per Fuel Type**

Coal remained the primary energy source, with its capacity increasing between 2019 and 2020. Renewable energy capacity showed only marginal growth during the same period (Figure 11).

A graph of different types of energy

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Figure 11 Capacity per fuel type in Mindanao

The reliance on coal capacity to meet the region’s energy needs suggests limited diversification in energy infrastructure. This addresses the gap in the literature related to energy infrastructure resilience, highlighting the need for greater investment in renewable capacity to mitigate risks associated with over-reliance on fossil fuels.

**3.4Cost Profile**

One of the study’s objectives is to analyze the cost implications of energy resiliency during the pandemic. Despite economic disruptions, distribution rates remained stable due to long-term power purchase agreements (Figure 12).

A graph of numbers and a number of different colored bars

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Figure 12 Average distribution rates (PhP/kWh) in Mindanao per region

The stability of distribution rates during the pandemic suggests that Mindanao’s power system was financially insulated from short-term price fluctuations. This finding contributes to addressing the gap in understanding the economic resiliency of power systems during crises and highlights the importance of stable long-term contracts in maintaining financial sustainability.

**3.5 Reliability Profile**

System reliability, as measured by SAIFI, SAIDI, and MAIFI indices, improved from 2015 to 2020, indicating enhanced system resilience during the pandemic (Figure 13).

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Figure 13 Reliability indices (average) in Mindanao from 2015-2019

The improvement in reliability indices directly aligns to assess the system’s robustness under stress. The reduction in the frequency and duration of power interruptions during the pandemic is a key indicator of improved resiliency, filling a gap in the literature concerning the relationship between reliability improvements and resiliency during extreme events.

**3.6 Implications for the Resiliency of Renewable Energy During Extreme Events**

The overall resiliency score of 40.5/48 indicates that Mindanao’s power system was able to withstand the challenges posed by the pandemic (Table 6).

Table 6 Summary of effect of Pandemic to the RE resiliency profiles.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RE Resiliency Metric Profiles | Profile Components | Reference (baseline) | Points | Categories |
| Energy Balance profile | energy delivery | 2018-2019 | 6 | Tolerable |
| peak demand | 2013-2019 | 6 | Tolerable |
| power supply-demand scenario | 2019 | 3.67 | Tolerable |
| Energy Mix profile | generation per fuel type | 2018-2019 | 4 | Tolerable |
| conventional vs renewable generation | 2018-2019 | 5.5 | Tolerable |
| capacity per fuel type | 2018-2019 | 4 | Tolerable |
| Cost profile | average distribution rates | 2016-2019 | 6 | Tolerable |
| Reliability profile | reliability indices | 2015-2019 | 3.67 | Tolerable |
|  |  | **TOTAL** | **40.5 / 48** | |

This finding addresses the central research objective of assessing renewable energy resiliency during extreme events. The high resiliency score demonstrates that, while there are areas for improvement (such as increasing renewable energy capacity), the system overall showed strong performance. This insight fills a gap by providing quantifiable evidence of system resiliency during a global crisis.

**3.7 Limitations of the Resiliency Model**

While the resiliency model offers valuable insights, its predictive capabilities are limited, and it does not incorporate future power cost projections or probabilistic metrics such as VOLE, LOLP, and VOLP. The model’s limitations suggest that future iterations should incorporate probabilistic risk metrics and financial forecasts. This will address the gap in understanding how long-term risks and costs might affect the resiliency of renewable energy systems in future crises.

1. **CONCLUSION**

The study successfully developed a resiliency model for the Mindanao power system during the COVID-19 pandemic, utilizing existing performance and reliability metrics. However, these metrics are not specifically designed for resilience, highlighting a gap in dedicated resiliency measures for power systems. Renewable energy (RE) systems demonstrated resilience in terms of generation and capacity during the pandemic, largely due to pre-pandemic planning and existing policies that ensure fair market performance alongside conventional energy systems.

1. **RECOMMENDATIONS**

The study recommends establishing dedicated resiliency metrics for power systems, including renewable energy (RE) systems, to better capture resilience beyond standard reliability measures. Incorporating predictive and probabilistic metrics such as VOLE, LOLP, and VOLP into the existing framework would provide a more comprehensive assessment. Furthermore, extending the study to include power systems across the entire Philippines, particularly in the competitive electricity markets of Luzon and Visayas, could offer broader insights into RE resilience. Additionally, further research is needed to develop a more robust resiliency model for REs, one that considers a wider range of factors, including economic, social, political, safety, and public health impacts. Such research should aim to establish logical correlations between these areas and the power system's resilience, especially in the context of rare events like pandemics.

**ACKNOWLEDGEMENTS**

With deep gratitude, I thank God for His grace and wisdom. I appreciate my family, especially my parents, siblings, and wife, Marigold, for their support. Thanks to my advisers, panel committee, DOE, NGCP, ERC, colleagues, and friends for their invaluable contributions and encouragement throughout this study.

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