AFRICA ELECTRICITY SYMPOSIUM 2025

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ERA

ELECTRICITY REGULATORY AUTHORITY

MINISTRY OF ENERGY AND MINERAL DEVELOPMENT

THE REPUBLIC OF UGANDA

DESIGN AND SIMULATION OF AN AUTOMATIC GENERATION CONTROL SYSTEM FOR REAL TIME POWER BALANCE OF UGANDA'S POWER GRID

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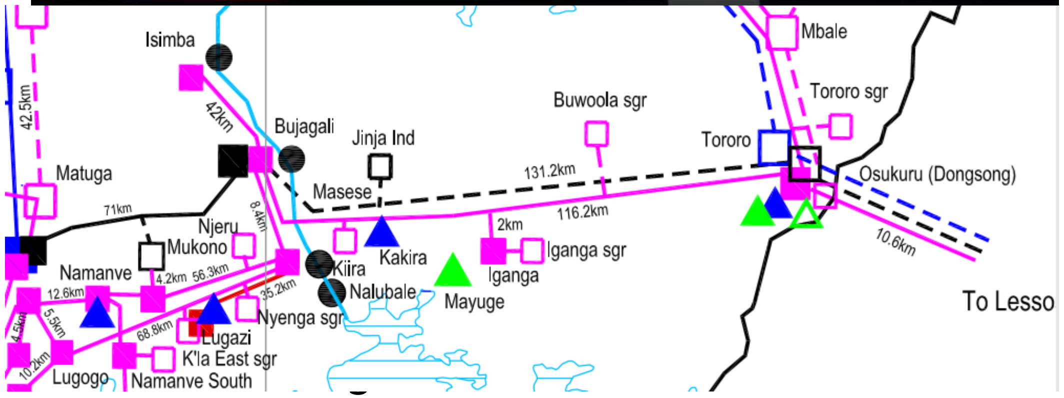
PRESENTATION OUTLINE

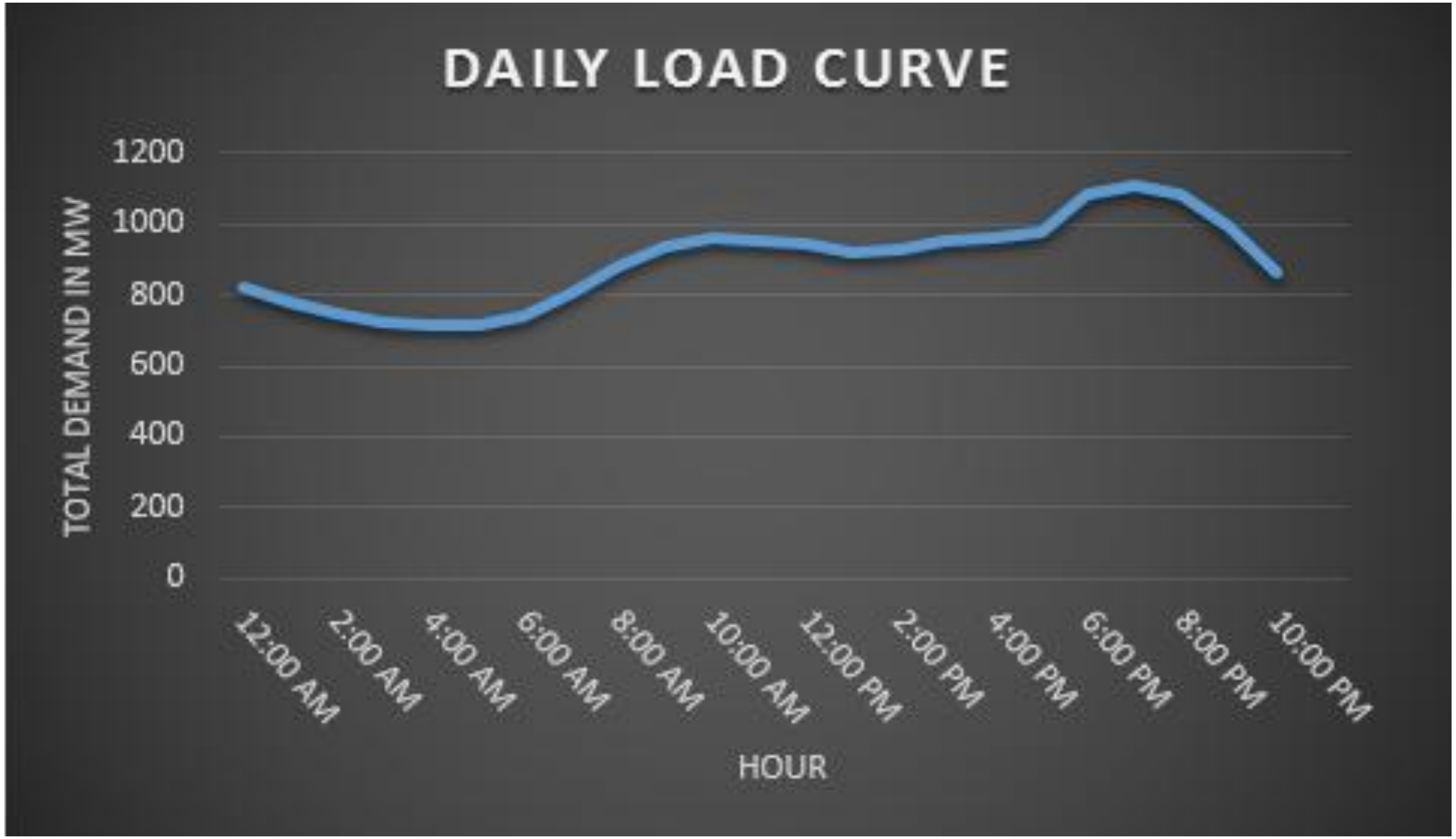
1. Introduction/Background
2. Methodology
3. Results/Findings
4. Technical Analysis
5. Conclusion
6. Recommendation

Introduction/Project Background

- Uganda Electricity Transmission Company Limited (UETCL) manages high-voltage power transmission, grid dispatch, and real-time monitoring and load balancing in Uganda.
- Uganda's grid connects to Kenya's grid via a tie-line, enabling power sharing that requires monitoring [1].
- The grid experiences a lot of instability due to several factors which cause variations in the grid frequency away from the nominal value of 50 Hz [2].



