Grid Frequency Control with 5G Communication

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1. INTRODUCTION

In the evolving environment of modern power systems, integration of renewable energy sources (RES) such as solar, wind, and hydro is both an opportunity and challenge. One of the major domains to be addressed is the power grid's stability and resilience, particularly in frequency control. Traditionally, grid control communication has relied on wire-based infrastructure in the form of industrial Ethernet and optical fiber, which, despite being robust, limits flexibility and scalability.

Recent technological advances in wireless technology, especially 5G, offer new paradigms for managing grids. With its incredibly low latency, high dependability, and ability to support enormous levels of device connectivity, 5G will reshape how control commands are transmitted over energy networks.

This project presents the use of grid frequency control using a Power-Hardware-in-the-Loop (PHIL) laboratory testbed supplemented by private 5G communication networks. The demonstration system consists of distributed generation units (DGs) representing actual-system elements like supercapacitors, batteries, and fuel cells, manipulated by real-time computers (RTCs). These units are interfaced using a dedicated 5G network to execute realistic, time-varying frequency control scenarios.

The goal of the project not only is to integrate and make work the frequency control logic via a 5G channel but also to compare its performance with that of conventional wired communication on the basis of latency, reliability, and the responsiveness of the system in general

2. Subsystem Overview

The project is divided into four primary subsystems, each having its own unique and vital role for the development and validation of a 5G-capable frequency control system for smart grids. These subsystems cooperate for the successful deployment, testing, and performance evaluation.

Subsystem A: PHIL Lab Familiarization

This initial subsystem is designed to equip with the hands-on experience and technical familiarity necessary to work in the PHIL (Power Hardware-in-the-Loop) environment. It involves acquiring an understanding of the operation of some of the main components such as real-time controllers, distributed generators (DGs), and grid emulators. It also involves the study of Simulink-based control models that model frequency control in a power system. Learning this subsystem is crucial since it forms the basis for secure and effective experimentation in later phases of the project.

Subsystem B: 5G Communication Setup

This subsystem sets up a secure 5G communications infrastructure in the PHIL system that addresses particular real-time control needs in the PHIL environment. Team members deploy the 5G installation and install relevant modems onto the PHIL hardware. As fully operational, it tests the communications system for determinations regarding its latency, jitter, and overall performance. This subsystem enables wireless low-latency, high-speed data transfer that will be invaluable with future-smart grid use, where the use of fixed wired configurations is unworkable or limiting.

Subsystem C: System Integration

Following the installation of the individual components, this subsystem is responsible for integrating them into a single testbed. It ensures that UDP communication links between grid emulation hardware and the DGs are accurately set up in order to enable bidirectional data flow. Control logic which is responsibility of frequency control is tested and implemented during this stage. This Integrationn becomes the operational core of the project that ensures the system elements' interaction correctly under real-time conditions, with wired and 5G communication channels.

