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FINAL RESEARCH PROJECT REPORT

TITLE: National Automatic Generation Control Approaches for Hydro-Thermal power systems

MASTER OF SCIENCE IN RENEWABLE ENERGY COHORT 5

Names: Pascaline TUYISENGE

Ref No: 217107370

Name of Supervisor: PROF. KAYIBANDA Venant

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I. ABSTRACT

This research project deals with automatic generation control of an interconnected hydrothermal system considering reheat type turbine in thermal plant area and low head turbine in hydro plant area using optimal controllers (PID) and artificial intelligence(PLC). The main goal of AGC is to keep the operating frequency under prescribed limits and maintain the interchange power at the intended level[1].

The optimal control is determined by minimizing a performance index under the proposed output feedback conditions. The results indicate that the controllers exhibit better performance. In fact, the control systems designed on these methods satisfy the load frequency control requirements with a reasonable dynamic response. As in simulation run in Programmable Logic Controller (PLC), indicate the implementation of AGC for two areas where one or two generators are supplying the load but as load change the frequency deviate, so this problem solved by PLC Controller where it senses the under frequency automatically command other generators to support the failure.

The stability and reliability of power systems are critical for maintaining economic growth and operational efficiency in modern energy sectors[2]. In Rwanda, the hydro-thermal power system faces significant challenges in addressing frequent load changes, which lead to frequency deviations and potential damage to turbines and generator blades. Automatic Generation Control (AGC) has emerged as a pivotal mechanism for maintaining system frequency and ensuring a balance between power generation and demand. Rwanda's economy has grown at an average rate of 7.2% over the 5 past years, As a result demand for electricity is increasing at a rate of almost of 8% per year[2].

This study explores national approaches to implementing AGC for hydro-thermal power systems, focusing on optimizing power system stability, enhancing response times, and achieving economic operation. Various control strategies, including proportional-integral-derivative (PID) controllers, fuzzy logic, and artificial

intelligence-based methods, are analysed for their applicability in the Rwandan context[3]. The research identifies key challenges, such as slow response times and integration of renewable energy sources and proposes tailored solutions to enhance AGC performance in hydro-thermal systems.

The dynamical response of the load frequency control problem in an interconnected power system under consideration is improved with a practical viewpoint by designing the optimal output feedback controller. Optimal control methods are proposed, and their dynamic responses are compared. A few modern control techniques are adopted to implement a reliable stabilizing controller. A serious attempt has been undertaken aiming at investigating the load frequency control problem in a power system consisting of two power generation unit and multiple variable load units. The robustness and reliability of the various control schemes is examined through simulations[4].

The findings of this study contribute to the development of sustainable and reliable power systems, offering actionable insights for policymakers, engineers, and researchers in improving power system operations in Rwanda and similar regions.

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V. LIST OF ABBREVIATION

AGC: Automatic Generation Control

PID: Proportional Integral Derivative

PI: Proportional Integral

GRC: Generation Rate Constrains

LFC: Load Frequency Control

PLC: Programmable Logic Controller

APF: Area Participation Factor

ISE: Integral Square Error

REG(Rwanda Energy Group)

DISCO Participation Matrix (DPM) Distribution Companies

APF: Area Participation Factor

ANN: Artificial Neural Network

VI. APPROVAL AND CERTIFICATION

This thesis titled “National Automatic Generation Control Approaches for Hydro-Thermal Power Systems”, submitted by Engineer Pascaline TUYISENGE, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN RENEWABLE ENERGY COHORT 5 at ACE-ESD, has been examined and approved by the undersigned.

We Certify that this work is the result of the candidate’s independent research efforts and meets the required academic and ethical standards.

Name of Candidate: TUYISENGE Pascaline

Supervisor: Professor KAYIBANDA Venant 

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Thank you all.

CHAPTER 1 INTRODUCTION

1.1 Background and meaning of the topic

This Research project is concerned about linking of two power system which are hydropower system and thermal power system. It consists study in solving problems in power system where there are some systems which meet with difficulties of frequency fluctuation these results in instability and unreliability of power system in RWANDA.

Modern power system normally consists of several subsystems interconnected through tie lines. For each subsystem the requirements usually include matching system generation to system load and regulating system frequency. This is basically known as the load-frequency control problem or automatic generation control (AGC) problem. Generation in large, interconnected power systems comprises of mix type of thermal, hydro, nuclear and gas power generation. Nuclear units owing to their maximum efficiency and controllability problem are usually kept at base load close to their maximum output with no participation in system's automatic generation control[4].

Gas power plants are ideal for Automatic Generation Control, but these plants form a very small percentage of total system generation. Thus, the natural choice of AGC falls either on thermal or on hydro unit. However, the characteristics of hydro turbines are altogether different from steam turbines in terms of transfer function, torque characteristics, generation rate constraints, speed governing system etc.

Therefore, it is difficult to achieve a suitable control strategy, which will work well in interconnected hydro-thermal system because they have entirely different characteristics. Conventional control schemes viz. Integral, PI and PID are slow and lack efficiency in handling the system non-linearity[5]. Many investigations in the field of automatic generation control of interconnected power systems have been

reported over the past few decades. These investigation deals with how to select frequency bias, selection of controller parameters and selection of speed regulator parameter of speed governor. Investigation regarding the AGC of interconnected hydrothermal system is limited to the selection of control parameters and effect of GRC (generation rate constraints) on dynamic response. To the best of authors' knowledge, an intelligent control scheme (fuzzy, neural network and neuro fuzzy control) for interconnected hydro-thermal systems considering generation rate constraints is yet to be examined[6].

Electrical power systems operating in an interconnected grid are normally composed of control areas or regions and interconnected through tie-lines. Each control area is obliged to manage in parallel, the important tasks of covering the customers' load requirements as well as maintaining the interchanged power and the system frequency at their respective scheduled values so that the power system remains at its nominal state characterized by nominal system frequency, voltage profile and load flow configuration. To maintain the power system in its nominal state, at each instant, the generated power should exactly match the demanded power plus the associated system losses. But in a practical power system, the load is changing continuously.

Automatic generation control can track the change of power grid load in real time and control the generator output to adjust according to load variable. AGC Control keeps the system frequency quality within specified range, which is the main way of power control in power grid[7].

Further, the ability of the generation to track the changing load is limited due to physical or technical considerations. Thus, the exact power generation-consumption equilibrium and hence, the nominal states of the power system can't be satisfied in practice. Thus, automatic generation control (AGC) of an interconnected power system is concerned with main objectives: instantaneously matching the generation to the system load and adjusting the system frequency, tie- line loadings at their scheduled values as close as possible so that the quality of the power delivered is maintained at the requisite level and maintain Each unit's generation at the most

economic value[8].

A literature survey shows that most of the work concerned with AGC of interconnected power systems pertain to tie-line bias control strategy. Supplementary controllers are designed to regulate the area control errors to zero effectively. Even in the case of small load disturbances and with the optimized gain for the supplementary controllers, the power frequency and the tie-line power deviations persist for a long duration. In these situations, the governor system may no longer be able to absorb the frequency fluctuations due to its slow response[9].

1.2 Problem statement

The power system in RWANDA by considering national energy sector strategic plan indicates that there is problem of stability and reliability of the power system due to load changes continuously and this implies the frequency deviation. This frequency deviation causes the turbine and generators blades to get damaged. Here for hydrothermal power system in Rwanda when the load change on grid requires contacting generation units to turn on the generators for compensating power failure this took long time to respond to generate in relation with demand at economic optimum point.

The frequency deviation has a very big impact on the country's economy so that it is required to be stable and power to be sustainable and match the power generated and demand. The fluctuations in load demand cause discrepancies between the generation and demand resulting in variation in system frequency and tie flows from their corresponding supposed values and the main challenges to resolve this problem is To effectively alleviate the variations in system frequency, generation and tie-line flows from their stated borders via utilizing a new AGC controller and the selection of an appropriate optimization technique to adjust the factors of the designed controller[10].

