MONITOR ELECTRIC™

REAL-TIME INFORMATION SYSTEMS FOR CONTROL CENTERS

OPERATOR TRAINING SIMULATOR

FINIST™

TECHNICAL DESCRIPTION

REVISION 11.4

FINIST AT A GLANCE

Performance

- Installed in more than 60 control centers of Russian Federation, Belarus system operators and in OES-NA, USA.
- Unlimited model size and modest hardware demand. In practice FINIST successfully handled the model of 3,500 substations, 1,000 generators, 4,500 high-voltage powerlines, and 40,000 breakers and disconnects on a single high-end desktop.

Functionality

- Examiner's Workplace provides automated operator action scoring and training session report generation. Besides manually entered scores, Examiner's workplace calculates integral parameters that indicate the quality of operator actions such as total outage duration, integral area control error, etc.
- Technologist's Workplace – allows advance training session preparation and debugging.
- System state snapshots. During a training session, Finist allows to save the state in a snapshot. This snapshot can then be used to roll rollback the training session to, or to restart it later or to use it as an initial case for a new training session.
- SCADA-driven training. FINIST connects to the SCADA/EMS system by replacing the real telemetry data stream with the simulated. This way the operators train using the same or similar SCADA that they use in practice. This provides familiar interface and increases realism of the training.
- Multi-control center training session support. FINIST can be easily configured to connect to multiple machines either locally or remotely. Moreover, FINIST can generate multiple telemetry data streams for different control centers. This facilitates joint exercises of operators at several control centers.

Model and Interoperation

- Realistic dynamic power system model. The model's fidelity is certified by NIIPT research institute (St.Petersburg, Russia).
- Export and import of model data in CIM (IEC 61970).
- Import of powerflow and voltage profile parameters in CIM-like format.
- Interaction with SCADA/EMS applications: GID (GDA, HSDA) IEC 61970, part 40x.
- Telemetry communication protocols: IPC, rtdbcon, OPC.
- Data representation protocols: CIM10, CIM12 ready (IEC 61910 part 301).
- Implemented using C# and .Net 4.0.

OBJECTIVES AND CAPABILITIES

The function of an electric power transmission system operator is critical in maintaining the system's reliability and efficiency. The consequences of inadequate actions of the operational personnel may be catastrophic. The operator's situational awareness, power system knowledge and skill in handling emergencies under stress are indispensable. This makes operator training, testing and certification key for ensuring the power system reliability. As providing such training or testing on a live system is hardly feasible, an operator training simulator becomes a must-have tool.

FINIST is an advanced operator training simulator designed by Monitor Electric. FINIST has a sophisticated model of the power system. It allows the simulator to accurately model a wide range of system behaviors: disturbances, outages, faults, system partitioning, restoration, etc. FINIST is designed to seamlessly operate with industry supervisory control and data acquisition energy management systems (SCADA/EMS). This increases the realism of the simulation as the operators train using the same SCADA system they use for real system controls. FINIST has a sophisticated set of tools to configure, conduct and evaluate the training session to achieve maximum realism and training effectiveness.

FINIST can be used in two modes: operator training and power system analysis.

FINIST provides:

- sophisticated power system model,
- convenient role-based user interface,
- modern, modular, standards-based architecture and interfaces.

