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REAL-TIME SIMULATION FOR PROTECTION AND SUBSTATION CONTROL WITH MATLAB / SIMULINK

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ABSTRACT: - This paper presents the design of a simple real-time simulator to protection electrical power system tests, whose the operation principle is based on closed feedback in the loop. The hardware system has a series results from scientific projects carried out at the Protection and Control Laboratory of electrical power system.

Models interface supports MATLAB / Simulink control system, and LabVIEW interface, and others. This gives not only Simulink, but also provides full support for any test software in real time, which uses the same interface. To run in the Hardware-in-the-Loop (HIL) simulation and the model has a measurement of the variables of the devices, whose receive the calculated variables in the form of mathematics. Testing has an integral part of modern controller development. Hardware-in-the-Loop (HIL) simulation plays a prominent role as test method. In HIL, the implemented controller is tested against a computer model of the process. Besides the communication between simulation and controller, HIL requires their synchronization.

Besides the communication between simulation and controller, the program is based on the MATLAB / Simulink package including libraries, while the hardware installed measuring cards segment consists in PC computers, amplifier CMS 156 dedicated and matching circuit.

The last section of this article and a brief description of possible improvements expected for simulation in the future. The study involves xPC Target as a real time operating system in charge of executing a control task is focusing on the built in control and simulation capabilities. We will try to see how accurate and how fit xPC Target is for multiple Targets control, here the xPC Target is used as an operating environment for real time simulation in electrical power sub stations system.

Keywords*: Hardware-In-the-Loop (HIL), protection devices, SimPowerSystem, Real-Time Simulation RTs, Software-In- the-Loop (SIL)***,** *MATLAB /Simulink, xPC Target.*

1- INTRODUCTION

Power system generation studies using a detailed model can be difficult to perform with a conventional offline simulation program. Due to the computational power and high-speed input and output, a real-time simulator is capable of conducting repetitive simulations of power system in a short time with detailed models of critical components and allows testing of prototype controllers through hardware-in-the-loop (HIL).

This paper discusses methods to overcome the challenges of real-time simulation of electrical power systems, characterized by their power system and high-frequency switching. The energy storage system, coupled in a generator to electrical power, is studied by real-time

HIL simulation**.** In recent years, HIL for power systems has been used for verifying the stability, operation, and fault tolerance of large-scale electrical network. Current-generation real-time processing platforms have the capability to model large-scale power systems in real-time. The real time simulation platform bases on MATLAB/Simulink, which built for testing and verification of protection devices and automation system in power distribution network. Testing results show to the step time size and data accuracy of the simulation bases on SimPower Systems toolbox. Simulation has benefits of different aspects:

- Planning and designing of high voltage equipment with the associated protection and control systems.
- Accurate and precise analysis of faults events, e.g. after a line failure or a blackout.
- Development of protection and control devices and systems including hardware, software and firmware.
- Education, training, counseling.

Firstly a complete simulation system have been including protective devices in operation must have adopted, by using a computer hardware with the highest possible on computing power system, with the advent of real time simulation and compact reconfigurable I/O controllers , electrical power systems can be simulated and their behavior can be analyzed in both steady state and faulted conditions. Based on this analysis, protection system and power system controllers can be developed for more efficient, reliable and safe operation of power systems. real time simulation RTS are currently being used for HIL, validation, developing algorithms for adaptive protection, designing system protection and other applications [1].
So I found the basic capabilities and limitations of simulation in:

- Correctness and accuracy of the simulation.
- Requirements for simulation computer hardware which has been depending on model size, frequency range and step time size.
- Opportunities for real-time and off-line simulation base on the same model parameters.
- Integration of protection algorithms and devices in the simulation (instead of real devices).
- Extensibility and openness, for example, on Wide Area Protection, simulation of current transformers with saturation, modeling not available in the control system components, and systems with several types of protection.

2. STRUCTURE OF REAL-TIME SIMULATION SYSTEMS

The structure of the real-time simulation systems has consisted of:

- Host PC for the creation and operation of the model to a"target PC" with MATLA/Simulink.
- Target PC with a special real-time operating system on which the build model inreal

time, which has simulated and the PCI interface cards digital, analog signals can read and print. These signals have with the help of relays and amplifiers led to a protection and control device, whereby a hardware-in-the-loop simulation has possible.
The simulation system has installed in the real-time simulation for a protective device and construction of hardware, the required software has installed, configured and tested. In the subsequent test or familiarization phase, the functionality of the individual components and the complete system has tested and verified. [2]
You can test a control system design running on target computer hardware while it is connected to physical plant or system.
Here, the target computer acts as your hardware system, figure (1).
For selecting the interface card and accuracy of the analog outputs have the essential criterion. Which have proven suitable PCI boards? The computer Boards PCI-DA08/16: 8 channel 16-bit D/A card, 48bit digital I/O channels. The connection to the modules has the SCB-100 (100-Pin Shielded Desktop Connector Bloc) show in figure (2).

