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Summary: In modern electric power systems there are thousands of control devices, spanning from low-voltage distribution networks, that manage the energy flows, ensure secure operation, and stabilize the system, to high-voltage applications that control the operation of generators. Time-domain simulations are most frequently used to analyze the performance and assess the impact of controllers on the electricity grid. In recent decades, all the new controllers introduced in electric power systems are digital controllers and their analog counterparts are gradually being replaced. Nevertheless, many of the most frequently employed controllers are still modeled as analog (continuous) systems in time-domain simulations. This approach introduces a discrepancy between the real response of digital controllers and the simulated one. In this paper, we investigate the impact that correctly modeling digital controllers has on simulation accuracy and performance.

Digital controllers modeled either through their difference equations or even their actual control code incorporated into the power system DAE model leads to a hybrid DAE system that is computationally intensive. Specifically, their discrete nature results in numerous discrete time events (interruptions) in the simulation process, stagnation, and a limitation of the time-step size to the time between control events. Moreover, the hybrid nature of the system makes it impossible to use many of the classical analysis methods.

A frequently used approach to overcome the challenge is to employ a continuous equivalent of the digital controller [1]. This approach alleviates the time events and allows the use of classical analysis methods such as variable time-step methods that significantly accelerate the simulation performance. However, capturing the accurate response of digital controllers, along with their Analog-to-Digital (ADC) and Digital-to-Analog converters (DAC), in a continuous DAE simulation is difficult. In addition, the analog representation of digital controllers might conduct artificial problems that might not exist in the real system due to the Zero-Order-Hold (ZOH) time delays introduced. For instance, deadlocks in the simulation due to the limits imposed on controller variables – as in the case of the IEEE Anti-Windup (AW) controller shown in [2–4] – can arise. Another challenge is that not all digital controllers (e.g., optimization-based, artificial intelligence, etc.) have straightforward analog, equation-based, equivalents.

To address these challenges and provide insight into the modeling requirements for digital controllers, this paper:

- Investigates the challenges of modeling digital controllers in power system dynamic simulations.
- Investigates the impact of the sampling time of digital controllers on the power system dynamic results.
- Provides a comparison and discussion on the accuracy, modeling, and performance of digital controllers against their continuous equivalents.
- Investigates the impact of modeling on the deadlock situations observed in the IEEE AW PI model.

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