REAL TIME SIMULATION: RECENT PROGRESS & PERSPECTIVE

Article · July 2010

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International Journal Of Electrical Engineering And Electrical Systems (IJEEES) July 2010 – September 2010 Volume 03, Issue No 01, pp [45-59]
Scientific Engineering Research Corporation

REAL TIME SIMULATION: RECENT PROGRESS & PERSPECTIVE

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ABSTRACT

In order to compete in the global market, engineering organizations are under increasing pressure to design, develop, and deploy products in the market place as quickly as possible with first time quality. In order to achieve these objectives, it is necessary to streamline the design and development process, namely, "transfer of analytical design of Intelligence to Mechatronics intelligence" in an efficient and expedient manner. An increasing pressure exists on the development cycle of control systems to serve this widening application spectrum. The time-to-market of a new product often determines its commercial success. Consequently, design problems have to be discovered as early as possible in the design process in order to take remedial actions. Efficient and accurate tools and procedures are required to support short yet successful development processes. Over the last two decades, commercially available computer has become both increasingly powerful and increasingly affordable. This, in turn, has led to the emergence of highly sophisticated simulation software applications that not only enable high-fidelity simulation of dynamic systems and related controls, but also automatic code generation for implementation in industrial controllers. Today, electric drives, power electronic systems and their controls are getting more and more complex, and their use is widely increasing in all sectors: power systems, traction, hybrid vehicles, industrial and home electronics, automotive, naval and aerospace systems, etc. Advances in Microprocessors, Microcomputers, and Microcontrollers such as DSP, FPGA, dSPACE etc. and Power Semiconductor devices have made tremendous impact on electric motor drives. Due to advancement of the software tools like MATLAB/SIMULINK with its Real Time Workshop (RTW) and Real Time Windows Target (RTWT), real time simulators are used extensively in many engineering fields, such as industry, education and research institutions. As consequences, inclusion of the real time simulation applications in modern engineering provides great help for the researcher and academicians. Simulation tools have been widely Used for the design and improvement of electrical systems since the mid twentieth century. The evolution of simulation tools has progressed in step with the evolution of computing technologies. In recent years, computing technologies have improved dramatically in performance and become widely available at a steadily decreasing cost. Consequently, simulation tools have also seen dramatic performance gains and steady cost decreases. Researchers and engineers now have access to affordable, high-performance simulation tools that were previously too cost prohibitive, except for the largest manufacturers and utilities. The purpose of this paper is to review major milestones that set the stage for the development of the today's real time simulation including sufficient detail to acquaint reader with their basic principles, strength, limitations and its applications.

KEYWORDS- Real Time Simulation, Real Time Lab (RT -Lab), Rapid Control Prototyping (RCP), Hardware in the Loop (HIL), Real Time Workshop (RTW).

I. NOMENCLATURE

COTS	Commercial off- the -shelf
DSP	Digital Signal Processor
EMT	Electromagnetic Transients
FACTS	Flexible AC Transmission System
FPGA	Field Programmable Gate Array
HIL	Hardware-in-the-Loop
HVDC	High Voltage Direct Current
RTW	Real Time Workshop
RT LAB	Real Time Laboratory
RTWT	Real Time Windows Target
RBS	Rapid Batch Simulation
RCP	Rapid Control Prototyping
RES	Renewable Energy Sources
SIL	Software –in –the Loop
SoC	System-on-Chip
TNA	Transient Network Analyzer
VLSI	Very Large Scale Integration
VHDL	Very High Speed Integrated Circuit Description Language

II. OVERVIEW OF REAL TIME SIMULATION

It is believed that engineers, who were mainly trained in Power Electronics, have developed the area of Real Time Control. Real Time Control area is a result of applying control theory to power electronics and electrical drives. Currently it is a fairly matured field, which is almost three decades old. The research on application of microprocessors for electrical drive control in 1970's laid the foundation stone for the Real time control of electrical machine-drives. The historical development of the Motion Control field is shown in Fig.1.