The Serial Control Board SCB-100 has two manual switch ports. This allows control of two screens or a screen and a projector lift in dependently.
The SCB-100 has two RS-232 ports. Port1 and Port 2 can control either motor 1 or 2.
Both ports are marked with RX, G, TX.

- RX-data being received into the SCB-100.
- TX-data going out of the SCB-100.
- G-ground.

As part of the project addition interface modules between the real-time network model and the protection of control devices, or the amplifier Omicron CMS 156 was built. To operate the control panel as shown schematically in Figure (2) the following controls are available:
• Relay 0. 3: From model 4 binary outputs, for example, to protection relay opto coupler inputs, including LED status display.

- EXT_0 .. EXT_3: Control of 4 model binary inputs, such as from the protection relay-message output, including LED status display.
- **A_0 .. A_7 :** LED display of model binary outputs.
- **E_0 .. E_7 :** Push button / switch for manual setting of the model inputs, eg to turn on a line or enter the short circuit occurrence , including LED status display The back of the control panel is used to connect the model output (G : 38 -pin connector from the terminal box SCB -100) and the external CMS156 Amplifier analog inputs (U1. . U3, I1.. I3) protection unit- binary outputs (K for EXT 0 . 3) and protection unit.

The line model already shown in combination with a real protection device provides virtually the same results as in the of fline simulation. The achievable time step sizes are in the range of 20 to 50 microseconds. [4]

2.1 Modeling of the primary and secondary systems

This paper focuses on a new methodological approach based on a mathematical programming model for secondary distribution network design. Many factors reveal the importance of this part of the electric power system, among them:

1. The secondary system direct links with the consumers;
2. It operates on a low-voltage level;
3. The costs involved in its construction, operation and maintenance are very high.

The secondary network design problem is basically concerned with defining the number, the location and sizing of distribution transformers, the feeder routing and sizing, and the primary-transformer interconnection.
The interaction of components need to be considered as in figure(3), which shows various circuit elements in a current-type switching coordination. Analysis of this circuit aids in understanding how the various components involved in a protection solution work together when tested with a generator.

Figure (3) shows the test generator with voltage VG and internal resistance RG. The voltage VS required to operate the secondary protector is developed across the load, RL. The primary protector operating voltage is defined as VP and the voltage developed across the coordination element is identified as VZ. The current through the coordination element is IS.
From figure 4, if no overvoltage protection elements operate during the test, the level of voltage
Stress seen by the load, RL, is established where VS will be: [5]

$$V_S = V_G \left[R_L + \frac{Z + R_G}{R_L + Z + R_G} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Understanding how the primary protection behaves is an important aspect of the protection design. If the primary voltage is not activated then the secondary protection will need to support the following current for the duration of the fault event:

$$I_S = \left[\frac{V_G}{R_G + Z}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

In this case the secondary protection must be capable of withstanding the full current of the surge as though the primary protection was not present.

Figure (4) has shown an example of the interaction of the high-voltage system with primary equipment for simulation, with account of both the primary and secondary equipment .The overall systems primary and secondary have consisted of automation system protection controller Supply, power line, circuit breaker, protection and control equipment, secondary systems converter and short circuit.

For account the effect of protection and control devices, the simulation routine has consists of the following:

- Simulation of the protection and control algorithms.
- Inclusion of real devices, which has, hardware-in-the-loop (HIL) simulation. The systems of electrical power engineering have modeled graphically comfortable with MATLAB/Simulink and SimPowerSystems toolbox. Primary equipment and secondary technical functions can be seamlessly connected. Now the full range of MATLAB Libraries, figure (5) shows a simple example of a model of a high voltage transmission line by including a complete line protection. [6]

The integration of the differential equations, discrete-time or continuous-time has crucial for modeling the Protection and control devices with a single model, different steps time size which have supported. In addition to the consideration here, time profiles during dynamic and stationary conditions can be investigated if necessary.

2.2 Offline simulation

After modeling, all the simulations provide desires model sizes in the selected time range. The results for a 2-poleEarth fault in the models shown in Figure(5), as recorded by the scope block and evaluated after the simulation as show in Figure(6).

The results has provided by the simulation which broadly in line with the expectations and the results of other calculation programs. This verified among others, have taken from [7] model of a three-terminal line. Protection and control devices can be used in the simulation without real existing hardware, "Software-in-the-loop" (SIL) can be considered as:

- For setting the timing of output signals.
- For modeling of signal processing (for example, analog and digital filters) and logic with Simulink functions.
- Integration of device firmware into the model via the concept of Simulink function for high-level languages e.g. (C++).

The Scope recording of Figure (7) illustrate. The sampled voltage and current values have based on the reaction of the protection software.

3. REAL-TIME "HARDWARE-IN-THE-LOOP" (HIL) SIMULATION

If real protection-/control units have integrated into the simulation (HIL), the real-time simulation has to be performed, ie they may run either faster or slower than real time. The typical configuration has shown in Figure (8).

