Revised Specifications for Hydro Power Plant Simulator

I. General specifications for the Simulator:

1. Should be compatible to Matlab / Simulink, Dymola, AMESim etc.
2. The proposed digital real-time simulator should take full advantage of modern multi-core processors as soon as they become available from AMD/INTEL. Models should then be executed in parallel with minimum communication overhead by using on-chip and on-board shared-memory. The quad core processors which are in use now by major manufacturers will be preferred.
3. The real-time digital simulator should be implemented using very fast and low-latency commercial communication fabric to take advantage of communication technology evolution. The communication will be on protocols like OPC and Ethernet. For the OPC,
   - OPC Server : Visualization Compatible with Industry Tools (PanoRAMa, Intouch, etc.)
   - OPC View Manager (Must be provided with OPC Server) should be able to Read/Write Simulation Signals
   - Read Dynamic Acquisition Signals
   - Write Control Signals (From the Console)
   - Read/Write Model Parameters
4. User programmable FPGA Chips and Development Software: The proposed simulator should have an option to include fast FPGA chips that can be programmed by users through graphical interface to implement specialized communication protocols, signal processing, control and protection systems.
5. It should be possible to execute the simulator software on standard Windows multi-core computer for non-real-time simulation to execute the same model used for real-time simulation. The simulator software should take full advantage of all processors cores available on the work station or on the computer server to execute the simulation as fast as possible. This feature would be useful to execute several optimization and Monte Carlo studies in non-real-time mode before executing real-time simulations with actual simulator.
6. The proposed simulator should include optional single-processor prototyping systems to implement controller or protection system algorithms in real-time on separate computers. These prototyping systems should have all necessary input-output interfaces to enable its connection with the main simulators.
7. **Other essential features**
   - This solution must be predominantly designed to meet the needs of electrical utilities
   - This must allow accurate setting of speed regulator PID gains, in turn assessing the stable behavior of the generating unit. It should be possible to achieve this without taking the generating unit under test offline from the overall power system, and ensuring that simulated power system disturbances do not place the machine or overall power system at risk.
   - It should be possible to conduct Real-Time simulation at the power plant, directly on the actual AC generator, while recording signal data needed in

order to effectively model the turbine and regulator under test. In addition, it should be possible to drive the actual generator as if it were actually operating in islanded mode.

- One should also be able to provide preliminary settings based on specs provided by turbine and generator manufacturers
- It should be possible to model and perform parameter identification tests in the power station
- It should be possible to carry out off-line stability studies to recommend appropriate settings, based on models and parameters determined by tests carried out in the power station
- The product should allow these operations to take place in a single test run from within the power station, translating into significant returns on investment including:
    - Improved accuracy and stability of speed regulator settings in islanded mode, ensuring that each machine has a stabilizing effect on the overall power system
    - Improved accuracy of regulator and turbine models
    - Improved stability of and reduced demand on servomotors by applying appropriate settings
    - Productivity gains for model identification and control settings
    - Shorter tests in the power station.

8. Special capabilities :

- **Fixed-time-step simulation**

It should contain a Simulink toolbox for the fixed-time-step simulation of hybrid systems involving dynamics and discrete events asynchronous with respect to the simulation clock. Working with a fixed step size, it should be compatible with the Real Time Workshop (RTW). The following capabilities are essential:

- Improve accuracy for discrete simulation of event-based systems
- Compensate for the errors introduced when events occur between samples
- Accuracy to depend on the time step selected with respect to the frequency content of continuous signals
- Fast simulation of event-driven systems
- No iteration, should use fixed time-step algorithm
- Simulation to be faster than variable-step algorithms
- Support for distributed real-time simulation
- To be suitable for hard real-time applications such as hardware-in-the-loop or embedded simulations
- Compatibility with. Simulink & RTW