Figure 1. FINIST in action

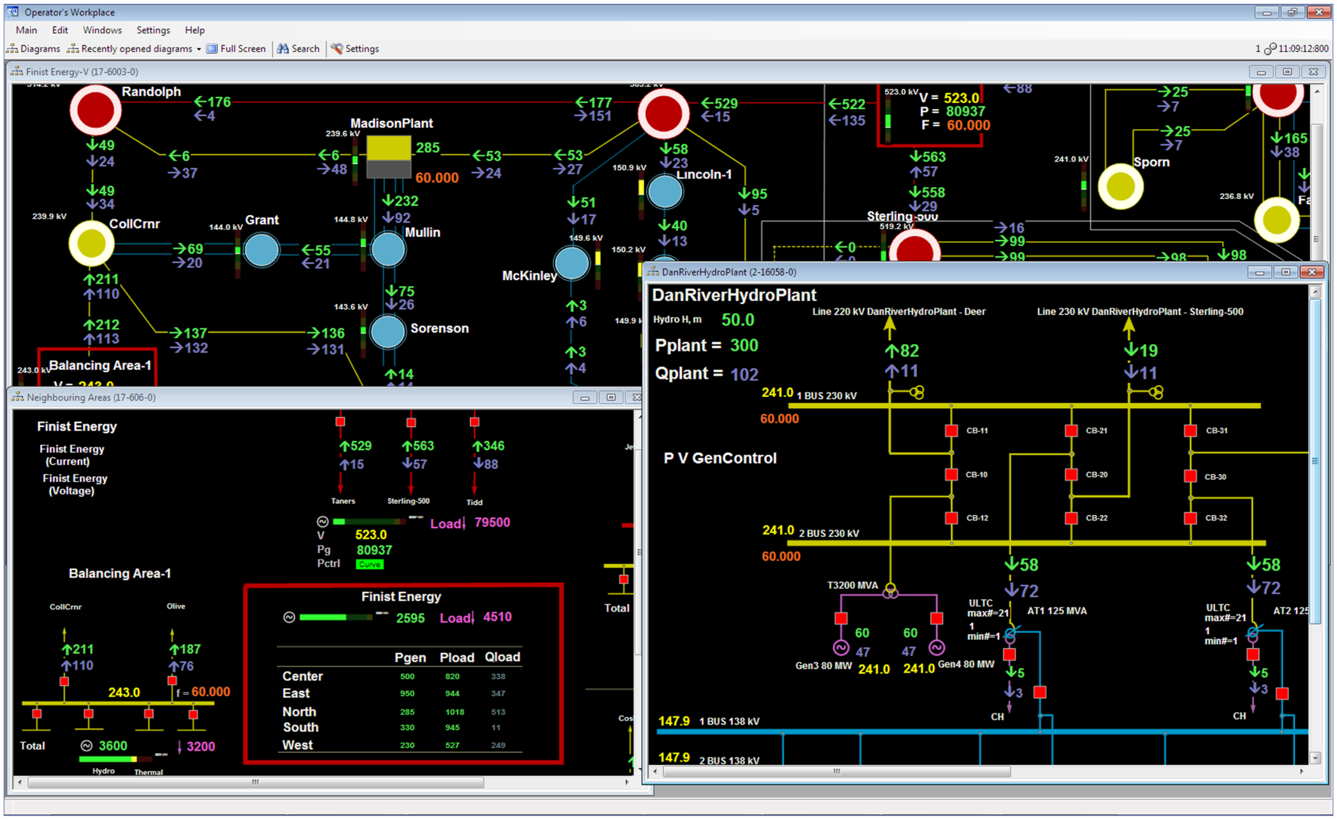

Figure 2. Oneline diagram examples

Operator Training

FINIST takes operator training to a qualitatively new level. Its extensive array of tools makes it possible to configure and conduct a variety of training exercises. FINIST can be used at any stage of operational personnel training: initial instruction, self-education, testing, certification and promotion, re-training for a new system or new set of duties.

FINIST can be used for both individual operator and team practice as well as for practicing operator cooperation between several control areas or across several levels of power system management hierarchy.

The objectives of a FINIST-based training may be: learning the system behavior and practicing operator actions during routine situations; disturbance response drills and system restoration tactics training; equipment maintenance scheduling.

Power System Analysis

FINIST can recreate the system behavior in a particular situation. For example, FINIST can be used to reconstruct a stable system state or system dynamics to match the specified telemetered data of a real contingency. Thus, our simulator can be used as a system analysis tool.

FINIST can be used for:

- event sequence determination;
- post-factum evaluation of the adequacy of operator actions;
- protective relay operation analysis and configuration: set-point tuning, operation testing, etc.;
- steady state and dynamic stability analysis.

INTERACTING WITH FINIST

Roles

FINIST structures user interaction into the following functional roles:

Trainee – the person whose knowledge and skills are trained and tested in the interaction with FINIST.

Instructor – the person who conducts the training session. The instructor also responds for the personnel of the simulated control centers with whom the trainee interacts during the training session.

Technologist – the person who prepares the model of the transmission system as well as training scenarios.

> Role-based workspaces supply users with the right tools to accomplish the task at hand.

Examiner – observes the training and grades the actions of the trainee.

A single person may share roles. For example, a single person may act as a Technologist and as an Instructor. Conversely, multiple people may share a role. For example, two people may act as Instructors: one person handles the communication with the trainee while the other controls the training sessions, starts training scenarios, etc.

Graphics Presentation System

In a training session, FINIST is usually connected to a SCADA/EMS system. Therefore, the trainee uses the graphics capabilities of the SCADA. However, FINIST has its own full-graphics presentation system. During the training session, it is used by the Instructor and the Examiner. If external SCADA is not available, the trainee can use this system as well.

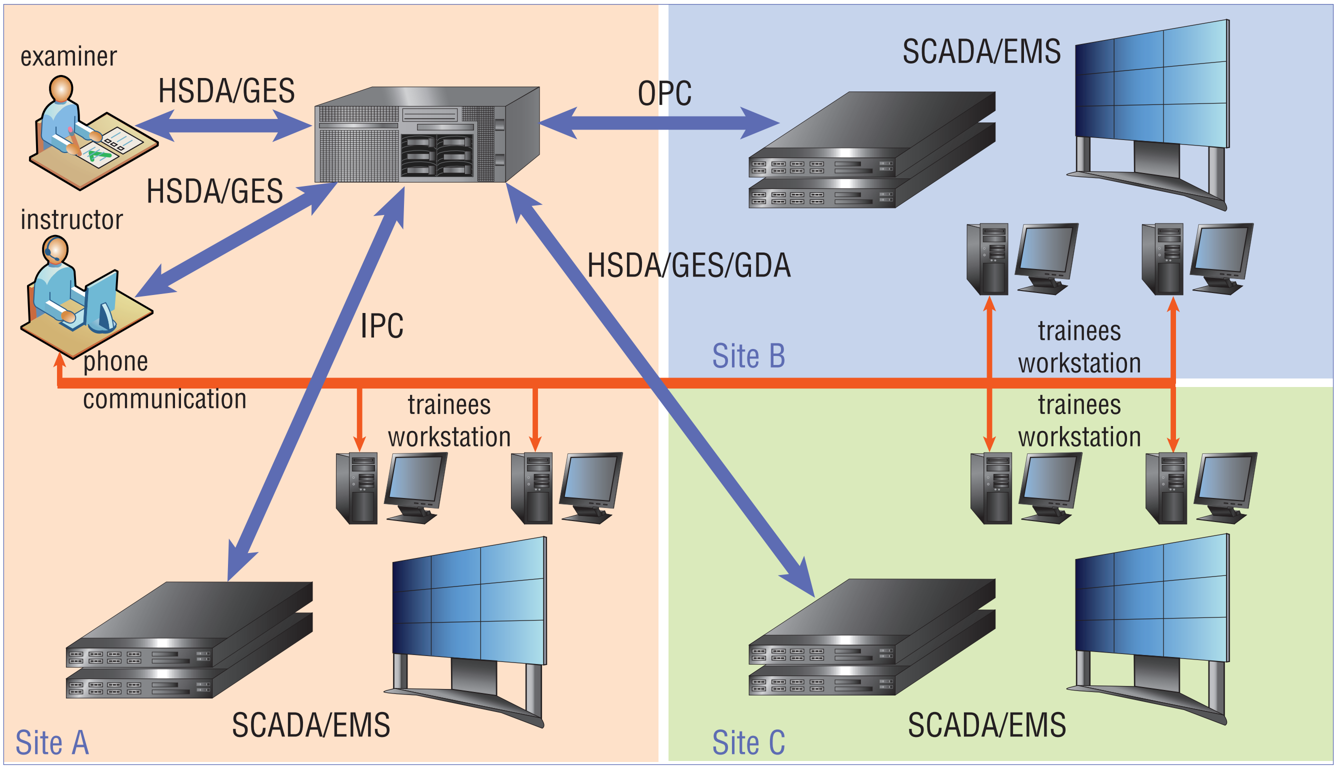

Figure 3. Multi-control center training session exampe

This presentation system displays the true state of the modeled power system: powerline and breaker states, generation, powerflow, frequency, voltage levels, etc. FINIST can also calculate and display pseudo-measurements: aggregate parameters that are not themselves present in the system: for example, powerflow across a flowgate or an area control error.

