Review Article

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Applications of Real-Time Simulation Technologies in the Power System of Mongolia

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Abstract

The stability control of Mongolia's power system is currently in critical condition due to insufficient power generation. Therefore, it needs to be accurately estimated and simulated. Real-time digital simulators are used to perform calculations that require high accuracy and precision, such as transient analysis and steady-state calculations of power systems, to solve this problem. A real time digital simulator (RTDS) differs from other simulators in that its simulation time-step is synchronized with real-time and is simulated using instantaneous values rather than RMS values, which is the basis for making the test process closer to the real environment. RTDS testing methods are classified into two main parts: fully digital simulation and hardware-in-the-loop testing. Fully digital simulation involves modeling the entire power system from generation to distribution in a digital environment. In contrast, hardware-in-the-loop testing involves replacing specific parts of the power system model with real physical hardware, such as protection devices and power electronic devices. The real-time digital simulator implementation commenced in Mongolia in 2023. One of its notable accomplishments lies in the accurate estimation of the parallel connection of battery storage to the power system.

Keywords: Hardware-In-the-Loop, Stability

Introduction

As technology continues to rapidly evolve, the power grid has become more intricate and necessitates a high level of dependability. Consequently, determining the power system's transition process and steady-state has become challenging. Therefore, a computing device that encompasses the mathematical modeling of power system elements have become essential.

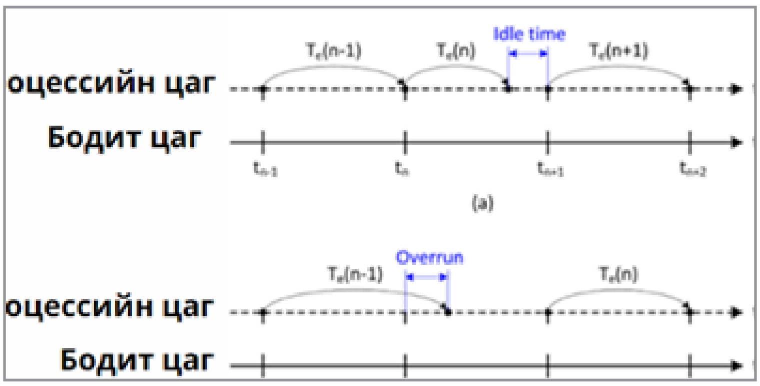

Figure 1: Time-step of real time simulation

In the field of power systems, it is crucial to accurately simulate the transition process within a short timeframe. Achieving this requires high-precision simulations using a time-step of high accuracy. Furthermore, to ensure that simulation results closely mirror those of the real system, the time-step is modeled to align with real-time in the digital simulator.

Real-time digital simulation of the Power system is the reproduction of output(voltage/currents) waveforms, with the desired accuracy, that are representative of the behavior o the real power system being modeled. To achieve such a goal, a digital real-time simulator needs to solve the model equations for one time-step within the same time in a real-world clock. The RTDS Simulator uses a piece of hardware called a Giga Transceiver WorkStation Interface (GTWIF) card to generate the time-step and supervise the simulations. The time-step clock is produced by a crystal oscillator onboard the GTWIF. RTDS Technologies has developed a facility which allows the GTWIF to synchronize to a highly accurate time source. The development of a new peripheral called a Giga Transceiver Synchronization (GTSYNC) card was required. The GTSYNC can provide synchronization to IEEE 1588 v2, copper BNC one pulse per second (1PPS), or optical ST 1PPS time sources. The GTSYNC also has an onboard clock which it uses in the absence of an external time source (ie. itcan act as the master time reference for the simulation and external equipment). [1].

Therefore, it produces outputs at discrete time intervals, where the system states are computed at certain discrete times using a fixed time-step [2] [3].