- **Real-Time Solvers for SimPowerSystems with the following features:**

  - To be designed for Fast Simulation and Hardware-in-the-Loop
  - Fixed-time-step integration algorithms to be designed for real-time applications
  - Compatibility with the Real-Time Workshop(RTW) code generator
  - Compatibility with real time environments for distributed real-time execution on PC clusters
  - Should have high precision for linear circuits with high frequency components
  - Should improves the simulation precision
  - Eliminate the phase-shift error
  - Should exhibit better accuracy with nonlinear elements
  - Improve the simulation accuracy of systems with nonlinear elements
  - No numerical oscillations
  - Use stable integration methods that are free from numerical oscillations
  - Should be easy to install and use
  - Drag-and-drop from this product must be available in the Simulink library browser
  - Online documentation.
  - Variable-step accuracy with fixed-step performance
  - Innovative fixed-step solvers and efficient computational techniques that improve the computational performance of SimPowerSystems, to allow developing real-time simulations with power systems models.
  - Ability to create distributed real-time simulations on PC clusters.
  - Should integrate fully into the Simulink environment in the form of a Simulink blockset, and be fully compatible with Real-Time Workshop (RTW) for real-time execution, or for simply accelerating the model.
  - Should optimize and allow to automatically convert SimPowerSystems schematics into real-time simulations. This should allow the distribution of a large, complex power systems model over several processors, in order to get the computational power required to achieve high-performance, real-time execution on low-cost, off-the-shelf PCs and non-proprietary hardware.
  - Improved accuracy of solvers
  - Provide the best of both worlds: real-time performance with variable-step accuracy

II. Hydro plant library

A. Specifications for the models

A library of models for the simulation of a tandem hydro plant should be delivered. The models should be built in a digital format adapted for real-time and faster than real-time simulation.
Models should be built using Matlab/Simulink.
The library may comprise but not be limited to the following **elementary models**:
Integrator;
First order filter;
Derivative on a first order filter;
Second order filter;
Derivative on a second order filter;
First order Lead-Lag function.

The library should also comprise of **basic models** of Francis, Kaplan & Pelton hydraulic turbines and speed regulators and all the necessary elements for adequately modeling a complex hydraulic power plant system, viz.:
Reservoir;
Head race tunnel;
Tail race tunnel;
Intermediary pond;
Surge shaft;
Penstock;
Manifold;
A hydraulic plant including upstream reservoir, head race tunnel, surge shaft, manifold, many penstocks, tail race tunnel, and downstream reservoir, many synchronous generators & corresponding voltage regulators inside the same powerhouse with their dynamic behavior including electric power variations, mechanical power variations, water flow variations, and net head variations.

B. Validation method for elementary models

Each elementary real-time model of the library should be delivered with a Matlab directory including:

- A Simulink Model designed for the validation of the element;
- A ".m" data file for the initial values;
- A ".fig" data file showing the expected simulation results.
- Mathematical basis to be provided to ascertain accuracy of models.
- The elementary models to be validated by comparison between Matlab / Simulink results in off-line mode using a variable step solver and real-time simulation results of the simulator using a fixed step solver with a time step value small enough to meet the accuracy criteria of section E.
- This validation test is for the modeling technique itself.

C. Validation method for basic models

Basic models of turbine and speed regulator and all the necessary elements for adequately modeling a complex hydro power plant system should be provided with a Matlab directory including:

- A Simulink Model designed for the validation of the model, including Matlab SimPowerSystem's Turbine and/or Speed Regulator built-in models;
- A ".m" data file for the initial values;
- A ".fig" data file showing the expected simulation results.
- Mathematical basis to be provided to ascertain accuracy of models.
- Moreover, the basic models of turbine and speed regulator shall be validated by comparison between Matlab / Simulink results in off-line mode using a variable step solver and real-time simulation results of the simulator using a fixed step solver with a time step value small enough to meet the accuracy criteria of Sec.E.

D. Validation method for complex hydraulic power plant

For composite systems including many functions that are to be included within the hydraulic power plant model, a methodology will be provided describing how to set the parameters in order to simplify the model and make it behave as if it were a simplified model to be compared with an existing Matlab Simulink/SimPowerSystems model.

The hydraulic plant model including upstream reservoir, head race tunnel, surge shaft, manifold, penstocks, tail race tunnel, downstream reservoir and synchronous generators shall be validated by comparison between Matlab Simulink results in off-line mode using a variable step solver and real-time simulation results of the simulator using a fixed step solver with a time step value small enough to meet the accuracy criteria of section E.

E. Criteria for acceptation

- Any deviation between the results obtained with Simulink and the Real-time models should be explained.
- The simulation time step will be adjusted to a maximum value in order to keep the maximum deviation between the results obtained with Matlab/Simulink using a variable step solver and the results obtained with the simulator using the fixed step solver below 5 %.