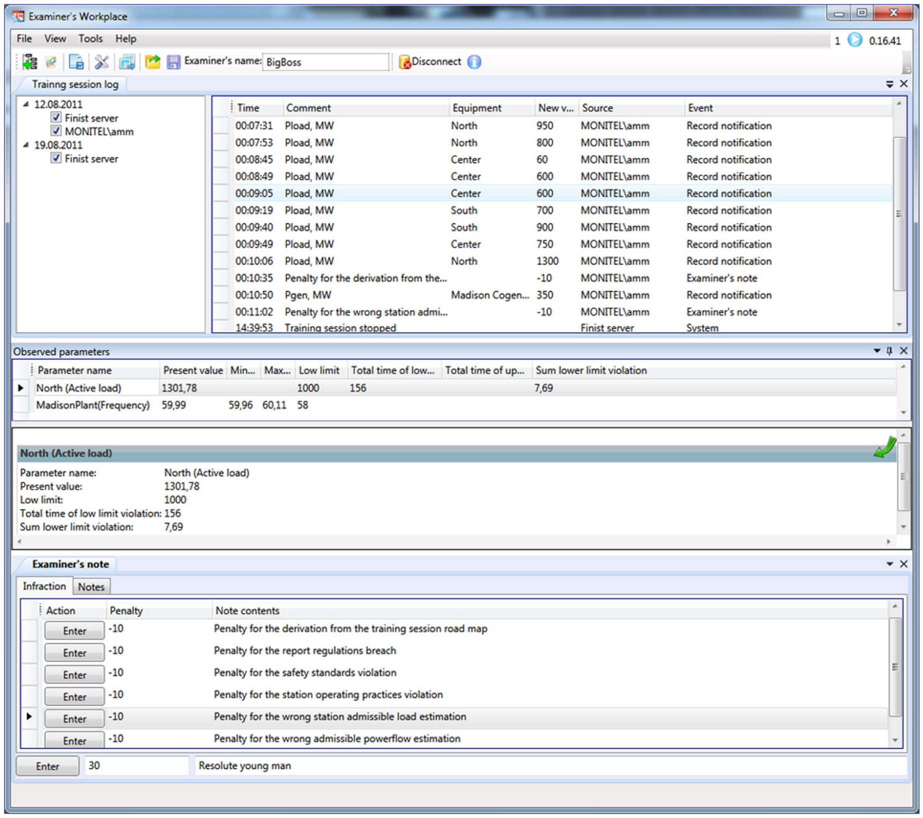

Figure 4. Examiner's Workplace

Training Session Preparation

A training session preparation requires two procedures: (1) designing the initial state of the system: the bus voltages, the powerflows, etc. (2) developing training session scenarios. A scenario consists of a sequence of steps or actions, such as equipment outage or load change, to be executed at the specified time during training. Several such scenarios may be executed in parallel. For example, in a joint exercise with several participating control centers, each control center may prepare their own scenario. An example of a multi-control center training session configuration is shown in Figure 3.

Training Session Control and Evaluation

The Instructor starts, controls and terminates the training session. The Instructor may accelerate the session simulated time, e.g. to speed up powerplant ramp up; or decelerate the time to focus the trainee on essential parts of the training session or system behavior, e.g. generators pulling out of synchronism. The instructor stars scenarios and may delay or cancel some of the scenario steps.

FINIST's logging system provides a detailed record of the training session events. It enables effective evaluation of the trainee and feedback on his actions. The logged events can be filtered for presentation to different users: instructor, examiner, and technologist. FINIST's log may be exported in XML and processed by common office automation software such as Microsoft Office.

As a part of the log, FINIST maintains an electronic evaluation sheet to be filled out by the examiner. As the training session progresses, the examiner enters his records into the evaluation sheets. There are several types of records: comments, infractions, bonuses, evaluations and others. Each record may carry a standardized score. The examiner can later edit the log and add further comments to the records. An example of an evaluation sheet in the Examiner's Workplace is shown in Figure 4.

ARCHITECTURE DESCRIPTION

FINIST is an advanced modern training simulator. Its architecture reflects the demands of today's power engineering business. From the ground up, FINIST was designed to use the latest industry standards established by International Electrotechnical Commission (IEC). This orientation on standards streamlines both its internal architecture and interoperation with external programs. FINIST stores the power system model in Common Information Model (CIM, IEC 61970-3xx). The inter-component communication is carried out using Generic Interface Definition (GID, IEC 6194-40X) group of standards.

FINIST architecture outline is shown in Figure 5. The simulator's software components are divided into server- and client-side modules.

Server-Side Modules

The server-side components are FINIST-server and GDA-server. Generic Data Access (GDA, IEC 6197-403) server stores the description of the electric power system in CIM format. The access to the model specification is provided over the GDA protocol.

The FINIST-server is composed of several modules. According to their function, these modules are classified into processing and interface modules. The processing modules carry out most of the computation required for modeling the power system behavior. These modules are:

- Computation Engine. It carries out the core computations of the simulated system and coordinates other modules. The Computation Engine calculates the system state, powerflow as well as short and long-term system dynamics.