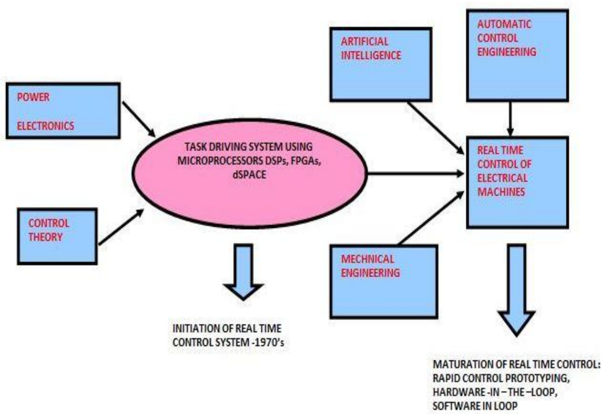


Fig.1 Development of Real Time Control

Though initiated by power electronic engineers, current status of motion control is such that conventionally trained power electronic engineers will probably require following complementary courses in motion control to grasp the development in this area. Now this field is an extremely competitive one. Nowadays, power electronics and motion control can be treated as two distinct fields that emerge as the technology advances. Power electronics is mainly the transformation of electric power. High speed (in component switching), energy efficiency, environmental friendliness are keywords in the ongoing researches in this area. Achieving complete real time control over the conventional off line control is the fundamental idea of real time control. Obviously, this incorporates multiple fields as a typical system consists of not only power electronics, but also embedded systems i.e. Microprocessors, Microcontrollers, Digital Signal Processors etc. Thus, real time control demands more control strategies with higher degree of reliability. In most of the real time control problems, the processes under consideration are electrical machines controlled by some embedded controller and Power electronics devices. The invention of thyristors can be considered as the foundation stone of the area of power electronics. This triggered the development of sophisticated commutation circuits, as the thyristor does not have turn-off capability. This is the first phase of the development of power electronic area[1-4].

Power electronic area went through an extensive expansion during the second stage of the development, when large and small fast-switching power devices and microprocessors were introduced into the market in mid 70's. The introduction of microprocessors into the field enhances the possibilities of incorporating a vast amount of control theory in power electronic systems. The key feature in the third phase of the development is the high-frequency power electronic devices. Device size can be made smaller by increasing the switching frequency[3]. The introduction of Digital Signal Processors (DSPs) in place of microprocessors was another big step forward in this phase, which can be located in the late 80's. With the great advances in the microelectronics and Very Large Scale Integration (VLSI) and Very High Speed Integrated Circuit Description Language (VHDL) technology, high-performance DSP's can be effectively used to realize real time control of electrical machines. New emerging technologies in semiconductor industry offered the means to create high-performance digital components allowing implementation of more complex control applications. Embedded systems (ESs) are computers incorporated in devices in order to perform application specific functions. Application Specific Integrated Circuit (ASIC) is a generic term which is used to designate any integrated circuit designed and built specifically for a particular application. ESs can contain a variety of computing devices, such as Microcontrollers, Application-Specific Integrated Circuits (ASICs), Application Specific Integrated Processors (ASIPs), and Digital Signal Processors (DSPs). Recently, the System-on-Chip (SoC) capabilities have provided the opportunity to have a more performance digital control solution. A renewed interest is devoted to Field Programmable Gate Arrays (FPGAs) for full integration of all control functions. New FPGA technology containing both reconfigurable logic blocks and embedded cores becomes quite mature for high-speed power control applications. Hard Ware (HW) and Soft Ware (SW) components interact in order to perform the given task. Such systems need a co-design expertise to build a flexible embedded controller that can execute Real Time closed-loop control [6-12].

The literature about real-time systems presents digital control or computer controlled systems as one of its most important practical application field in electrical machines and drives. It seems to be more natural that these applications should be treated as part of digital control. In spite of that, control system literature rarely includes extensively the real-time control of electrical machines and it does not normally pay attention to real-time aspects beyond algorithms and choice of sampling times. The implementation of digital control systems and real-time systems of electrical machines together due to advancement of the power semiconductor device and various digital controller. In general, real-time issues are gradually becoming "transparent" to the control of the various electrical machines. This transparency has been considerably increased in the last years with the advent of software tools like MATLAB/Simulink with its RTW (Real Time Workshop) and RTWT (Real Time Windows Target). They certainly do the implementation of real-time experiments easier and save much time, but on the other hand they put more distance regarding to the real life problems, which can emerge during the real-time implementation of control system of electrical machines [9].The progress in power electronics device and embedded controller is as shown in Fig.2.

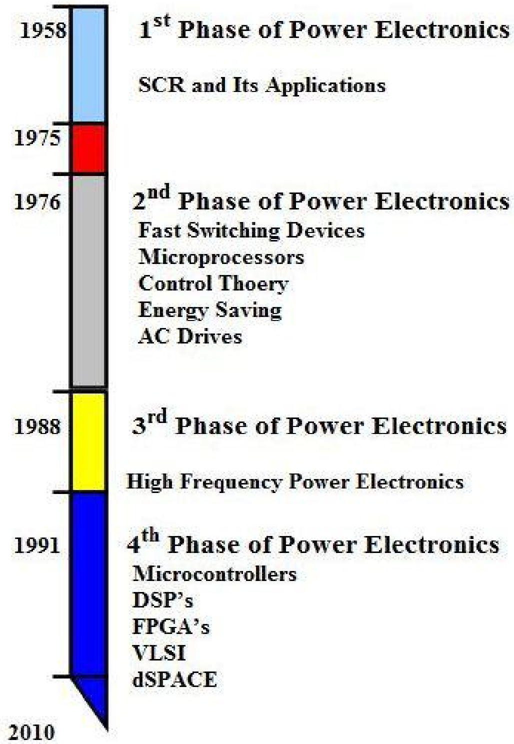


Fig.2 Development of Embedded System

It is again appropriate to quote one of the great scientists in automatic control, Karl Astrom

"Many important aspects on implementation are not covered in textbooks. A good implementation requires knowledge of control systems as well as certain aspects of computer science.

