Offshore wind energy integration via liquid air energy storage system

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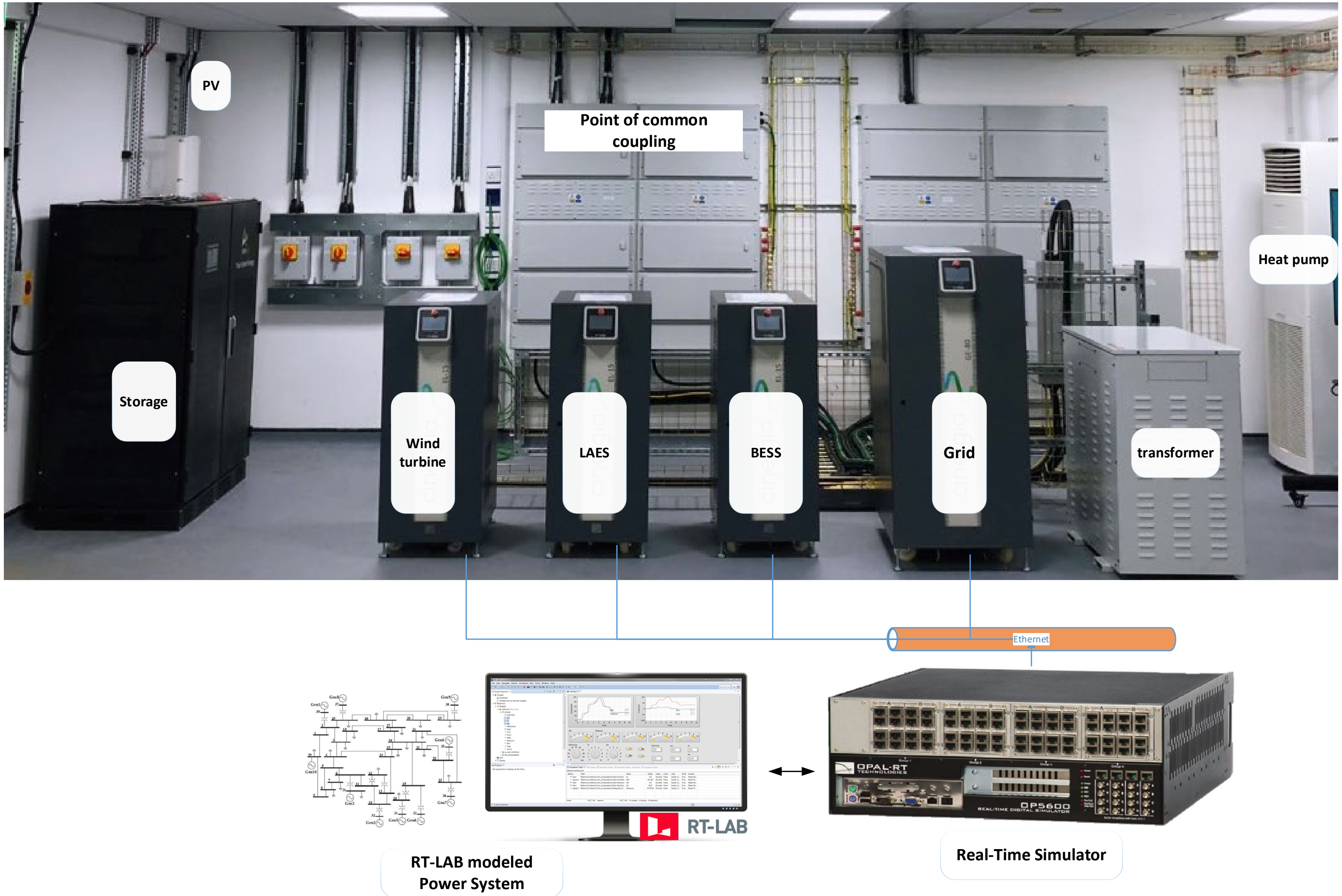
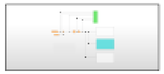
September 2022