Introduction/Project Background

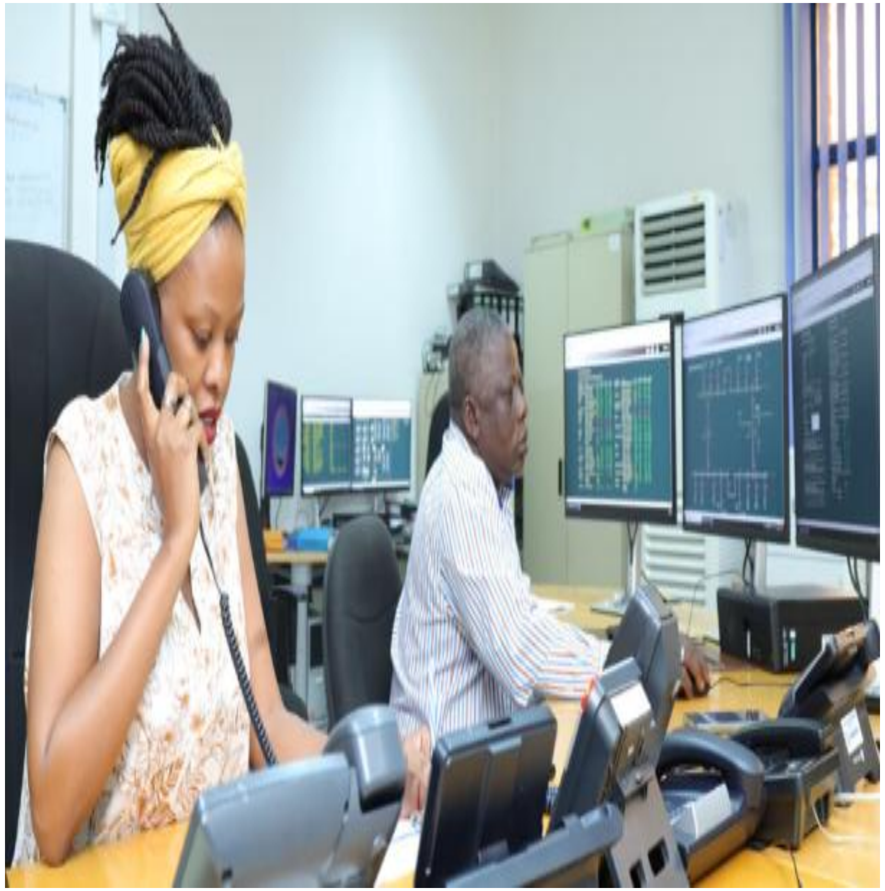


- 2 am to around 6 am
  - base load
- 8 am to around 5 pm
  - intermediate load
- 6 pm to around 9 pm
  - peak load.

The average daily load as of on 14th of May, 2025.

Problem Statement

- The existing operational framework of Uganda's power grid relies heavily on manual processes to balance between generation and load demand.
- This reliance increases human error risks and limits the efficiency and responsiveness to demand-supply fluctuations, increasing instability potential of the grid.
- Additionally, the tie-line interconnections introduce complexities like cross-border flow variability, challenging generation-load balance and frequency stability within the preferred range.



Objectives

Main objective

To design and simulate an Automatic Generation Control (AGC) system for real time power balance on Uganda's power grid.

Specific Objectives

1. To determine the technical requirements essential for integrating the AGC system within Uganda's grid.
2. To develop a design framework for the AGC system tailored to the specific needs of the power grid.
3. To simulate and evaluate the performance of the AGC system.

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Justification and Scope

Justification

- **ERA Vision:** This project addresses generation-demand imbalances and tie-line fluctuations that cause grid frequency deviations from nominal operating range.
- **MEMD Mission:** This project ensures grid stability and efficient power dispatch, enabling sustainable utilization of energy resources.
- **SDG 7 (Affordable and clean energy):** This project automates frequency control, reducing outages and fossil fuel dependence ensuring reliable electricity access.

Scope

- Our study focused on Uganda's power grid as a control area with four largest dispatchable hydropower plants as the generation backbone, incorporated the Kenya tie-line for cross-border power flows and mini power plants.
- Assumptions included accurate load forecasting, responsive governor dynamics, sufficient spinning reserves, reliable transmission network and communication system for effective AGC operation.