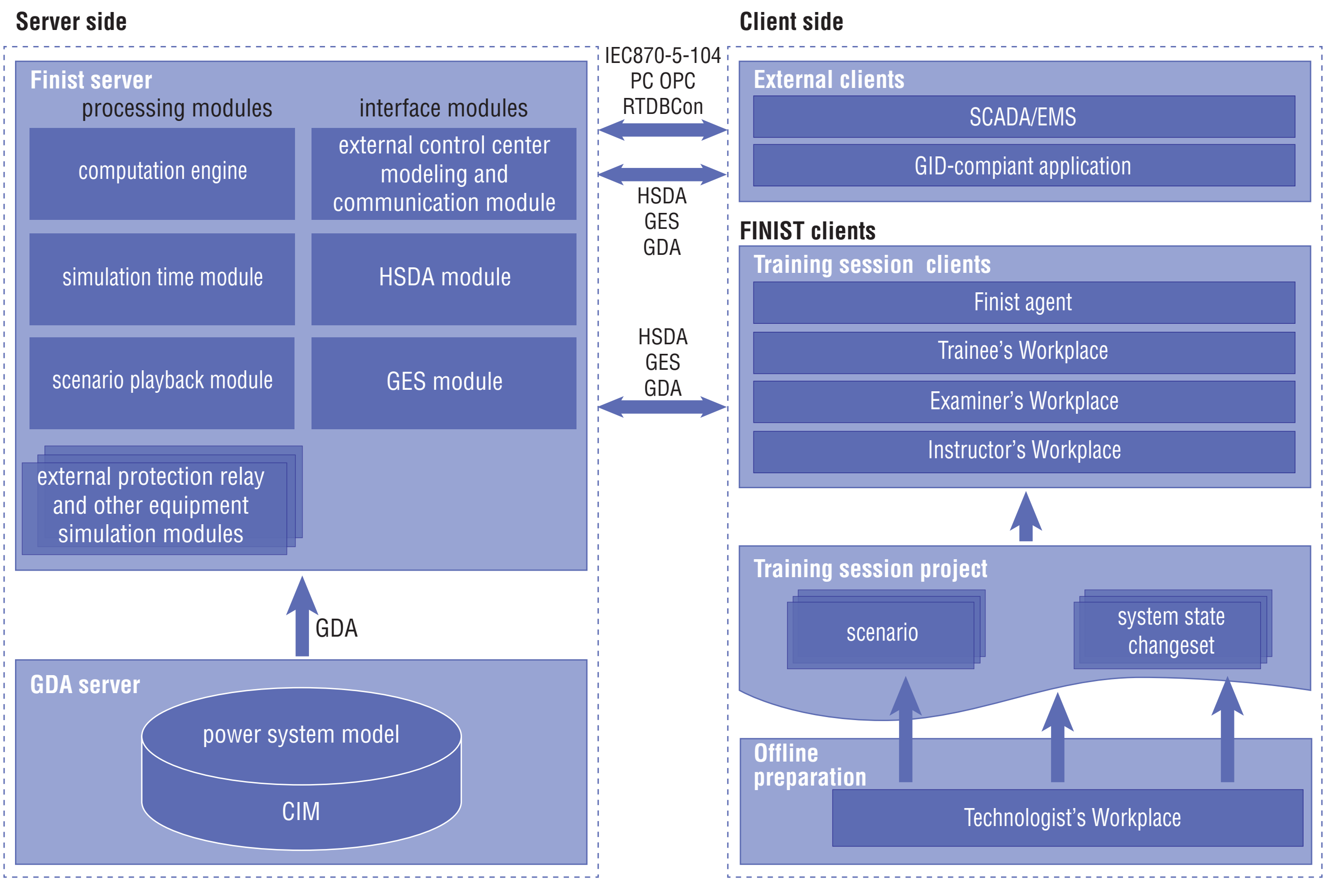

Figure 5. Finist architecture

- Simulation Time Module. For the convenience of the training session, the simulation time differs from real-time. The Simulation Time Module may speed up, slow down or suspend the simulation time as required.

Scenario Playback Module

This module loads the external events of a particular scenario and executes them at the appropriate simulated time moment.

Standalone equipment simulation modules

Although the computation engine carries out most of the model calculations, for the purposes of modularity and parallelization, the operation of some equipment, such as protection relays and automatic generation control system (AGC), is implemented as separate modules.

The interface modules provide communication with the client modules and external systems. These modules are:

- HSDA module - implements High-Speed Data Access (HDSA, IEC 61970-404) communication protocol. This protocol is used to supply telemetry data to FINIST clients and external programs.
- GES module - implements Generic Events and Subscription (GES, IEC 61970-405) protocol that allows FINIST Clients and External Programs to supply the external events, such as operator actions, to the servers. Similarly, GES is used to notify the clients of alarms in the modeled system.
- External Control Center Modeling and Communication Module. This module communicates with the SCADA/EMS system used by the operators. Similar to FINIST client modules, this communication can be carried out using HSDA and GIS. However, FINIST can translate the data streams into other SCADA/EMS and telecommunication protocols. Specifically, to IPC, OPC, RTDBCON and IEC 870.5.104. To simulate real system behavior, this module can introduce delays or errors in the supplied data stream.

For joint multiple control center training sessions, FINIST may communicate with multiple SCADA/EMS and generate separate data streams for each one.

Client-Side Modules

The client-side modules are grouped into Workplaces according to user roles. The Workplaces are classified as configuration clients and training session clients. Users interact with the training session clients during the actual training. These clients are:

- Instructor's Workplace. This module uses the training session project to instantiate the system, launch training scenarios, control the execution of individual scenario steps and manipulate simulation time. This module also provides access to the session log whose events can be grouped or filtered as required.
- Examiner's Workplace. This module automates the process of evaluating the training session, allows quantifying trainee's performance and makes its evaluation more objective. The module allows the examiner to assign bonuses or penalties to specific trainee actions. The examiner may add comments during the training session, monitor pre-defined system parameters on a trend graph, receive alarms on operating limits violations.
- Operator's W orkplace. This Workplace is to be used by the operator instead of a SCADA/EMS system. It allows the operator to directly issue remote control commands, such as opening a breaker, shedding load, changing generation, relay set-points or transformer tap positions.