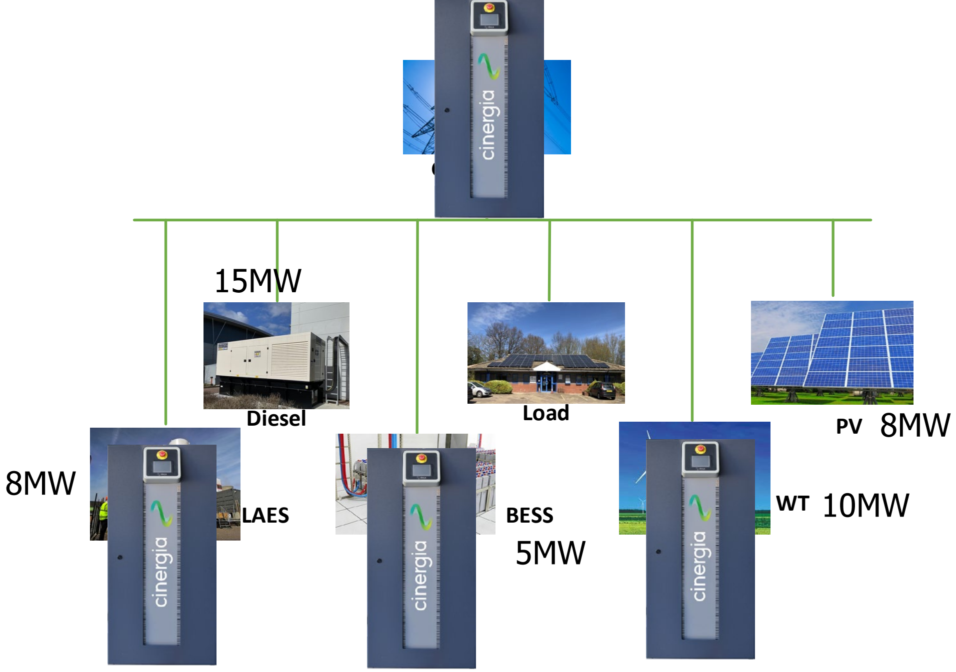
Real-Time HIL test rig at ICSE, University of Warwick

