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Development of a real time simulator based on ATP-EMTP and sampled values of IEC61850-9-2

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ABSTRACT

This paper addresses the implementation of a real time simulator based on an existing electromagnetic simulating program called ATP-EMTP. The simulator is developed to stream sampled values on an Ethernet network using the protocol IEC61850-9-2. This implementation is done on a general purpose PC. The minimum simulation time step and the maximum sample rate achieved were 69 µs and 240 S/cycle respectively. The main components of the development as well as the evaluation of the performance of the simulator for different cases are described in this paper.

Introduction

During the past three decades, real time simulators (RTS) have been developed and used on power system analysis, rapid control prototyping, machine testing, and relay testing, among others [1–5]. According to the IEEE PES Task Force on Real-Time Simulation of Power and Energy Systems, RTS can be classified into two types [6]. The first type, a fully digital real time simulation, is a purely numerical simulator that does not include input/output (I/O) interfaces to interact with external devices. The second, called hardware in the loop (HIL), uses a hardware that performs a real time simulation including I/O interfaces (filters, digital-to-analog and analog-to-digital converters, and signal conditioners, among others) to interact with actual physical devices (e.g., protective relays, electric drives, controls, etc.) [7–10].

HIL-type RTS are composed of two main parts. One related to digital real time simulation of the power system and the other related to the I/O interfaces.

The digital simulation is made by very fast platforms composed, in general, of a high performance computing hardware, which represents dynamically the power system. This simulation uses fast numerical methods that guarantee a very short computational time. The most traditional methods used on RTS to reproduce electromagnetic transients are based on trapezoidal rule integration methods [11,12]. The main constraint of an RTS is that it needs to make its computation fast enough to keep up with real–world time [13,14]. If this aspect is not fulfilled during any time of the simulation, the results will present distorted signals compared to those obtained from real world systems [6,11]. Another aspect to take into account is the bandwidth of the simulation. The bandwidth defines the maximum time step of the simulation. To this end, the selected time step must be short enough to reproduce accurately the desired dynamic of the electric phenomena. Usually for a 2 kHz bandwidth, an RTS uses a time step within 30–50 µs [11,15].

The I/O interfaces of the RTS may vary depending on the applications to be used. Currently, most commercial RTS include, at least, digital to analog and analog to digital converters [16,17]. When the application is focused on relay testing, analog amplifiers capable of managing the typical current and voltages of the relay must be used [2,7]. This architecture allows keeping up low computation time and accurate analog signals; however, it makes them very expensive devices.

New trends in the automation of electric power systems, based on standard IEC61850 [18], use only digital signals, eliminating the need of the analog ones. As a result, the architecture of RTS used for relay testing has been simplified.

The standard IEC61850 [18] provides advantages on the levels of functional integration and flexibility of communications [19]. This standard has allowed the automation of power systems to

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be sped up, giving a common framework of communications between devices from different vendors.

One of the main components of the standard is based on the concept of the process bus. This bus is a high speed Ethernet which replaces the hardwire connection between the instrument transformers and control and protection equipment. One of the main tasks of the process bus is to stream digitally the current and voltage sampled values (SV) from merging units to multiple devices.

With this concept, most of the protective relays and other Intelligent Electronic Devices (IED) will not have analog interfaces for their operation. They only have to interact with digital signals through the process bus network to receive the SV and send operational messages based on IEC61850 protocols [20].

Taking advantage of the current computation capacity of personal computers, and current electromagnetic transient simulation packages, Wehrend [21], presents the theoretical concept for converting the Alternative Transients Program (ATP-EMTP) [22] software as a data generator for IEC61850 compatible IEDs. As a new contribution, this research presents the implementation of an RTS for relay testing using the same concept as that of Wehrend, but focusing on achieving real time characteristics on a general-purpose computer. This simulator is intended to interact with actual IEDs which handle IEC61850-9-2 [20]; therefore, it can be considered a low budget HIL-type RTS for research and testing purposes.

The paper is organized as follows: Section 'Implementation methodology' presents the description of the RTS implementation. Section 'RTS performance test' presents the RTS performance evaluation. Section 'Analysis of the results' shows the analysis of the results and comments. Finally, Section 'Conclusions' provides comments and conclusions.