III. Hydro power plant simulator

Introduction

Nathpa Jhakeri Hydro Electric Project (NJHEP) comprises of 6 x 250 KW Francis turbines which are currently operational. A new project in the downstream to NJHEP is being proposed, viz. Rampur Hydro Electric Project (RHEP) comprising of 6 x 68.67 MW Francis turbines. The Rampur & Jhakri machines have the same discharge.

The discharge of NHEP will be fed as intake to RHEP with no reservoir in between except for a small tail pond and a surge shaft. NJHEP and RHEP have to be operated in tandem, with RHEP being slave to NJHEP. To achieve this, a Tandem Operation System (TOS) is proposed. The TOS includes a Simulator, which is required to simulate the upstream & downstream Hydro power plants Viz. NJHEP & RJHEP, which includes the Nathpa Dam, the NJHEP HRT, NJHEP surge shaft, NJHEP penstocks and the 6 x 250 MW Francis machines at Jhakri, the Tail Pond at the tail race of NJHEP, the NJHEP TRT outfall gates, the TRT Spill way tunnel of NJHEP with surge gallery, the Rampur HRT, Rampur Surge shaft, the penstocks & 6 x 68.7 MW Francis turbines of RHEP and the Tail Race of Rampur. The Simulator should also include the simulation of the proposed Tandem Operation System (TOS) Controller. The details of the TOS Controller will be provided at a later date to the successful bidder. In broad terms, the TOS Controller will provide start, stop, trip, and load set points to the Jhakri & Rampur machines.

The TOS Controller will acquire all field signals and communicate with the Simulator via OPC. The Simulator will be an OPC client and the TOS Controller will be the OPC server. The TOS controller is not in the scope of the bidder. However the simulator should have a minimum of Input / output capability as described in N3.1.

The specifications of the proposed Simulator are as follows:

A faster than real time simulator is proposed to be used for assisting tandem operation to predict the consequence of an operator instigated action within **ONE SECOND**.

The simulator shall display in graphical form the calculated outcome of the Operator Instigated Action. Displayed shall be all important parameters of the Nathpa Jhakri and Rampur units, Nathpa Jhakri Tailpond level, Surge Tank water levels and spillway flow against time starting at the instigation of the action and finishing when all unit parameters have reached steady state conditions with the Nathpa Jhakri Tailpond at the “null” level. The simulation shall also take into consideration any flow passing through the spill way (Overflow) at El. 1016.0 m near to Nathpa Jhakri tail water pond.

Physical description of Nathpa Jhakri and Rampur

a) Nathpa Jhakri is located on river Satluj in Himachal Pradesh. It has a concrete dam at Nathpa; de-silting chambers and 27.3 KM head race tunnel and Power House at Jhakri, with six units of 250 MW.

b) It is a run of the river project with small pondage to cater to the peak load demand. It has a rated head of 428 m. and the water from its tail race is presently being released back to river Satluj.

c) Rampur will be in the downstream of Nathpa Jhakri and shall utilize the water released from Nathpa Jhakri Hydro Power Station. At present the water released from Nathpa Jhakri re-enters river Satluj through tail race vertical lift slide outfall gates. In the final configuration with Rampur these gates will normally remain closed and will only be manually open in the event of serious problems with Rampur necessitating Nathpa Jhakri again operating as a single station. It is also being proposed to upgrade the control mechanism of these gates to permit set point control for the opening of the gates. This will enable differential operation of NJHEP and RHEP in case situation demands. For example, if a Rampur unit trips, it should be possible to operate without reducing the generation from NJHEP. This will be possible if excess discharge from NJHEP is allowed to escape from the tail race tunnel outfall gates in to the river.