- The simulation has performed on designated target computer. The standard PC has equipped with interface cards to replace the analog and digital signals with the protection and controller. It has booted with the optimized kernel PC Target, so that no stresses caused by a Windows operating system. Monitor and keyboard allow for comfortable use and operation of the simulation.
- The model has built in the host computer for creating offline-simulation. For the communication with the analog and digital inputs, inputs/outputs have library blocks for

easy configuration. Simulation program code has generated by the MATLAB/Simulink Component Real-Time Workshop in conjunction with a C compiler. Communication with the target-computer typically runs over the local network (e.g. LAN).

- As an interface to the protection and control devices have used , the current, voltage amplifier of the Omicron CMS156 , and the potential for adaptation of the binary Signals optcouplers have used.
- Switch / push button allow manual intervention, for example, to activate a short-circuit.

You can test your controller hardware, which can include a production or embedded controls implementation, using a simulation of your system. (The target computer hardware acts as your controller.)[8]

4. GENERATOR PROTECTION AND BUS-BAR CHANGE-OVER

The modeling of electrical machines (synchronous generators, transformers, and induction machines) is possible with the standard library elements of SimPowerSystems. Any missing components can be taken into account via custom sub systems, such as the current and voltage transformer circuits with account the non-linearity and burdens. The steady-state load flow initial conditions for dynamic processes can also be found easily in figure (9).

The simulation of a bus-bar fast change-over for the power plant's own requirements. Figure (10) shows that realistic simulations are possible even for complex switching operations which are with the participation of various electrical machines, show in Figure (10). A System under test is a Hardware that is tested to determine performance. A System under test also may be a component of a unit known as a unit under test, is checked for defects to make sure the device is working. The results of an offline simulation are shown in Figure (11). The connection is performed in system view at a bad time with about 60 degrees of phase shift to the new power supply and has a relatively large motor currents and unwanted negative torque result.

Here were "hardware-in-the-loop" carried out tests with a real controller successfully and with the expected results. A number of other applications was simulated with the success:

- Saturation of current transformers by the nonlinear magnetizing inductance.
- Generator protection with over current & excitation, reverse power, under frequency, etc.
- Generator differential protection without and with (at both measuring points different) has saturation of the current transformers.[9]

5. NETWORK STABILITY

This paper concentrates on the design of a controller for electrical power system. The controller proposed for use with each distributed generation system in the electrical network contains inner voltage and current loops for regulating the three-phase grid-interfacing inverter, and external power control loops for controlling real and reactive power flow and for facilitating power sharing between the paralleled distributed generation systems when a utility fault occurs and the electrical network. For investigations of network stability, wide-area monitoring and protection must be considered often with dozens of nodes and lines networks. To demonstrate the feasibility of the simulation, it was based on the 400/130-kV-network created the simplified model shown in Figure (12), with the dynamic network behavior can be determined by the failure of a north-south transmission line. The handling of the models facilitates through the preparation and use of appropriate library elements for nodes and lines. The parameterization of the library elements is done systematically by MATLAB/Simulink script files. Those, the parameter can also optionally be changed uniformly. Likewise, an adaptation of the library elements used is easily possible. The figure below view dynamic systems as they run in real time using MATLAB/ Simulink. [10]

The electrical power station is controlled by a real-time system simulator that is capable of simulating electrical networks and control systems of substantial, typically with a 50-mus time step. Substantial input/output allows the feedback of measured quantities into the simulation. A generator set is used to demonstrate some critical aspects of the concept including the implementation of a proposed network-based sensor less energy capture control. From the dynamic test results presented, it is concluded that the proposed system shows great potential for the development of a unified energy design, test, and research platform. For a time step size of approximately 40 microseconds achieved in Figure (13). This is still sufficient for the testing of protective devices which has essentially based on operational frequency measurements. [11]

6. CONCLUSIONS AND EVALUATION OF RESULTS

Design of controlled systems requires the integration of the electrical and controls systems during the simulation phase to efficiently ensure proper results. This integration is done at different steps of the process – first with software-in-the-loop (SIL) and then in hardware-in-the-loop (HIL). The integration of plant models with a control model or code ensures the required accuracy as well as accessibility of the variables needed for controls.

- The Transmission networks will benefit from real time HIL simulation for developing new technologies.
- Modeling for real time simulation is necessary:
- Developing more models for protection functions like Distance protection, over/under voltage and frequency protection etc. to have available a library for protection functions.
- Consideration of actual measurement and automation streams is necessary:
- Developing a Real-Time controller which can read data from power system / substation components irrespective of the vendor protocol and can translate it to take either Distributed.