> To ensure model fidelity FINIST continuously computes power system dynamics switching between long-term and transitional process computation. The actual system state is computed concurrently. Switching between models allows adequate computation time while ensuring convergence in critical system states.

- Agent. This module is used to initialize the power system model, establish communication with the SCADA, launch and manage server-side modules.

The configuration clients help prepare and manipulate training session package to be used during training.

- Technologist Workplace. This module is used to configure and debug the parameters of the training session: the initial state and scenarios. Initial state configuration. The state may be designed “from scratch” or imported from a FINIST snapshot or from a SCADA telemetry log. The state then can be further manually tuned to suit the particular training session requirements. If the power system is large, seeing its state at a glance or navigating through all the equipment may be challenging. Technologist’s Workplace may connect to the Operator’s Workplace graphics system, display the system state, record the Technologist’s actions (such as closing a breaker or changing transformer taps) and then incorporate the changes into the initial state. Technologist’s Workplace also provides a powerful set of table and graphics navigation tools. The system is presented as a set of tables linked by hyperlinks for ease of navigation. Thus, proceeding from a balancing area to the power plant then to a generator and then to the properties of a particular generator is straightforward. The information can be presented as an automatically generated power system graph. This tool proves invaluable in case the graphics forms of Operator’s Workplace are not available or are incorrect.

The user can configure individual equipment units as well as system-wide simulation parameters such as maximum power flow calculation mismatch, integration step length, etc.

- Scenario editing. This part of Operator’s Workplace deals with training scenario design. Each step in a scenario contains a trigger and an action to be executed. This trigger can be arbitrarily complex and can contain an arbitrary combination of Boolean and algebraic functions. The triggers may use constants as well as the modeled power system parameter values. The actions of a step can be simple or nested. Mutually exclusive triggers can generate diverging story lines inside a single scenario. Scenario Editor has the capability of eventually merging these diverging story lines into a single one. The scenarios can be generated out of the logs of previous training sessions.
- Librarian. Technologist’s Workplace provides convenient means of cataloging the training sessions, their initial cases and scenarios for future reuse and modification.

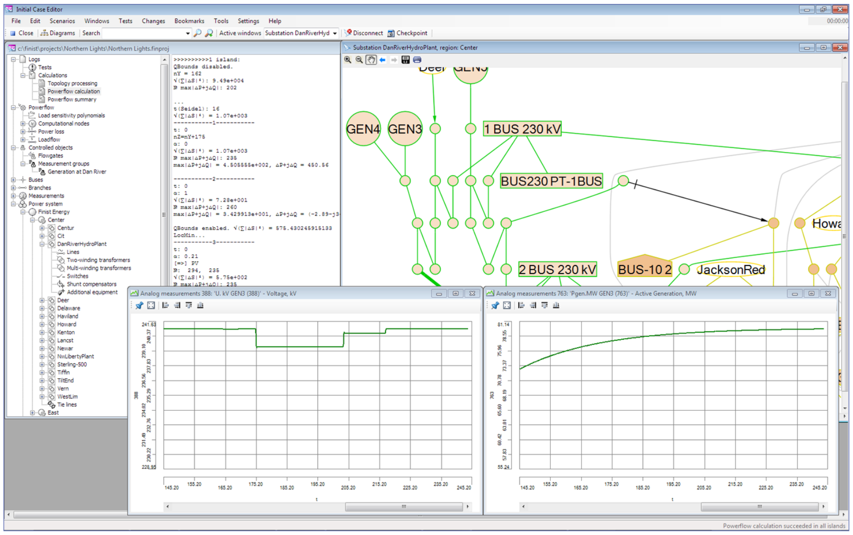

Figure 6. Technologist’s Workplace. Demonstrates topology graph and variable trending during ongoing training session

FINIST POWER SYSTEM MODEL

Introduction

The feature that truly sets FINIST apart is its power system model calculation. Traditional operator training simulators often model the operation of the electric power system as a sequence of steady states. More sophisticated ones may model transitional and dynamic processes that result from a disturbance. However, there is always an assumption that the system reaches a steady state before the occurrence of the next disturbance or other external event. Such an approach significantly simplifies the simulator design as there is no need to consider the next disturbance while the effects of the previous one are still being computed. However, such simplification sacrifices the realism of the power system operation and diminishes the usefulness of such simulator for operator training.

FINIST takes a radically different approach to power system modeling. FINIST continuously models the system dynamics and processes the effect of external events as they happen. Instead of forcing the system into a steady state, FINIST periodically computes the state and powerflow of the system to be exported to its clients as it continues to calculate the system dynamics.

The choice of this sophisticated model places additional demands on the efficiency of the model calculation as the dynamics of the system regardless of its scale, has to be computed in real-time. In fact, if the simulation time is accelerated, the model has to be computed even faster. FINIST successfully meets these performance expectations.

Computation Algorithm Outline

FINIST's model computation algorithm is shown in Figure 6. The computation is iterative. Each iteration computes a fixed simulated time period. By default, the length of this time period is 200 ms. The processing of each period starts with simulation time adjustment.