1.3 Objectives

1.3.1 Main objective

The primary objective is to explore, analyze, and compare various national automatic generation control (AGC) approaches for hydro-thermal power systems. The study aims to assess the effectiveness of these approaches in maintaining grid stability and improving operational efficiency. In an interconnected power system, as the load demand varies randomly, the area frequency and tie-line power interchange also vary. Hence This project comes up with solution of maintaining stability and reliability of the power system between hydro-thermal power systems connected automatically together to support each other in case of frequency fluctuation.

The objective of Automatic Generation Control (AGC) is to minimize the transient deviations in these variables and to ensure for their steady state values to be zero. That means the AGC performed by only governor control imposes a limit on the degree to which the deviations in frequency and tie-line Power exchange can be minimized and The steady state frequency error following a step load perturbation should be zero. Also, the steady state change in the tie flow following a step load change in an area must be zero. An automatic generation controller providing a slow monotonic type of generation responses should be preferred to reduce wear and tear of the equipment[11].

The main objectives of the research project are:

- ✓ To hold system frequency at or very close to a specified nominal value.
- ✓ To maintain the correct value of interchange power between control areas.
- ✓ To maintain each unit's generation at the most economic value.

1.3.2 Specific objectives

Specific objectives for maintaining stability and reliability of the power system are:

- **Voltage Stability:** Ensure that the voltage levels across the power system remain within acceptable limits under all operating conditions to prevent voltage collapse or instability that could lead to blackouts.
- **Frequency Regulation:** Maintain the system frequency within a narrow band around the nominal frequency 50 Hz to ensure the proper functioning of electrical equipment and avoid frequency-related disturbances.
- **Power Quality Control:** Minimize disturbances such as harmonics, voltage sags, swells, and flickers to ensure that the power delivered to end-users is of

high quality and does not damage sensitive equipment.

- **Load Balancing:** Continuously balance the power supply with demand in real-time to avoid overloading the system, which could lead to equipment failures or widespread outages.
- **Contingency Planning and Response:** Develop and implement robust contingency plans to quickly identify and respond to potential failures or faults in the system, minimizing the impact on the grid and ensuring a rapid recovery from any disturbances.
- **Provide new practical automatic generation control(AGC) models to fulfill the needs of modern restricted hydro-thermal power systems.**

1.4 Scope and limitations

By clearly defining the scope and limitations, the research can be more focused and manageable, ensuring that the findings are relevant and meaningful within the defined boundaries. This approach helps set realistic expectations and guide future research efforts in the field of AGC for hydro-thermal power systems in Rwanda.

1.4.1 Scope

The scope of this research is presented under the following key points:

- **Geographical Focus:**

The study is focused on Rwanda, considering its unique energy infrastructure, geographical features, and socio-economic conditions. This research has been conducted at NYABARONGO, RUKARARA and MUKUNGWA hydro power plants connected directly with KIVUWATT and GISAGARA thermal power plants.

- **Technological Aspects:**

Examination of the technologies and systems used for AGC in Rwanda, including:

- SCADA (Supervisory Control and Data Acquisition) systems.
- Communication infrastructure.
- Control algorithms and techniques tailored to Rwanda's grid.
- Integration with potential renewable energy sources.

➤ **Operational Strategies:**

Analysis of the operational strategies for AGC, including:

- Load frequency control (LFC) methods.
- Economic dispatch strategies for hydro and thermal units.
- Real-time balancing mechanisms and contingency response.

➤ **Performance Metrics:**

Evaluation of key performance metrics for AGC, such as:

- Frequency stability.
- Response time to load changes.
- Economic efficiency in power generation.
- System reliability and resilience.

➤ **Regulatory and Policy Frameworks:**

Review of Rwanda's regulatory and policy frameworks affecting AGC, including:

- National energy policies.
- Market structures and pricing mechanisms.
- Compliance with regional and international standards.

➤ **Case Studies and Data Analysis:**

In-depth analysis of specific case studies within Rwanda's power system to illustrate best practices, challenges, and outcomes. Collection and analysis of data from relevant stakeholders, including utility companies, regulatory bodies, and power producers.

1.4.2. Limitations

This research is limited to the following:

➤ **Data Availability and Quality:**

- Access to comprehensive and current data on Rwanda's AGC practices may be limited. Data quality may vary, affecting the depth and accuracy of the analysis.

➤ **Technological Heterogeneity:**

- Differences in technology and implementation across Rwanda's power plants may complicate comparisons and standardizations, potentially leading to oversimplifications.

➤ **Geopolitical and Economic Factors:**

- The study may not fully capture the influence of geopolitical and economic factors on AGC practices in Rwanda, such as regional power agreements, funding constraints, and political stability.

➤ **Focus on Hydro-Thermal Systems:**

- The primary focus on hydro-thermal power systems may not fully account for the growing role of renewable energy sources like solar and wind in Rwanda's energy mix and their impact on AGC.

➤ **Dynamic Nature of Technology and Policy:**

- AGC technologies and regulatory frameworks are continuously evolving. The study's findings may become outdated as new technologies and policies are introduced, necessitating ongoing updates.

➤ **Scope of Case Studies:**

- The number of case studies analyzed may be limited by time and resources, affecting the generalizability of the findings to the broader Rwandan power system.

➤ **Complexity of Hydro-Thermal Coordination:**

- Coordinating hydro and thermal power generation involves complex dynamics, including water resource management and fuel supply issues. Simplifications made to address this complexity may overlook important details.

➤ **Interdisciplinary Nature:**

- The topic spans multiple disciplines, including electrical engineering, economics, environmental science, and public policy. Ensuring comprehensive coverage while maintaining depth in each area can be challenging[12].

➤ **Resource and Time Constraints:**

- Limited resources and time may restrict the scope of field studies, stakeholder interviews, and on-site evaluations, potentially affecting the comprehensiveness of the research.

1.5 Structure of the dissertation

- **Introduction:** Provide an overview of the importance of automatic generation control (AGC) in maintaining the stability and reliability of national hydro-thermal power systems. Present the research objectives and the significance of exploring AGC approaches in this specific context.
- **Literature Review:** Review existing AGC methods and approaches in hydro-thermal power systems, focusing on national-scale implementations. Discuss the algorithms, control strategies, and performance evaluation metrics used in these approaches. Identify the strengths and weaknesses of each method.
- **Methodology:** Describe the methodology employed in the study, including data collection, modeling techniques, and simulation or analysis methods. Explain how the selected AGC approaches will be evaluated and compared in the context of national hydro-thermal power systems.
- **Results and Analysis:** Present expected findings of the study, including the performance evaluation of the selected AGC approaches. Analyze and compare their effectiveness in maintaining system stability, response time, and energy efficiency. Discuss any notable trends, challenges, or limitations observed.
- **Conclusion and Future Work:** Summarize the key findings of the research and their implications for national hydro-thermal power systems. Reflect on the overall effectiveness of the AGC approaches examined and propose potential areas for improvement or further research. Highlight the significance of advancing AGC techniques to enhance the reliability and efficiency of national power grids.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Automatic Generation Control (AGC) plays a crucial role in ensuring the stability and efficiency of power systems that incorporate both hydro and thermal generation sources. This literature review explores various AGC strategies used in national grids, comparing methodologies, control algorithms, and recent advancements in hydro-thermal power systems. The review highlights the significance of AGC in maintaining frequency stability, minimizing tie-line power deviations, and optimizing economic dispatch.

The integration of hydro and thermal power generation in national grids poses unique challenges due to their distinct dynamic characteristics. Hydro plants provide quick response but suffer from water inflow variability, while thermal plants ensure steady power output but have slower response times. AGC is essential in balancing these generation sources to maintain grid stability. This chapter reviews existing approaches to AGC in hydro-thermal systems, addressing their benefits, limitations, and advancements[3].

