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Ref. PR No.: 1000051217 Rfx. No.: 6100002534

Technical Specifications of a Real-Time Digital Simulator for Power Systems and Power Electronics Applications

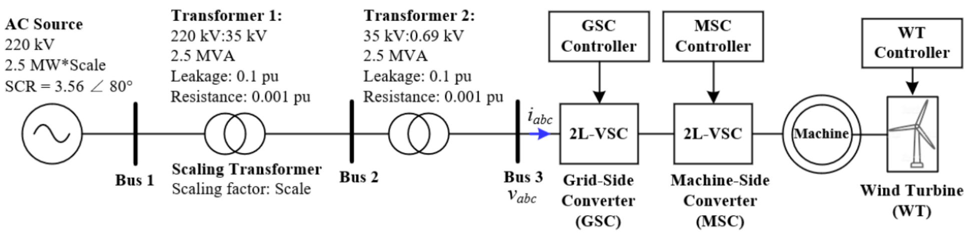
The Power Systems and Power Electronics Simulator must be a digital system able to perform electromagnetic transient simulations continuously in real time. The main purpose of the simulator will be to test physical controllers and protection devices, for general power system and power electronics studies, and training.

Sr. No	Item Description	Detailed Technical Specification	Technical Compliance (Yes / No)	Additional Information (if any)
1. Real-Time Digital Simulator				
A : HARDWARE SPECIFICATIONS				
1.	**Computational Units**	• The power and control system computation shall be performed by a processor housed on a printed circuit board. • The processor core(s) shall not be dedicated to simulating specific models and the function of each core shall be completely defined by the simulator software.		
2.	**Analogue Output (high resolution / optically isolated)**	• A minimum of 12, 16-bit analogue output channels shall be available on the simulator to facilitate connection to external devices. Input voltage range +/- 10 Volts. • For simulations operating with timesteps up-to 50 microseconds, the analogue output signal shall be capable of being oversampled at a rate of 1 microsecond. • The analogue output shall be equipped with a "watch dog" circuit to ensure the output voltage is set to zero within 1 millisecond of a simulation being stopped. The zeroing of the d/a output shall be within 1 millisecond		

		regardless of how the simulation is terminated, either intentional or accidental.		
3.	**Analogue Input (high resolution / optically isolated)**	A minimum of 12, 16-bit analogue input channels shall be available on the simulator to facilitate importing analogue signals from external sources. Input voltage range +/- 10 Volts.		
4.	**Digital Input (optically isolated)**	• A minimum of 32 optically isolated digital input channels shall be available to allow the connection of multiple external devices to the system. The digital inputs must be sampled with a resolution of at least 10 ns.		
5.	**Digital Output (optically isolated)**	• A minimum of 32 optically isolated digital output channels shall be available to allow the connection of multiple external devices to the system.		
6.	**Ethernet Communication**	• The basic simulator module shall have ability to connect directly to a 100/1000 BaseT Ethernet Local Area Network (LAN) so that it can be accessed over Ethernet network locally or remotely. • It shall also be possible via the simulator software and the Ethernet communication to control, monitor and interact with simulations during execution, allowing the user to "operate" the simulated power system in a manner similar to that of a real power system (i.e. the simulator operator must have continuous communication with and control of the simulator during real-time simulations).		
7.	**Expandability**	• If needed in future, it shall be possible to expand the simulator by adding additional modules to the system, which can communicate over dedicated Fibre optic communication.		

B :SIMULATION SOFTWARE/ ALGORITHM/ CAPABILITIES				
1.	Real time capabilities	For the purpose of this specification, real-time simulation shall be interpreted as hard real-time simulation as per the following definition: • The calculation time for the entire power system model, including the time required for communication and servicing of I/O, is completed with respect to real world time in less than the timestep selected for a particular simulation case. • Each simulation timestep is equidistant from the next with respect to real world time.		
2.	**Electrical network simulation**	• The real-time simulation must use nodal analysis to solve the main circuit node voltages and branch current equations. • The nodal approach finds the solution of the node voltages by solving the equation [I] = [Y] x[V] where Y is the corresponding admittance matrix of the network.		
3.	**Electrical Network size**	• The size of the admittance matrix which is decomposed every timestep must be a minimum of 54 x 54 elements. Therefore, 54 single-phase main circuit nodes must be allowed as one tightly coupled system, and must allow time-varying admittance elements at and between each and every node. • It shall also be possible to simulate radial feeders, such as those typical of distribution networks, with at-least 375 single-phase circuit nodes within one tightly coupled subsystem with average models of power electronic components.		
4.	**Power electronics simulation requirements**	**(a) Line Commutated Power Electronic Converters (LCC)** • The simulator shall be capable of capturing the firing instant with an accuracy of 1 micro second or better. • The accuracy shall be maintained at all times and regardless of whether the firing pulses are generated internally by a simulated controller or externally by a physical controller. • The converters be solved as embedded parts of the main network solution and not as isolated		

