OPAL-RT REVIEW

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ABSTRACT

OPAL-RT enables the simulation of large-scale, complex systems efficiently. Systems that would typically require hours or even days to simulate on a conventional personal computer can be executed in real time using OPAL-RT, with time steps in the microsecond or nanosecond range. High performance, flexibility, and low entry-level cost are key attributes of the OPAL-RT platform. The OPAL-RT real-time simulation platform is an advanced model-based engineering design and testing environment. It delivers outstanding real-time performance for experimental studies and is widely used in engineering design applications. Therefore, it is essential to examine its hardware architecture, software structure, and real-time performance in detail. A comprehensive understanding of its hardware and software architecture, along with its simulation process, provides a structured overview of the platform. Furthermore, the application of OPAL-RT in electrical power systems serves as a valuable reference for microgrid, smart grid, and other real-time system implementations.

KEYWORDS

Simulation platform, Real time applications, Hardware platform, OPAL

1. INTRODUCTION

1.1. What is OPAL?

OPAL is a French abbreviation that stands for 'Ordinateurs Parallèles et Applications Logicielles,' which translates to 'Parallel Computers and Software Applications.

OPAL-RT is a Real-time simulator. It functions in two modes namely, hard real time mode and non-real time mode. Real time mode is also called on-line mode and non- real time mode is also called off-line mode.

1.2. What is OPAL-RT?

"OPAL-RT Technologies is the company name. 'OPAL-RT' is the abbreviation of the company name. 'OPAL-RT Software' refers to the software developed by OPAL-RT Technologies.".

OPAL-RT is a real-time simulation platform. It is a radical archetype engineering design and test application platform. It is a set of test application platform based on modelling, which is developed by Canada's company of Opal-RT. It brings the ability to simulate the most complex model-based design and have them interact in real-world surroundings.

In 1998, OPAL-RT handed over its first simulator, fabricated by using six Pentium 2 computer-233MHz adjoined by Fire Wire links. After a while, a cluster of multi- CPU shared-memory computer (2 CPU with one core each on one motherboard) were used, soon after clusters of

multi- core computers (2 or 4 CPUs of 4 to 8 or 12 cores each) are adjoined with very fast communication network i.e. a switches.

1.3. Importance of OPAL-RT

It was very herculean task to carry out real-time simulation of hefty system 20 years ago, before OPAL-RT was not introduced. Indeed, giant simulators for electrical systems were fabricated by using analog peripherals such as inductor, capacitors, resistors, transformer, and switches. In order to replace the hefty analog simulators, Companies such as IREQ (Hydro-Quebec, Canada) were also busy in fabricatingtheir own super computers. But, super computers at that period were very expensive and also not upgraded for real-time operations. OPAL-RT technology aids in simulating a larger system. It carries out simulation in micro or nano seconds, whereas other simulators would take hours or days to simulate on a personal computer.

1.4. OPAL-RT Mission

OPAL-RT's aim is to provide vanguard real-time simulation technology to engineers and researchers all over the planet. It relentlessly endeavour for novel methods to consolidate parallel, distributed computing with commercial prefabricated technologies, which provides a matchless synthesis of efficiency, susceptibility and affordability. In order to assure customer satisfaction, company is also providing illustrative engineering and consulting services in addition to products. Parallel Real-Time Simulators provides high precision with sub-microsecond response time.

1.5. OPAL-RT software

OPAL RT-LAB, completely assimilated with MATLAB/Simulink, is the open real-time simulation software. It has revamped the process of designing the model.

OPAL-RT RT-LAB's attributes, such as adaptability and scalability, enable it to be used in a wide range of simulation and control system applications. It also enhances computing power for simulations whenever and wherever it is required.

OPAL-RT provides the following software solutions:

eFPGASIM uses an FPGA-based HIL platform for the development and verification of control and protection systems. It supports sub-microsecond time steps to perform high-speed simulations

eMEGASIM is the fastest Simulink software. It uses hardware-in-the-loop (HIL) simulation for the advancement and verification of control and protection systems.

ePHASORSIM is used to simulate the electro- mechanic transitory strength phenomena in very hefty power grids with thousands of buses, loads, transmission lines, transformers, generators, and controllers.

HYPERSIM is the only real-time digital simulator. It has the ability to simulate and examine very hefty-scale power systems with several thousand nodes. It is used to test the factory approval and system synthesis. Also used for Research and Development and assign tests.

1.6. Applications of Opal-RT

Aerospace & Defense:

In large-scale electrical energy production, space and defense system development, avionics systems development, distribution and active load control development, and integration testing.

Electrical:

In large scale simulation, control system testing, protection system testing, research, training and power grid maintenance.

Automotive:

In verification of electric motor ECU (Electronic Control Unit), development of ECU model, function and system verification of ECU, communication testing of ECU, verification of research, training and production test.