It consist study in solving problems in power system, the load change occurs continuously so that cause frequency fluctuation in power system this sudden change cause the turbine blades and generator damaged so for handling this, Applying Automatic Generation Control approaching hydrothermal power system in RWANDA at National grid where the communication done by generators themselves and stabilize frequency and power change in tie line connecting hydrothermal power systems.

2.2 Fundamentals of Automatic Generation Control

AGC is a real-time control mechanism that adjusts generation outputs to match load variations while keeping frequency deviations within permissible limits. The primary objectives of AGC in hydro-thermal systems include:

- Maintaining system frequency stability, System frequency stability is maintained by balancing power generation and demand using AGC, governor response, load shedding, and flexible resources to prevent blackouts and equipment damage.
- Managing power interchange between interconnected regions, insures efficient and reliable electricity transfer while maintaining system stability between regions using flow control, scheduling, and real-time adjustments to maintain stability and prevent congestion.
- Optimizing economic dispatch minimizes generation costs while meeting demand and system constraints. It allocates power output across generators based on fuel costs, efficiency, and transmission limits to ensure cost-effective and reliable operation.
- Minimizing oscillations due to sudden demand fluctuations.

AGC is typically implemented through three control levels: primary control which is stabilizing frequency deviations, secondary control (load frequency control) Adjusts generation to restore frequency and power interchange to scheduled values, and tertiary control (economic dispatch) Optimizes generation dispatch for cost efficiency while maintaining system stability.

2.3 Motivation and Importance

The integration of hydroelectric and thermal power plants presents unique challenges in AGC due to the distinct dynamic characteristics of each generation source.

Hydroelectric plants offer rapid response capabilities but are influenced by water availability and hydraulic constraints. In contrast, thermal plants, including coal, gas,

and nuclear facilities, have slower response times and are subject to fuel supply and thermal limitations.

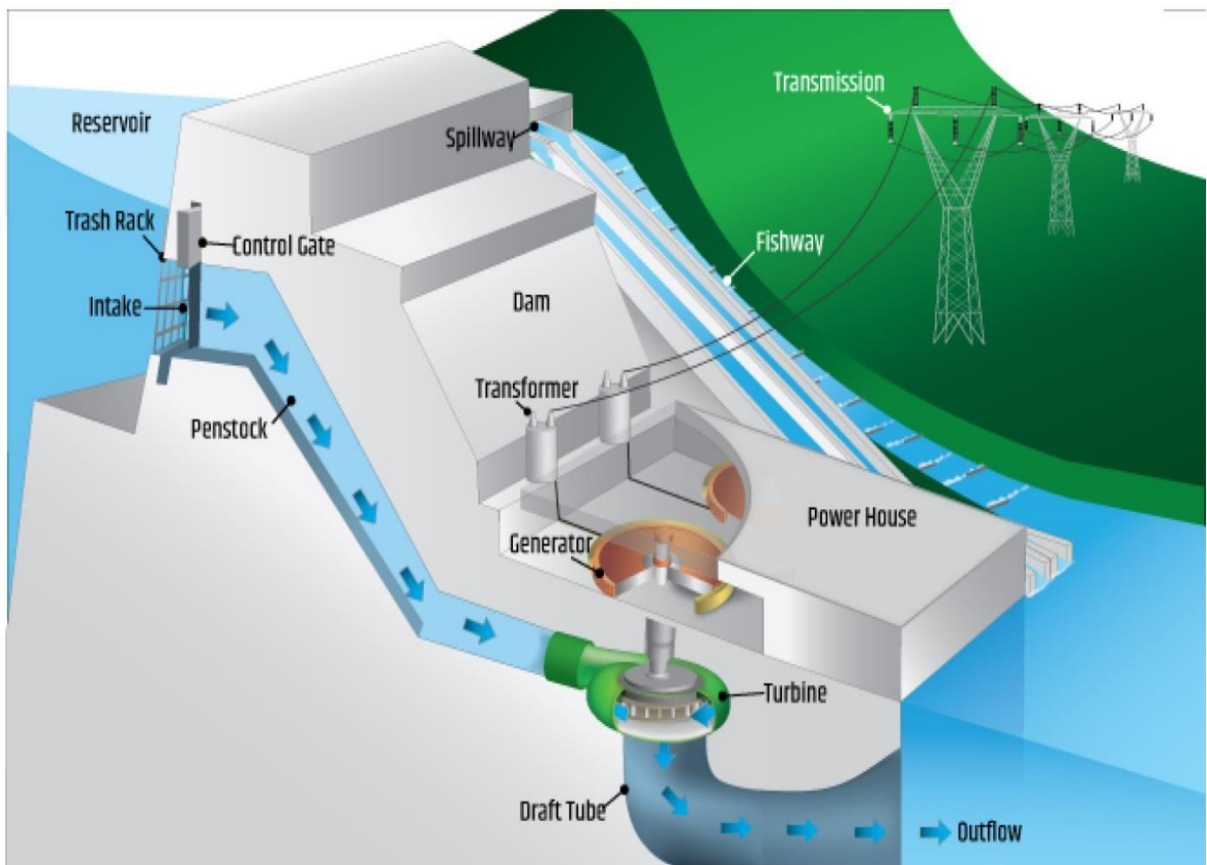


Figure 1 Hydroelectric plants offer rapid response[13]

Hydroelectric plants provide a rapid response to power system demands due to their fast governor action, instantaneous start-stop capability, and high ramp rates. Pumped-storage hydro plants further enhance flexibility by allowing both power generation and storage. These features make hydroelectric plants crucial for grid stability and automatic generation control (AGC).

- Frequency Stability: Maintaining a consistent system frequency is crucial for the proper functioning of electrical equipment and overall grid stability.

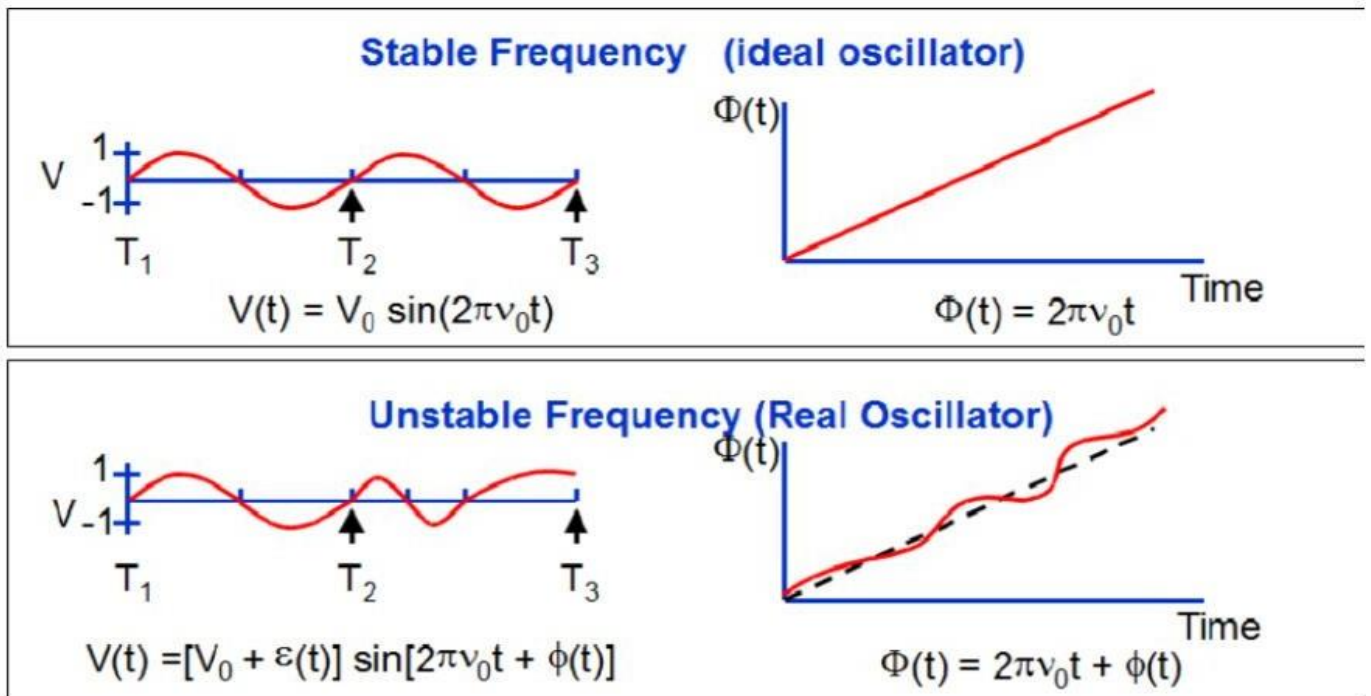


Figure 2 Frequency Stability [14]

- Economic Dispatch: Efficiently allocating generation resources to meet demand at the lowest cost while considering operational constraints.
- Renewable Integration: Facilitating the incorporation of variable renewable energy sources by leveraging the flexibility of hydro-thermal systems.