The HIL platform is based on innovations in switched piecewise linear circuit modeling for real-time simulation and testing for power electronics control software, hardware, and firmware. Using Matlab/ Simulink has allowed practical simulations of simple and complicated dynamic processes in electrical power networks. Protection and control devices for networks, transformers, generators and bus-bars can be integrated into almost any network simulation. In addition to a software modeling (SIL) real devices can be also used in a real-time simulation via suitable interfaces (HIL) are implemented. The interface algorithms are described, and their characteristics with respect to the system stability are compared. Through MATLAB simulations and the experiments of representative power HIL examples, it is revealed that certain interface algorithms exhibit higher stability and accuracy than the others under the given conditions. For more protection, control devices can be considered both as real devices in a "hardware in the loop" Real-time simulation as well as in a combination of software model and real devices. This means that both the simulation for individual devices is possible as well as for their interaction in a station with associated substation control or even in an entire network. [12]

The cost of hardware simulation is assessed for the selected PC platform as very favorable. Cost of the software licenses have alternative solutions which can be compared. Since a large part of the software functionality comes in the entire industrial automation used towards specialized solutions are cost advantages as well as safe and efficient development of support tools expected by the manufacturer. Developing of a Real-Time controller which can read data from power system / substation components irrespective of the vendor protocol and can be translated it to take either distributed or global control actions. The goal of the HIL system is to develop new control algorithms and to investigate the effect of faults, both in sensors and actuators, and the engine itself.

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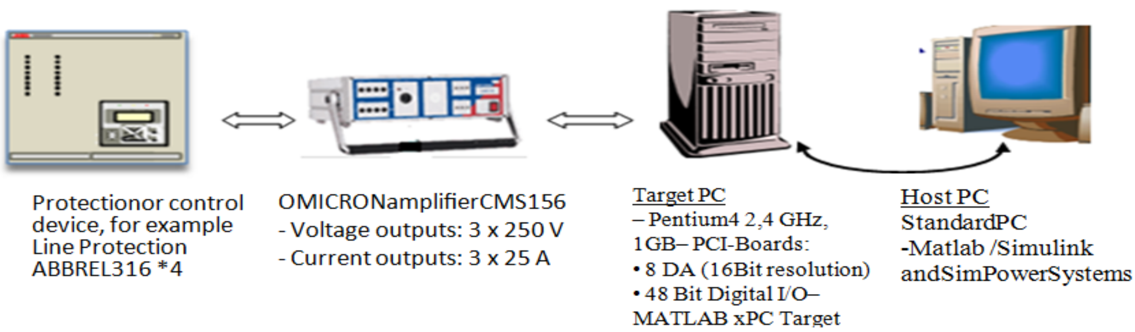