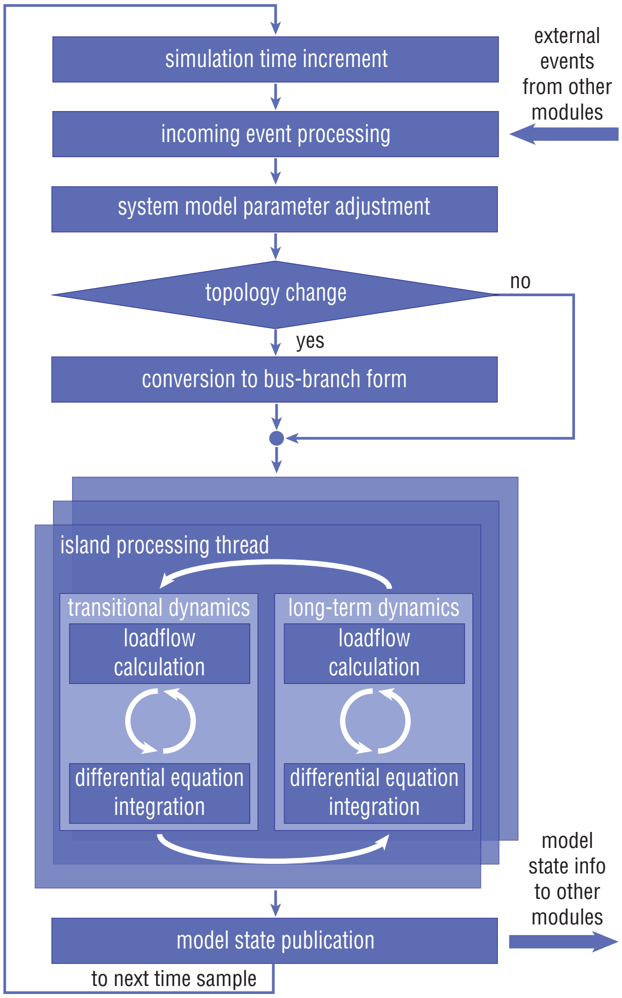

Figure 7. Finist system model dynamics computation flowchart

The computation engine then inputs the external events that occur during the new time period.

Some of the events, such as closing a breaker or grounding a bus, change system topology. After each topology change, the topology processor of the computation engine converts the system into a bus-branch model by collapsing each portion of the system with zero impedance (such as bus segments connected by a closed breaker) into a single computational node. The computation engine then determines electrically independent islands and proceeds to compute the dynamics for each island. FINIST is fully capable of modeling the power system that consists of several islands. The simulator can handle rather sophisticated cases such as when the generators of the same power plant are electrically separated into several islands.

After the dynamics for the specified time period has been computed, the computation engine calculates and publishes the resultant system powerflow for other modules and external programs to use and moves to the next time period. The powerflow publication can proceed concurrently with the next time period computation. In effect, FINIST continuously processes the dynamics of the power system periodically importing external events and publishing the powerflow.

Island Dynamics Calculation

The computation engine calculates the dynamics for each island concurrently. There is a separate thread for each island. For computational efficiency, the simulated time can flow at different rate in each island. However, these simulated time flows are periodically aligned for all islands. This alignment enables taking global system state snapshots for the purposes of publishing the complete system powerflow. The default alignment period is 200 ms.

Depending on the speed of the simulated processes occurring in each island, FINIST models them as transitional processes or as (long-term) dynamic processes. These two computation models in FINIST are different. However, FINIST can switch between the models as needed. Synchronous machines, specifically generators, are the major objects of dynamic processes modeling. Certain control systems, such as automatic generation control (AGC), are also treated as dynamic system elements. The two computation models place different assumptions on the behavior of these objects.

In case of long-term dynamics model, some of the fast electromechanical processes are not significant. Therefore, they are not taken into account. In this model, FINIST assumes that the rotors of all synchronous machines rotate with the same speed. FINIST does not consider delays in generator excitation systems or the transitional processes in the generator armature. FINIST determines rotor acceleration by using system powerflow calculation: the power used to accelerate the rotor of a synchronous machine attached to a certain bus is considered as one of the components of power balance of this bus. FINIST computes the island frequency by integrating the rotor acceleration of the synchronous machines of the island. In this model FINIST computes prime mover dynamics of the power plants.

FINIST uses transitional process model to represent electromechanical phenomena that occur in power systems after topology change or during loss of synchronism. Such processes develop fast and require a significantly more detailed model. In this model, FINIST factors in the changes of generator rotor angles, the excitation system inertia, as well as transitional processes in the generator's electromagnetic circuits. Also in this model, the acceleration of each individual rotor is another state variable to be computed. The synchronous machines are represented in the form of subtransient EMF and subtransient impedance.

The power system processes are modeled as a system of differential and algebraic equations. The differential equations are solved by time step integration. In a single integration step, the system parameters are assumed to be fixed and the algebraic equations are solved to obtain the powerflow: the voltage magnitude and angle for each node. The length of a step and thus frequency of state calculation depends on the particular dynamics model.

Powerflow Calculation

The challenge of powerflow calculation is to ensure its convergence. FINIST switches between the transitional process and long-term dynamics model as needed. The transitional process model is used after topology change or if the long term dynamic computation does not converge. The lack of convergence usually signifies the lack of dynamic stability which leads to the loss of generator synchronism. FINIST switches back to long-term dynamics model when the difference between speed and acceleration of the synchronous machines falls below certain thresholds.

The powerflow calculation in transitional process and long-term dynamics model differs. The objective of long-term dynamics powerflow calculation is to provide adequate fidelity and fast state processing. The objective of transitional process calculation is to ensure convergence. FINIST ensures the overall convergence of the powerflow computation by switching between models. For example, if the system is in or near loss of synchronism, the powerflow calculation in long-term dynamics model may not converge. If the long-term dynamics model does not converge, FINIST switches to transitional process dynamics whose convergence is guaranteed.