Power Simulation can be Divided into Two Types

1. Full digital real-time simulation (for example: model-in-the-loop, software-in-the-loop, or processor-in-the-loop)
2. Hardware-in-the-loop (HIL). [4]

A fully digital real-time simulation is capable of simulating all control devices, relay protection, and automation devices from the basic system elements up, in the simulator. It does not require additional input/output (I/O) [5]. This means that the simulator is capable of replicating the behavior of the actual system with a high degree of accuracy, without the need for additional hardware. This is highly desirable in a business or academic setting as it allows for the simulation and testing of complex control systems in a controlled environment. The result is a better understanding of the system's behavior, which can help improve the design, performance, and safety of the system. Hardware-in-the-loop, on the other hand, means that a part of the system model created in the real-time simulation is replaced by real hardware. This requires additional input/output I/O.

- RTDS testing method is Hardware-in-the-loop or HIL, and this test method has two types depending on the type of device being tested.
- Hardware-in-the-loop (HIL) testing is a crucial part of the development process for electrical devices. There are two main types of HIL testing: Control Hardware-in the-Loop (CHIL) and Power Hardware-in-the-Loop (PHIL).
- CHIL testing is used to test the performance and reliability of relay protection devices. This involves connecting the device under test to a simulated control system and measuring its response to different scenarios.

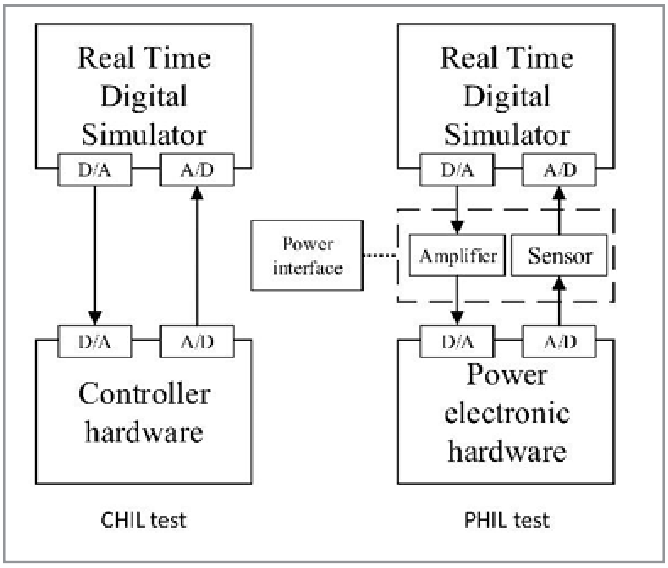

Figure 2: PHIL and CHIL Testing Method

On the other hand, PHIL testing is used to test devices that are involved in the power system, such as generators, inverters, and transformers. In PHIL testing, the device under test is connected to a simulated power grid, and its performance is evaluated under different conditions. Both CHIL and PHIL testing are essential for ensuring that electrical devices are safe, reliable, and perform as expected under different operating conditions.

Suuliin uguulber Co sumilation dutagdaltai tal, mongol dahi turshiltiig yvuu;lahad gants lab tai dutagdmal baigaa ch tsaashdaa hugjij bn relay hamgaalalt system ni rtds ni wams tai holbogdohosd nuluu uzuulne. Hardware talaas bichih urgusuh tusam yachek dotorh. Togtvorjilt deer mongoliin erchim huch sergeegdeh erchim huch ih bolohiig hynahiin tuld simulation hiih shaardlagatai.

RTDS Modeling

To conduct PHIL tests accurately, it's essential to have phase time-synchronized data from a specific part of the power system. This can be achieved through a phase measurement device called PMU, which collects40-60 parameter values per second and transmits them with GPS time tags. This ensures that the RTDS simulation remains perfectly synchronized. The PMU data frequency should match the RTDS time-step interval, maintaining synchronization throughout the simulation [3].

In 1964, Dr. Hermann Dommel developed an algebraic expression of the power node analysis algorithm, which revolutionized the modeling and simulation of power systems. This algorithm enabled the precise and accurate modeling of the electromagnetic transition process, which is a crucial aspect of power system analysis. The algebraic expression developed by Dr. Dommel allowed for the efficient calculation of the nodal currents and voltages in power systems, which was previously a cumbersome and time-consuming process. With this breakthrough, power system engineers were able to more effectively design, operate, and analyze power systems, leading to significant advancements in the field. Dr. Dommel's contributions to the field of power systems engineering continue to be celebrated today and have had a lasting impact on the industry [5].