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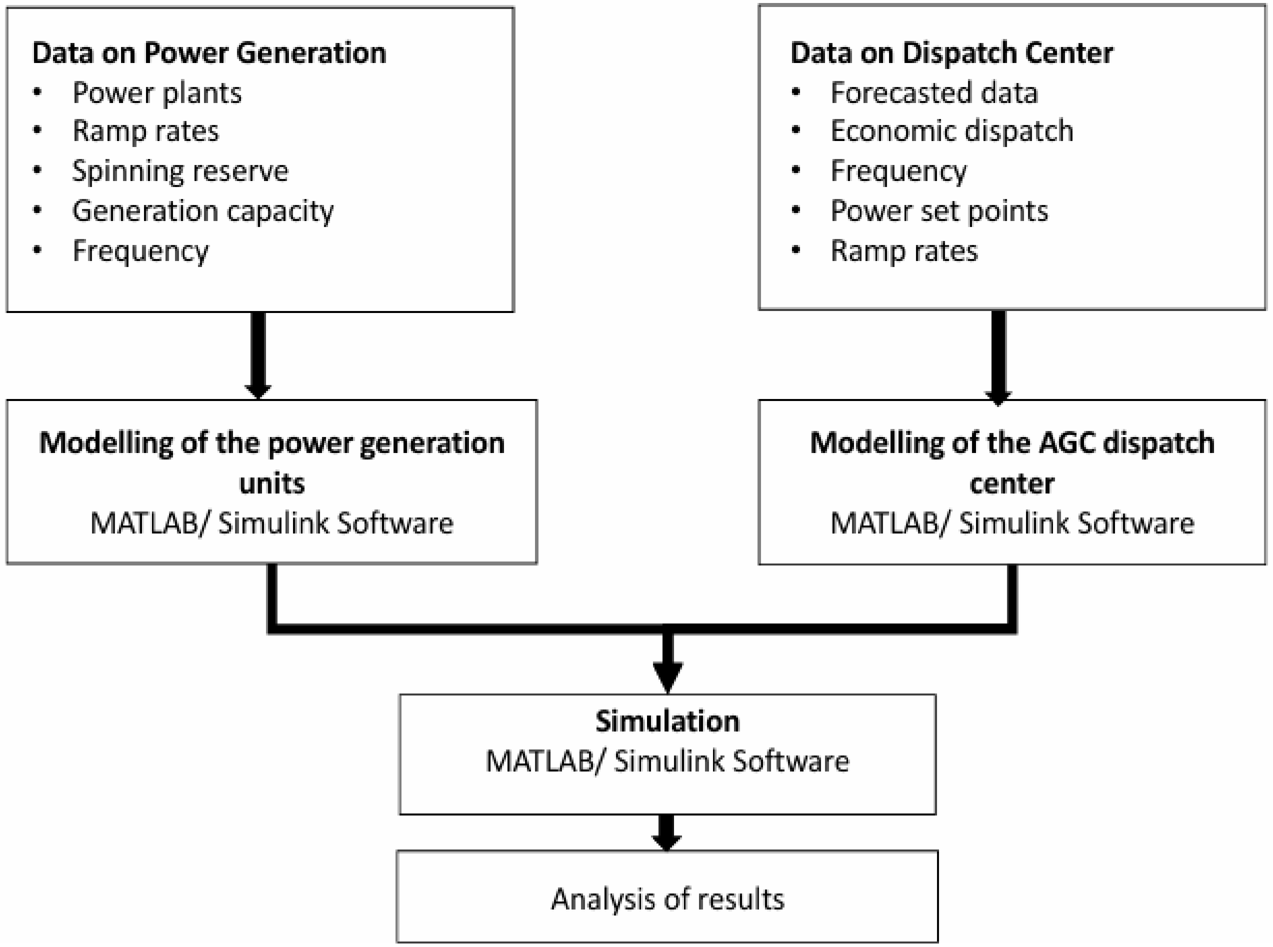
Methodology

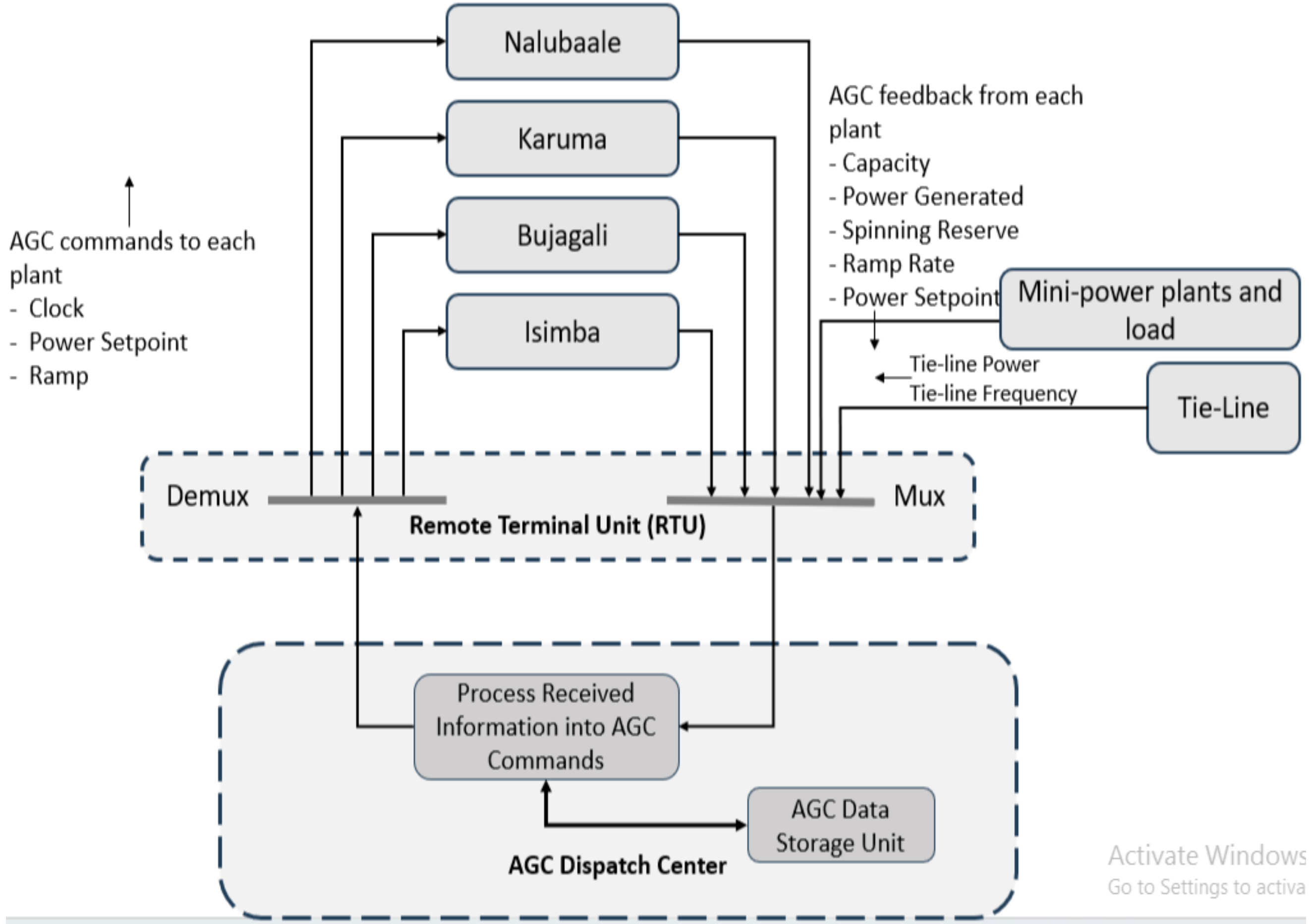
- The first objective was achieved by reviewing past papers and articles and collecting data from NCC and major power plants.
- The second objective was achieved by using MATLAB/Simulink software to model and design the AGC system on Uganda's grid.
- The third objective was achieved by simulating key operational scenarios to evaluate the AGC system's performance under realistic grid conditions.