- In long-term dynamics model, FINIST computes bus voltages using Gauss-Newton minimization method possibly augmented with Siedel iterations for fast convergence. The basic algorithms are enhanced with a number of optimization techniques. FINIST implements integration step-size adjustment. FINIST has protection against jitter caused by a generator operating near its reactive power supply limit and alternating between voltage level regulation mode and reactive power limitaion mode. FINIST allows flat start or a start from some pre-defined state.
- FINIST can use one of the several methods of balancing the powerflow calculation: with one or several slack busses and set frequency; with distributed slack bus and set frequency; with generator governor adjustment and the effect of load on frequency. If the system is separated into several islands FINIST can apply different balancing methods to different islands.
- FINIST uses Z-method to compute powerflow in transitional process model. Each load is divided into two parts that are related to: (i) load admittance and (ii) current injected into the system. The load admittance is considered constant during the iterations of the powerflow calculations. Moreover, the load admittance is fixed across

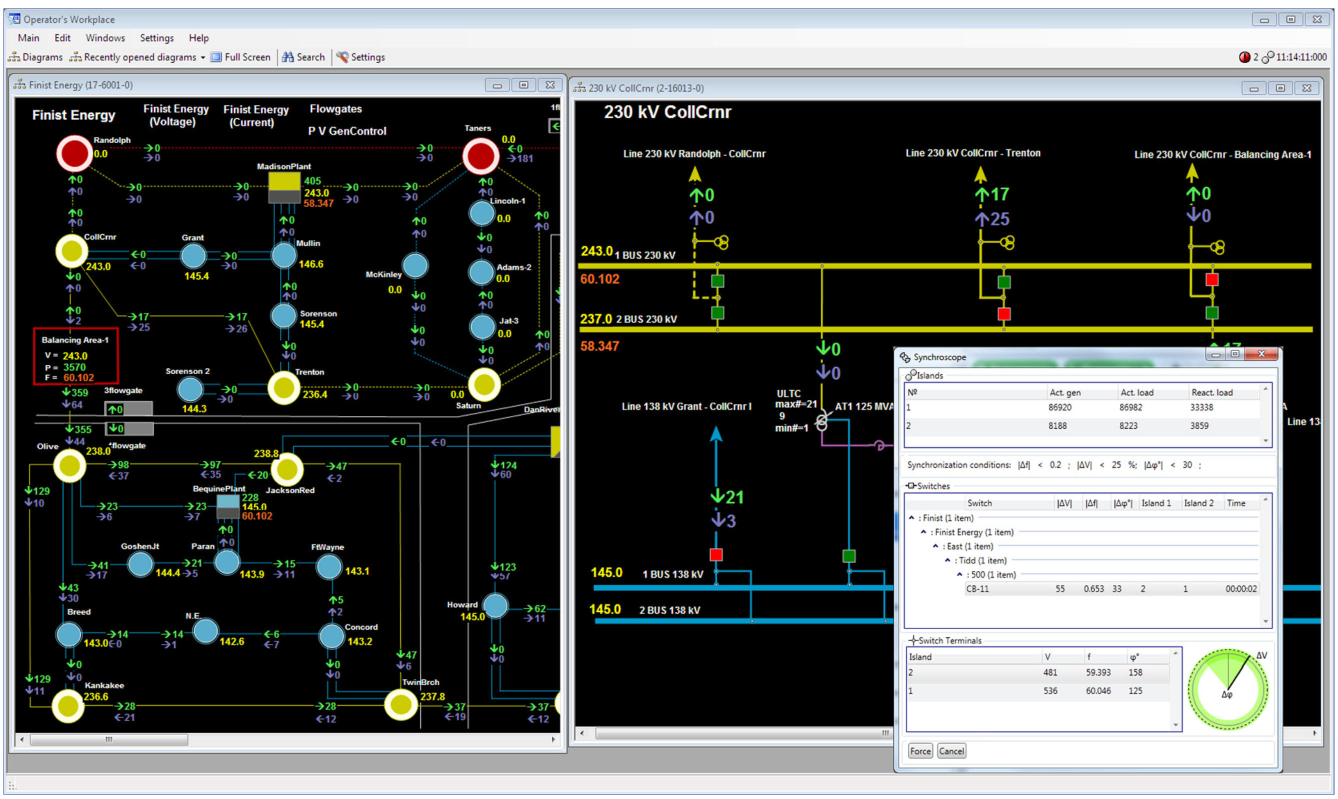

Figure 8. Island synchronization using synchroscope

several adjacent integration steps of the differential equations solution. The current, on the other hand, is computed according to the load sensitivity function. It is re-computed in every iteration. This approach has good convergence properties. In rare cases, Z-method may not converge fast enough at a particular integration step. Then, the load admittance is recalculated and the powerflow calculation is repeated. In case the method still does not converge, the load admittance is fixed. The powerflow then devolves to directly solving a system of linear equations. That is, the powerflow calculation in FINIST's transitional process model always converges.

Differential Equation Solutions

In long-term dynamics model, FINIST uses explicit multi-step predictor-corrector variable-order method derived from Adams method. The method considers the stiffness of the differential equations. The integration step size is selected individually for each step. Proportional-integral law is used for step selection. Specifically, the step size is selected such that the logarithms of the three adjacent steps constitute a second order linear differential equation to be solved explicitly. For every step, the coefficients for such an equation are adjusted based on the predicted and computed values. This step size control allows FINIST to optimize the step size, eliminate unnecessarily frequent small step recalculations, and thus speed up the overall calculations. Even though step sizes in each island may be different, the integration computations at each island periodically synchronize. The duration of this period is fixed and is significantly larger than integration step sizes. By default it is set to 200 ms. This synchronization allows FINIST to determine the state of the complete system and publish it for the external programs.

Different groups of state variables are integrated using either explicit or implicit methods. Implicit methods result in increased step size which speeds up the computation without numerical stability loss. They are used for simulating stiff dynamics. Explicit methods are used for the simulation of generating units with slow dynamics such as thermal or nuclear generators.

In transitional process model, FINIST uses diagonal Runge-Kutta method to solve the set differential equations. The step size for this method is fixed. By default it is set to 20 ms. The second order of this method has an optimal combination of speed and reliability of convergence.