It is necessary that we have engineers from both fields with enough skills to bridge the gap between the disciplines. Typical issues that have to be understood are windup, real-time kernels, computational and communication delays, numerics and man machine interfaces. Implementation of control systems is far too important to be delegated to a code generator.

Lack of understanding of implementation issues is in my opinion one of the factors that has contributed most to the notorious GAP between theory and practice."

The objective of this paper is to present overview of the various real time simulation technologies and their engineering applications. The typical viewpoint one must have on this approach of the paper is further clarified from the following quotation of Karl Åström

".....A long experience with journals and conferences has shown that it is very difficult to get good applications papers. The engineers, who really know about the applications, do not have the time or the permission to publish. Many of those who write have only a superficial knowledge about the applications. This sends distorted signals in all directions. There are occasional efforts with special issues of journals, where really good applications papers sometimes appear. We need those badly for better education of the next generation of control engineers."

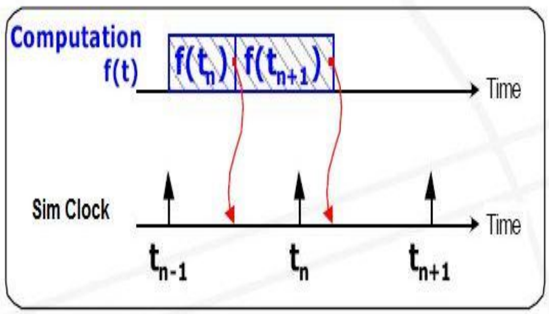
III. WHAT IS REAL TIME SIMULATION?

Real-time simulation, based on automatic code generation, is used in many engineering field and applications such as: aircraft flight control design & validation, industrial motor drive design, complex robotic controller design and power grid statistical protection tests. These applications benefit from the use of real-time simulators in a number of ways. First, real-time simulation produces a set of requirements and specifications that can be used by all disparate teams involved in a project. Secondly, it enables testing of simulated devices at or beyond their normal operating limits without the risks involved with testing of real devices, especially when high power levels are present. Third, it is easier and less risky to test fault responses on a simulated model. Finally, the simulation acceleration factor obtained by the use of compiled code (instead of the interpreted code used by most simulation tools) enables the realization of rapid batch simulations. The main idea using real time control is to smoothen transition from the non real analysis and simulation to the real time experiments and implementation [1].

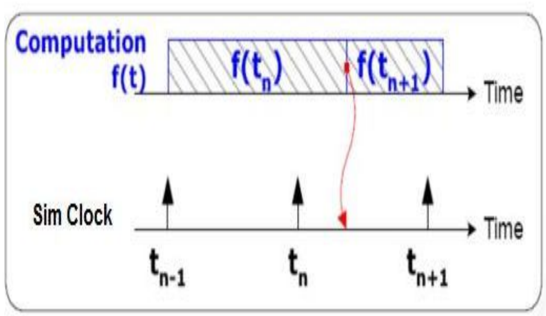
Simulators have been used extensively in the planning and design of electrical systems for decades. From the layout of transmission lines in large scale power systems to the optimization of motor drives in transportation, simulation has played a critical role in the successful development of a large number of applications such as aerospace to home electronics. For the last three decades, the evolution of simulation tools has been driven by the rapid evolution of computing technologies. As computer technologies have decreased in cost and increased in performance, the capability of simulation tools to solve increasingly complex problems in less time has improved. In addition, the cost of digital simulators has also steadily decreased, making them available to a larger number of users for a wider variety of applications[96,100]. As per the American Heritage Dictionary of the English language:

"A Simulation is representation of the operation or features of a system through the use or operation of another"

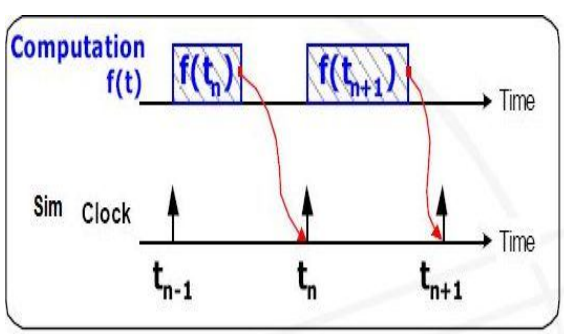
For digital simulation it is assumed that a simulation with discrete-time and constant step duration is performed. During discrete-time simulation, time moves forward in steps of equal duration. This is commonly known as fixed time-step simulation [1]. It is important to note that other solving techniques exist that use variable time-steps. Such techniques are used for solving high frequency dynamics and non-linear systems, but are unsuitable for real-time simulation. To solve mathematical functions and equations at a given time-step, each variable or system state is solved successively as a function of variables and states at the end of the proceeding time-step. During a discrete-time simulation, the amount of real time required to compute all equations and functions representing a system during a given time-step may be shorter or longer than the duration of the simulation time step as shown in Fig. 3 (a) & Fig.3 (b). In Fig. 3 (a), the computing time is shorter than the fixed time-step (also referred to as accelerated simulation) while in Fig.3(b) the computing time is longer. These two situations are referred to as offline simulation. In both cases, the moment at which a result becomes available is irrelevant. Typically, when performing offline simulation, the objective is to obtain results as fast as possible. The system solving speed depends on available computation power and the system's mathematical model complexity.