Academic & Research:

It provides assurance for teachers and researchers to be benefitted from this novel technology. It also aids the researchers with flexible apparatus which can be reused for multiple projects.

➢ Industrial and Utilities–70%
➢ Academic and Education–30% Out of which,
➢ Power electronic and power grids project accounts for- 80% and
➢ Mechatronicprojectaccountsfor–20%

2. REAL TIME SIMULATION

2.1. What is real time simulation?

There are basically two ways to perform simulation-

i) Free Running Simulation: (offline mode simulation) It can be –
a) Faster than Real-Time i.e. it takes less than 1 second to compute 1s simulation.
b) Slower than Real-Time i.e. it takes more than 1 second to compute 1s simulation.

ii) Real-Time Simulation: (online mode simulation) the computation is faster than the real clock,

However it is also integrated with the real time/clock.
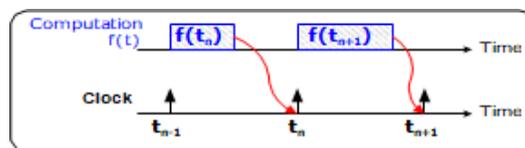1second of simulation is equal to 1second of wall clock.

Offline simulation: Faster than real-time
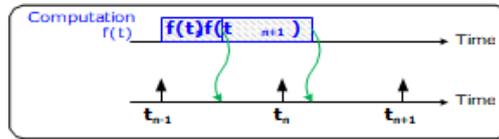
Offline simulation: Slower then real-time
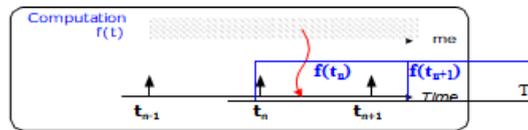
Real-time simulation: Synchronized

Real-time simulators are created by parallel computers integrated with Input Output systems. Real time simulator software are proficient in explaining control and electrical circuit differential mathematical statement in real-time.

The real-time computer and its operating system are fabricated to compute the system design within a transient interval, which is called the time step of model. All model computation should be completed within the model time step and the computational cycle should be integrated with a hardware timepiece.

For classical electrical systems, time step should be in the order of 10 to 50 us. Depending on system dynamics, time step may go below one micro second.

2.2. Evolution of Real Time Simulator

Real-time simulators have evolved in the following order:"
- Analog simulator
- Hybrid simulator
- Digital simulator
- Digital custom-built simulator (Type 1 simulator)
- Digital supercomputer simulator (Type 2 simulator), such as ARENE by Électricité de France, HPCONVEX, and HYPERSIM by Hydro-Québec on Silicon Graphics International ALTIX systems (for headquarters internal use only)
- Digital PC-based simulator (Type 3 simulator), such as eMEGA sim, eDRIVE sim, and RT-LAB
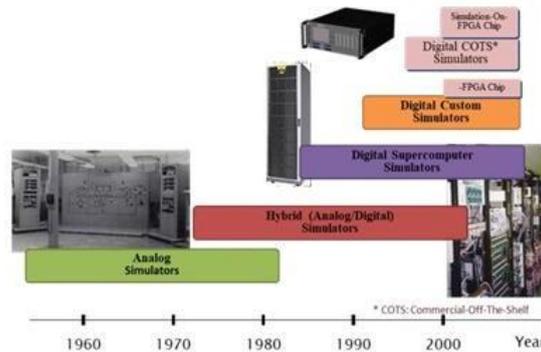
For the makers of real-time simulators, it is very difficult to synthesis the grid of technologies just as very fast motor drives, plug-in hybrid vehicles, photovoltaic distributed generation, wind farms and other devices using power electronic converters with high-frequency PWMs.

Specifically, high simulation speed is hard to obtain even with custom or commercial supercomputers. In order to increase the efficiency, OPAL-RT was founded in 1997.

For the parallel simulation of large power grids, discovery of OPAL-RT is accomplished. Initially, the notion behind OPAL-RT's discovery was to draw the billions of dollars invested by governments in scientific research, and also by companies such as INTEL and AMD in order to establish

The fast processors for the gaming, internet and personal computer markets.

Conclusively, for the last 10years, OPAL-RT has become the leader in the advancement of power electronic simulators used by electrical hybrid vehicle OEMs.

Moreover, OPAL-RT is also preferred to use FPGA (Field Programmable Gate Array) chips to handle time-demanding Input Output system and to operate fast model subsystems with time step below 1us.

Performance can also been hanced by connecting AMD and INTEL processors with FPGAs chips.