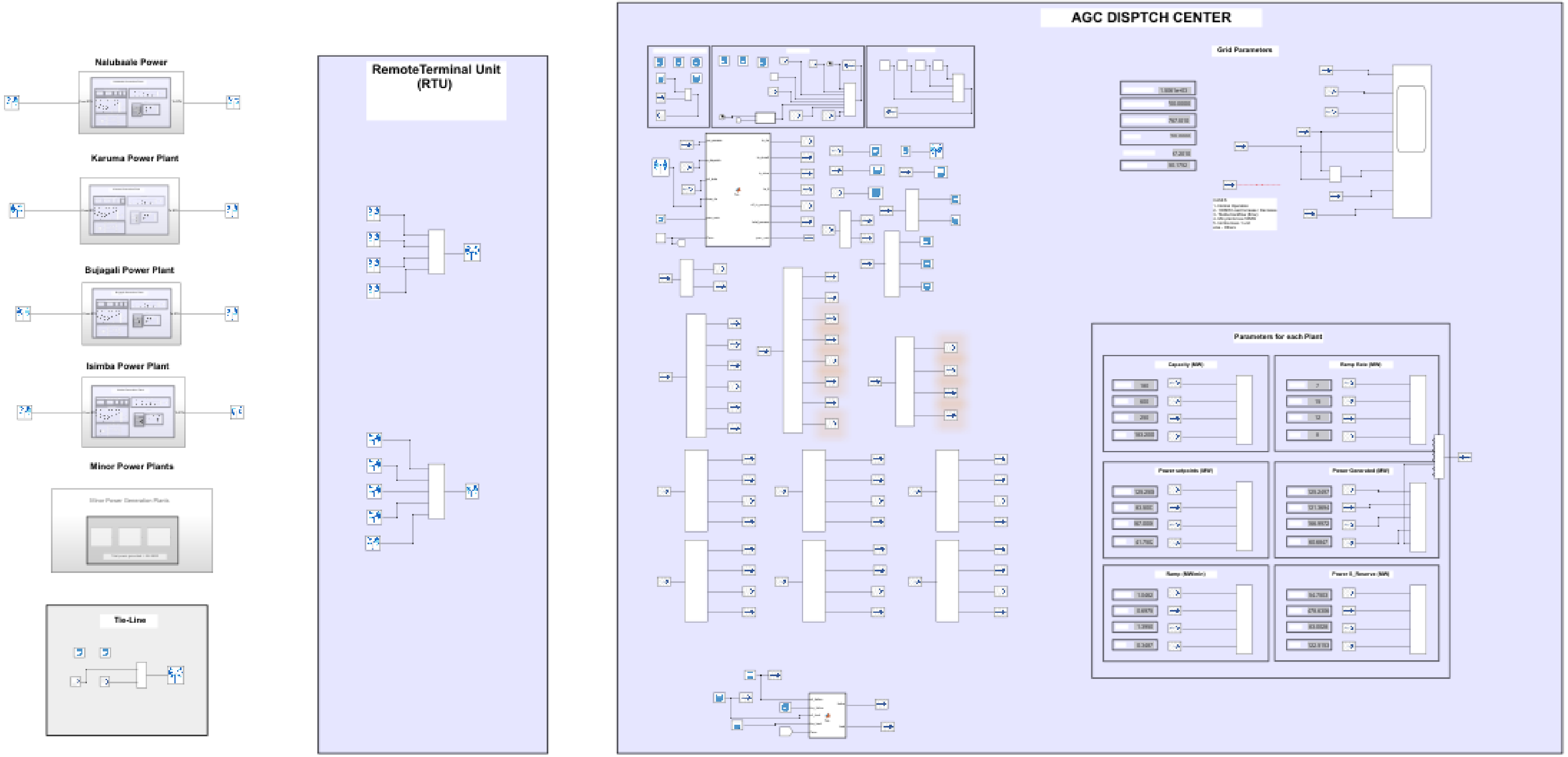
Modeling the Dispatch Operations Framework

Critical Input Data

1. Real-Time Measurements
   - Grid operational frequency
   - Tie-line power flows
   - Real-time generation and load
2. Generator Constraints
   - Generation Capacity
   - Generation unit ramp rates
   - Generation tariff
3. Forecasted Data
   - Load demand (24-hour profile)
   - Scheduled exports



Modelled System with AGC



AGC Mathematical Expressions

$$f = 50\left(\frac{P_t - P_r}{P_r}\right)$$

f is frequency
P_r is total power required
P_t is total power generated

$$\min \sum_{i=1}^{N} C_i P_i$$

N is total number of power generating units in a system
$C_i P_i$ is cost function of the *i*-th generator which represents the cost of producing P_i megawatts (MW) of power.
Subject to;

- Power Purchase Agreement Constraints
- Plant Efficiency Limits
- Grid Constraints

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Model-Based Simulation of AGC

- The AGC system was modeled and simulated under various operational scenarios.
- Key observations included frequency deviations, generator output adjustments, and tie-line power flow dynamics in response to each scenario.