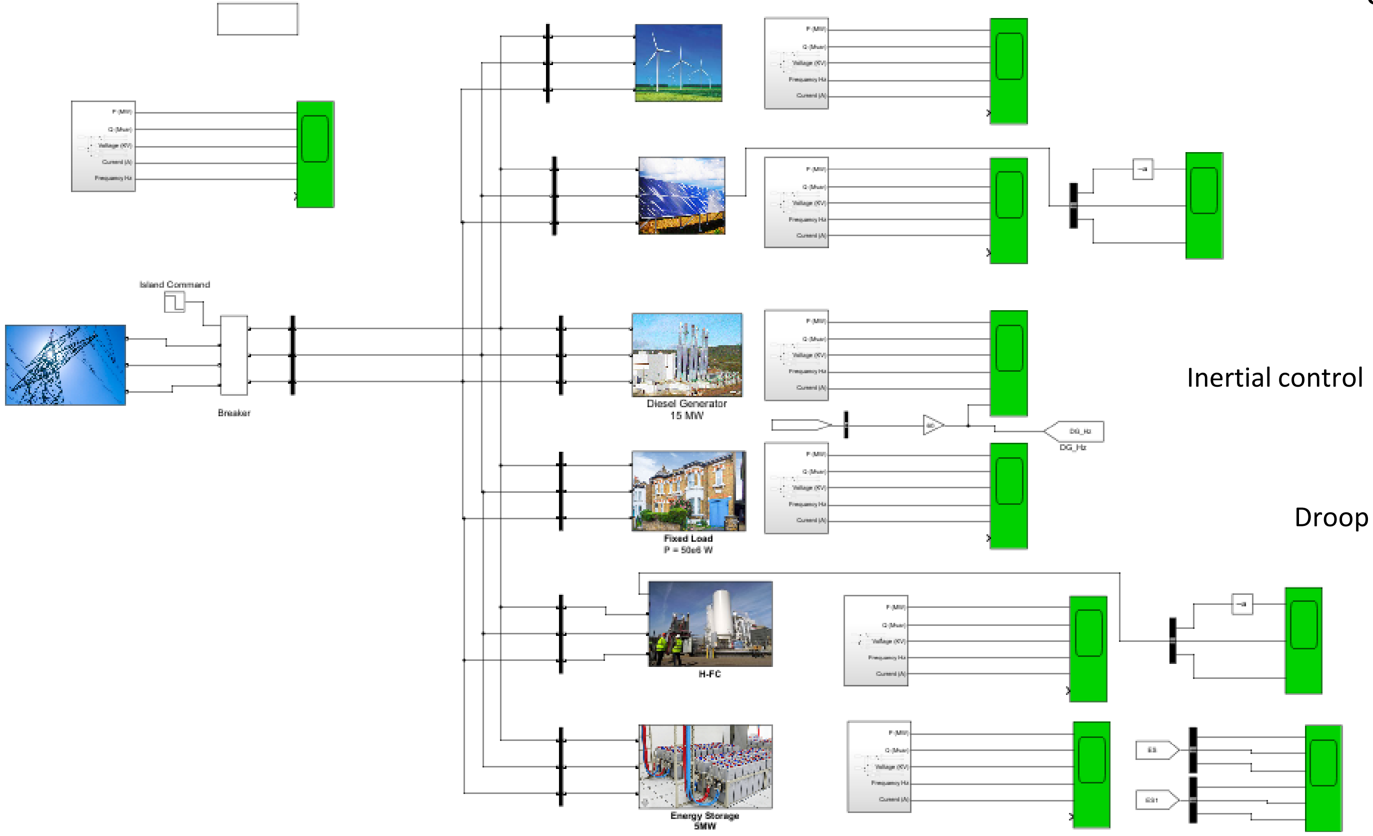


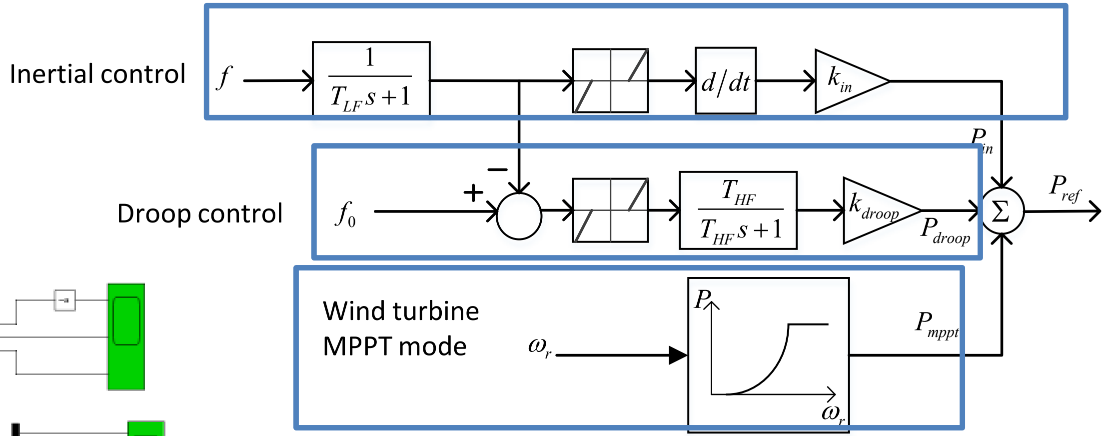
PHIL test of wind-LAES-BESS frequency control

- Inertial control and droop control schemes used on RES systems
- Wind energy, LAES, Battery Energy Storage used to provide frequency control
- Communication protocol: Modbus