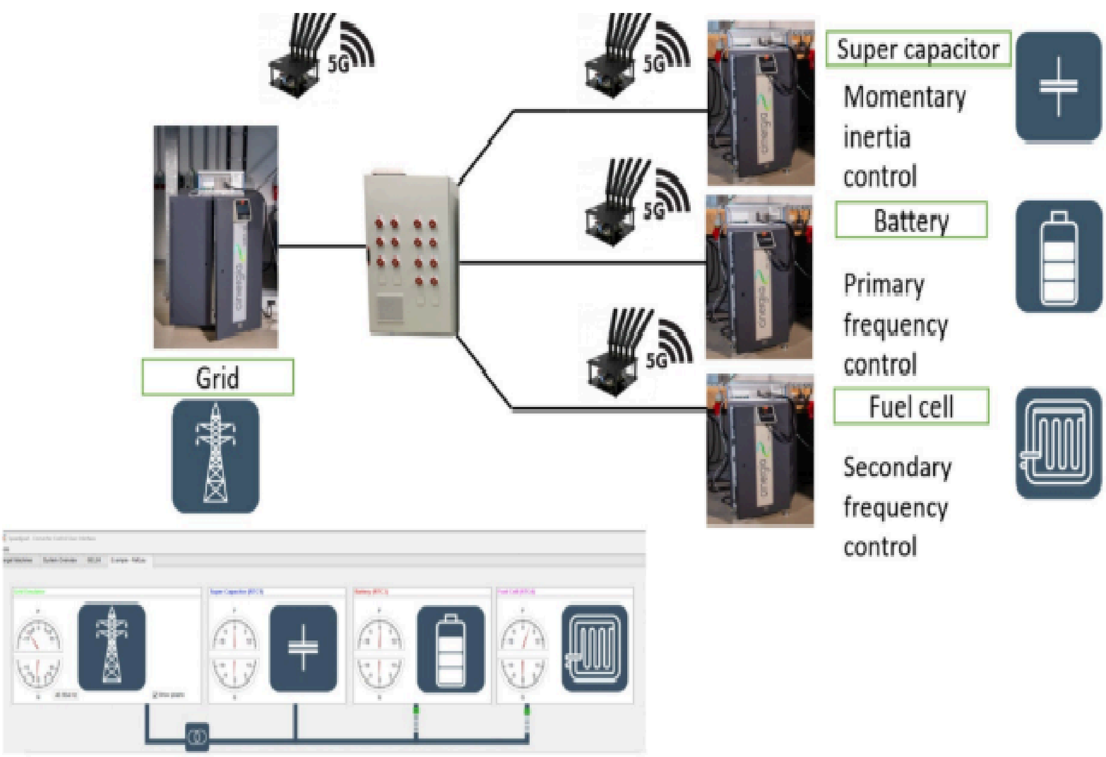

Figure 1: Setup for the Grid voltage control in the PHIL laboratory

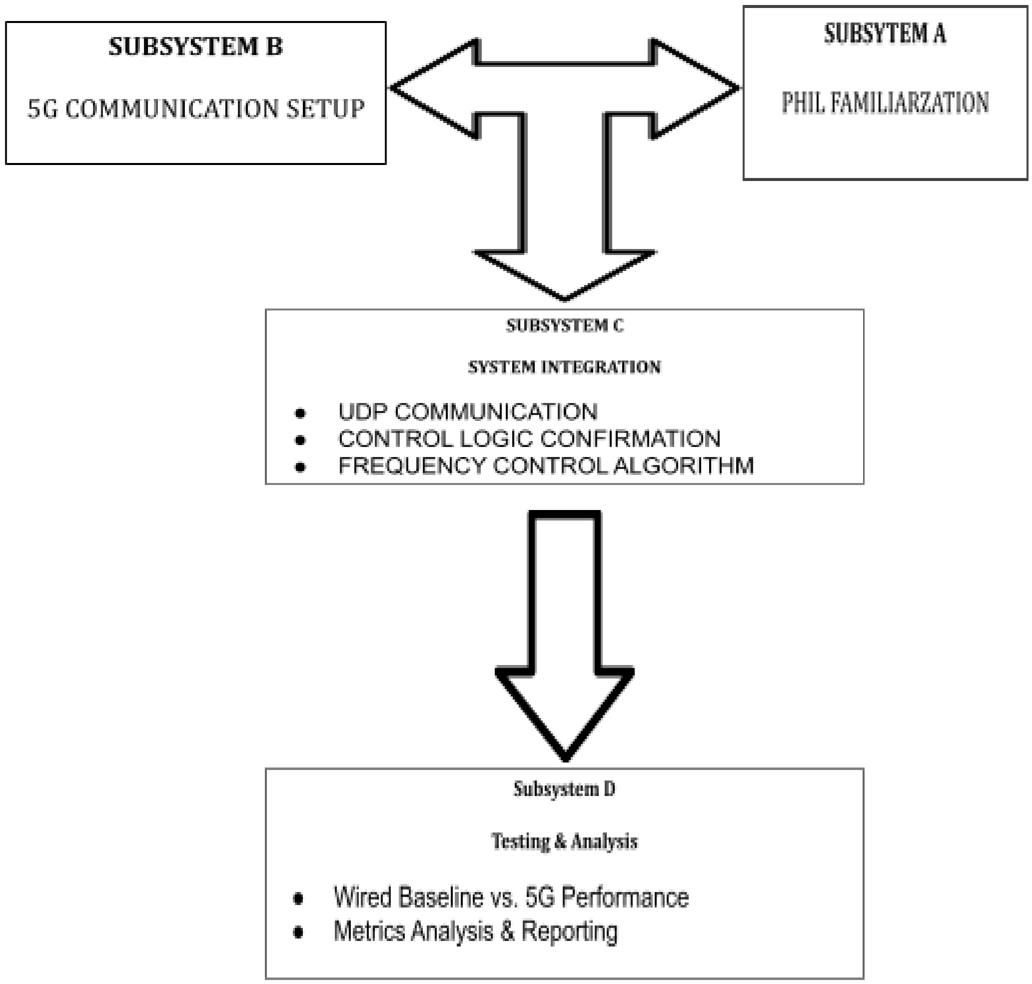

Figure 2 : Flowchart of Subsystems

Subsystem D: Testing & Analysis

The final subsystem tests the performance of the overall setup by systematic experimentation and data analysis. The system is tested under both wired and 5G communication setups to see how they perform. Latency, control stability, and system reliability are the parameters compared. The results are used to test the feasibility and effectiveness of using 5G for grid frequency control. This subsystem terminates by producing an integrative report which provides the results and advantages and limitations of the methodology being followed.

Subsystem		Function	Task	
A	PHIL Lab Familiarization	Understand the demo setup including PHIL lab components, RTCs, DG units, and the Matlab/Simulink environment.	TA1	Study the PHIL lab documentation and hardware setup.
			TA2	Explore the Matlab/Simulink models used for system control.
			TA3	Test individual DG units and RTC integration.
B	5G Communication Setup	Implement and validate the 5G communication interface for the demo setup.	TB1	Study the 5G module interface and configuration.
			TB2	Test 5G network slice setup for communication.
			TB3	Defining the variables to be communicated from the RTCs by using topics.
			TB4	Test the 5G network setup after adding delay blocks.
C	System Integration	Integrate all components and test the overall frequency control loop.	TC1	Implement the frequency control scheme across distributed RTCs with delay blocks.
			TC2	Integrate communication and control systems.
D	Testing and Analysis	Analyze and compare results, and prepare documentation.	TD1	Evaluate system performance with both communication systems with and without delays in both simulation and hardware.
			TD2	Evaluate different topologies like Centralized, Decentralized and Distributed systems.
			TD3	Document setup, testing procedures, and findings.
			TD4	Prepare final project report and presentation.