2.3. Timing and Constraints

Real-Time Simulation is rested on discrete time steps. Real world events such as INTERPOLATION or AVERAGE MODELS are not integrated with simulator time steps.
One time step can have a multiple events. To simulate multiple events, multi-rate simulator is needed. Here, the multiple simulation tools can be used collectively.
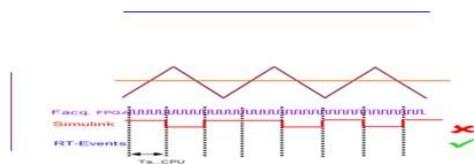
2.4. Choosing the Right Time Step
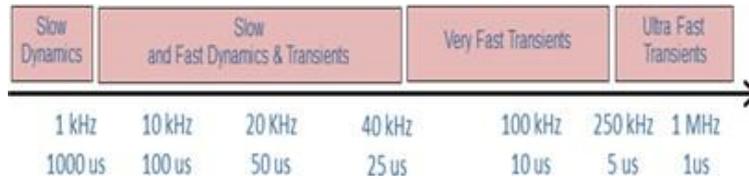
Time step less than (5 to 10%) of the period. It is called as very fast transients and ultra-fast transients i.e. 50 us for 2 kHz and 10 us for 10 kHz.

Time step less than (0.2 to 1%) of the period of the Pulse width modulation carrier i.e. 2 to 10 us for 1000Hz, 0.2 to 1 us for 10 KHz

Depending on solver and model, Time step should be small enough in order assure numerical stability.

Selection of Time step is done by comparing results by applying off-line simulation i.e. free running simulation with very narrow time step or variable step solver.
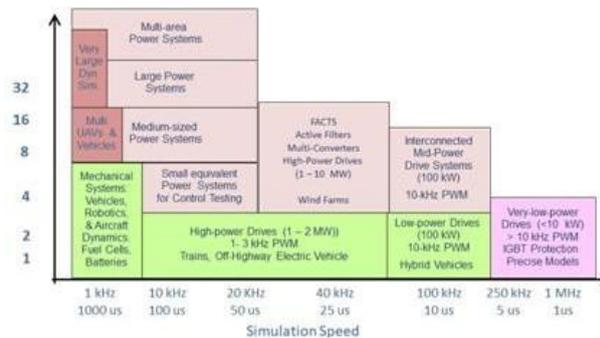
2.5. Why do you need it?

• Fabricating design settlement in advance-Issues related to design can be completed in advance without waiting for verification on a physical prototype of car, aircraft, train and industrial drives.
• Diminishing length of development cycle – Synchronized engineering, sooner the test systems are ready for use; primary computation is done in the laboratory.
• Diminishing testing expenses –Testing is mainly performed in aniterative ambience and so does the test automation.
• Improved and greater assessment – Assessment is too hard to carry out with physical proto types by diminishing the cost of it. Numerous tests are performed in various extreme operating conditions.
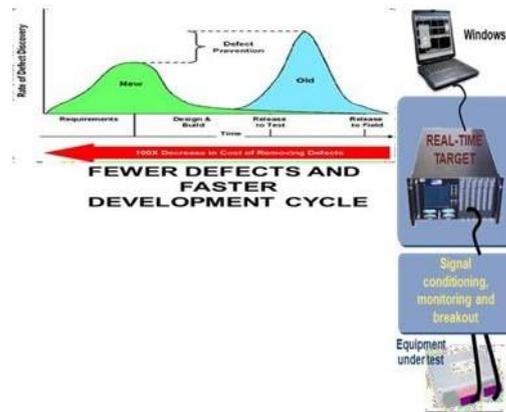
Concurrently, it is very hard to get the flexibility, speed and scalability in a system, which is also a prerequisite to it.

Project delays can be minimized by identifying problems at an early stage of the design cycle. This approach also helps reduce system costs and shortens the time-to-market for complex products.

2.6. Fast or Real Time Operating Modes

To test real control and protection systems in a closed-loop configuration, real-time simulators are typically used at the final stage of the system design cycle. Numerous test cases, including both normal and fault conditions, are conducted to validate the model's performance. Directly connecting controllers to a real power system for testing control and protection strategies can be highly risky and impractical.

Hardware-in-the-Loop (HIL) testing is also widely used for training purposes and damage control analysis. For effective problem identification and solution development, real controllers can be interfaced directly with the simulator.

Real-time simulators are also employed at the initial stages of the design cycle to simulate the entire system in a fully numerical mode. This is achieved using real controller code generated through tools such as Real-Time Workshop or implemented manually in C language. In this stage, the simulator may operate in an offline real-time mode.

Therefore, extensive testing and optimization can be performed within a limited timeframe—tasks that would be impractical or impossible using a single-processor computer and conventional software tools.

3. SIMULATOR ARCHITECTURE

3.1. Hardware & Software Simulator Architecture

Initially, OPAL-RT simulators are based on the standard host-target design. To do the simulation, window host system is used. It is also used to control model parameters in real-time and to see the results with virtual oscilloscopes as long as the simulator is running.