2.4 Historical Perspective

The concept of AGC has evolved significantly since its inception. Early power systems relied on manual control and operator intervention to manage generation and load balance. With the advent of advanced control theories and digital technologies, AGC systems have become more sophisticated, enabling real-time automated control of complex interconnected power networks[15].

2.5 Overview of Automatic Generation Control

AGC is a feedback control system that automatically adjusts the output of multiple generators in response to changes in load demand and system frequency. The primary objectives of AGC are:

1. **Frequency Control:** Keeping the system frequency within specified limits by balancing real power generation and consumption.
2. **Tie-Line Power Flow Control:** Managing the power exchange between interconnected areas to adhere to scheduled values.
3. **Economic Operation:** Optimizing the generation mix to minimize operational costs while satisfying system constraints.

2.6 AGC Approaches and Techniques in Hydro-Thermal Systems

The dynamical response of the load frequency control problem in an interconnected power system under consideration is improved with a practical viewpoint by designing the optimal output feedback controller. The optimal control methods are proposed, and their dynamic responses are compared. The optimal control is determined by minimizing the performance index under the proposed output feedback conditions. The results indicate that the controllers exhibit better performance. In fact, the control systems designed on these methods satisfy the load frequency control requirements with a reasonable dynamic response.

PLC Controller is designed to automatically control the generation of two areas interconnected by tie line of the power flow and regulate the frequency change at the same time change in power flowing in tie line capacity of two areas.

2.6.1 Classical AGC Techniques

Traditional AGC strategies are primarily based on Proportional-Integral-Derivative (PID) controllers and linear control theories. These methods, while effective, exhibit limitations in handling non-linearities and uncertainties present in hydro-thermal systems.

Enhanced classical AGC models incorporate supplementary controllers for hydro-thermal coordination.

2.6.2 Modern AGC Techniques

Recent advancements have led to the development of intelligent and adaptive control techniques to enhance AGC performance.

2.6.2.1 Adaptive Control Methods

- Adaptive AGC approaches dynamically adjust control parameters based on real-time grid conditions.
- Artificial Neural Network (ANN)-based AGC systems improve response time and reduce oscillations in hydro-thermal grids.

2.6.2.2 Fuzzy Logic and Artificial Intelligence-Based AGC

- Fuzzy logic controllers for AGC in a multi-area hydro-thermal system achieve superior dynamic performance compared to classical techniques.
- Integration of fuzzy and ANN approaches for real-time AGC tuning reduces error margins significantly.

2.6.2.3 Optimization-Based AGC

- Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are used to fine-tune AGC parameters, improving system robustness.
- Hybrid optimization techniques in multi-area hydro-thermal AGC reduce frequency deviations.

2.7 Challenges in AGC for Hydro-Thermal Systems

Despite advancements, AGC in hydro-thermal power systems faces several challenges:

- **Hydro variability:** Seasonal water inflows impact generation capacity.
- **Thermal plant constraints:** Ramp rate limitations affect response time.
- **Cybersecurity threats:** AGC systems relying on digital communications are vulnerable to cyber-attacks.
- **Integration with renewable energy:** Growing penetration of solar and wind power complicates AGC operations.

2.8 Future Directions and Research Gaps

- Development of **self-learning AGC algorithms** that adjust dynamically to grid conditions.
- Integration of **blockchain technology** for secure AGC communications.
- **Hybrid AGC models** incorporating renewable energy sources.
- Enhanced **cybersecurity frameworks** for AGC in smart grids.

2.9 Recent Advances and Research Trends

Recent research in AGC for hydro-thermal systems has focused on:

- **Hybrid Control Strategies**[16] Combining classical, modern, and intelligent control methods to leverage their respective strengths. Traditional PID controllers are combined with advanced techniques like optimal control, fuzzy logic, and neural networks to improve frequency stability, adaptability, and response speed[17]. These hybrid strategies optimize AGC actions using real-time data, ensuring a more flexible, efficient, and resilient power system[18]
- **Decentralized and Distributed Control:** Developing control schemes that operate with limited information and coordinate through local interactions, enhancing system resilience and scalability.
- **Cyber-Physical System Security:** Ensuring the security and resilience of AGC systems against cyber threats and attacks. Decentralized control and redundancy further improve resilience, ensuring secure and reliable AGC operations against cyberattacks.[6]
- **Integration of Energy Storage:** Utilizing energy storage systems to provide additional flexibility and support for frequency regulation[18].

2.10 Comparison studies

National automatic generation control approaches hydrothermal power systems deal with the applications of automatic generation control (AGC) of a hydrothermal systems in a power system deregulated environment and tries to provide a new practical AGC model to maintain the stability and reliability of the power systems needs of a modern restructured hydrothermal power system. Several Distribution Company, distribution Participation Matrix, and area participation factor have been tried out and dynamic responses for frequency, tie line flow and power generations are obtained to examine the performance of the system in deregulated environment considering integral controllers. Investigations have been also carried out to study the effect of generation rate constraint and the importance of APF in deregulated environment[12].

The researchers discussed the simulation model of hydrothermal systems. They showed that the difficulty in extending the traditional approach for such systems was overcome by assuming that all areas in a system operate at the same frequency. They obtained the model by ignoring the frequency difference between the control areas. Have presented the formulation of AGC of interconnected systems and investigations via linear control theory. They compared three relatives to their ability to influence the transient response of important system variables. Later, the effect of generation rate constraint (GRC) was included in these types of studies, considering both continuous and discrete power system models.

The small signal analysis is justified for studying the system response for small perturbations. However, the implementation of AGC strategy based on a linearized model on an essentially nonlinear system does not necessarily ensure the stability of the system. Considerable attention has been paid by researchers to consider the system nonlinearities[19].

Study also reveals that the conventional integral controllers are quite robust than PI and PID controllers and the optimum integral gains once set for nominal condition need not be changed for +25% variations in system parameters and +20% variations in operating load condition from their nominal values.

Generation and distribution of electric energy with good reliability and quality is very Important in power system operation and control. This is achieved by Automatic Generation Control (AGC). In an interconnected power system, as the load demand varies randomly, The area frequency and tie-line power interchange also vary[12]

The objective of Load Frequency Control (LFC) is to minimize the transient deviations in these variables and to ensure for their steady state values to be zero. The LFC performed by only a governor control imposes a limit on the degree to which the deviations in frequency and tie- line Power exchange can be minimized. However, as the LFC is

fundamentally for the problem Of an instantaneous mismatch between the generation and demand of active power[20].

J. Kaliannan, A. Baskaran, investigated AGC of hydrothermal in deregulated environment, The concept of DISCO participation matrix (DPM) and area participation factor (APF) to represent bilateral contracts are introduced. However, they have not dealt with reheat turbines, GRC and hydro-thermal system in their work. This paper deals with the AGC of hydro-thermal and thermal-thermal systems considering reheat turbine and GRC constraints in deregulated environment[15].

2.11 Conclusion on Literature review

This literature review highlights the evolution of AGC strategies in hydro-thermal power systems, emphasizing the transition from classical to AI-driven techniques. While significant advancements have been made, future research should focus on enhancing adaptability, security, and integration with renewable sources. The insights gained from this review provide a foundation for developing robust AGC mechanisms suited to modern power grids[21].