Implementation methodology

ATP-EMTP – overview

The ATP-EMTP is widely used by the electrical engineering community as a specialized software intended to reproduce accurately the electromagnetic and electromechanical transients of complex power systems networks. This type of software is based on a very fast and stable numerical method named the trapezoidal integration rule [23]. With this method, it is possible to convert the differential equations into recursive equations. This representation provides a set of linear equations, which are easy to solve.

ATP-EMTP has extensive modeling capabilities of many different power system devices including non-linear elements, such as transformer cores and surge arresters, among others [24]. The software libraries also include models for electric machines, as well as transmission lines with and without frequency dependent parameters. Additionally, it is possible to implement custom models by means of proprietary programming language called MODELS [25].

MODELS is a very limited programming language for simple computations. Nonetheless, it can be linked to external functions or models named "*foreign-MODELS*", which can be written in high-level languages, such as C++, FORTRAN and C#, among others [25,26]. The foreign MODELS have to be linked with ATP-EMTP re-compiling the executable file.

Algorithm characteristics

In order to convert the ATP-EMTP into an RTS, it was necessary to implement a custom model using the MODELS language, which is called at every iteration of the simulation. Since the programming language of MODELS is limited to the required functions, a *foreign MODEL* was used to link with other advanced libraries to enhance time resolution. In order to maintain accurate time resolution, a library is written in C++ using a high resolution clock provided by the library *boost::chrono*, which allows a time resolution of nanoseconds. The accuracy of the clock relies on the PC clock.

The purpose of this model is to emulate a virtual Merging Unit (MU) as described by the standard IEC61850. This standard defines a Merging Unit (MU) as a device capable of accepting multiple inputs from CT/VT and switch status and of generating synchronized messages with the instantaneous SV to be transmitted according to IEC 61850-9-2 [18,27].

The model reads the voltage and current values calculated in each simulation iteration by ATP-EMTP, sends them through the Ethernet bus, and receives a message from the external device utilized for controlling a switch.

The algorithm of the model can be divided into three modules. The first module deals with reading and quantizing of the computed voltage and current at a specific time. The second one encodes the message, and sends it at a specific time in order to emulate a real sample rate. The third one deals with receiving the transmitted messages by the IED(s), and if necessary, changes the status of the switch. A simplified flow chart of the algorithm is shown in Fig. 1.

One of the most critical steps of this algorithm is given by the second module. This module has to assert that the execution time during each iteration is shorter than the defined sample rate. If it is shorter, a waiting routine is launched to synchronize the SV with real time. If the execution time is larger than the required time step, an overrun is detected, and a warning flag is set. In this case, the next simulation iteration must be performed in a shorter time than the time step in order to keep up the average sample rate.

In order to send the simulated information to external devices, the algorithm uses the SV protocol IEC 61850-9-2 [28] based on the implementation guide known as IEC61850-9-2LE [29]. This guide defines two types of sample rates, one of 256 S/cycle for measurement applications and one of 80 S/cycle for protection applications. Nonetheless, the sample rate is defined as 80 S/cycle, the simulation time step can be set shorter. For instance using a power frequency of 60 Hz, the time step can be set to 52.08 μs, 69.44 μs, 104.2 μs or 208.3 μs. It is preferable to use the shortest value that is capable of computing during this period to keep a better accuracy on the electromagnetic transient.

The SV protocol is based on a data link layer and the headers are defined in IEC 61850-9-2 [28]. The Ethernet frame defined for the SV protocol contains the header MAC, a priority tag, and an Ether type Protocol Data Unit (PDU). The Ether type PDU encapsulates the Application Protocol Data Unit (APDU), which also encapsulates the Application Service Data Units (ASDU). Finally, the ASDU contains the SV data and other relevant information.

The APDU can contain more than one ASDU. For protection purposes the message contains just one ASDU, while for measurement purposes the APDU contains eight ASDU, obtaining an equivalent transmission rate of 32 APDU/cycle. The structure of the APDU with one ASDU is shown in Fig. 2.

RTS performance test

The RTS performance depends mainly on the time constraints; therefore, it is important to evaluate the execution performance of the different processes involved in the implementation. The processes that have a large burden on the implementation are the computation time of the numerical solution and the execution time to complete the sending process.

In addition, another important task of this process is related to the evaluation of the quality of computation, which relies on the solution technique of ATP-EMTP, the sophistication of electric