(a) Offline Simulation: Faster than Real Time



(b) Offline Simulation: Slower than Real Time



(c) Real Time Simulation: Synchronised

Fig.3 Real-Time Simulation and Other Simulation Techniques

During real-time simulation, the accuracy of computations not only depends upon precise dynamic representation of the system, but also on the length of time used to produce results as shown in Fig.1(c). For a real-time simulation to be valid, the real-time simulator used must accurately produce the internal variables and outputs of the simulation within the same length of time that its physical counterpart would. In fact, the time required to compute the solution at a given time-step must be shorter than the wall clock duration of the time-step. This permits the real-time simulator to perform all operations necessary to make a real time simulation relevant, including driving inputs and outputs (I/O) to and from externally connected devices. For a given time-step, any idle-time preceding or following simulator operations is lost; as opposed to accelerated simulation, where idle time is used to compute the equations at the next time-step. In such a case, the simulator waits until the clock ticks to the next time step. However, if simulator operations are not at all achieved within the required fixed time-step, the real-time simulation is considered erroneous. This is commonly known as an "overrun". Based on these basic definitions, it can be concluded that a real-time simulator is performing as expected if the equations and states of the simulated system are solved accurately, with an acceptable resemblance to its physical counterpart, without the occurrence of overruns [61].

Real-time digital simulation is based on discrete time-steps where the simulator solves model equations successively. Proper time-step duration must be determined to accurately represent system frequency response upto the fastest transient of interest. Simulation results can be validated when the simulator achieves real-time without overruns. For each time-step, the simulator executes the same series of tasks:

- Read inputs and generate outputs.
- Solve model equations.
- Exchange results with other simulation nodes.
- Wait for the start of the next step.

IV. EVOLUTION OF REAL TIME SIMULATION TECHNLOGIES

Simulator technology has evolved from physical/analogue simulators (HVDC simulators & TNAs) for EMT and protection & control studies, to hybrid TNA/Analogue/Digital simulators capable of studying EMT behaviour to fully digital real-time simulators, as shown in Fig 4. Physical simulators serve their purpose well. However, they were very large, expensive and requires highly skilled technical teams to handle the tedious jobs of setting up networks and maintaining extensive inventories of complex equipment. With the development of microprocessor and floating-point DSP technologies, physical simulators have been gradually replaced with fully digital real-time simulators. DSP-based real-time simulators are developed using proprietary technology, and is used primarily for HIL studies, the first of the new breed of digital simulators to become commercially available. However, the limitations of using proprietary hardware were recognized quickly, leading to the development of commercial supercomputer-based simulators, such as HYPERSIM from Hydro-Quebec, which is no longer commercially available. Attempts have been made by universities and research organizations to develop fully digital real-time simulators using low-cost standard PC technology, in an effort to eliminate the high costs associated with the use of high-end supercomputers [8]. Such development was very difficult due to the lack of fast, low-cost inter-computer communication links. However, the advent of low-cost, readily available multi-core processors [11] (from INTEL and AMD) and related COTS computer components has directly addressed this issue, clearing the way for the development of much lower cost and easily scalable real-time simulators. In fact, today's low-cost computer boards equipped with eight processor cores provide greater performance than 24-CPU supercomputers that were available only 10 years ago. The availability of this low-cost, high performance processor technology has also reduced the need to cluster multiple PCs to conduct complex parallel simulation, thereby reducing dependence on sometimes-costly inter-computer communication technology. COTS-based high-end real-time simulators equipped with multi-core processors have been used in aerospace, robotics, automotive and power electronic system design and testing for a number of years [7]. Recent advancements in multi-core processor technology means that such simulators are now available for the simulation of EMT expected in large-scale power grids, micro grids, wind farms and power systems installed in all-electric ships and aircraft. These simulators, operating under Windows, LINUX and standard real-time operating systems, have the potential to be compatible with a large number of commercially available power system analysis software tools, such as PSS/E, EMTP-RV and PSCAD, as well as multi-domain software tools such as SIMULINK and DYMOLA. The integration of multi-domain simulation