CHAPTER 3 METHODOLOGY

In this research project of National Automatic generation control approaches hydrothermal power systems using different techniques. In gathering information related to it, occasionally consist use of existing data from national Grid and observe the grid connection as these techniques used in data collection for interconnected hydrothermal power systems of two areas, where area 1 thermal power and area 2 hydro power systems[17].

The evaluation about Automatic Generation Control (AGC) strategies for hydro-thermal power systems, focusing on performance metrics such as frequency deviation, settling time, overshoot, and control effort. It compares Proportional-Integral-Derivative (PID), Fuzzy Logic Control (FLC), and Artificial Neural Network (ANN) controllers, identifying optimal tuning strategies through sensitivity analyses [8]. The research also considers the economic implications of each AGC method, assessing factors like fuel consumption and equipment wear. With the integration of renewable energy sources introducing variability, the study explores advanced AGC techniques incorporating machine learning and artificial intelligence to enhance adaptability. Additionally, it addresses challenges related to communication delays and cybersecurity in AGC implementation, proposing mitigation strategies to ensure system reliability. A case study using real operational data validates the proposed methodologies, offering practical insights into AGC implementation challenges and solutions[19].

3.1 Observations

At National Grid at GIKONDO there is grid interconnecting different power systems as stated in existing data, but all interconnected has the same characteristics and the same control objectives as:

- One is to be able to buy and sell power with neighboring systems whose operating costs make such transactions profitable.
- Improvement to overall reliability for events like the sudden loss of a generating unit
- Provide a common frequency reference for frequency restoration.

3.2 Tools used

In this project in a way of simulation the use of MATLAB based Simulink and PLC for obtaining expected results, programing PID and PI controllers is good method for steady state response. But Programmable Logic Controller (PLC) is better in simulation of automatic generation control of different areas in the interconnected of hydrothermal power system it needs tie line connection and load frequency control for stabilizing the system frequency and reduces frequency deviation[22].

In this project the outcome of the project where the generators of different power generating units are interconnected on the same tie line and synchronized as having the same characteristics. National automatic generation control approaches hydrothermal power system is achieved by better performance of PI with good dynamic response as compared to other ways of automatic feedback control of two areas like artificial intelligence or conventional controllers and superconducting magnetic energy storage and logic controller.

PLC Programmable Logic Controller is better in simulation of automatic generation control of different areas in the interconnected of hydrothermal power system. It needs tie line connection and load frequency control for stabilizing the system frequency and reducing frequency deviation[10].

CHAPTER 4 RESULTS AND SIMULATIONS

In this represented work, the areas of hydro-thermal reheat interconnected power system have been developed by using fuzzy logic, PI, PID Controllers to illustrate the performance of load frequency control using MATLAB/SIMULINK and PLC.

4.1 Reading existing data at Grid

This implies that at national grid there are connections of different power systems especially HYDRO from NYABARONGO I, MUKUNGWA I and RUKARARA and THERMAL from GISAGARA and KIVUWATT these power are synchronized on the same bus bar and tie line flow because they have the same characteristics of voltage, Phase angle and frequency. The generation capacity and frequency of the studied power plants are reported in the table below.

Table 1: Representing data

POWER PLANT	TYPE OF PLANT	CAPACITY	FREQUENCY
NYABARONGO I	HYDRO	28 MW	50 HZ
MUKUNGWA I	HYDRO	12 MW	
RUKARARA I	HYDRO	9.5 MW	
GISAGARA	THERMAL	80 MW	50HZ
KIVUWATT	THERMAL	26MW	

4.2 Simulations and Discussion

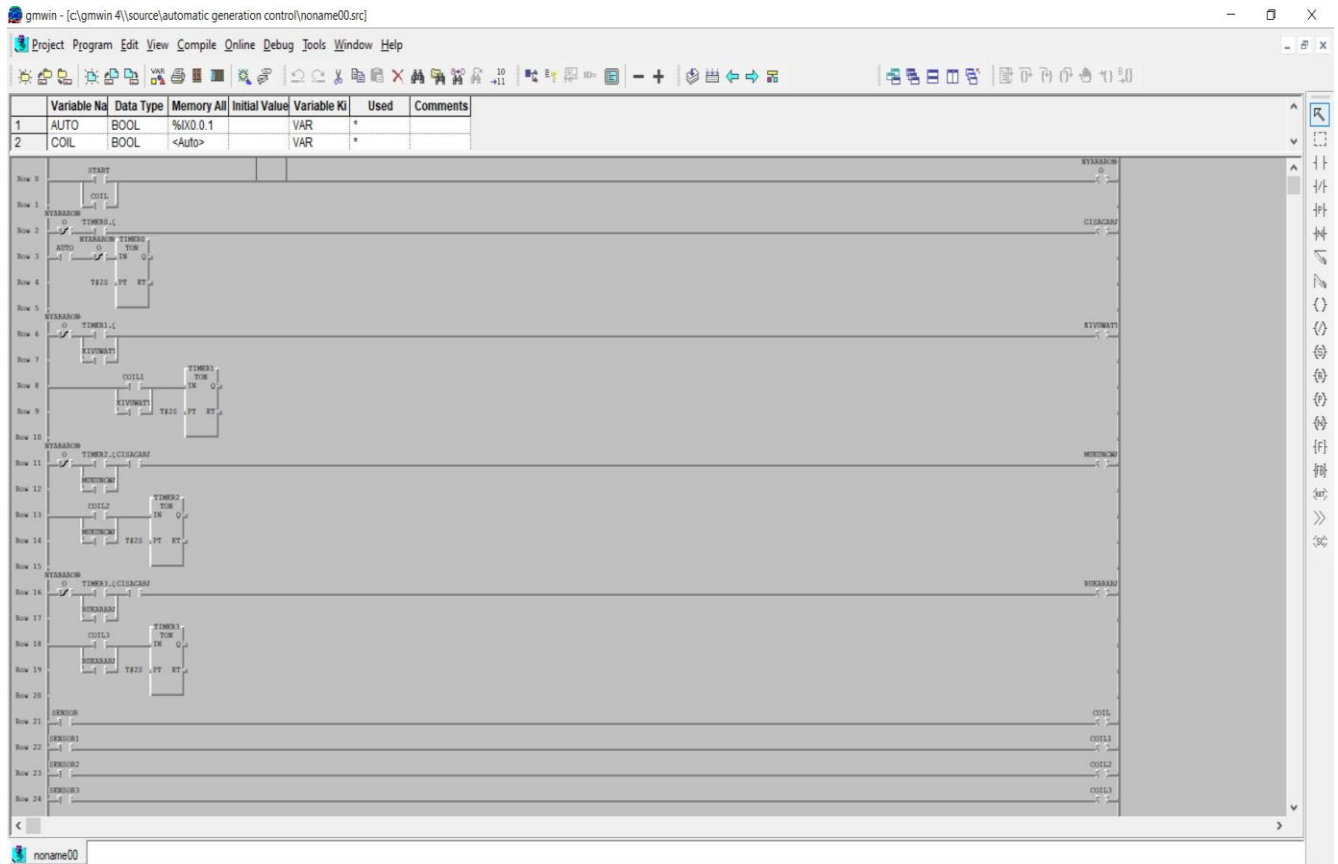


Figure 3 Automatic Generation Control Programmable Logic Controller program

Figure 3 represents the AGC Topology, Showing AGC setup of all the Generating plants used in the modelling of the project Without any active power supply inputs. Which means the logic is in place but not yet executing control actions.

The ladder logic diagram includes rungs representing different conditions and control logic for managing multiple-generating plants. The AGC circuit monitor the output signal level and if the output deviates from the reference, a control signal adjusts the gain of amplifier, either increasing it for weak signals or decreasing it for strong signals.