Table1 : Functions and Tasks associated with subsystems

3. Task Organization

The project is structured into four main subsystems that follow a logical progression from setup to testing. The working plan has been designed to maximize efficiency through parallel task execution where possible, while maintaining necessary dependencies between subsystems.Initial Phase focuses on parallel foundational work. Subsystem A begins with equipment familiarization in the PHIL laboratory (TA1), while Subsystem B simultaneously initiates the 5G communication setup (TB1). This concurrent approach allows both technical areas to advance without delays.

Development Phase sees more specialized work. Subsystem A progresses to advanced Simulink model training (TA2), while Subsystem B conducts critical performance testing of the 5G network (TB2-TB3). During this period, Subsystem C commences integration work (TC1), establishing the crucial UDP communication links between system components.

Integration Phase represents the project's technical core. Subsystem C completes the implementation of frequency control logic (TC2), ensuring all components interact correctly under both wired and 5G configurations. This phase demands careful coordination as it builds upon the completed work of both Subsystems A and B.

Final Testing Phase provides comprehensive evaluation. Subsystem D executes a structured testing regimen (TD1-TD4), comparing system performance across key metrics like latency and stability. The extended duration allows for thorough data collection and analysis under various operating conditions. The total project timeline spans approximately 60 days. This structured yet flexible approach ensures all technical objectives are met while allowing for necessary iterations. The plan's emphasis on parallel task execution in early stages helps mitigate potential bottlenecks later in the project lifecycle. Each phase flows logically into the next, with clear handoff points between subsystems to maintain project momentum.