Figure (1): Components in the real-time simulation for a protective device

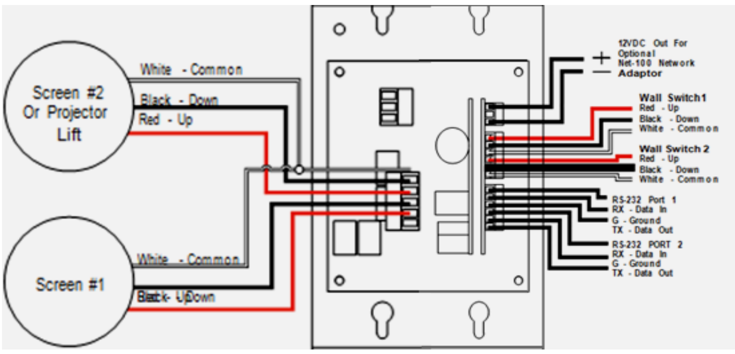

Figure (2). Instruments SCB-100 Shielded 100-Pin I/O Connector Block

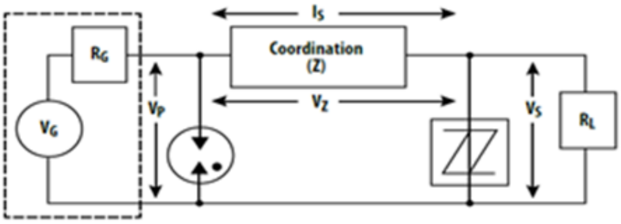

Figure (3) circuit elements in a current-type switching coordination

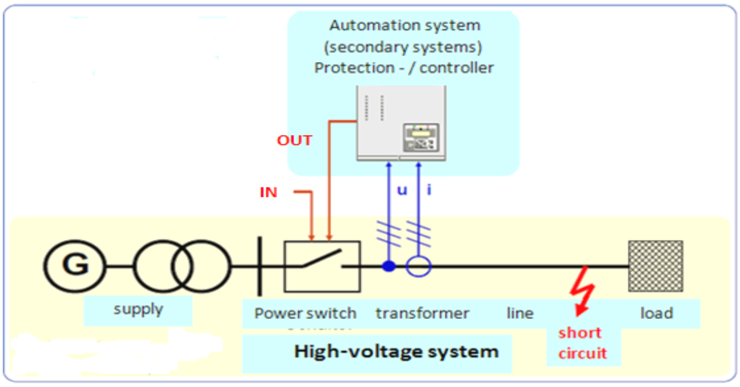

Figure (4) primary and secondary equipment in the line protection

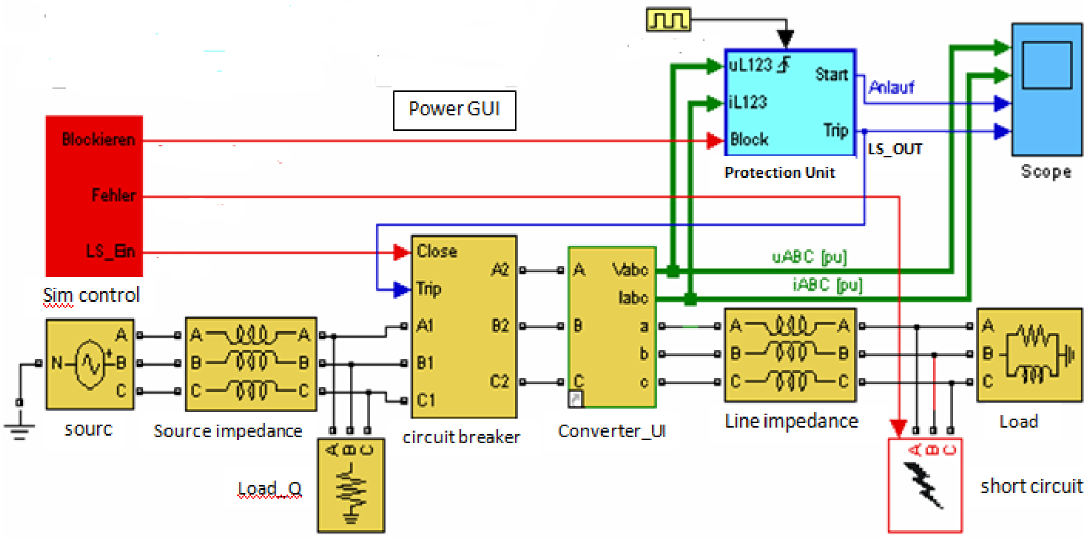

Figure (5) Model of a high-voltage line,with line protection

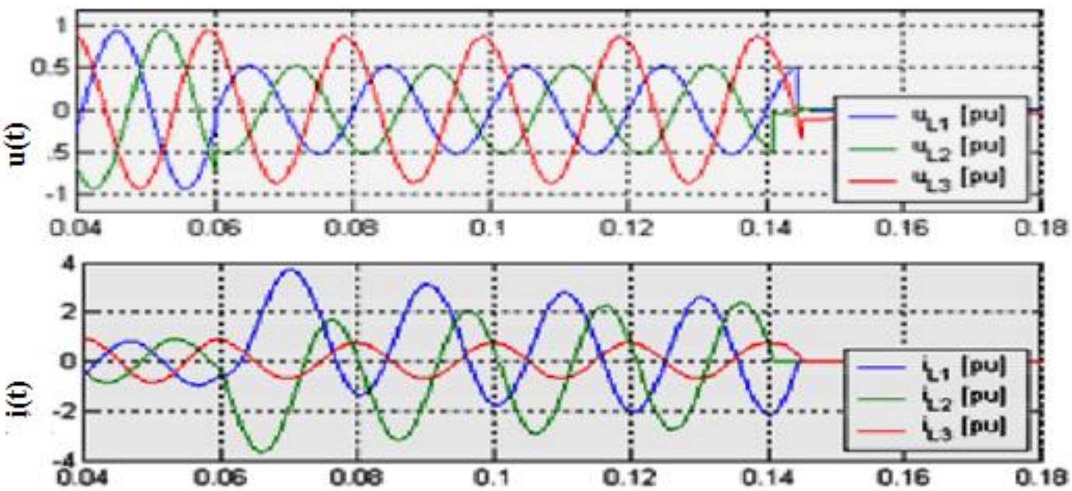

Figure (6) Voltages and currents with a protective response in a 2-pole earth fault

