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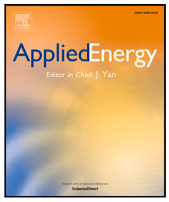

Real-time co-simulation of transmission and distribution networks integrated with distributed energy resources for frequency and voltage support

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ABSTRACT

This paper proposes a real-time co-simulated framework to experimentally validate the dynamic performance of network-level controllers in power systems. The experiment setup includes the coordinated emulation of a transmission network linked to a distribution feeder and real distributed energy sources, working in a multi-platform and multi-manufacturer environment. The operation of an optimal hierarchical controller for voltage and frequency support of the transmission network, which exploits the power injection from battery energy storage systems (BESS), is investigated to demonstrate the feasibility, accuracy and effectiveness of the proposed setup based on a co-simulation environment. The results of different study cases implemented in the laboratory are presented, where a successful interconnection between real-time emulators and real hardware from different manufacturers was realised. The fast and timely response of the controller to disturbances caused by sudden load changes, three-phase faults and renewable generation losses is experimentally validated. Finally, the robustness of the developed test bench against noise and harmonic distortion of real signals is also demonstrated.

1. Introduction

Carbon emissions are the primary source of global warming. Agreements such as COP26 encourage the abandonment of fossil fuels as energy sources, promoting the massive integration of renewable power plants in modern electrical systems [1,2]. However, the high penetration of power electronics-based energy sources drastically impacts the stability and reliability of traditional control schemes on a millisecond time scale [3,4]. As a result, the development of advanced control schemes that take advantage of the capabilities and flexibility of electronic converters and energy storage systems to promptly support the grid is a growing concern for researchers and system operators [5–8].

The recent trend towards digitisation and integration of distributed energy resources in power networks has created a promising research field to analyse the impact of new actors on frequency and voltage deviations [9,10]. Actors such as smart measuring devices, multiple power sources, rapidly changing loads, new protection systems, among others, as depicted in Fig. 1. Unlike other disciplines, where impact analysis of new equipment and controllers is performed directly on real systems, testing of new assets or control strategies in electric power systems can be extremely unsafe or, in some cases, unfeasible to perform [8,11,12].

For this reason, real-time simulations (RTS) with power hardware-in-the-loop (PHIL) are a cost-effective, low-risk and highly repeatable alternative for experiments in electrical power systems [13]. This simplifies the validation process and allows parameter fine-tuning of the control architectures. Furthermore, the co-simulation between transmission and distribution networks in RT platforms with PHIL is useful to analyse critical operating conditions interacting with real hardware. However, these test environments require additional considerations for handling the non-ideal conditions, like noise and harmonic distortion, present in actual signals, which imposes additional challenges compared to offline simulations [14,15]. In this context, real-time co-simulation setups with real interaction of distributed energy resources (DERs) are imperative to better understand the short-time dynamics of modern power systems [7].

A comprehensive comparison of various real-time co-simulation approaches for transmission and distribution (T&D) networks is presented in Table 1. In [16], a simultaneous strategy for frequency support in transmission networks and voltage control in distribution feeders

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