Scenarios include;

1. Normal operation
2. Load decrease or increase
3. Tie line back flow of power
4. Reduction in power output from mini power plants
5. Generator unit trip

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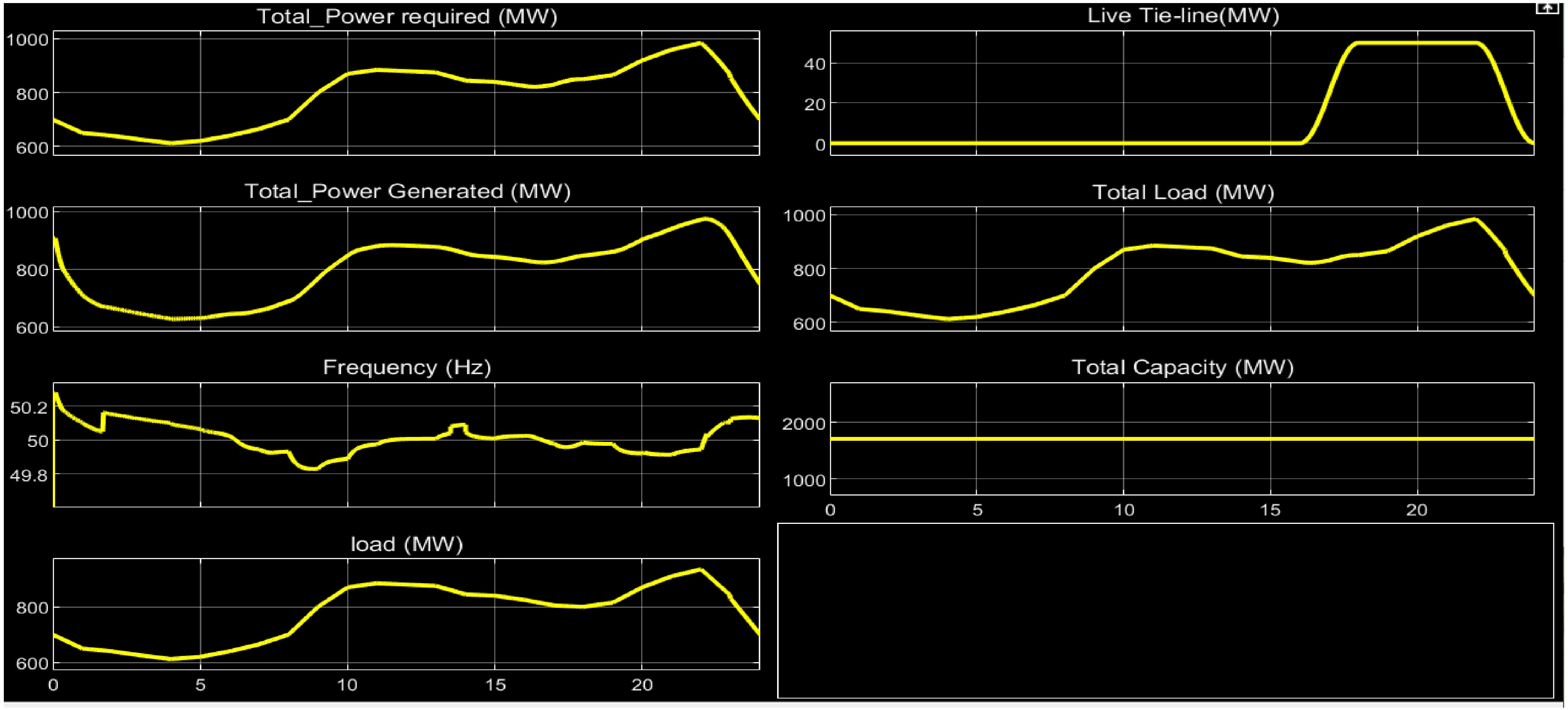
Normal Operation



Under normal operating conditions, the system frequency remains within the nominal range, indicating a stable and balanced power system state.