		subsystems. This is important to ensure maximum numerical stability and the proper representation of harmonics. • These models shall also allow the representation of internal faults. **(b) Voltage Source Converter (VSC)** • VSC when operating with a real-time EMT simulation timestep of 30 µs, the simulator shall have the ability to run detailed switching models of VSCs, capturing characteristic harmonics up to 14 kHz. The simulation should introduce only minimal non-characteristics harmonics. • VSC when operating with a real-time EMT simulation timestep of 1 µs, the simulator shall have the ability to run detailed switching models of VSCs with PWM frequencies of at least 100 kHz. The simulation should accurately capture the characteristic harmonics at-least up to 200 kHz for 100 kHz PWM frequency, and should introduce only minimal non-characteristics harmonics. • The VSC should not be simulated using artificial decoupling elements. • It should not introduce spurious oscillations due to the switch modelling methodology. • These models must be available for at least the following converter topologies: 2-level VSC, 3-level VSC (both T-type and NPC), Buck converter, Boost converter, Flying capacitor converter, and Dual Active Bridge. In addition to power electronic components, it shall also be possible to include any model from the standard power system library in the VSC subnetworks, including transformers, transmission lines, cables, permanent magnet synchronous machines, double fed induction machines, breakers, filters, etc.		

5.	**Test system**	• The simulator shall be capable of representing, in real time with full matrix decomposition every timestep, the power system defined in Figure I. • Breakers shall be included at Bus 1 and Bus 3, and the simulation shall not use artificial decoupling elements like travelling wave transmission lines. • The simulator shall be capable of representing, in real time with a timestep of **25 us microseconds**, the circuit defined in Figure I. • The simulation must be capable of testing PWM control with a carrier frequency of at least 8 kHz. • The compilation time of the circuit shall be less than 5 seconds. **<u>Numerical Stability</u>** • The simulator shall be capable of simulating the system shown in Figure I continuously in real time for a minimum duration of twelve (12) hours with a maximum simulation timestep of 25 microseconds. • The operator should be able to manually apply faults at random times during the test to ensure the numerical stability and continuous operation of the system.		
 **Figure I**				
6.	**Software**	**<u>Graphical User Interface</u>** All aspects of the simulator operation, from construction of simulation cases, to operation of the simulator, to post analysis of results must be controlled by a single Graphical User Interface (GUI). The GUI shall consist of modules for the following functions: • **Circuit Construction:** a module to allow the construction of simulation circuits. It shall be possible to use predefined modules from		

		a library of components to assemble new simulation cases. • **Transmission Line and Cable Constants**: a module to calculate the travelling wave and pi-section parameters for transmission lines and cables. It shall be possible to input the physical parameters of transmission lines and cables to calculate the parameters. Alternatively, for overhead transmission lines it shall be possible to input positive and zero sequence data for 3 and 6 conductor transmission lines to calculate the parameters. • Configuration tool for substation automation related communication, as per the industry standards. • **Simulator Operation:** a module for operation of the simulator and the retrieval of simulation results. This module shall allow simulation cases to be started and stopped. The operation of the power system (i.e. changing of set-points and breaker operations), fault applications, monitoring of system status (e.g. RMS voltages and currents), and the retrieval of details simulation results (similar to a fault recorder) must be possible without interrupting the simulation (i.e. while it is running). • **Storing of Results:** it shall be possible to save simulation results directly from the GUI in ASCII, jpg, emf (vector format), pdf or COMTRADE format. • Post-Analysis of Simulation Results. **<u>Batch Mode Operation</u>** • Software shall be provided to allow the user to program a series of simulations to run automatically (i.e. batch mode). • The batch mode software shall be capable of nested looping (e.g. if, for and while) to allow adaptive algorithms to be used during automatic operation.		