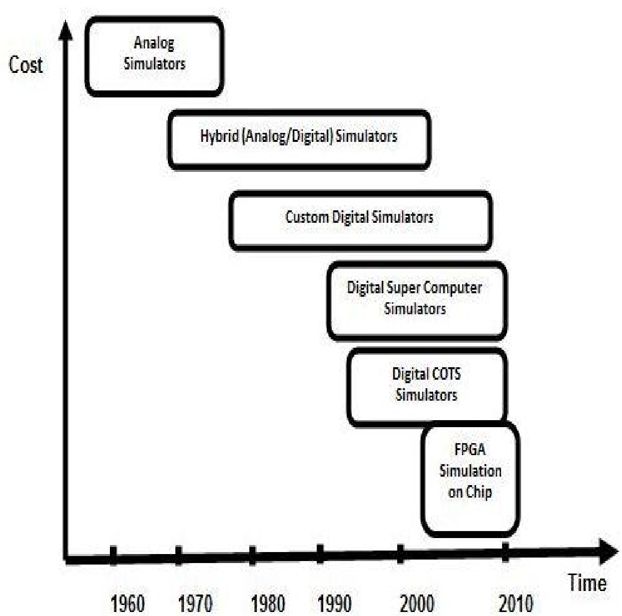


Fig.4 Evolution of Real-Time Simulation Technologies

tools with electrical simulators enables the analysis of interactions between electrical, power electronic, mechanical and fluid dynamic systems. The latest trend in real-time simulation consists of exporting simulation models to FPGA [12]. This approach has many advantages. First, computation time within each time step is almost independent of system size because of the parallel nature of FPGAs. Second, overruns cannot occur once the model is running and timing constrains are met. Last but most importantly, the simulation time-step can be very small, in the order of 250 nanoseconds. There are still limitations on model size since the number of gates is limited in FPGAs. However, this technique holds promise.

V. REAL TIME SIMULATION TECHNIQUES

As the advancement in power semiconductor devices and the digital controller such as Microprocessor/Microcontroller, Digital Signal Processors (DSP), Field Programmable Gate Array (FPGA), dSPACE and other Artificial Intelligence (AI) such as Fuzzy, Neural are now satisfactory implemented for real time applications[5,8]. Traditionally, validation of the system was done by non-real-time simulation of the concept at early stage in the design, and by testing the system once the design is implemented; but this method has two major drawbacks: first, the leap in the design process, from off-line simulation to real prototype. It is so wide that it is prone to many troubles and problems related to the integration at once of different modules; second, the off-line, non-real-time, simulation may become tediously long for any moderately complex system, especially for Electrical Machine drives with switching power electronics[3]. Various techniques that can be used for real time control and simulation in many engineering applications:

(i) Microprocessor/Microcontroller:

The conventional control has been replaced by the new dynamic microprocessor based control techniques The advancement of microprocessor technology has followed a rapid pace since the advent of the first 4-bit microprocessor in 1971. From simple 4-bit architecture with limited capabilities, microprocessors have evolved towards complex 64-bit architecture in 1992 with tremendous processing power. The evolution of microcontrollers has followed that of microprocessor, and consists of three main families: MCS-52, MCS-96 and i960. These families are based on 8-bit CISC, 16-bit CISC, 32-bit and 64-bit RISC microprocessor architecture respectively. The digital technology is developed in a order such as: General-purpose microprocessors, microcontrollers, Advanced processors (DSP's, RISC processors, parallel processors), ASIC's and SoC. The recent development of control techniques for several kinds of electrical machine require better and modern machine drivers, since digital control techniques usually require microprocessor computation for their implementation. A microprocessor based electrical machines control using PWM modulation was implemented by using PMACP16-200 microprocessor for induction motor and results were supported by the experiment setup [5]. As the fast changes in the technology of microprocessor occurs a newly developed Motorola MC68HC11E-9 microcontroller based fully digital control system has been implemented to control the induction motor. The high-performance microprocessor and PC based real time control schemes for electrical machines have been presented in [6], [8] and the controller performance was checked and verified experimentally [5], [6].

(*ii) Digital Signal Processors (DSP)/ Field Programmable Gate Array (FPGA)*

Digital Signal Processors(DSPs) began to appear roughly around 1979 and today advanced (Digital Signal Processors), RISC (Reduced Instruction Set Computing) processors, and parallel processors provide ever more high computing capabilities for most demanding applications. With the great advances in the microelectronics and Very large scale Integration (VLSI) and Very High Speed Integrated Circuit Description Language (VHDL) technology, high-performance DSP's can be effectively used to realize real time simulation of electrical machines. The basic function of real time control for electric drive is shown in Fig. 3. The real time simulation of electric machine drives has been developed and successfully integrated in the first course of power electronics and electric drives [9], [16].