On the local network, host computer is attached to the target computer using a standard Ethernet connection, or in far distance using a secure VPN (Virtual private network) connection.

Here, heart of the simulator is the target computer system which is used to compute the model at each time step.

Sending of data to the Input Output system is made using the fast local bus and to the host computer using the Ethernet. Data logging i.e. collecting the recorded data in its local dedicated memory is also managed in real-time by target computers and data is also moved to the local hard disk or to the host systems.

A software module is also used to integrate data communication between processor cores and monitor. The IO systems get interfaced with peripherals, such as control and protection systems, to the model using fast analog and digital converters. To adjust voltages and current levels to the apparatus being interfaced, signal conditioning is performed. Special signal conditioning

Apparatus, just as optical fibers or high-power amplifiers are also required.

3.2. Typical Simulator Architecture
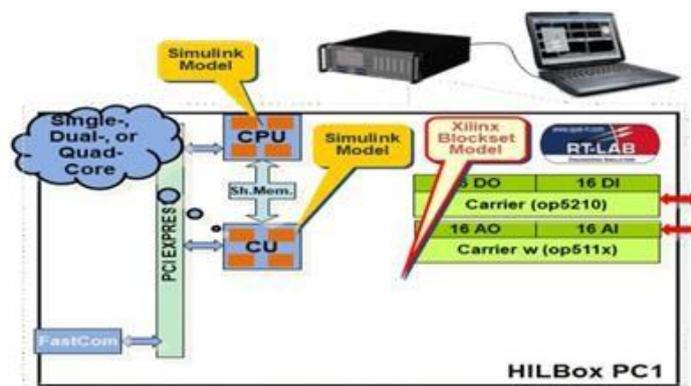
Here, the main real-time computer unit is the classic computer mother board which is commercially available and is analogous to what is being used in high-end workstations or servers. These computer motherboards are developed since 1997 with single processor Pentium II and in June 2009 with dual quad-core 3.2 GHz processors.

The given system can be divided across four sub systems and function on quad-core processors. Data transfer through a very fast on-chip cache memory happens with the help of processor core.

Then processor core transfer their Inter-processor communication. Date is communicated at very low rate by using custom computers employing old single-core processors and a local parallel commutation bus.

To simulate power system approximately upto1003-phase buses, a second quad-core computer is being added.

Point-to-point communication between each processor core is being established by using off-the shelf computer architecture. Then communication is established between each processor core of each processor chips by a very high- speed on-board shared-memory.

This avant-garde technology is much expeditious than the old generation of custom computers.

FPGA processor controls the input output system by using 10-nano second hardware timers. It also helps in controlling the data communication between the main processor memory and the FPGA memory using direct memory transfer (DMA), without disturbing the main processors.

Thus the main processor estimates the model while the FPGA processor manages the Input output and the data transfer to the system. Such a parallel method is responsible for reduced model time step. This is one of the most prominent attribute of OPAL-RT real-time simulators.

The number of Input Output channels can easily be enhanced by accumulating Input output and FPGA boards.

3.3. RT-LAB Open Software   Architecture

SIMULINK

MATLAB

RTW

RT-LAB – QNX – LINUX – XSG -ORCHESTRA

RT PC CLUSTER | IO Interface | **FPGA**

In RT-LAB, Real-Time Simulators are dependent on the usage of MATLAB, SIMULINK and Real-. Time Workshop (RTW) automated code generator. In general, this concept is applicable for all simulators used in the automotive and aerospace industries. However, it is novel for electrical system real-time simulators which are based on the application of system software and solvers.

RT-LAB is a real-time evenly spreaded software platform. In 1997, RT-LAB is developed by OPAL-RT. It tests the SIMULINK block diagram and also does the code generation that will be accomplished on each processor and on FPGAs (Field Programmable Gate Arrays). Data communication between processors, IO systems and the host through Ethernet is controlled by OPAL-RT. It also manages on-line model parameters changes and real-time data logging.

3.4. Application Classification: areas follows-

3.4.1. Apparatus licensing and damage control.
3.4.2. Complete digital simulation for Software-In-The- Loop (SIL).
3.4.3. Rapid Control Prototyping (RCP) accompanying Physical or Virtual plants.
3.4.4. Hardware-in-the-Loop (HIL) accompanying real or model controllers.
3.4.5. Administrator and Specialist training.

CONCLUSION

In this paper the advanced real time simulation system i.e. OPAL-RT and its RT-LAB is introduced in detail. It also includes hardware structure, flow of simulation implementation and rules for software modeling.

Smooth linkage is being developed between real time simulation system RT-LAB and MATLAB/Simulink. It can also identify the problem and provide the solution by getting the correct simulation waveform. Moreover, the simulation code is generated automatically in the real time simulation.

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