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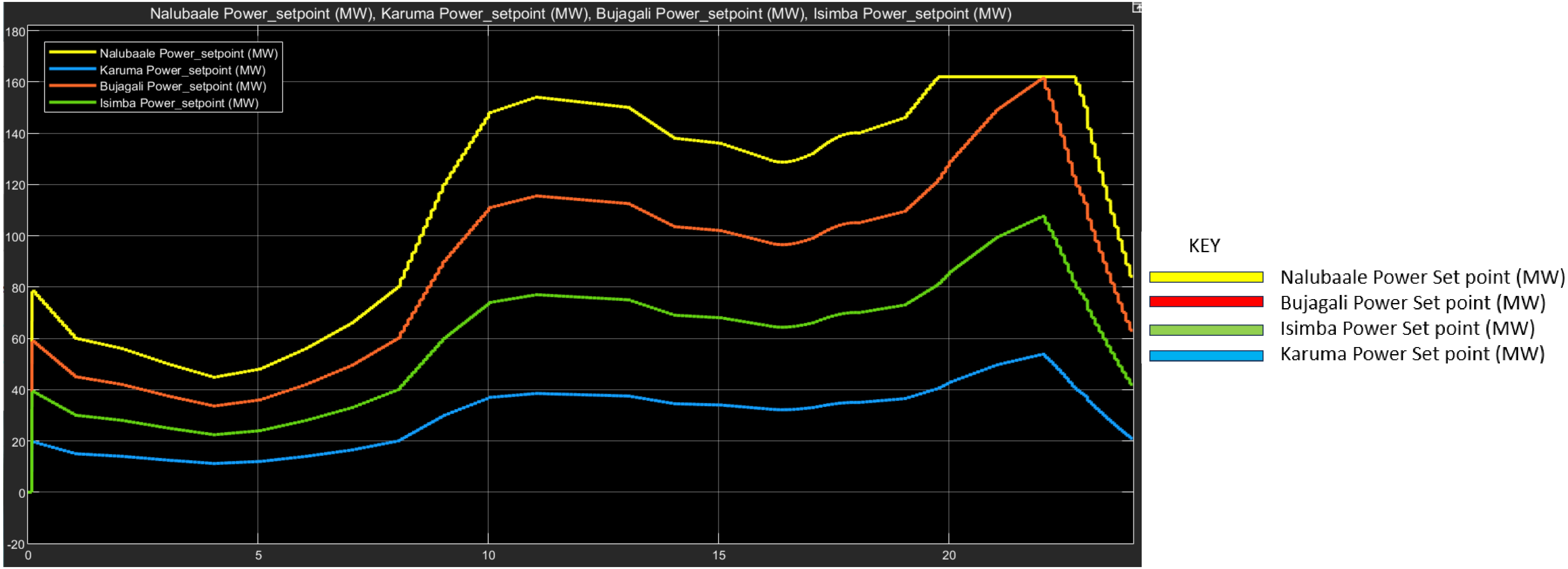
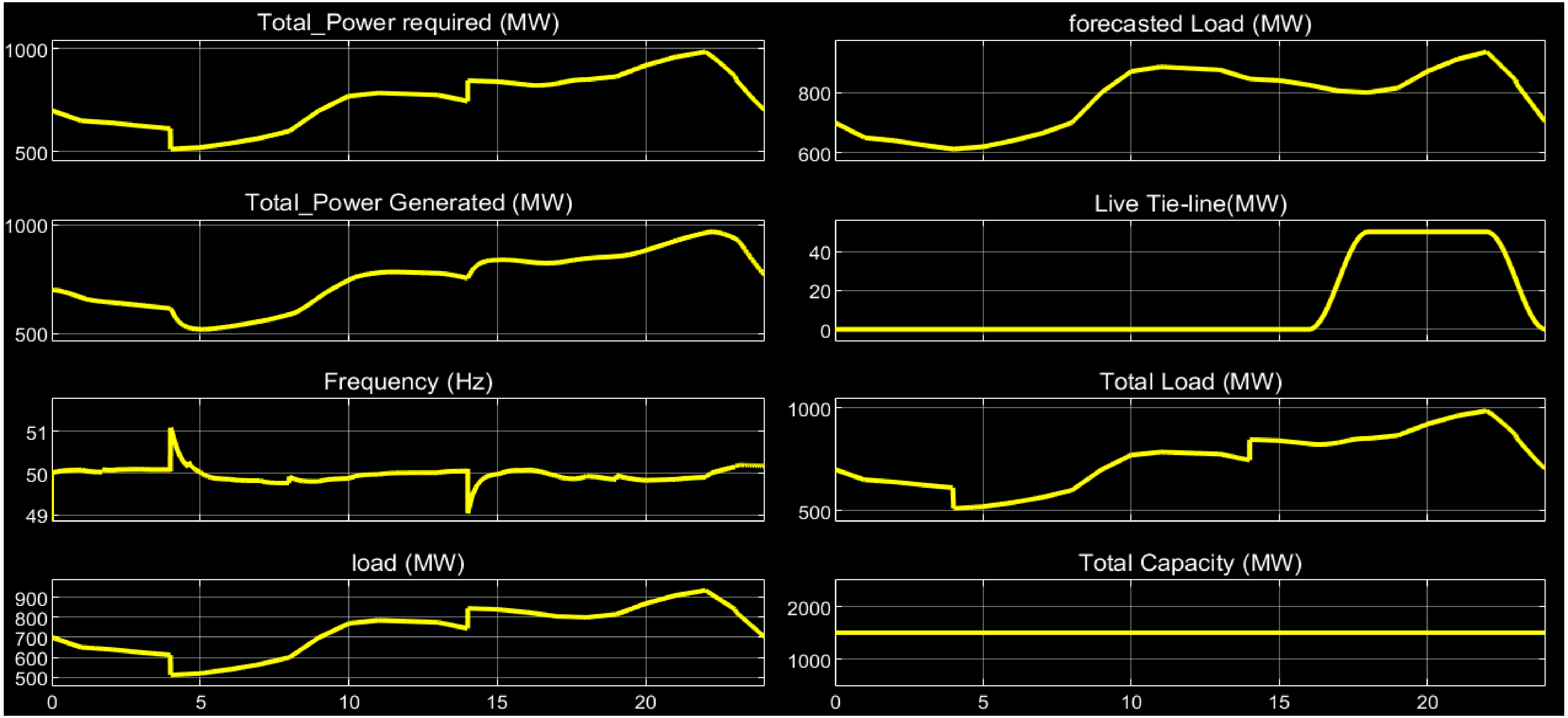
Power Setpoints



- The AGC assigns power set points to different generation units based on spinning reserve available while prioritizing the capacity-dispatched plant.
- Remaining demand is then distributed by economic merit order, dispatching lowest-cost plants first while respecting operational limits.

Load Decrease or Increase



- A 10.48% decrease or increase in system load causes a significant deviation in frequency above and below the desired range respectively.