New emerging technologies in semiconductor industry offered the means to create high-performance digital components allowing implementation of more complex control applications. Embedded Systems (ESs) are computers incorporated in devices in order to perform application specific functions. Application Specific Integrated Circuit (ASIC) is a generic term which is used to designate any integrated circuit designed and built specifically for a particular application. ESs can contain a variety of computing devices, such as microcontrollers, Application Specific Integrated Circuits (ASICs), Application Specific Integrated Processors (ASIPs), and Digital Signal Processors (DSPs). Recently, the System-on-Chip (SoC)(Eshraghian,2006;Nurmi, 2007) capabilities have provided the opportunity to have a more performance digital control solution [12]. A renewed interest is devoted to Field Programmable Gate Arrays (FPGAs) for full integration of all control functions. New FPGA technology (Rodriguez-Andina *et al*., 2007) containing both reconfigurable logic blocks and embedded cores becomes quite mature for high-speed power control applications. Hard Ware (HW) and Soft Ware (SW) components interact in order to perform the given task. Such systems need a co-design expertise to build a flexible embedded controller that can execute Real Time closed-loop control. The power of these FPGAs has been made readily available to embedded system designers and SW programmers through the use of SW to HW tools. Field-Programmable Gate Arrays (FPGA's) are a special class of ASIC's which differ from mask programmed gate arrays in that their programming is done by end-users at their site with no IC masking steps. During the last ten years embedded systems have moved towards System-on-Chip (SoC) and high-level multi chip modules solutions. A SoC design is defined as a complex IC that integrates the major functional elements of a complete end-product into a single chip or chipset [17], [20]. Today System-on-Chip (SoC) devices target high performance applications in which fast time to market is of prime importance. The evolution of VLSI and microprocessor technologies is expected to continue with an accelerating pace during the next decade. The FPGA based real time simulation of electrical machines has been implemented [12], [16].

(iii) dSPACE Controller

Testing and verification of motor control algorithms is very demanding and time consuming. Test systems use usually electrical connections to signal lines or pins to get information from tested device. Algorithms implemented in FPGA circuit are even more complicated to test because of the amount of internal signals. These signals are only accessible through test modules implemented inside the circuit [20].dSPACE hardware platform is based on digital signal processors (DSP). This platform has two characteristics which discern it from other similar products. First one is that this microprocessor board is mounted in the PCI slot of a personal computer, and the second one is that system uses MATLAB/SIMULINK as a software development tool. Hardware platform consist of two DSPs, which share different application-communication tasks in order to achieve real-time application running. For the development of software, dSPACE system uses MATLAB/SIMULINK. Almost all SIMULNK features and tools can be used for creating a user algorithm[17].dSPACE software package includes additional SIMULINK toolboxes which define different hardware characteristics like timers, counters, PWM generators, encoders, etc.,[19]. When the user algorithm is created in SIMULINK, target DSP code must be generated. MATLAB's Real time workshop and the specific builder, installed with dSPACE software package, provide building and downloading of user algorithms are possible directly from SIMULINK. When the user algorithm is downloaded real time debugging, parameters adjustment and signals observing are realized with the Control Desk software package. dSPACE real time platform allows simulation and verification environments to be created from SIMULINK models [31-32].

(iv) Artificial Intelligence Control

In recent years, there is an increased interest in combining artificial intelligent control with real time control techniques. In this paper, review on the different techniques based on the fuzzy logic and neural network in vector control of induction motor drive are presented in [16], [21]. dSPACE implementation of Fuzzy logic based real time vector control was presented [18]. The efficiency of the controller has been verified through hardware and MATLAB implementation [18].The real time implementation of IRFOC using dSPACE controller is presented. The performance of complete vector control of the single phase induction motor and PI controllers has been investigated and verified experimentally [35].

VI. APPLICATIONS OF THE REAL TIME SIMULATION TECHNOLOGIES

The first challenge faced by simulation specialists is to select a real-time simulator that will meet their needs. Simulator capabilities, size and cost are determined by a number of criteria, including (i) The frequency of the highest transients to be simulated, which in turn dictates minimum time-step, and (ii) The complexity or the size of the system to simulate, which along with the time-step duration, dictates the computing power required. The number of I/O channels required for interfacing the simulator with physical controllers or other hardware is also critically important, affecting the total performance and cost of the simulator. Fig. 5 outlines typical time-step and computing power requirements for a variety of applications. The left side of the chart illustrates mechanical systems with slow dynamics that generally require a simulation time-step between 1 and 10 milliseconds, according to the rule of thumb that the simulation step should be smaller than 5% to 10 % of the smallest time constant of the system. A smaller time-step may be required to maintain numerical stability in stiff systems. When friction phenomena are present, simulation time-steps as low as 100 microseconds to 500 microseconds may be required. Real time applications which can be used in modern engineering are:

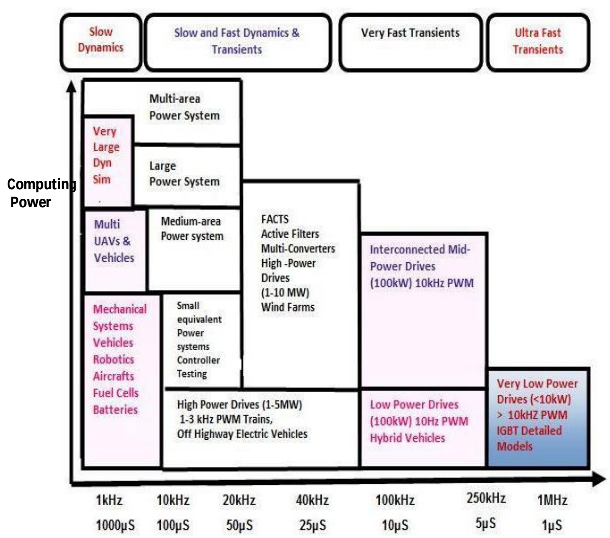


Fig. 5 Simulation Time-step by Application

(i) *Rapid Control Prototyping (RCP)*

Real-time simulators are typically used in three different application categories, as illustrated in Fig 6. In RCP applications, a plant controller is implemented using a real-time simulator and is connected to a physical plant. RCP offers many advantages over implementing an actual controller prototype. A controller prototype developed using a real-time simulator is more flexible, faster to implement and easier to debug. The controller prototype can be tuned on the fly or completely modified with just a few mouse clicks. In addition, since every internal controller state is available, an RCP can be debugged faster without having to take its cover off[1,48].

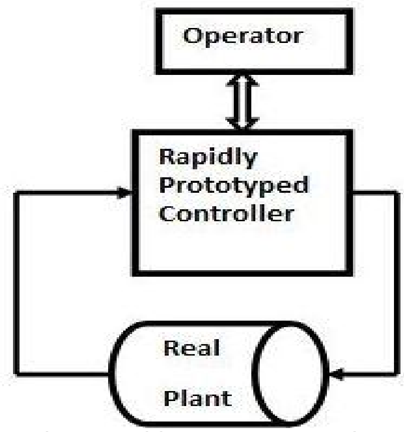


Fig. 6 Rapid Control Prototyping

(ii) *Hardware –in –the –Loop testing (HIL)*

For HIL applications, a physical controller is connected to a virtual plant executed on a real-time simulator, instead of a physical plant. Fig. 7 illustrates a small variation to HIL; an implementation of a controller using RCP is connected to a virtual plant via HIL. In addition to the advantages of RCP, HIL allows for early testing of controllers when physical test benches are not available. Virtual plants usually cost less and are more constant. This allows for more repeatable results and provides for testing conditions that are unavailable on real hardware, such as extreme events testing[34].

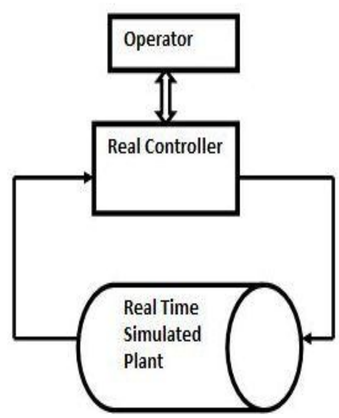


Fig.7 HILSimulation

(iii) *Software in the loop (SIL)*

SIL represents the third logical step beyond the combination of RCP and HIL as shown in Fig. 8. With a powerful simulator, both controller and plant can be simulated in real time in the same simulator. SIL has the advantage over RCP and HIL that no inputs and outputs are used, thereby preserving signal integrity. In addition, since both the controller and plant models run on the same simulator, timing with the outside world is no longer critical; it can be slower or faster than real-time with no impact on the validity of results, making SIL ideal for a class of simulations called accelerated simulation. In accelerated mode, a simulation runs faster than real-time, allowing for a large number of tests to be performed in a short period. For this reason, SIL is well suited for statistical testing such as Monte-Carlo simulations. SIL can also run slower than real-time. In this case, if the real-time simulator lacks computing power to reach real-time, a simulation can still be run at a fraction of real-time, usually faster than on a desktop computer[53].

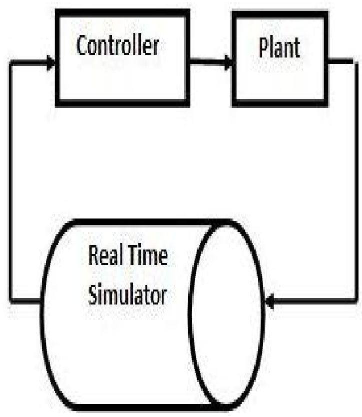


Fig.8 SIL Simulation

(iv) *RT Lab Real Time Platform*

RT-LAB is an integrated real-time software platform that enables model-based design by the use of rapid prototyping and HIL simulation and testing of control systems, according to the V-cycle design process. RT-LAB is a powerful, modular, distributed, real-time platform that lets the engineer and researcher to quickly implement block diagram. SIMULINK models on PC platform, supporting thus the model-based design method by the use of rapid prototyping and Hardware-in-the-Loop simulation of complex dynamic systems [6]. The major elements integrated in this real-time platform are: distributed processing architecture; powerful processors, high precision and very fast input/output interface, hard real-time scheduler, modelling libraries and solvers specifically designed for the highly non-linear motor drives, power electronics and power systems. The RT Lab applications are verified experimentally [53-54.]