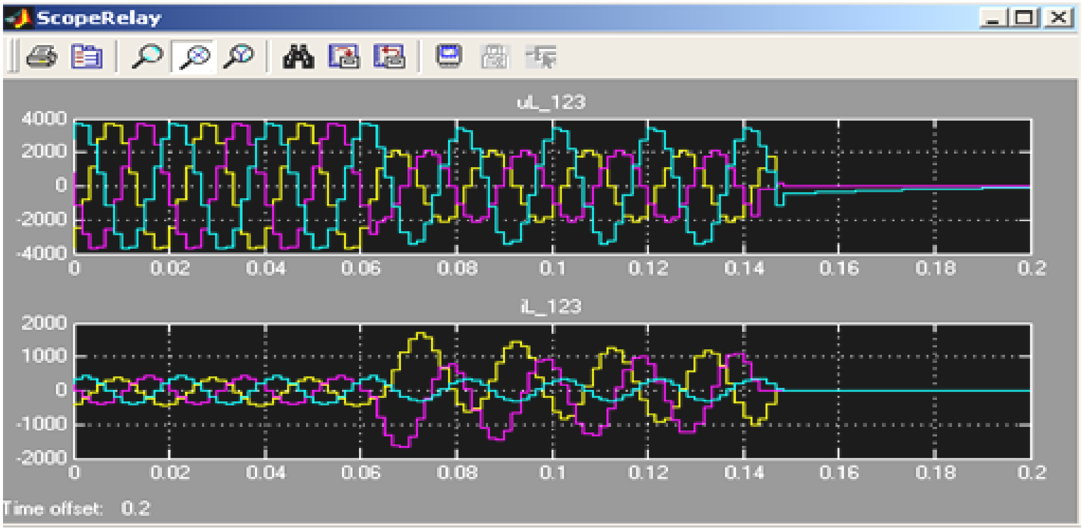

Figure (7) Sampled "protective device" of analog inputs for earth fault

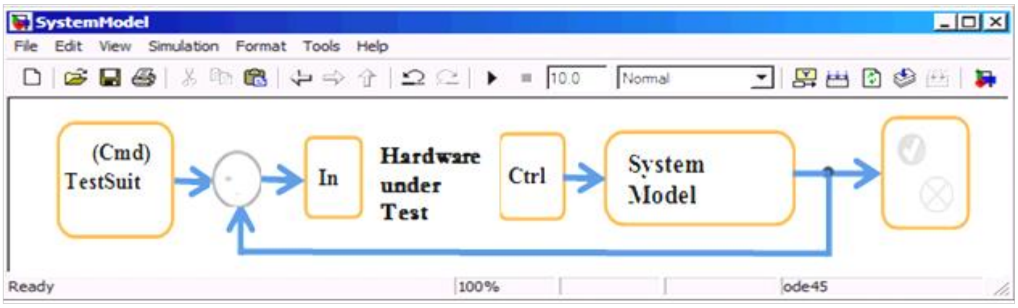

Figure (8) Using Real-Time HIL Simulation to Test Virtual Controllers and Systems