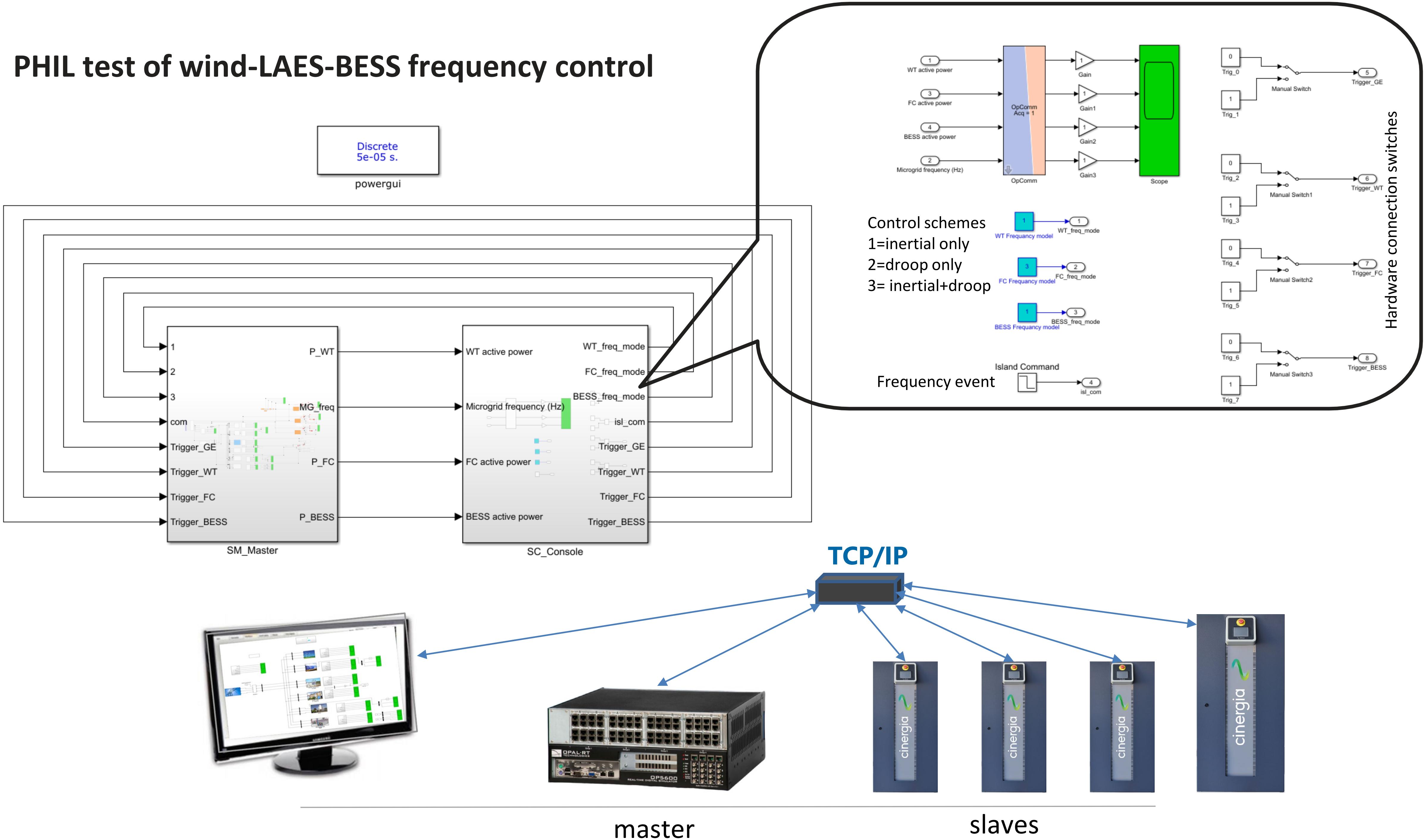




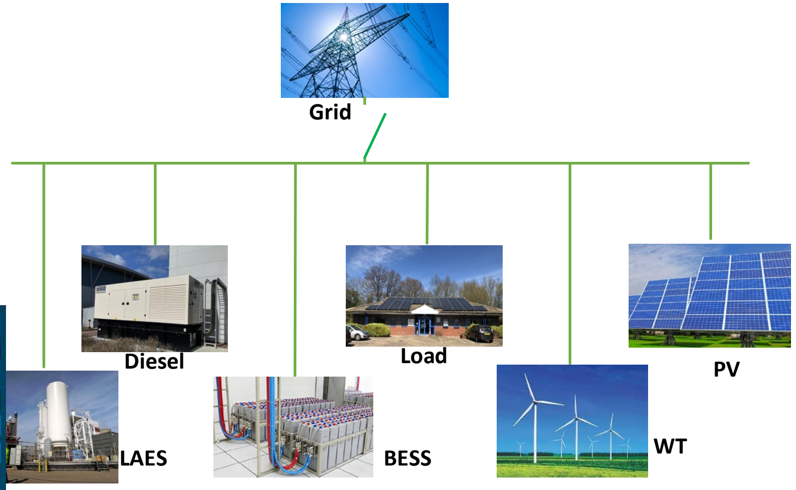