VII. FOOD FOR THOUGHT

Some of the real time applications that can be used in modern engineering are:

(i) Electric Machine Drives

A critical aspect in the deployment of motor drives is the early detection of defects in the design process. The later in the process that a problem is discovered, the greater the cost to fix it. Rapid prototyping of motor controllers is a methodology that enables the control engineer to quickly deploy control algorithms and find eventual problems. This is performed using an RCP connected in closed-loop with a physical prototype of the drive to be controlled [8].This methodology implies that the real motor drive is available at the RCP. Furthermore, this set-up requires a second drive (such as a DC motor drive) to be connected to the motor drive under test to emulate the mechanical load. While this is a complex setup, it has proven very effective in detecting problems earlier in the design process. In cases where a physical drive is not available, or where only costly prototypes are available, an HIL-simulated motor drive can be used during the RCP development stage. In such cases, the dynamometer, real IGBT converter and motor are replaced by a real-time virtual motor drive model. This approach has a number of advantages. For example, the simulated motor drive can be tested with borderline conditions that would otherwise damage a real motor. In addition, setup of the controlled-speed test bench is simplified since the virtual shaft speed is set by a single model signal, as opposed to using a real bench, where a second drive would need to be used to control the shaft speed.

(ii) *Mechatronics: Robotics & Industrial Automation*

Mechatronics systems that integrate mechanical and electronic capabilities are at the heart of robotic and Industrial Automation applications. Such systems often integrate high frequency drive technology and complex electrical and power electronic systems. Using real-time simulation for design & test helps ensure greater efficiency of systems deployed in large-scale manufacturing and for unique, but growing applications of robotics.

(iii) *Electronic Circuit & Networks*

To keep pace with the current technological revolution universities must change. New ways must be found to teach future engineers using a transdisciplinary approach; leveraging the possibilities offered by new tools that talented engineers are seeking, while providing them with practical experience that cultivate their creativity [40]. In this context, electronic circuit simulators such as Circuit Logix, based on PSpice, have been used as teaching aids for many years in electronics and control system classes. Their workflow is quite straightforward; builds the circuit with the circuit editor tool, run the simulation and analyzes the results. However, when it is necessary to study the effect of the variation of many parameters (oscillator frequency, duty cycle, discrete component values) this process can take a great deal of time [2]. In such situations, interactive simulation, based on a real time simulator enables model parameter changes on the fly and becomes a valuable teaching tool. With such a tool, changes to the model are instantly visible, providing students with the live feedback required for them to get a feel for how a system reacts to the applied changes.

(iv) *Technician Training*

Real-time simulation can also be used for operator and technician training. While this application category is in an early growth stage, it offers great potential. For this category of application, both controller and plant are modelled in the same simulator using an SIL-like approach. The difference is that user interfaces are added in order to allow the operator to interact with the simulation in a user-friendly way. Interfaces such as control panels and joysticks manage user inputs, but also provides feedback to the user about the simulation state. The advantage of using a real time simulator for training is that the user can get a feeling for the controller and plant that correctly represents the real system, without the delays and limitations commonly found in training environments based on pre-recorded scenarios.

(v) *Power System*

Protection & insulation coordination techniques for large power systems use statistical studies to deal with inherent random events, such as the electrical angle at which a breaker closes, or the point-on-wave at which a fault appears [29]. By testing multiple fault occurrences, measured quantities can be identified, recorded and stored in databases for later retrieval, analysis and study. While traditional off-line simulation software (e.g. ATP, EMTP) can be used to conduct statistical studies during the development of protection algorithms, once a hardware relay is built, further evaluation and development may require using a real time simulator. Typical studies include digital relay behaviour evaluation in different power system operating conditions. Furthermore, relay action may influence the power system, increase distortions, and thus affect other relays. Because it is a two-way street, closed loop testing in real time is necessary for many system studies and for protection system development. By using real-time simulation, the overall stability and transient responses of the power system can be investigated in a timely matter, both before and after the integration of Renewable Energy Sources and Distribution generation. Statistical studies can be performed to determine worst-case scenarios, optimize power system planning and mitigate the effect of the integration of these new energy sources.

VIII. CONCLUSION

In this paper an overview of various real time simulation techniques and its applications in modern engineering have been presented. The real time simulation allows for physical controller to be simulated so that its performance can be evaluated. The various approaches available for real time simulation such as RT real time platform, Rapid Control Prototyping (RCP), Hardware in the Loop Simulation (HIL) and Software in Loop (SIL) have been discussed systematically. Such a tool can be integrated into the interdisciplinary engineering because it facilitates a number of benefits over purely off-line simulation. Real time simulation is a valuable technique that has been used for decades in the development and testing of complex systems such as missiles, aircraft, hybrid vehicles and spacecraft. By taking advantage of low-cost, high-powered computers and I/O devices, the advantages of real time simulation can be realized by a much broader range of system developers. A properly designed and implemented real time simulation can help you develop your products faster and test them more thoroughly at a cost that may be significantly less than the cost of using traditional system test methods The most important of these being the exposure to many practical problems associated with the real physical system. As the modern engineering is becoming more complex and costlier, simulation technologies are becoming increasing crucial to their success. Modern engineering would be more benefited from the inclusion of the real time simulation techniques because of the wide use of simulation software's, both by the academia, researchers and industry.

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