		• The batch mode software shall also be capable of recording key results in ASCII format and selectively printing or storing simulation results. • The batch mode software shall have the ability to embed text and simulation results (in .jpg or .emf format) directly into Microsoft® Word™ documents. • The batch mode software will be used to conduct automated relay testing where many hundreds or thousands of cases may be simulated during a day.		
7.	**Power System Models**	A minimum of the following power system models shall be available for the simulator: • Pi-section and multi-phase transmission travelling lines with ability to model 1 to 18 conductors, coupled transmission line and cable models. It shall be possible to embed breakers in each end of the transmission line models with a maximum of 6 conductors. The nodes introduced by the breakers shall be solved by the transmission line model and shall not count as part of those solved by the main network solution. • A phase domain frequency dependent transmission line model shall be available to represent a minimum of 12 coupled conductors. • Transformers with 2 or 3 windings and autotransformers with an optional tertiary winding. It shall be possible to include saturation with hysteresis, and online tap changers in the models. It shall also be possible to represent the transformers with internal turn-to-turn and winding to ground faults. A terminal duality-based model shall be available for representing faulted 2 and 3 winding transformers. • Synchronous machines (standard and permanent magnet). The synchronous machine models must be solved as part of the main network and are not allowed to		

		be numerically interfaced to the network solution. The synchronous machine model shall optionally allow the unit transformer and/or stator side breaker to be embedded as part of the model so the transformer secondary nodes or breaker nodes do not reduce the number available in the network solution (i.e. if breaker and/or transformer are embedded to the machine model, no extra nodes need be counted as solved by the network solution). Also, the possibility of initialization of the machine based on the load flow results, as well as entering the machine parameters in both "R & X" and "impedance and time constant" formats, and inclusion/exclusion of magnetic saturation and saliency must be provided. A synchronous machine model must be available that will allow a true stator-ground fault. The machine model must also be solved as part of the main network and is not permitted to be interfaced or decoupled from the network solution. It shall be represented in the network solution as continually varying admittance elements. The model shall also make the field winding available as power system nodes to allow faults to be placed on the field. • Multi-phase synchronous machines. A multi-phase synchronous machine model with access to the neutral point and both ends of the stator windings must be available. Modelling of the machine with any number of phases (up to 12 phases) including ones that are not a multiple of 3, such as 5, 7 or 11 must be possible. Disabling/enabling damper windings must also be available. Multi-phase (3-12) control components (e.g. ABC to DQ		

		transformation) must also be available for use. • Induction machines (squirrel cage and double fed). • DC machines. • Voltage sources with definable equivalent impedances, source magnitude, frequency and phase. • Passive Resistive, Inductive and Capacitive components (including various filter configurations). • Circuit breakers and fault switches. • Bus arrestors. • Series capacitors with ZnO arrestors and bypass switches. • Thyristor Controlled Series Capacitors (TCSC) with ZnO arrestors and bypass switches. • HVDC valve groups for transmission and back-to-back schemes. The HVDC valve groups shall include 6-pulse and 12-pulse configurations. The 12-pulse configurations shall be fed from a 3-winding transformer with an option to include a 4th winding for the freely configurable connection of filters and or reactive power compensation. The valve group models shall support internal valve faults and shall be solved as part of the main network solution. It is not acceptable that the valve groups are numerically decoupled from the network solution or interfaced to the network solution. • Filter bank model to allow multiple banks of up to 12 switchable filters to be added to simulations without reducing the number of switches or nodes available in the main network solution. • Static VAR Compensators (SVC) including TCR and TSC branches. The TCR and TSC branches shall be embedded in the		

		network solution as continuously variable conductance elements. • Instrument transformers including current transformers (CT), inductive voltage transformers (PT), and capacitive voltage transformers (CVT) with full support for saturation and hysteresis loop modelling. • Voltage Source Converters: STATCOM, UPFC, SSSC, VSC-based HVDC, DFIG wind generation, etc. • 2- and 3-level VSC bridges using switched resistances to represent ON/OFF statuses. • Boost and buck converter models. The switches representing HVDC, SVC, and TCSC thyristor valves must be embedded in the main network solution and not solved as independent subsystems.		
8.	**Control System Models**	A minimum of the following control system components shall be available for the simulator: • **User-Input:** slider, switch, button, dial, etc. • **Constants:** integer, floating point, PI. • **Data Conversion**: deg-rad, rad-deg, int-float, float-int. • **Math Functions:** gain, exp, log, ln, ex, xy, sqrt, inverse, abs, sum, multiply, divide, max, min, etc. • **Complex Math Functions**: multiply, divide, add, subtract, etc. • **Trigonometric Functions:** sin, arcsin, cos, arcos, tan, arctan, arctan2. • **Standard Control Blocks**: deadband, pulse generator, edge detector, time, counter, ramp, ramp limits, limiters, phase-locked loop (PLL), flip-flops, Fourier transform, integrator, lead-lag, wash-out, lookup table, non-linear gains, etc. • **Logic Functions:** and, or, nor, bit shift functions, bit → word, if-then-else, etc. • **Meters:** real and reactive power, RMS (single- and three-phase), angle difference, frequency. • **Signal Processing**: sample and hold, down sampler, moving average, FIR, DFT, ABC-		