- **Salient Features of Nathpa Jhakri:**
- A concrete dam of 62.5 m height at Nathpa,
- Intake and De-silting chamber.
- 10.15 m diameter 27.3 km long Head Race Tunnel from Nathpa to Jhakri
- A surge tank of 21.6 m diameter and 306 m height.
- 3 Nos. pressure shafts 4.9 m diameter and 571 m to 622 m long each bifurcating into two near the power station connecting 6 units each of 250MW of the Nathpa Jhakri power station.
- An underground power station at Jhakri housing 6 units of 250 MW each, 220 m long, 20 m wide and 49 m high with the centreline of the turbine at EL 987 m.
- A draft tube collection gallery of 10.15 m diameter tunnel, which receives water from all the 6 units and connecting to tailrace tunnel, 982 meters long, 10.15 m diameter and to the tail race pond and discharging water to river Satluj.
- Tail pond level
- with one Unit EL-1002
- with all 6 units EL-1005
- Flood EL-1024 m
- In case there is change in the tail pond levels given above due to the extension work of tail pond storage, the contractor will consider the new levels
- There are three number Tail Race Tunnel outfall gates at the tail race with sill level at 1000.63, width of gate is 7.5m and height is 4.33 m.

- **Storage Capacity at Intake of Rampur:**

The capacity of the current Nathpa Jhakri tail race will be increased by utilising additional tunnels and the existing diversion tunnel. The total storage between Nathpa Jhakri and the Rampur Head Race Tunnel soffit will be henceforth referred to as the Nathpa Jhakri Tailpond.

The expected Nathpa Jhakri Tailpond capacity/head curve will be given in the Specification Drawings to the successful bidder. This should be used for simulator design but will be revised according to measurements made at the completion of the works. The simulator shall then be adjusted accordingly by the Contractor.
There will be a free flowing spillway in the tunnel system with a sill at El. 1016.0 m. The spillway will discharge into the Satluj River and will be sized for full Nathpa Jhakri flow. Although the spillway will be gated, the gates will normally be open and will only be closed in event of major floods in the Satluj River in which the flood level exceeds the spillway sill level.

Important Notes:

N1. Detailed drawings and specifications regarding the Nathpa-Jhakeri and Rampur Hydro projects will be provided to the successful bidder.

N2. Final acceptance criteria for the complete model of the cascaded hydro power plants of Nathpa Jhakeri & Rampur shall be the validation of the simulator output with the behaviour of the actual systems at site.

N3. The vendor should have an established presence for at least 10 years, with reputed clientele comprising of well known companies.

N4. The hydro power plant simulation expert from the vendor should plan for at least four visits to site, each visit approx. one week in duration. The actual requirement will be finalized during negotiations.

N5. The hardware and software should be sourced from the same vendor to avoid integration problems. The hydro expert who develops the models for the hydro power plant simulator should have established credentials in the area of modeling and control of hydro power plants, with a working experience of more than 25 years in the relevant field with reputed companies, which should include considerable experience of working at actual hydro sites. The nature of experience should include carrying out transient analysis and implementing control strategies to achieve stable operation of a hydro power plant. The said expert should take total responsibility for site validation of the simulator and should be in a position to personally visit the site during validation trials as & when required. The academic qualifications of the expert should include doctorate in the relevant field of electrical engineering.

IV. Deliverables:

1. The faster than real time Simulator hardware should comprise of
    a. Several processor cores ($\geq$ 2.2 GHz), with a shared memory of at least 256 MB, with an option to expand to 2 GB, to meet the computational requirements.
    b. 16 simultaneous differential ADC channels, one 16 bit ADC per channel with 500 KS/s rate, independent programmable range from ±100 mV to ±16 V, independent software gain and offset and on board signal conditioning.
    c. 16 simultaneous DAC channels, one 16 bit DAC per channel with 1 MS/s update rate, on board signal conditioning & voltage range of ±16 V.
    d. 16 digital inputs,
    e. 16 digital outputs,
    f. 80 GB hard disk, video, Ethernet, keyboard and mouse interface ports and a suitable cabinet to house the hardware.
    g. Modular I/O hardware, with high speed data link of at least 128 Mbit/s between I/O and CPUs, with an option to increase it to 1 GB/s and it should be possible to double the above I/O channels in the same chassis.

2. The software which should meet the above mentioned simulation requirements. The simulink models delivered shall be configurable to meet the simulation requirements of any hydro power plant in general. OPC software should be integrated with the simulator along with drivers. Only proven RTOS such as Vxworks, QnX, etc. should be used for the simulator.

3. First prototype to be delivered within 3 months from the date of placement of firm order.

4. The second prototype shall be delivered after acceptance of the first prototype.