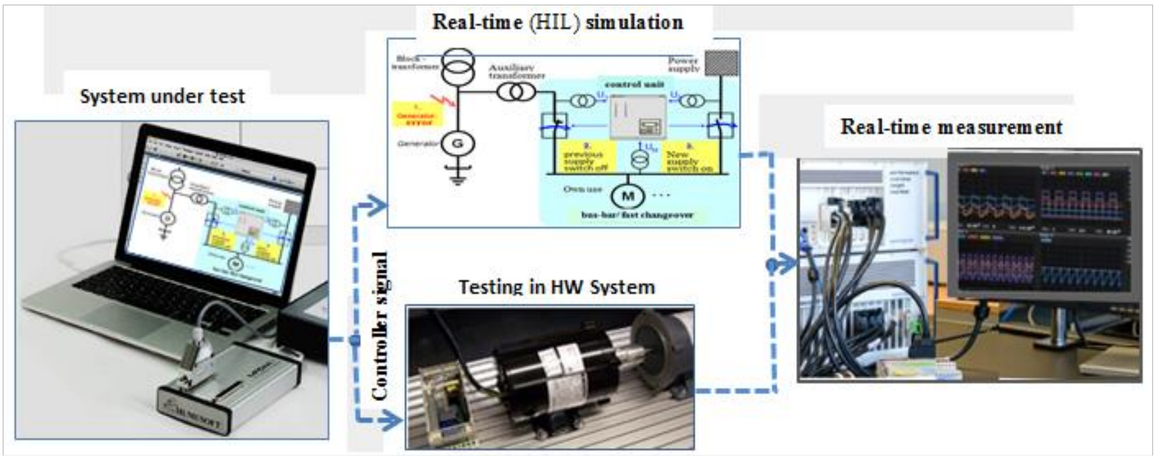

Figure (9) Demonstration of a hardware-in-the-loop (HIL) simulation

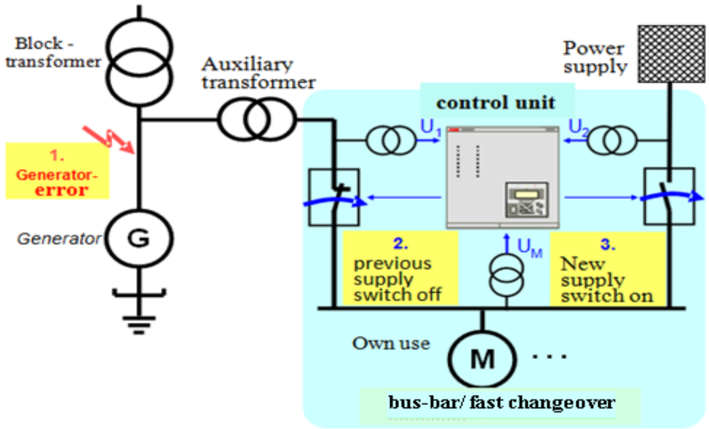

Figure (10) System configuration and control unit for abus-bar fast change-over

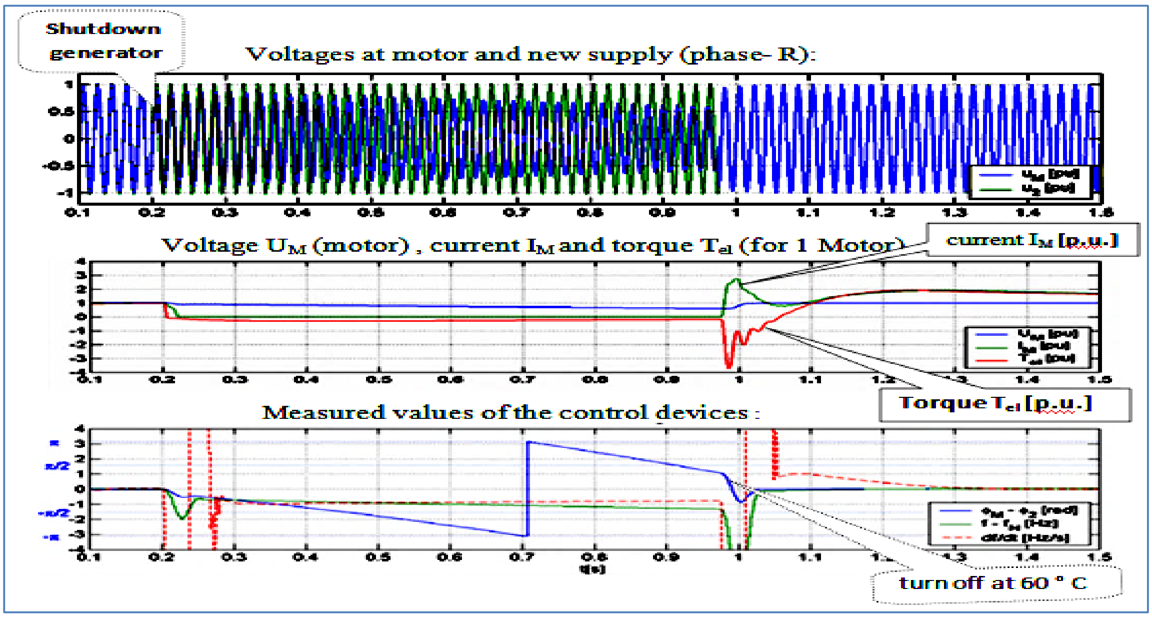

Figure (11): Timing a bus-bar/fast changeover

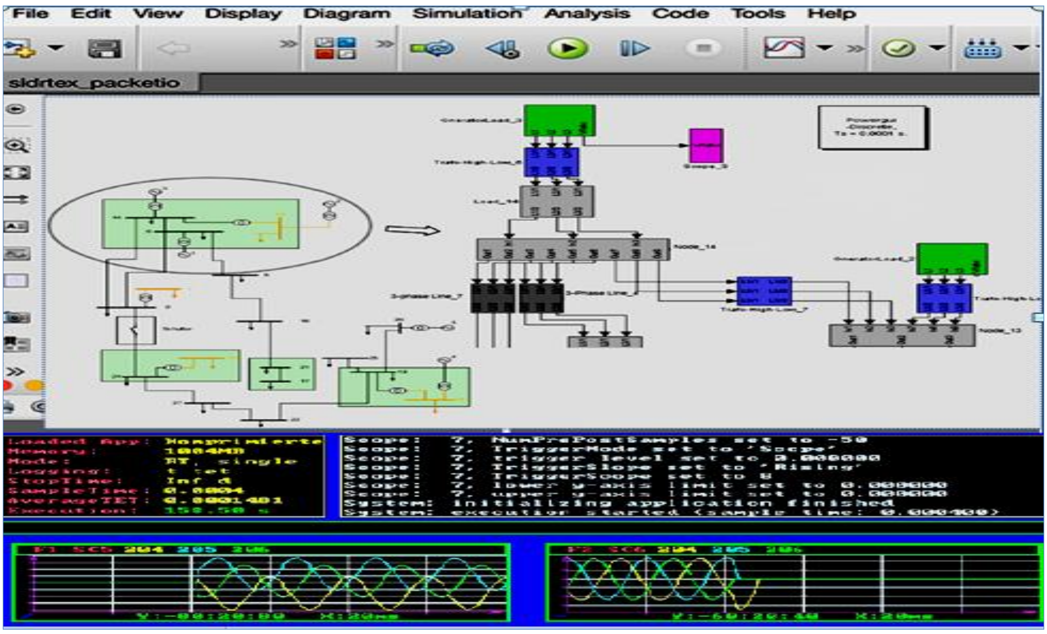

Figure (12) Simulated network configuration and model-cutout for stability studies