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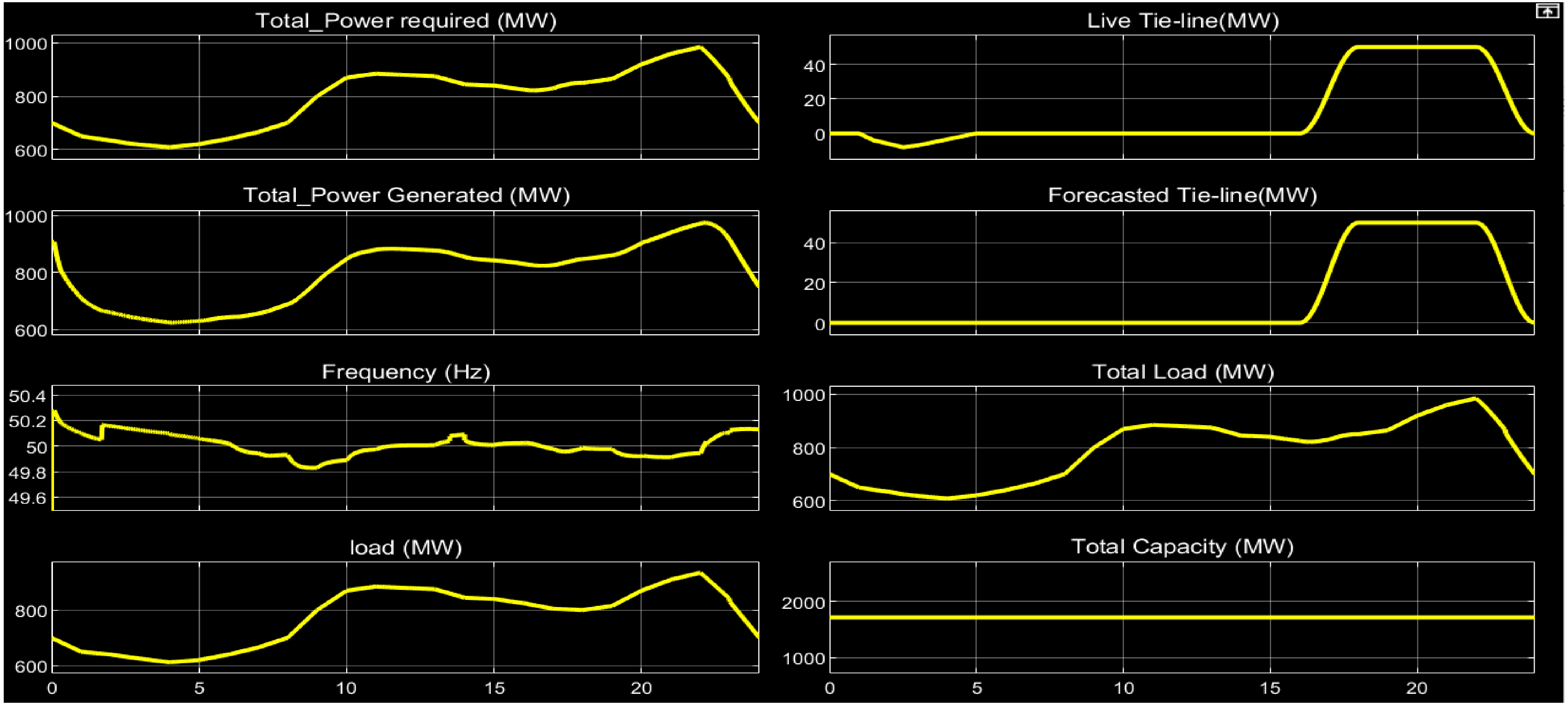
Tie Line Power Back Flow



- For a 16% power backflow from Kenya at t = 2 hours to t = 5 hours, the AGC system calculates the resulting Area Control Error (ACE).

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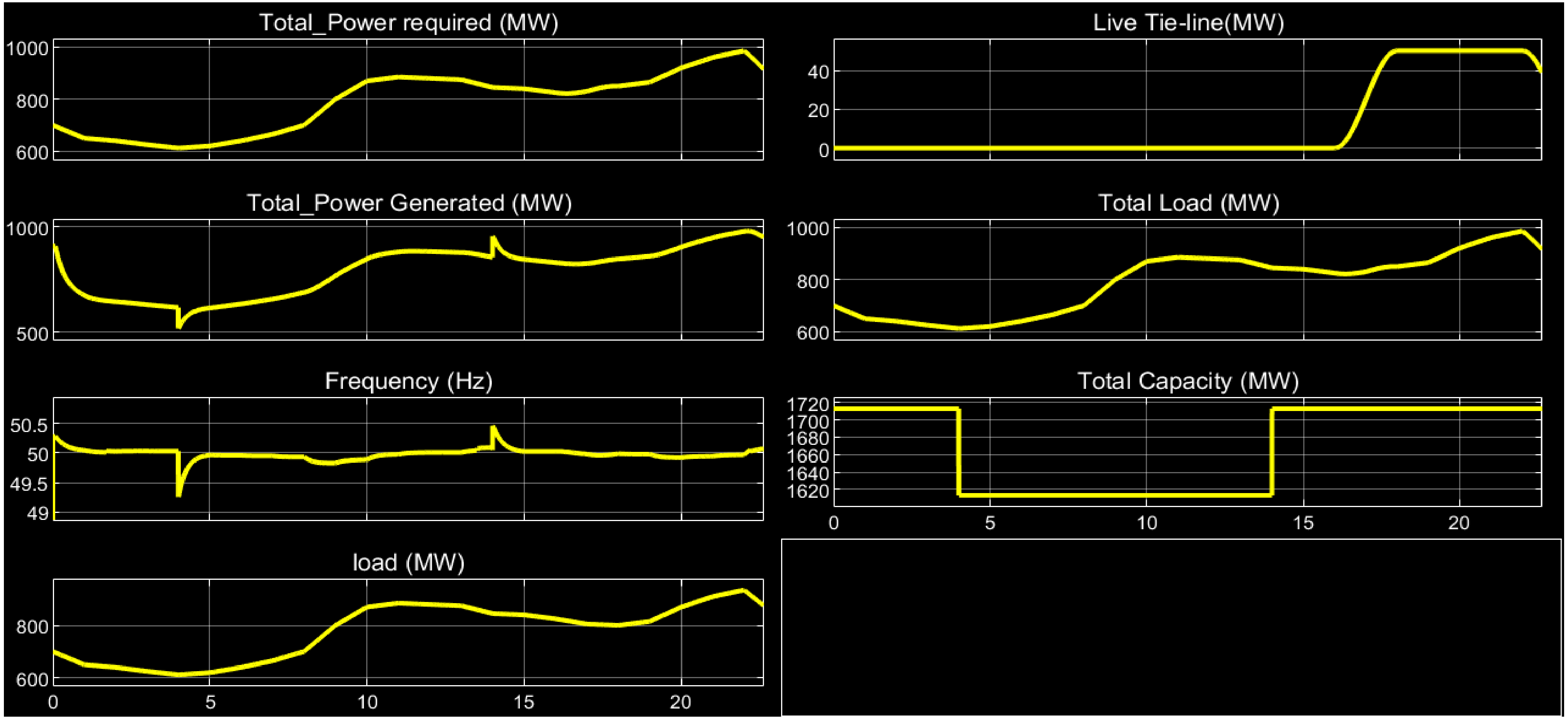
Mini Power Plants



- A 17.07% reduction in the generation capacity of mini plants at t = 4 hours and t =14 hours leads to a measurable frequency deviation.