EQUIPMENT MODELING

The selection of the equipment to be modeled by FINIST and the fidelity of such modeling is dictated by the concerns of the operational personnel training. The equipment model has to be adequate in the variety of the behaviors that FINIST has to represent during training sessions.

Generation

FINIST has a sophisticated generator model. It uses Park's synchronous generator equations. Generator reactive power capability curve is taken into account. FINIST uses a generalized excitation system model and automatic voltage regulator model to provide proportional integration differential (PID)-regulation of bus voltage. Field voltage, current channels, frequency regulation, reactive armature power and power factor regulation are also modeled. Individual generator automatic regulator as well as plant-wide regulation is modeled.

FINIST models the following power plant types:

- Fossil-fuel power plants. FINIST has separate models for condenser-type and cogeneration-type power plants. FINIST models the fossil-fuel power plants in great detail. The simulator models throttle pressure control loops, fuel supply control, valve opening, steam flow rate, frequency droop. Either the turbine or the steam generator may lead. FINIST explicitly models feedwater heater as well as reheater and superheater.
- Hydroelectric. FINIST uses non-linear hydro-turbine

model with PID-governor. FINIST also incorporates the ability to model outside generation control systems and unequal load distribution between several machines of the same hydro power plant. FINIST has different models for high- and medium to small-head power plants as different turbine types are used in those plants. FINIST models power plant reservoir and the dependency of static water pressure on head size. This dependency is significant for medium and small head power plants which have limited reservoir size, for sequences of hydro-plants and for pumped-storage plants. FINIST assumes that water column and penstock are non-elastic (rigid) and there are no hydraulic interactions between machines in multi-machine power plant.

- Pumped-storage. The pumped-storage hydro power plant model allows FINIST to implement the main operating states and state changes of operational concern: the dynamics of control in generation mode and power consumption in the pump mode. In FINIST, the static water pressure calculation in pumped-storage plant is similar to those of ordinary hydroelectric plants with limited reservoir size. FINIST models the changing operation from generation to pumping by introducing appropriate time delays. For example, switching to pumping is modeled by decreasing generated power to zero, pausing for pumping preparation procedures and changing the unit to active power consumption with fixed water flow from lower to upper reservoir.
- Nuclear. FINIST models nuclear power plants in a somewhat simplified manner. It is assumed that the plants are run in base load mode and do not participate in frequency or generation control. Primary and secondary coolant dynamics are not considered. Core neutron control and heat transfer are modeled with second-order differential equations.
- Every modeled generator unit can be monitored and controlled by the operator either as a single unit or as a part of a generation group. FINIST offers rather sophisticated generator models with a large number of parameters and controls.
- Transformers. FINIST represents transformers using equivalent-Y circuit. The equivalent circuit accounts for a number of transformer parameters including winding resistance loss, leakage flux and magnetizing current. The transformation coefficient can be either real or complex. A transformer may have an on-load or off-load tap-changer and provide regulation of either voltage or phase or both. FINIST correctly models both automatic and external regulation.
- Transmission lines. FINIST models a transmission line with a π-equivalent circuit. However, non-linear corona losses may be modeled as particular load with appropriate sensitivity function. Effective use of the variety of reactive power sources to control the power system is an essential skill of an operator. Hence, FINIST has to faithfully model the sources of reactive power. Specifically, FINIST models shunt and series capacitor and reactor banks as well as synchronous compensators. The capacitor and reactor banks can be switched or thyristor controlled.

FINIST models series reactor or capacitor banks as fixed admittance devices whose admittance changes in increments. The shunt reactors and capacitors are modeled as variable or fixed impedance devices. Thyristor controlled or switched devices are modeled, although thyristor control transients are not considered.

Load. Adequate load modeling in an electric power system simulator is challenging as the aggregate load data for system objects are not provided or even measured in real systems as the telemetered data is usually insufficient to adequately reconstruct the necessary load properties. This is especially true for the transient and dynamic properties of the load that are necessary to properly model system behavior during disturbances and outages. At the transmission level, the load is composed of transmission level customers as well as transformers to the distribution networks. The latter represent integral demand of the lower-voltage end customers.

FINIST implements several standard load components. Individual load components have customizable frequency and voltage sensitivity functions as well as a variety of other parameters. The most important operational load characteristics can be represented by adding a composition of such components to the appropriate modeled system buses. The load model can be further tuned by adjusting the parameters of these components. FINIST can also use Zipf model to bring further realism to the load representation. FINIST has a separate model for power plant auxiliary needs power circuits. FINIST can model gradual load change well as cold load pickup. In case of load change, the transition is linear; in case of cold (just connected) load, its pickup is exponential.

Control systems and protection relays. FINIST models protection relays as well as special protection schemes of arbitrary complexity. FINIST implements a generic controls model that is used adequately model of all such systems. This model has: a multi-stage trigger, an actuator and a reloader. There is an actuator for each stage of the trigger. There is an activation time delay for each trigger. That is, the actuator is executed if the trigger condition is continuously true during this time delay. The actuator may change various state parameters. The reloader's activation conditions are programmed similar to the trigger's. Using this generic model, FINIST implements most widely used standard relays. Triggers model over and under-voltage, overcurrent, underfrequency, out-of-step relaying and similar conditions over the system objects such as generators, transformers or power lines.

Model Extension and Development

FINIST power system models incorporates many years of experience of Monitor Electric engineers, researchers and authorities in the field. However, the model is designed to be easily extensible. Monitor Electric engineers continue to perfect the model and regularly release model updates. Moreover, FINIST APIs are open and well-documented. This allows third-party developers to add components and functionality to the model as needed.

IMPLEMENTATION

FINIST is implemented in C# using .Net framework. It is engineered to take full advantage of modern multi-core multi-processor architectures to provide scalability and adequate real-time performance. The implementation is aggressively parallelized and multi-threaded.

Figure 9. FINIST development team

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