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Application of analog and hybrid computation methods to fast power system security studies

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ABSTRACT

In analog emulation, a non-linear system model is implemented as a set of reconfigurable analog circuits referred to as the emulator. This hardware is actuated, initialized, and allowed to settle to a steady-state during which time the user utilizes voltage and current measurement devices to observe the system's transient response and constrained static solution. Because this method abandons the use of iterative numerical techniques, the length of time required to emulate a solution (this excludes the effects of actuation and data acquisition) is fully controllable and independent of the dimension of the system model. Analog computation has potential to perform many types of non-linear analyses significantly faster than is possible digitally; however, its popularity has traditionally been limited by a need for manual actuation and data acquisition. In this work, the authors examine the use of digital technology to automate actuation and data acquisition for emulation. They also discuss how intelligent design and control of the emulator may be utilized to minimize data collection and accelerate emulation-based power-flow analysis and system security studies.

1. Introduction

The term computer is used to describe any electronic device designed to accept data, perform prescribed mathematical and logical operations at high speed, as well as display the results of these operations. The modern digital computer, as a result of advances in personal computing technology, performs all three of the above-mentioned tasks efficiently.

In engineering and the sciences, digital computers are often utilized to predict the behavior of a non-linear system through simulation: a software implementation of iterative numerical techniques like the Newton–Raphson [1,2]. And although this method yields precise results, the length of time required to simulate a solution is dependent on the number and complexity of these expressions [3].

For the same purpose, analog computers use emulation. In it, a non-linear system model is implemented as a set of reconfigurable analog circuits referred to as the emulator [6]. This hardware is then actuated, initialized, and allowed to settle to a constrained solution. The user acquires results through observation of this hardware via voltage and current measurement devices. One may ask: Is it worth the additional effort associated with hardware design and construction to perform analyses (e.g. contingency) via analog emulation which may be performed digitally? The authors hypothesize that the answer is "yes." Because analog emulation abandons the use of iterative numerical techniques, the length of time required to yield a solution (this excludes the effects of actuation and data acquisition) is fully controllable and independent of the dimension of the system model [7]. Analog computation has potential to perform many types of non-linear analyses significantly faster than is possible digitally; however, its popularity has traditionally been limited by a need for manual actuation and data acquisition [7–9].

One example is power-flow analysis, the results of which are essential in the evaluation, control, and planning of an electric power network. This analysis provides a comprehensive description of the system state as well as complex power flow at each network bus and along each transmission/distribution line [1,10]. For security studies, a collection of practices designed to keep the system operating when components fail, access to frequently updated power-flow results is important [11,12]. This is problematic because terrestrial power systems are typically very large, and for such systems fast power-flow analysis via simulation requires expensive and highly parallel digital hardware [7,13].

Because of its speed, analog emulation is well suited for fast power-flow analysis and especially advantageous over simulation for the power system security studies [14,15]. In this paper, the authors discuss:

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