EMT Solution Methods

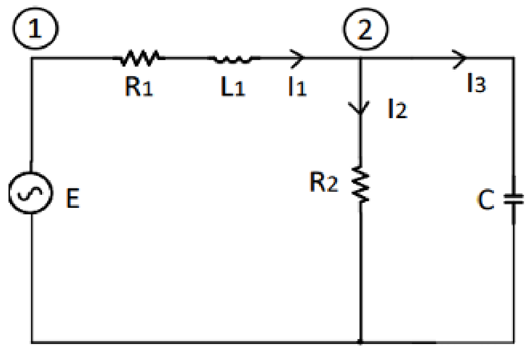

Figure 3

$$E = I_1 \cdot R_1 + L_1 \frac{dI_1}{dt} + V_2$$
$$V_2 = I_2 \cdot R_2$$
$$I_3 = C \frac{dV_2}{dt}$$
$$I_1 = I_2 + I_3$$

$$\begin{bmatrix} \frac{dV_2}{dt} \\ \frac{dI_1}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-1}{R_2 C} & \frac{1}{C} \\ \frac{-1}{L} & \frac{-R_1}{L} \end{bmatrix} \begin{bmatrix} V_2 \\ I_1 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{E}{L} \end{bmatrix}$$

$$[\dot{X}] = [A][X] + [B][U]$$

In Dommel formulation, any circuit element may be represented using equivalent resistors and current sources.

Use of RTDS

Use in Transmission Networks

The development of the transmission system on RTDS started in the 1990s, and the development of this system will cover a wide area. This includes the development of protection against voltage sags or loss of frequency stability, and the integration of power electronics and renewable energy into the grid [7].

Equipment Modeling

Real-time simulators offer significant economic and time savings over testing new equipment in a real-world environment before putting it into service. RTDS can perform this test with higher accuracy and shorter time than other simulator programs.

Prototyping

An initial physical model of the equipment is used during development and use, and the physical model approximates how the equipment will respond to the system for which it is modeled. This test method uses the HIL test method to test and improve pre-shipment prototypes for equipment applications such as induction motor prime mover speed control and synchronous compensator voltage regulation.

Equipment Testing

After the development of the first physical model is completed, testing will often be conducted using RTDS, and using the HIL testing method, the equipment under test will be tested as if it were being used in a real environment, resulting in a near-realistic analysis of how the equipment will react in the real environment before use. For example:

- A number of newly designed direct sequence directional distance relays used in power systems have been tested using HIL testing methods [10].
- Synchronous motor control experiments were conducted using RTDS [11].
- Many new management systems for microgrids have been tested [12].
- The phantom power and voltage control of a 500kW inverter were tested [13].
- A high-power generator with 15000 rpm at 1.5 KHz was tested using the PHIL test method [14].

Use in Training and Preparation

The education sector is a big sector that cannot be left out at a time when the manufacturing and technological sectors are developing by leaps and bounds. To bridge the gap between technology development and education, it is important to simulate real-world environments for future engineers to understand how the power system will respond to certain changes.

Power System Applications

RTDS of transmission systems started during the 1990s. The fields of interest for real time simulation applications in the transmission system are very wide. It could be used for many applications, such as improving the protection defense strategies to avoid voltage collapse or frequency instability, improving the integration of power electronic devices to support voltage, and testing the integration of large FACTS/HVdc transmission links. It is also used to assess the impact of large integration of renewable power generation in the grid [6].

PMU Implementation in RTDS

Following a significant incident within the integrated system on September 15, 2018, the Relay Protection and Automation Department of the National Dispatcher Center of Mongolia undertook the implementation of the Wide Area Monitoring System (WAMS) in the network [7].

The Power System of Mongolia is equipped with more than 40 points of phasor measurement units strategically placed in substations and power plants as part of the WAMS system. The implementation of PM Us allows for the execution of simulations. Although the process is currently underway, full PHIL testing on the Power System of Mongolia is imminent.