The operation of AGC in Ladder logic, it use conditional logic(Contacts and coils) to determine when to start, stop or regulate generators. If demand increases the system start additional generators using timers and sensor feedback, If the frequency deviates, the system adjusts

generation output accordingly, If a fault is detected the system shutdown affected units and send alerts.

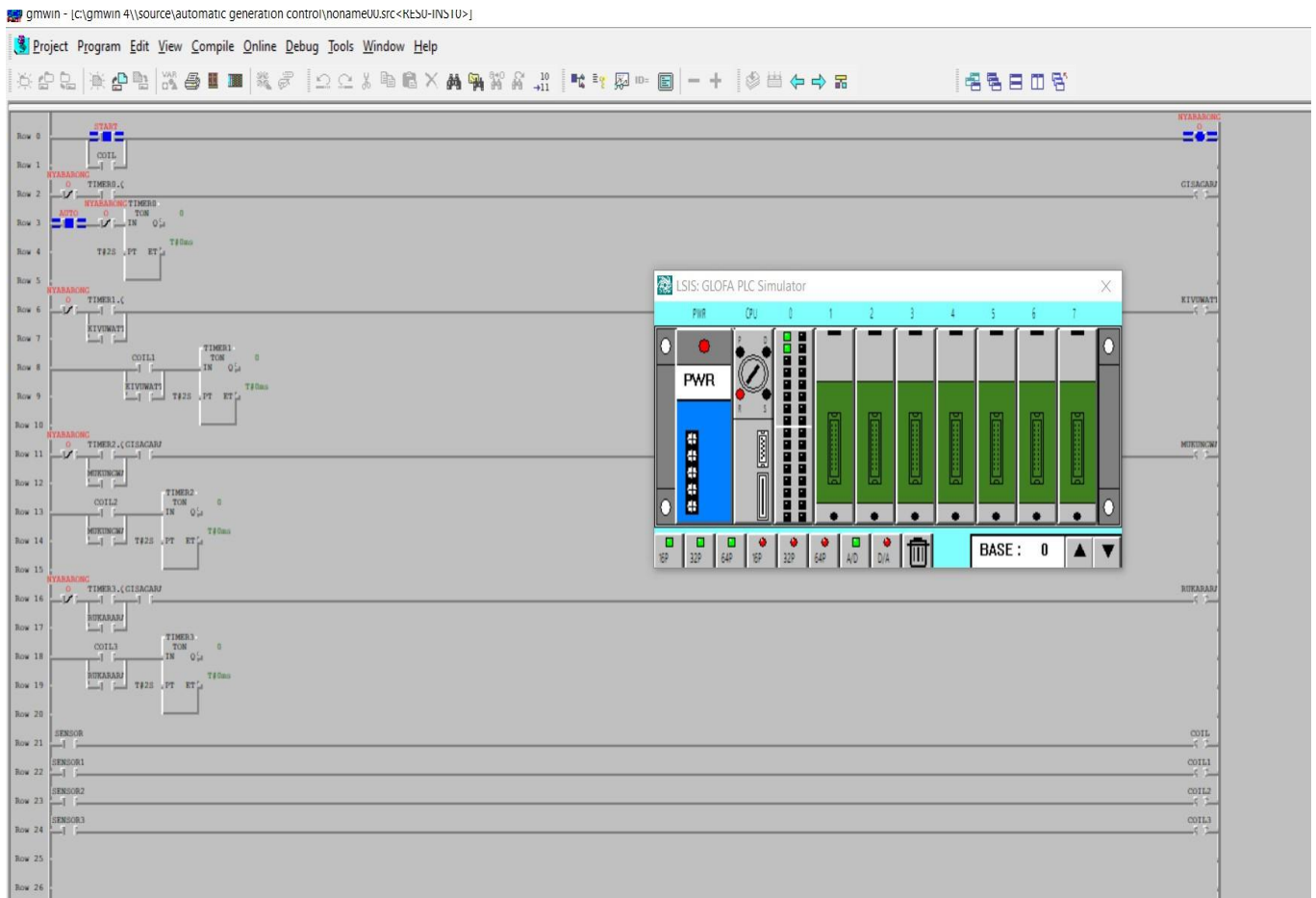


Figure 4 AGC First State Operation When There Is Single Generation Without Backup

This is the first state of Automatic Generation Control (AGC), When the main generation as Nyabarongo power plant is available and enough to meet demand, it will not allow the back up to send the power in the line.

In briefly, Nyabarongo Power Plant is the sole active generator, supplying sufficient power to meet the demand. As a result, the system logic prevents the backup generator from injecting power into the grid. The ladder logic program, as seen in the GLOFA PLC Simulator, ensures that the backup generator remains off unless the main generator fails, or demand exceeds the available supply. Timers (TMRs) are implemented to introduce delays, ensuring smooth transitions between power sources and preventing unnecessary switching. The simulator displays

active input and output states, allowing real-time monitoring of system performance. This state is crucial for efficient energy management, ensuring that backup power is only utilized when necessary, optimizing power generation and system stability.

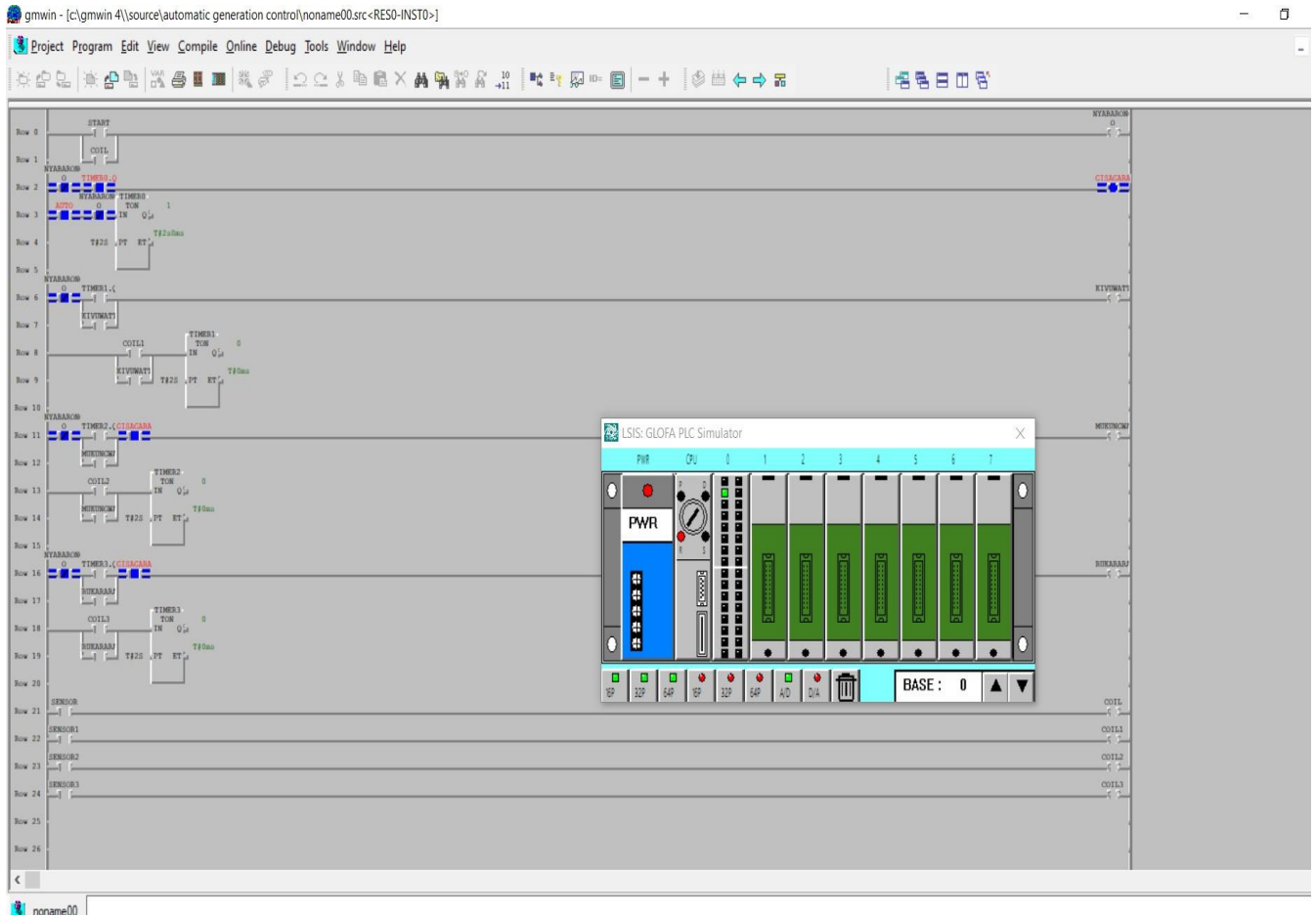


Figure 5 AGC 2nd State When Main Generation Dropout And Automatically Start Back Up As Gisagara