Subsystem	**SLOT 1**	**SLOT 2**	**SLOT 3**
Subsystem A	TA1	TA2	TA3
Subsystem B	TB1	TB2,TB3	TB4
Subsystem C	TC1	TC2	
Subsystem D	TD1	TD2	TD3
			TD4

Table2: Ordering for different tasks

SLOT 1	**SLOT 2**	**SLOT 3**
Subsystem A	Subsystem C	Subsystem D
Subsystem B		

Table3: Order in which each subsystem has to be addressed

4. Working Plan:

TASK	**DURATION**
TA1=TB1	3 Days
TA2= TB2 = TB3	5 Days
TA3= TB4	8 Days
TC1 = TC2	14 Days
TD1 = TD2	12 Days
TD3	3 Days
TD4	5 Days

Table 4: Proposed duration for each task.

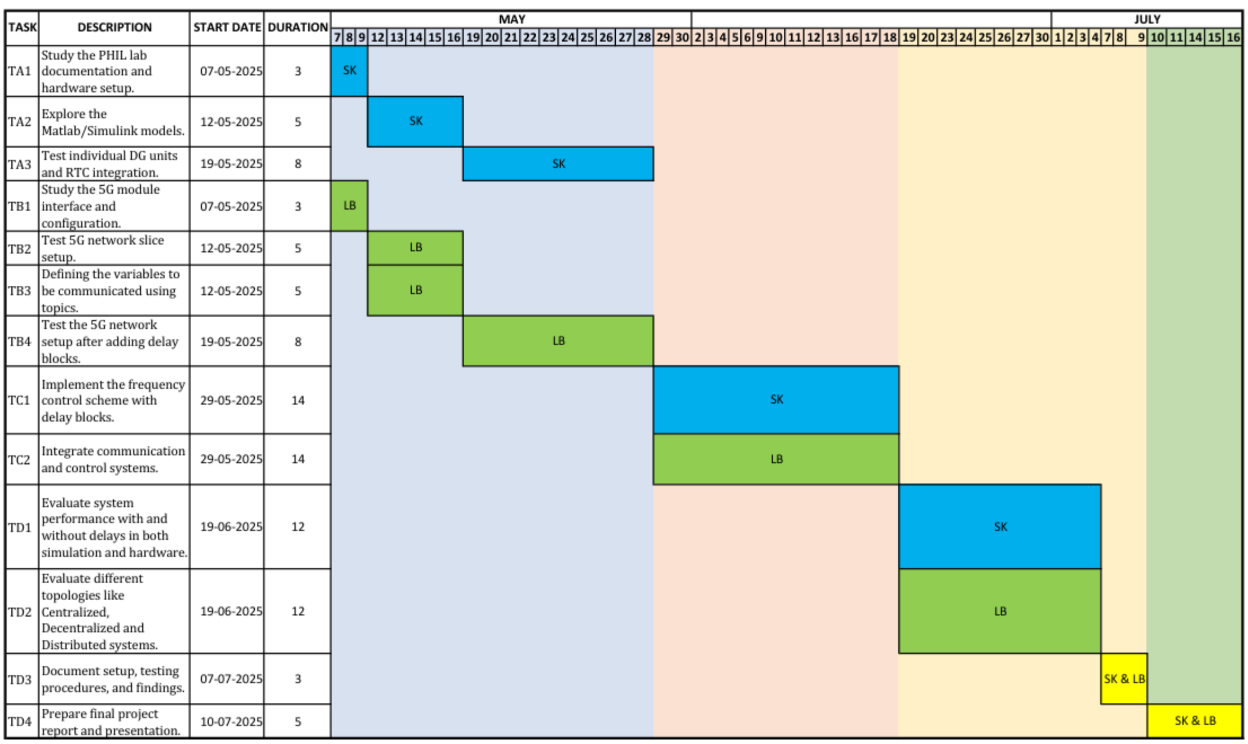

Figure3: Example of a working plan

Note on Timeline:

- Weekends excluded – All durations are based on working days (Mon-Fri).
- Buffer included – Additional time (10-15%) added for contingencies.
- Critical tasks prioritized – Integration & testing phases have extra flexibility.
- Total duration – ~30 working days (~6 calendar weeks).