Implementation in Mongolia

Simulation of battery storage parallel operation in the power system the operation of the 80 MW battery storage management and control device PCS and battery control BMS was analyzed by connecting it to the simulator device to determine its operating capacity and speed. Additionally, a simulation was conducted to establish the setting values and configurations for parallel operation in the power system. Furthermore, testing was carried out on the function for recovering TPP from battery storage or the black start function. The simulation uses a 3-Level UCM Inverter Module to simulate the logical operation of the inverter and PCS. 9567 control modules used in the battery storage station project. The advantage of the 3-Level UCM inverter module is that it can receive/output pulse signals between 1.0~-1.0 and allows it to work according to the signal coming from the control module during PHIL calculation. In the simulation environment, the changes in voltage, frequency, and power flow generated in the system are signaled to the control module connected outside the simulator. Based on the received signal or measurement value, the output value of the inverter is adjusted by controlling the IGBT gates of the inverter.

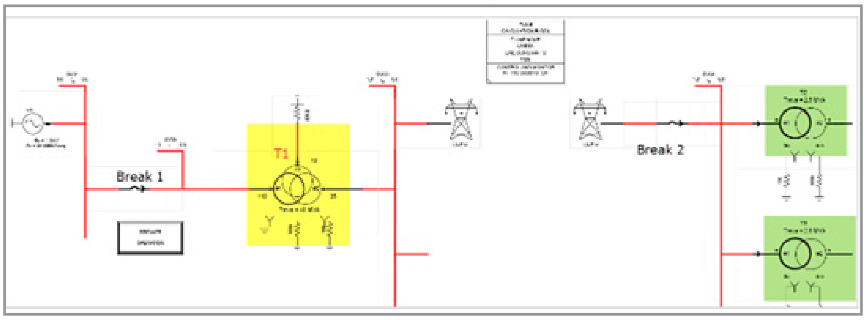

Figure 4

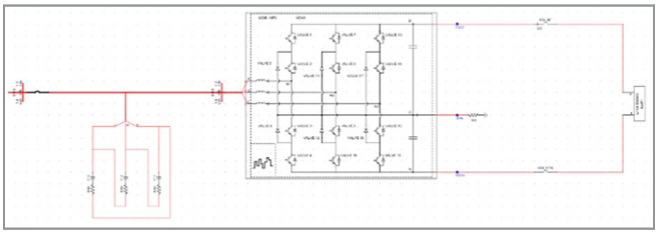

Figure 5: Battery storage inverter and its logic on RTDS.

Battery storage control logic / BESS control / and network side control logic /Source control/ are created in the simulation environment. Battery storage / BESS control/logic performs functions such as regulation of the power flow supplied to the network and overvoltage limitation. The network side management loki /Source control/ performs network side voltage, frequency change, and power flow control in a simulation environment.

Simulation of magnetic saturation process of the transformer of 110/35/6 KV east-2 substation and simulation to verify relay protection settings and settings. The differential protection of the transformer worked when the 110/35/10kV Dornod-2 substation transformer breaker was manually disconnected, or when the 110kV circuit breaker was connected after an external short circuit. The above problem was studied, and the recording of the outage accident and the process were entered into the RTDS simulator, and simulations and calculations were made.

Simulation results can help determine a transformer's normal operation and age based on factors such as its size and materials used. While in use, the transformer's magnetic relaxation, capacity, and depletion of the magnetic field are affected by its design. In the scenario described above, connecting the 110kV circuit breaker to the transformer causes an increase in inrush current and a decrease in the transformer's magnetic depletion capacity, leading to the formation of the conditions necessary for the transformer's differential protection to operate.

Device and Configuration of the 110 KV Aerial power line of the Monpolimet cement factory located in the area of Urgun sum, Dornogovi province To verify the efficient operation of the differential protection and the configuration of the 110-kV power line that supplies the Monpolymet cement plant in Urgun Sum, Dornogovi province, a CHIL simulation was executed using the RTDS simulator. This was done to ensure that the system is operating as intended, and to confirm that no issues are present that could lead to potential problems in the future.

Acknowledgment
The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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