Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-27 (2016) 178–182

The Role and Importance of Real Time Digital Simulation in the Development and Testing of Power System Control and Protection Equipment

Rick Kuffel*, Paul Forsyth*, Cyprian Peters*

RTDS Technologies Inc. Winnipeg, Canada

Abstract: In the past several decades there have been many advances made in power system technology. In order ensure the protection and control equipment used in the operation of power systems behaves as designed, advanced real time simulation and testing tools are utilized. As the industry adapts to the presence of high speed, sophisticated and interactive components, the role and importance of real time simulation is increased.

Keywords: real time simulation, EMT, HIL, WAMPAC, HVDC, VSC, MMC

1. INTRODUCTION

Over the past several decades electric power systems have changed and evolved substantially. With increasing pressure to improve economic efficiency and reduce environmental impact, today's networks are being pushed ever further towards the boundaries of stability and safe operation. To counteract these pressures, utilities are adding sophisticated new schemes and devices to their networks. Real time digital simulators have become a critical tool for utilities and manufacturers in this demanding and dynamic environment. It has become common place for manufacturers and utilities to utilize real time digital simulation to support their efforts in the study of power behavior/operation, the closed-loop testing of new equipment, and the strategic development of new protection and control functions.

This paper will describe the concept of real time digital simulation and illustrate how it is being applied to support the development and continued operation of today's modern power systems. In particular, it will focus on application of such technology in the development, testing and implementation of protection and control schemes used throughout the industry.

2. REAL TIME SIMULATION

Simulation has played an important role in the evolution of power systems into the modern, complex networks we see today. Before digital simulation was developed, analogue simulators, or **T**ransient **N**etwork **A**nalyzers (TNA's) were used to study electrical power systems and test physical protection and control equipment. These simulators were mainly composed of scaled-down physical models of power system components, and inherently operated in real time. Although they were important tools at their time, they did have several drawbacks. The limited size and complexity of the network representation, as well as the high procurement and operating costs, were among the notable disadvantages of this technology.

In the late 1960's, the digital electromagnetic transient simulation algorithm was developed and introduced by Dr. Hermann Dommel [1]. The algorithm applies the trapezoidal rule of integration to convert differential equations into linear algebraic equations that could easily be solved by a computer. This so-called EMT simulation technique has since been used in a number of non-real-time simulation programs such as EMTP, ATP and PSCAD.

It wasn't until the late 1980's that computer technology and modeling techniques had matured enough to make possible the *real time* digital simulation of power systems and the many complex components they include. The goal of real time digital simulation was to combine flexibility and accuracy of digital simulation techniques with the real time response of analogue simulators. Once achieved, this would bring a whole new level of accuracy and flexibility in the procedure used to design, implement and test power system control and protection equipment.

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.739

A digital simulator provides a discrete solution at different instances in time rather than the continuous waveforms measured in a real power system. However as the time separating the discrete solutions (referred to as the simulation timestep) becomes smaller, the simulation signals become more representative of a continuous waveform. A simulation timestep of 50 μs is an industry accepted target for accurate representation of a power system over a frequency range from DC to approximately 2-3 kHz. Such a frequency range is required for the proper testing of protection and control equipment. In fact some equipment (e.g. firing pulse controls for power electronic devices) will require an even faster response time, so even smaller simulation timesteps need to be considered. It should be clear that significant computing resources are needed to ensure the simulation can achieve and sustain real time operation and response. For this reason, specialized parallel processing architecture has been developed and used in the implementation of real time digital simulators. [2]

2.1 Network Representation

A fundamental requirement of a real time power system simulator is its ability to represent the various elements found in an actual network. Some of the more difficult and critical elements might include.

a) Transmission lines and cables
b) Synchronous and induction machines (generators/motors)
c) Distributed energy resources (wind, solar)
d) Transformers with saturation and tap changers
e) Instrument transformers (CT, PT, CVT)
f) Power electronics (e.g. FACTS and HVDC)
g) Controlled breakers and faults (many switches required)

Naturally it is important that models accurately represent the behaviour of the actual physical devices found in a network, but this is also not trivial. Nonlinearities are challenging to deal with using digital simulation and even more so in a real time digital simulation environment. For example, saturation effects and frequency dependent transmission line and cable models must be handled carefully to ensure not only accuracy, but also numerical stability.

2.2 Communication

The physical equipment (control/protection) being tested must communicate with the simulated power system in the same way it would while in service under normal and stressed conditions. That means voltages and currents measured and used by the protection and control must be actual sine waves which are at least proportional to the voltage and current signals that would be produced at the secondary terminals of Current and Potential Transformers (CT's and PT's). Typically digital to analogue (d/a) converters have been used by real time digital simulators to provide this type of output. A standard operating range of the d/a's is in the range of +/- 10 V. Depending on how the tests are being conducted and what signals are required, it may be necessary to amplify the analogue outputs using power amplifiers to produce secondary level voltages and current (typically 64 Vrms and 1 or 5 Arms respectively). Equipment interconnection also typically includes bidirectional exchange of digital signals to represent things like circuit breaker status, relay trip/reclose commands, firing pulses, etc. Digital signal exchange is normally accomplished using isolated, high speed digital input/output hardware.

In addition to the conventional input and output methods outlined above, it is also necessary for real time simulators to communicate using high level Ethernet based protocols. As the industry moves towards digital substations and introduces smart grid technologies, the ability to properly communicate and coordinate information between **I**ntelligent **E**lectronic **D**evices (IED) becomes an increasingly important aspect of real time simulator testing.

2.3 Protection and Control Models

Real time simulation tests of protection and control equipment range widely in terms of complexity. In some cases a single control or protection device may be connected to a relatively simple circuit model in order to study its behaviour over a predetermined set of contingencies. More typically however, in today's modern and complex networks, numerous devices should be considered simultaneously and the interaction between these devices must be reflected in the simulation study. Since the simulator user does not always have access to all of the physical control/protection devices needed for a particular study the simulator itself must contain internal models which can suitably reproduce the behaviour of the physical device. So-called generic component models must exist in the simulator library to allow this type of testing (i.e. where some of the control /protection equipment is physically connected and some is internally modelled).

3. CLOSED LOOP TESTING

To be effective as a testing tool, a real time simulator must be able to subject the equipment under test to any type of operating condition it will see when in service. This ranges from normal steady state operation, to emergency operation, to rarely seen fault conditions. During any study, device(s) under test continuously sense the output from the simulator and provide the corresponding feedback. This bidirectional connection is known as closed loop testing or **H**ardware **I**n-the **L**oop (HIL) testing. Figure 1 below illustrates the concept of HIL testing of an end-to-end line protection scheme using a traditional electrical interface including D/A Converters,