		DQ0, DQ0-ABC, ABC-αβ, αβ-ABC, vector rotator, etc. • **Generator Controls:** Commonly used exciter models like IEEE Type 1 to 5, AC1 to 4, ST1 to 3, X1, X2, 2A, SCRX, DC2, IVO, etc. Commonly used governor models like IEEE Type 1-3, IVO, European BBGOV1, Gas turbine, steam turbine, hydro turbine, etc. Commonly used power system stabilizer models like PSS2A, IEEEST, IEE2ST, etc. • **On-Load Tap Changer Control.** • **Relay models:** as a minimum the following relay models shall be available: o Line distance protection. o Differential protection. o Generator protection. o Overcurrent protection.		
9.	**User-Defined Models**	• It shall be possible for the user to create power and control system models for the simulator to run in real time together with standard models provided by the supplier. • The facility provided shall allow custom icon graphics and input menus to be created for the new component. • Furthermore, the facility shall allow high level programming (for example C code) of the real-time simulation algorithm and the facility shall include all necessary compilers.		
10.	**Load Flow Initialization**	The software shall include a load flow calculation which can be used to initialize the simulation components before the real-time electromagnetic transient simulation is begun.		
11.	**PSS/E Conversion**	It shall be possible for the simulator to import and convert PSS/E data for simulation in real time. Once converted, the PSS/E system must also be available in picture format for modification.		
12.	**PSCAD Conversion**	It shall be possible for the simulator to import and convert PSCAD network data for simulation in real time.		
13.	**Software Licensing**	• The software shall be provided with a site license so that it is possible to install all software included with the simulator supply		

		on any number of desktop or laptop computers. • If a site license cannot be provided a minimum of twenty independent licenses shall be provided for all software provided with the simulator.		
14.	**Availability and Maintainability**	• The real-time simulator will be a combination of both hardware and software, but for the purpose of the specification it shall be considered one entity. • Furthermore, to ensure fast and comprehensive support, the entire simulator shall be designed and manufactured by one supplier. • The manufacturer shall offer a maintenance program to extend the hardware warranty and provide software updates. • The manufacturer must further guarantee to provide maintenance, including replacement components, for the system for a minimum of 10 years.		
15.	**Software Maintenance and Updates**	• The simulator should include unrestricted software updates (all releases including major and minor releases) and maintenance (patches and fixes) for 10-years without any additional cost. • The upgrade and maintenance should cover all the software modules supplied as part of the simulator whether the software module was manufactured by the simulator vendor or purchased from third parties. • Identify third party software/modules and provide details (such as transferable contracts from original manufacturer) to support vendor’s ability to offer maintenance, upgrade coverage and guarantee compatibility for the requested period. • **The Institute will request at least two contact information of existing client sites of required to verify the history of satisfactory execution of such extended maintenance on vendor-developed and third-party products and if the feedback is**		

		<u>not positive the institute reserves the right to accept or rejected the submitted bid</u>		
16.	**Hardware Warranty**	• The proposal should include a <u>"repair or replace hardware warranty"</u> that covers parts and labour for at least 1 year with zero deductible. • The warranty should cover all the hardware supplied as part of the simulator whether the hardware was manufactured by the simulator vendor or purchased from third parties including off-the-shelf processor boards, power supplies, I/O modules, etc. • All third-party hardware boards should be identified and details (such as transferable contracts from original manufacturer) to support simulator vendor's ability to offer the warranty coverage for the requested period should be provided. **<u>The Institute will request at least two contact information of existing client sites of required to verify the history of satisfactory execution of such extended maintenance on vendor-developed and third-party products and if the feedback is not positive the institute reserves the right to accept or rejected the submitted bid.</u>**		