In the second operational state of the Automatic Generation Control (AGC) system, the main generator (Nyabarongo Power Plant) is disconnected due to a fault in the plant or transmission line. The Programmable Logic Controller (PLC) detects the loss of supply and initiates an automatic switchover to the backup generator, Gisagara Power Plant, ensuring uninterrupted power delivery to the grid. The ladder logic program governs this transition using real-time sensor feedback, interlocks, and timers (TMRs) to verify the fault condition before engaging the backup source. The GLOFA PLC Simulator displays the active rungs, showing the logical

execution of the backup activation process. This automated transition is crucial in power system stability and reliability, minimizing downtime and maintaining continuous power supply during main generator failures.

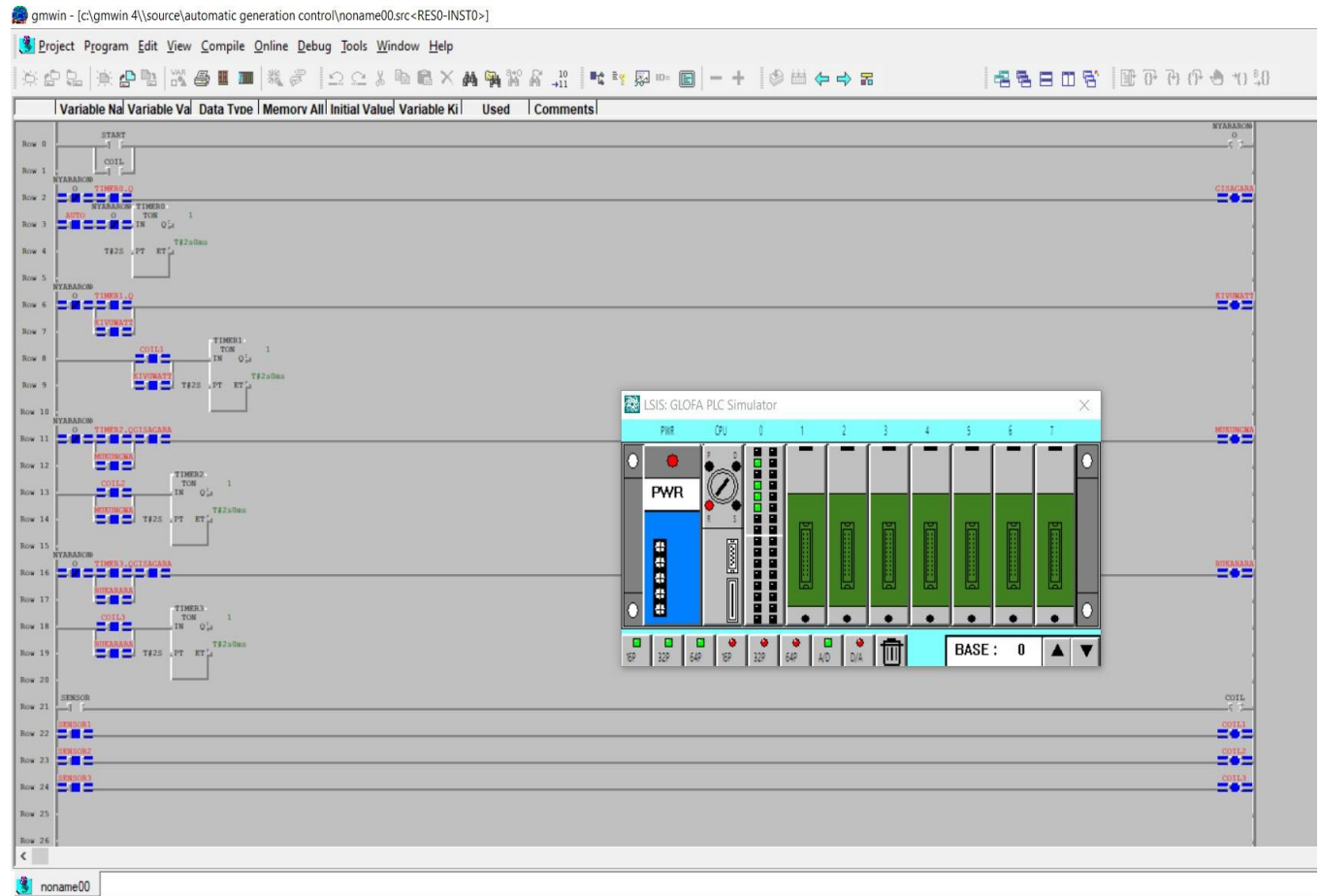


Figure 6 AGC 3rd state, when the line sensor detect over loading backup generation and automatically add a new generation in the system.

In the third operational state of the Automatic Generation Control (AGC) system, the backup generator (Gisagara Power Plant) is active but unable to meet the total power demand. The PLC continuously monitors the system load using line sensors, which detect an overloading condition. Once the demand exceeds the backup generation capacity, the PLC automatically initiates the addition of supplementary generation sources, including KivuWatt, Mukungwa, and Rukarara Power Plants, to stabilize the power supply. The transition process is managed through logical conditions, interlocks, and timers (TMRs) within the ladder logic program, ensuring a smooth and sequential activation of additional generators. The GLOFA PLC Simulator reflects this state

by indicating the execution of relevant control logic, activating additional power sources as required. This state is essential for load balancing, system reliability, and ensuring uninterrupted power supply across the network.