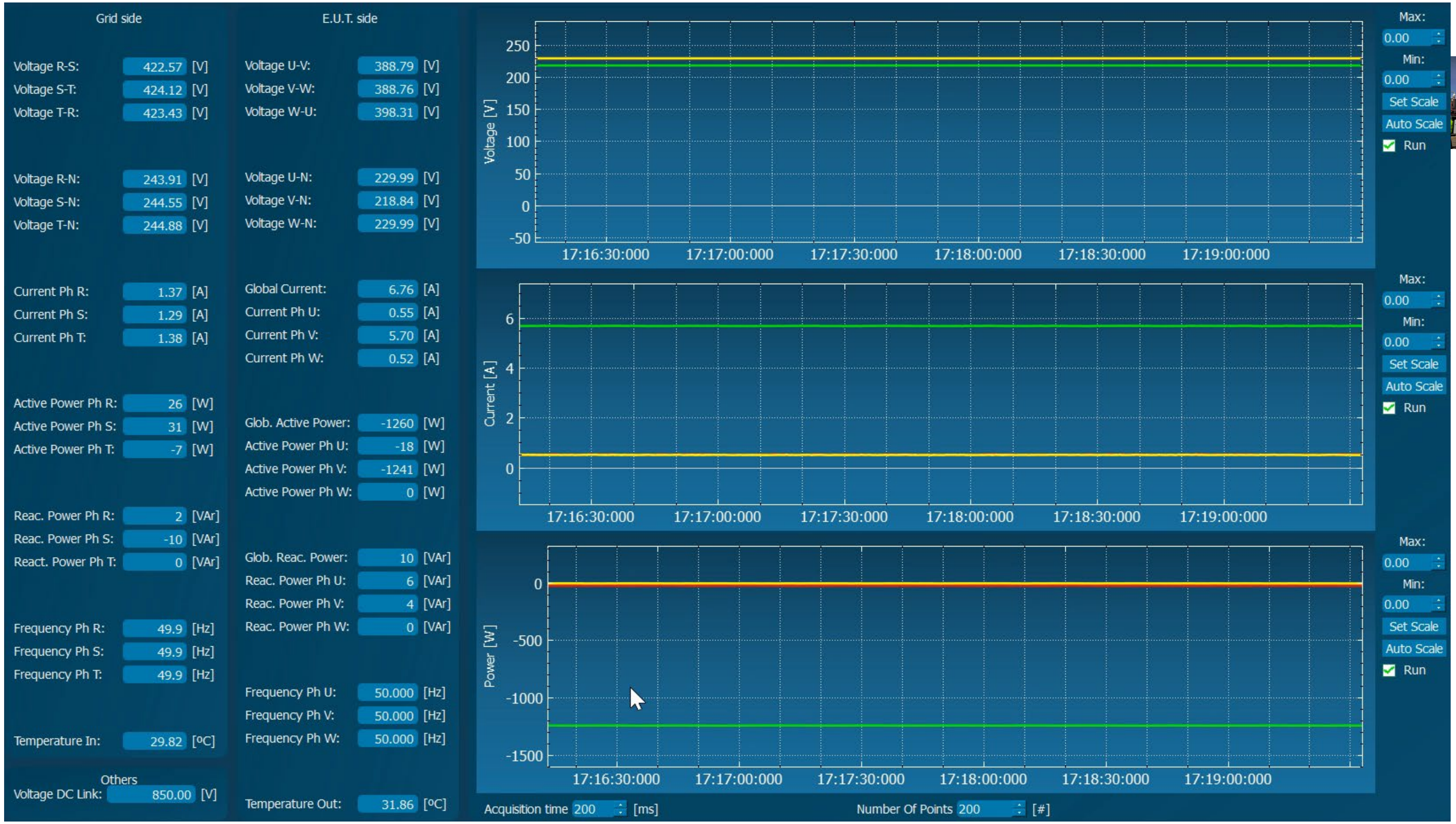
Inertial and droop control scheme for frequency control