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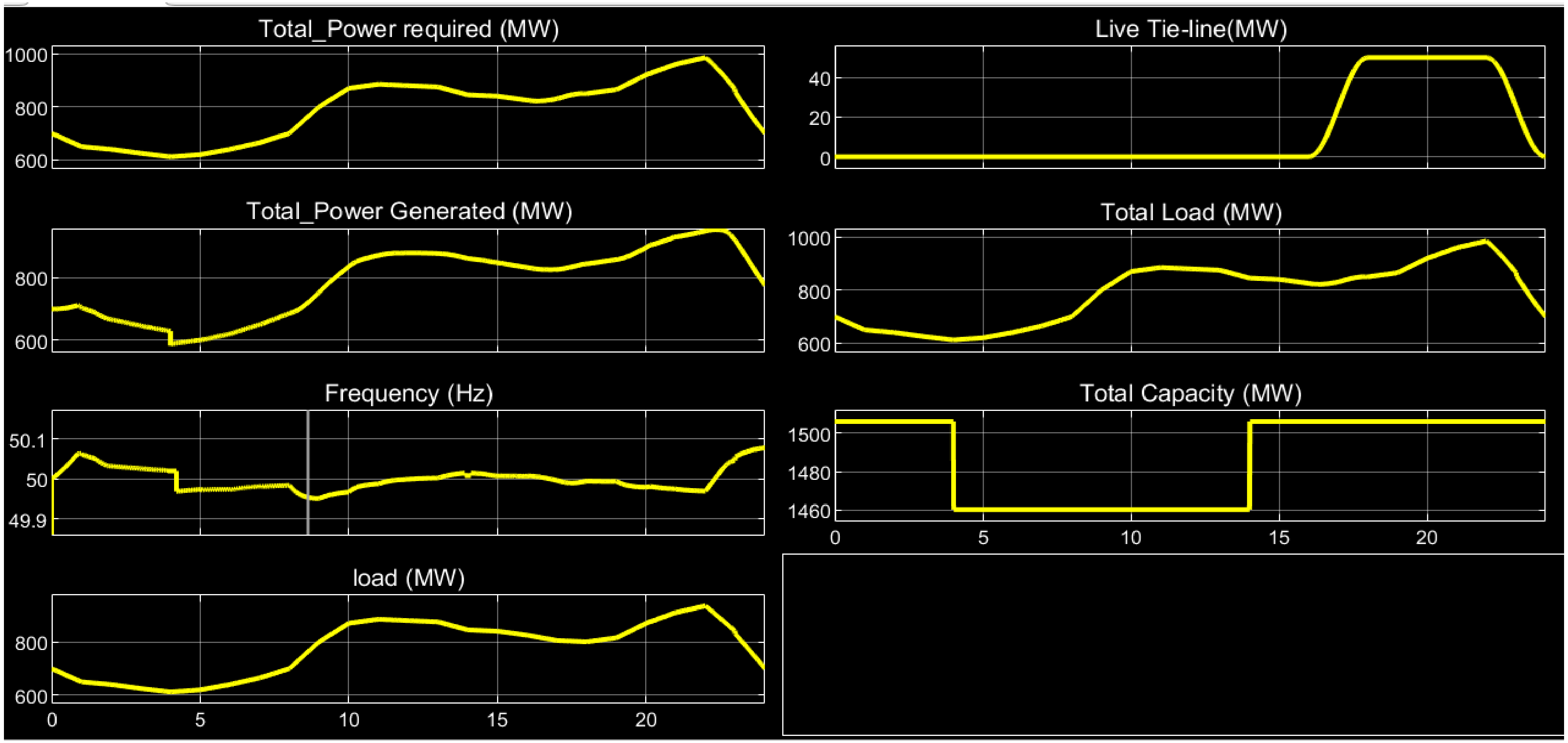
Generator Unit Trip



A generator unit trip from t = 4 hours to t = 14 hours results in a sudden loss of generation capacity, leading to a frequency deviation.

Technical Performance Analysis

Key Findings

1. System Response: AGC dynamically redistributed power in seconds during different variations, outperforming manual control capabilities.
2. Stabilization: Achieved smooth frequency recovery without delays.
3. Key Benefits: Prioritized plant dispatch and cost-effective responses than manual operations.
4. Grid Resilience: Managed disturbances locally while maintaining scheduled tie-line exchanges. should have the comparison bit.

Conclusion and Recommendations

Conclusion

- Implementing AGC in Uganda will enhance grid stability, frequency regulation, and real time management of the intermittent renewable sources like solar.

Recommendations

- Pilot implementation is recommended to validate field performance.
- Implement Congestion-Aware AGC for congestion management especially during peak hours or unexpected outages.
- Additional modifications are required to ensure the AGC solution can be implemented in the EAPP member countries.
- Analyse the AGC behavior in de-regulated versus regulated power systems.

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[2] M. Kuang, Y. Tian, Q. Liu, M. Zhao, and X. Wu, "A review of control strategies for automatic generation control in power systems with renewable energy," Progress in Energy, vol. 6, no. 2, p. 022001, 2024

[3] E. R. A. (ERA), "Reforms in the electricity sector," n.d., accessed: 2024-12-16. [Online]. Available: https://www.era.go.ug/index.php/faq/reforms-electricity-sector

[4] A. F. Hassan and P. R. Singh, "Automatic generation control: Advancements and challenges in sub-saharan africa," Power Systems Research Review, vol. 29, no. 4, pp. 98–105, Dec. 2022.

[5]] M. P. Musau, N. A. Odero, and C. W. Wekesa, "Asynchronous interconnection of the proposed east africa power pool (eapp)," pp. 7–11, 2017

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