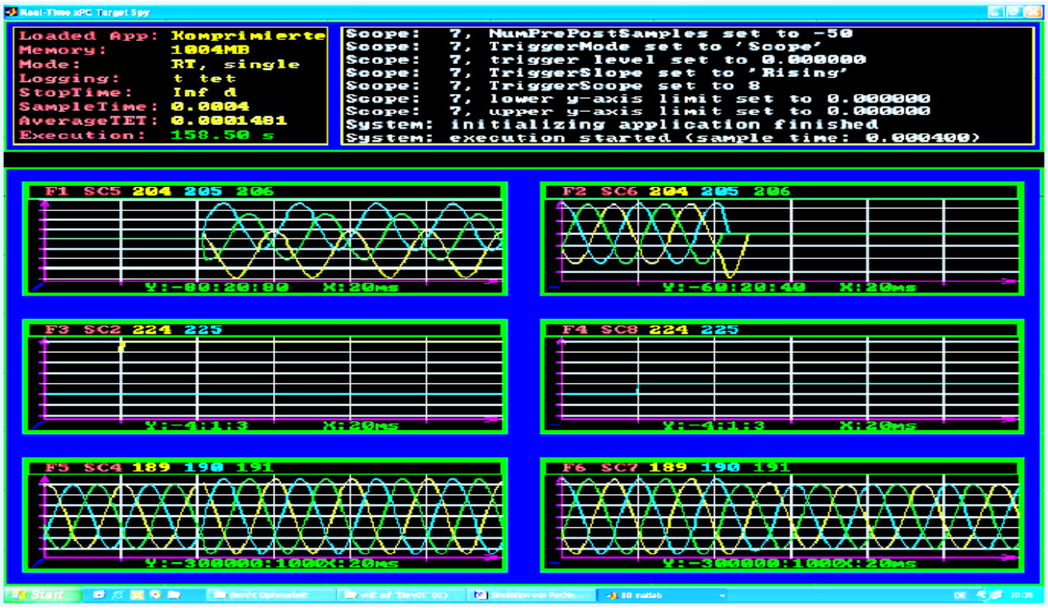

Figure (13): Target Scope in the stability analysis with real-time simulation

المحاكاة في الوقت الحقيقي لحماية ومراقبة المحطات الفرعية باستخدام برنامج ماتلاب/سيميولينك

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الخلاصة

يعرض البحث تصميم جهاز محاكاة بسيط في الوقت الحقيقي لاختبارات نظام حماية الطاقة الكهربائية، والتي تقوم على مبدأ عملية ردود الفعل في الحلقة المغلقة . الجهاز هو نتيجة لسلسلة من المشاريع العلمية التي أجريت في مختبر الحماية والتحكم في نظام الطاقة الكهربائية. نماذج واجهة دعم نظام السيطرة بواسطة برنامج المحاكاة (MATLAB/ Simulink) ، وواجهة (LabVIEW interface)، وغيرها. وهذا لا يعطي فقط السيميولينك، ولكنها توفر أيضا الدعم الكامل لأي برمجيات اختبار في الوقت الحقيقي، والذي يستخدم نفس الواجهة (interface) . ليتم تشغيلها في محاكاة الأجهزة داخل حلقة وبناء نموذج قياس المتغيرات لهذه الأجهزة, التي تستقبل المتغيرات المحسوبة بصيغة رياضيات.

الاختبار هو جزء لا يتجزأ من تطوير اجهزة التحكم الحديثة . محاكاة الأجهزة في داخل حلقة (HIL) يلعب دورا بارزا بطريقة الاختبار . في اجهزة المحاكاة (HIL) ، يتم اختبار وحدة تحكم نفذت على نموذج حاسوبي لهذه العملية . إلى جانب التواصل بين المحاكاة مع وحدة تحكم، يتطلب HIL التزامن الخاصة بهم. إلى جانب التواصل بين المحاكاة و وحدة التحكم، ويقوم هذا البرنامج على مجموعة (MATLAB/Simulink) بما في ذلك مكتبات النظام، في حين تتكون الأجهزة المثبتة على شريحة بطاقات قياس في أجهزة الكمبيوتر PC ومكبر اشاره CMS 156 مخصصة ومطابقة للدائرة . القسم الأخير من هذه المادة، وصفا موجزا لإدخال تحسينات ممكنة ومتوقعه للمحاكاة في المستقبل.

وتركزالدراسة التي تشمل (xPC Target) على نظام التشغيل في الوقت الحقيقي مسؤولا عن تنفيذ مهمة المراقبة وتركز على الدمج في قدرات التحكم والمحاكاة. وسنحاول معرفة مدى دقة وكيف يصلح (xPC Target) للسيطرة على أهداف متعددة, هنا يتم استخدام xPC لبيئة تشغيل المحاكاة في الوقت الحقيقي لحماية الاجهزة في محطة توليد القدرة الكهربائية.

الكلمات المفتاحية: محاكاة الأجهزة في داخل حلقة (HIL), أجهزة الحماية ، بطاقة نظام توليد الطاقة، محاكاة في الوقت الحقيقي RTs ، البرمجيات الداخلية للحلقة (SIL)، برنامج المحاكاة ماتلاب/ سيميولينك، الحاسوب الهدف xPC .