PHIL test of wind-LAES-BESS frequency control



Real-Time test results



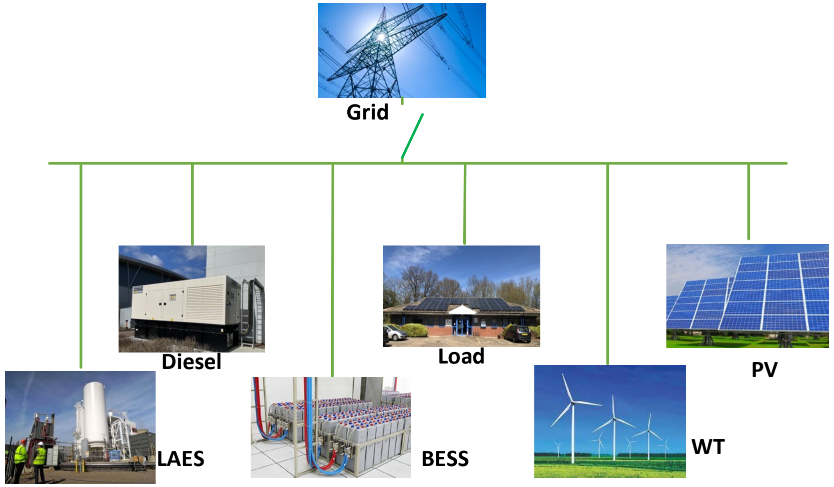


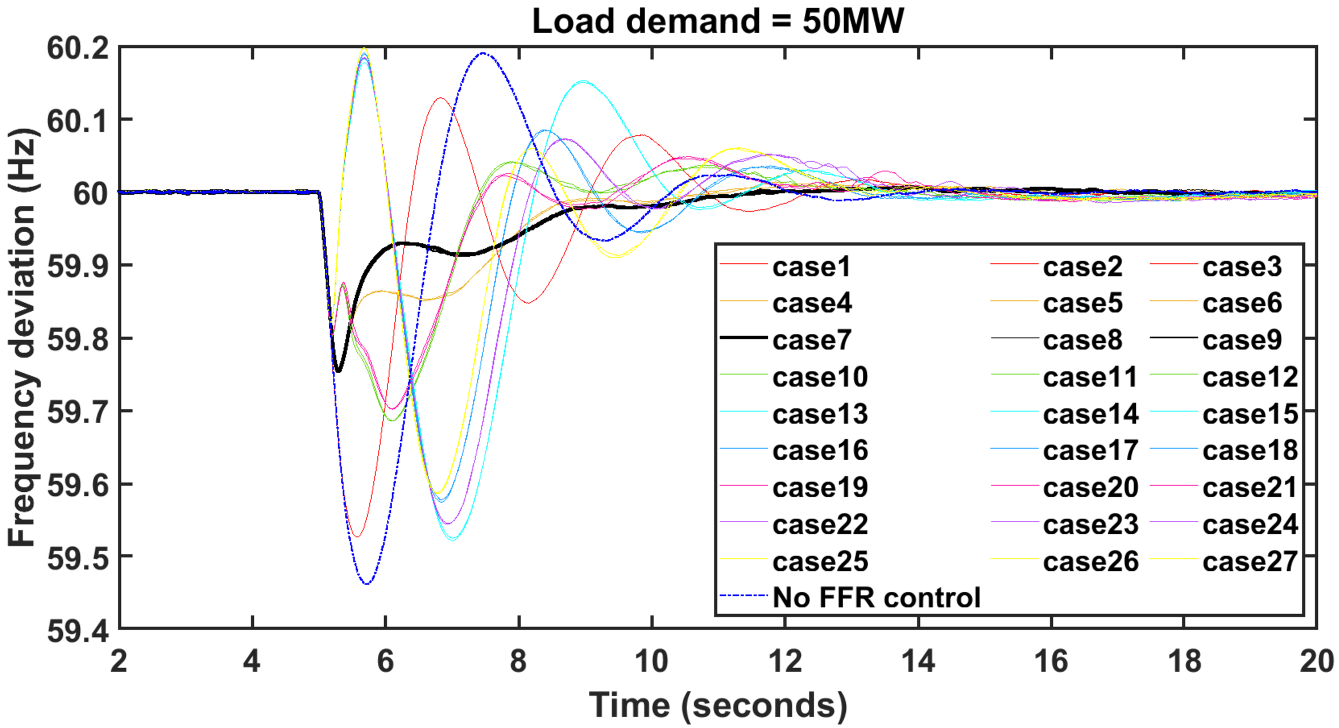
Frequency control using:

WT: inertial control
LAES: inertial+droop control
BESS: inertial control

Real-Time test results

Case no.	WT	H-FC	BESS	Frequency Nadir (Hz)
1	inertia	inertia	inertia	59.526
2	inertia	inertia	droop	59.526
3	inertia	inertia	inertia-droop	59.526
4	inertia	droop	inertia	59.754
5	inertia	droop	droop	59.754
6	inertia	droop	inertia-droop	59.754
7	inertia	inertia-droop	inertia	59.754
8	inertia	inertia-droop	droop	59.754
9	inertia	inertia-droop	inertia-droop	59.754
10	droop	inertia	inertia	59.685
11	droop	inertia	droop	59.685
12	droop	inertia	inertia-droop	59.685
13	droop	droop	inertia	59.524
14	droop	droop	droop	59.521
15	droop	droop	inertia-droop	59.521
16	droop	inertia-droop	inertia	59.577
17	droop	inertia-droop	droop	59.574
18	droop	inertia-droop	inertia-droop	59.574
19	inertia-droop	inertia	inertia	59.701
20	inertia-droop	inertia	droop	59.702
21	inertia-droop	inertia	inertia-droop	59.702
22	inertia-droop	droop	inertia	59.543
23	inertia-droop	droop	droop	59.544
24	inertia-droop	droop	inertia-droop	59.544
25	inertia-droop	inertia-droop	inertia	59.587
26	inertia-droop	inertia-droop	droop	59.585
27	inertia-droop	inertia-droop	inertia-droop	59.585