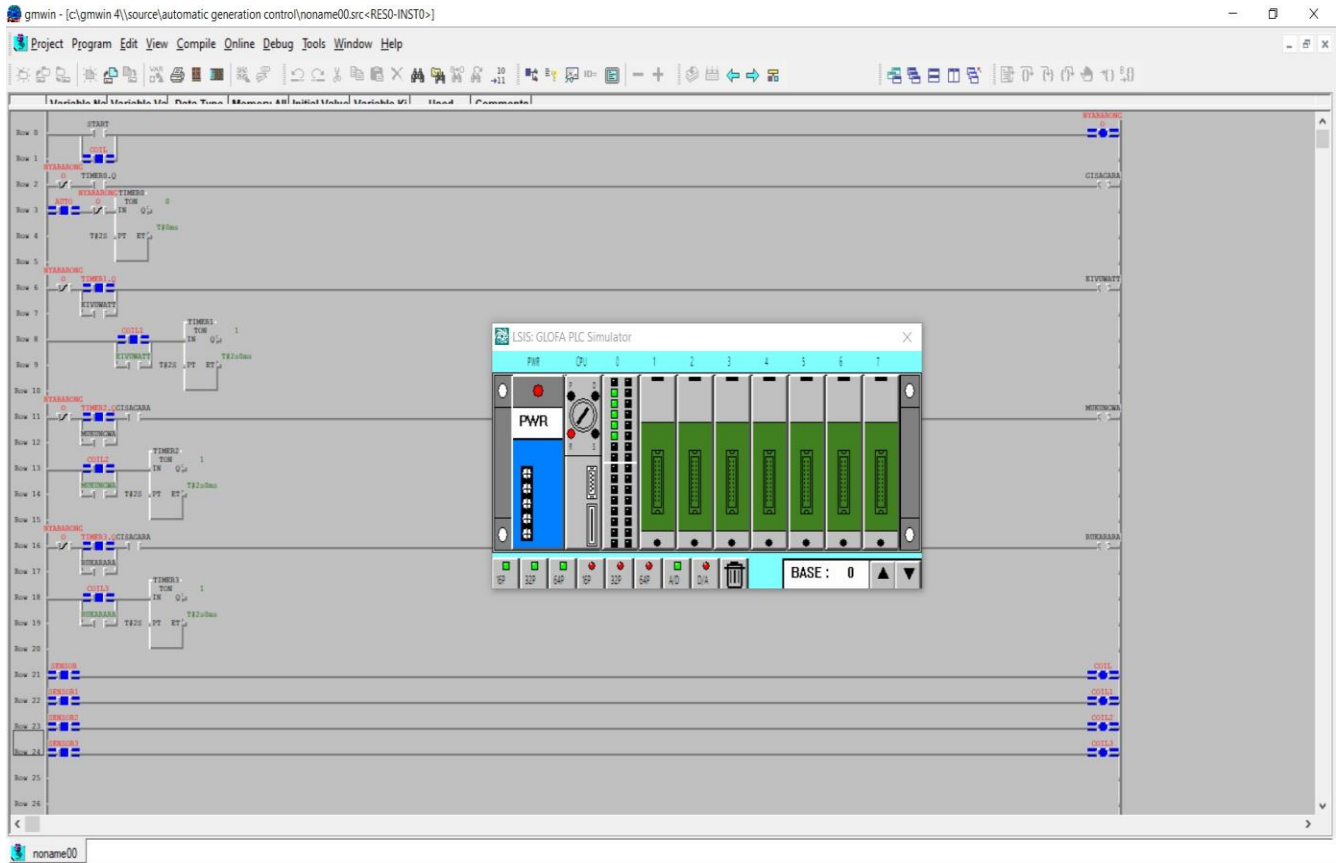


Figure 7 AGC 4th state when Main generation back to the network

In the fourth operational state of the Automatic Generation Control (AGC) system, the main generator (Nyabarongo Power Plant) is restored to the grid after being previously disconnected due to a fault or maintenance. The Programmable Logic Controller (PLC) continuously monitors the system and detects the reavailability of the main generation. Once it confirms that Nyabarongo can supply the required load, the PLC initiates an automatic disconnection sequence for all backup generation plants (Gisagara, KivuWatt, Mukungwa, and Rukarara) to optimize system efficiency and prioritize the primary generation source. This transition is managed using logical interlocks, real-time sensor feedback, and timers (TMRs) to ensure a smooth and stable

switching process without sudden power fluctuations. The GLOFA PLC Simulator reflects this by updating the active rungs in the ladder logic, executing the shutdown or load-shedding commands for backup plants. This state is crucial in reducing operational costs, maintaining grid stability, and ensuring efficient resource utilization by prioritizing the primary power plant.

4.3 Conclusion On Results and Simulations

The AGC PLC program ensures stable and efficient power generation by using timers for smooth transitions and sensors for real-time monitoring. Timers introduce delays to prevent abrupt switching, while sensors detect voltage, frequency, and load changes. This coordination helps maintain an optimal voltage profile, ensures power system stability, and prevents unnecessary generator operation, improving efficiency and reliability.

The inputs of the controller are Frequency deviation, Tie line deviation, Load demand and Area control error as combination of frequency and tie-line power deviations, And the output are Load Control Signals (in some systems), In certain scenarios AGC may also communicate with demand-side management systems to adjust the load. And Generation control and control signals.

As Conclusion, This AGC PLC program integrates timers for delays and sequencing and sensors for real-time monitoring to ensure stable and efficient power generation. Proper tuning of these components ensures optimal voltage profile improvement and power system stability.

Table 2: Instruction used to run the AGC

	Variable Na	Data Type	Memory All	Initial Value	Variable Ki	Used	Comments
1	AUTO	BOOL	%IX0.0.1		VAR	*	
2	COIL	BOOL	<Auto>		VAR	*	
3	COIL1	BOOL	<Auto>		VAR	*	
4	COIL2	BOOL	<Auto>		VAR	*	
5	COIL3	BOOL	<Auto>		VAR	*	
6	GISAGARA	BOOL	%QX0.0.1		VAR	*	
7	INST0	FB Instanc	<Auto>		VAR		
8	INST1	FB Instanc	<Auto>		VAR		
9	INST2	FB Instanc	<Auto>		VAR		
10	INST3	FB Instanc	<Auto>		VAR		
11	KIVUWATT	BOOL	%QX0.0.2		VAR	*	
12	MUKUNGW	BOOL	%QX0.0.3		VAR	*	
13	NYABARO	BOOL	%QX0.0.0		VAR	*	
14	RUKARAR	BOOL	%QX0.0.4		VAR	*	
15	SENSOR	BOOL	%IX0.0.2		VAR	*	
16	SENSOR1	BOOL	%IX0.0.3		VAR	*	
17	SENSOR2	BOOL	%IX0.0.4		VAR	*	
18	SENSOR3	BOOL	%IX0.0.5		VAR	*	
19	START	BOOL	%IX0.0.0		VAR	*	
20	TIMER0	FB Instanc	<Auto>		VAR	*	
21	TIMER1	FB Instanc	<Auto>		VAR	*	
22	TIMER2	FB Instanc	<Auto>		VAR	*	
23	TIMER3	FB Instanc	<Auto>		VAR	*	

CHAPTER 5 CONCLUSION

For maintaining stability and reliability of power system in Rwanda to handle the problem of frequency fluctuation with interconnected hydrothermal areas PLC is better in implementation of Automatic Generation Control (AGC) in modeling of interconnected hydrothermal power system consist of use of model of PI Controller. And it is a good way of analyzing its dynamic response. The results indicate that the controllers exhibit better performance. In fact, the control systems designed on these methods satisfy the load frequency control requirements with a reasonable dynamic response. As in simulation run in Programmable Logic Controller (PLC) indicate the implementation of AGC for two areas where one or two generators are supplying the load but as load change the frequency deviates, so this problem is solved by PLC Controller where it senses the under frequency automatically command other generators to support the failure. PLC Controller for these simulations requires a safe holder for maintaining the supporting generator to continue support until under frequency resolved in the interconnected system.

In summary, the integration of Automatic Generation Control (AGC) in interconnected hydro-thermal power systems is crucial for maintaining system stability and reliability. Hydroelectric units, with their rapid response capabilities, and thermal units, characterized by steady power output but slower response times, present unique challenges when coordinated within AGC frameworks. Traditional control methods, such as Proportional-Integral-Derivative (PID) controllers, have been widely used; however, they may not effectively handle the nonlinearities and time-varying nature of these systems. Modern control techniques, including optimal, robust, and adaptive control, offer improved performance but often require complex system modeling and significant computational resources. The integration of intelligent control methods, such as fuzzy logic, neural networks, and

evolutionary algorithms, has shown promise in managing uncertainties and enhancing system performance. Implementing effective AGC involves addressing challenges like nonlinear dynamics, parameter uncertainties, and the increasing incorporation of variable renewable energy sources. Studying research into advanced control strategies and robust system modeling is essential to enhance the performance and reliability of hydro-thermal power systems[23].

5.1 Recommendations for further work

To enhance Automatic Generation Control (AGC) in hydro-thermal power systems, future research should focus on developing advanced control strategies that effectively manage system nonlinearities and uncertainties. Investigating the integration of renewable energy sources, such as wind and solar power, into these systems is essential to address the variability they introduce. Additionally, exploring decentralized control frameworks can improve system resilience and flexibility. Ensuring robust cyber-physical security measures is crucial to protect AGC systems from potential threats. Finally, addressing real-time implementation challenges and scalability will facilitate the practical deployment of advanced AGC solutions in large-scale power systems.

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