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Circuit-Based Electromagnetic Transient Simulation

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Contents

Circuit-Based Electromagnetic Transient Simulation

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ABSTRACT

The growing penetration of inverter-based resources and associated controls necessitates system-wide electromagnetic transient (EMT) analyses. EMT tools and methods today were not designed for the scale of these analyses. In light of the emerging need, there is a great deal of interest in developing new techniques for fast and accurate EMT simulations for large power grids; the foundations of which will be built on current tools and methods. However, we find that educational texts covering the fundamentals and inner workings of current EMT tools are limited. As such, there is a lack of introductory material for students and professionals interested in researching the field. To that end, in this tutorial, we introduce the principles of EMT analyses from the circuit-theoretic viewpoint, mimicking how time-domain analyses are performed in circuit simulation tools like SPICE and Cadence. We perform EMT simulations for two examples, one linear and one nonlinear, including induction motor (IM) from the first principles. We anticipate that by the end of this monograph, the readers will have a basic understanding of how power grid EMT tools work.

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Introduction

This monograph is a tutorial to help students and working professionals learn the inner workings of tools that perform electromagnetic transient (EMT) simulations. The tutorial uses a circuit-theory based approach to EMT simulation. The tutorial is introductory in that it shows the workings through two simple examples and expects the reader to build expertise through more detailed readings. Nonetheless, this monograph is an excellent first step for anyone interested in the subject, especially those interested in building their own tools.

Before we dive into EMT models and simulation, it is pertinent to discuss and differentiate between the two types of commonly performed time-domain simulations in the power community:

- **Transient Stability (TS):** Performs time-domain simulations on balanced networks (only positive sequence components). It does not include network impedance transient response and models them moving from one steady state to another instantaneously. Therefore transient stability frameworks model the network constraints with algebraic equations and only model the injection components and controls with differential algebraic equations. TS is also sometimes called root-mean-squared (RMS) transient analysis. These have been traditionally the workhorse for system-wide time-domain power grid analysis.

- **Electromagnetic Transient Simulation:** Works exactly as circuit-simulation tools (for instance, SPICE and CADENCE). It models all three phases, including the transient response for the network impedance components. The industry demand for large-scale EMTs is growing rapidly due to the recent events involving power electronics devices.

This monograph focuses on electromagnetic transient simulation. These are becoming increasingly common (with significant active research) due to the introduction of inverter-based resources on the grid. The monograph provides a step-by-step tutorial on performing an EMT simulation for simple networks from the first principles. It uses concepts from circuit simulation, Newton-Raphson, and numerical integration with difference methods. Good references to brush up on these topics are [9], [4], and [1]. The monograph does not discuss modeling controls in EMT but provides sufficient background such that it can be tackled as the next step.

Furthermore, this monograph uses modified nodal analysis (MNA) and sometimes loop analysis to encapsulate network physics. Other alternate approaches like Tree Link Analysis (TLA) and Sparse Tableau Analysis (STA) [9] exist but are not covered in this monograph. In naive nodal analysis, the currents at each node are summed to zero (i.e., Kirchhoff's current law) to satisfy network physics. However, the method fails when the network includes voltage sources, as the current through the voltage source is not implicitly known. Therefore, to include voltage sources, the modified version adds one additional constraint per voltage source to the set of nodal equations. These additional constraints give us the currents through the voltage sources as new variables. The term *modified* in MNA refers to this modification. Finally, the readers must note that anytime in this monograph when they come across the following terms: system matrix, Y matrix, solution matrix, or simple nodal matrix, these all refer to the same thing: a set of nodal or loop equations (or sometimes a mix) for the linearized network that is being evaluated at a given time-step t.

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