M. Kheshti, X. Zhao, T. Liang, B. Nie, Y. Ding, D, Greaves, “Liquid air energy storage for ancillary services in an integrated hybrid renewable system” *Renewable Energy*, vol. 199, pp. 298-307, Nov 2022

Outcome

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Acknowledgement

This work was supported by Supergen Cross Hub Seedcorn Fund

Thank you!

Renewable Energy 199 (2022) 298–307

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Liquid air energy storage for ancillary services in an integrated hybrid renewable system

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ARTICLE INFO

Keywords:
ancillary service
Fast frequency response
Hybrid renewable sources
Liquid air energy storage
Microgrid
Wind energy

ABSTRACT

High shares of intermittent renewable sources cause volatile frequency movements that could jeopardize the continuous operation of the grid. Liquid Air Energy Storage (LAES) is an emerging technology that not only helps with decarbonisation of energy sectors, but also has potentials for reliable ancillary services. In this paper, a hybrid LAES, wind turbine (WT), and battery energy storage system (BESS) is used to investigate their contributions in fast frequency control. The inertial control, droop control and combined inertial and droop terms are applied on each source of the hybrid renewable system and a comprehensive analysis is conducted to study their impacts on the frequency nadir improvement. The analysis shows that LAES with combined inertial and droop control terms along with inertial control of WT and BESS provide reliable frequency control. To further improve the frequency nadir, a Fuzzy control is proposed and applied on the LAES. The proposed control system provides a more adaptive performance against disturbances. Also, experimental tests are conducted to validate the proposed control method using a real-time hardware-in-the-loop test rig. The simulation and experimental results show that LAES in a hybrid renewable system can significantly contribute to the frequency control when variable gain control schemes are implemented.

1. Introduction

With the emerging concerns on the global warming, there has been an unprecedented push towards decarbonisation. The UK government has set policies and commitments to decarbonise the UK electricity system by 2035. In this regard, the coal-based power plants will be phased out from the electricity network by October 2024 [1]. According to the British energy security strategy, 50 GW offshore wind power capacity will be accommodated into the electricity network, as well as production of 10 GW hydrogen by 2030, alongside large-scale and long-duration compressed air energy storage to achieve increased system flexibility [2]. Hybrid renewable energy sources (RES) have been put into development and operation as the key enablers to reach net zero targets. Around 90% of the global power capacity expansion between 2021 and 2022 has come from renewables [3,4].

Large shares of RESs into the power system cause reduction in the system inertia, where grid frequency movements become more volatile and unpredictable [5,6]. In particular, where the power system is small or even in the microgrids, ancillary service support from hybrid RESs along with energy storage technologies is essentially required. Battery energy storage (BESS) as a competitive solution, provides fast power response and with short duration storage up to 4h [7]. However, they remain unfavourable due to high maintenance costs, short life cycle and degradation in performance with aging [8,9].

Other forms of maturely developed large-scale energy storage technologies such as pump hydro energy storages (PHES) [10] and compressed air energy storage (CAES) [11] are restrained by the geographical locations. For PHES, water will be stored in an elevated reservoir, it is the most widely adopted electrical storage technology due to its low cost (5–100 \$/kWh), high efficiency and high technology readiness level [12], but is limited by geographical requirements. The compressed air energy storage requires underground caverns and costly high-pressure vessels, which has relatively high efficiency (up to 70%) with low cost (20–200 \$/kWh) [17]. But these storages have low energy densities and require large storage volumes [27]. Therefore, low-cost, long-duration and geographically unconstrained grid-scale energy

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https://doi.org/10.1016/j.renene.2022.09.010
Received 7 June 2022; Received in revised form 29 August 2022; Accepted 2 September 2022
Available online 8 September 2022

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