Power Grid Simulation and Analysis

Across the world, smart devices, distributed wind power plants, and roof-top photovoltaic panels are changing the nature of the power system. Commercial vendors need modeling and simulation tools that can support the seamless integration of these new assets.

Partner with PNNL to see how our innovative tools and technologies can help you solve the data simulation and analysis challenge. The technologies described here incorporate advanced analysis techniques that make sense out of complicated data streams, predict the state of the power system, and enable the integration of renewable energy.

Distributed Computing Architecture: This system architecture connects distributed power applications and individually running parallel programs to achieve real-time requirements. The architecture consists of an interface layer to wrap the High Performance Computing (HPC) code, data processing toolkits, and middleware pipelines that allow data exchange in the distributed applications. The architecture has an additional feature of partitioning the decomposition of a whole power system model to available HPC clusters to balance the computational and communication costs. The software architecture allows the entire power system model to be partitioned into subsystems based on the sensitivity analysis of bus lines. The computation of the subsystems is further partitioned to available HPC clusters that balance the computation and communication costs. Hence, individual state estimators (SE) run parallel programs to solve non-linear estimation procedures and communicate the intermediate results to their peers. The data exchange is built on top of a high throughput middleware, so that the individual state estimator is well encapsulated by interfaces for data communication and uniquely identified by endpoints. This leads to an extensible design, since the variation to the SE algorithms resulting in different data exchange structures (Harmonic SE versus Dynamic SE) are both allowed.

State Estimation Preprocessing: To reduce the computational load while maintaining the efficacy of the Kalman filter, this tool provides an optimization algorithm based on the generalized eigenvalue decomposition method to identify and select the most informative measurement subspace. When the number of measurements is large, the algorithm can be used to make an effective tradeoff between computational complexity and estimation accuracy. This algorithm can also be extended to other Kalman filters for measurement subspace selection.

Look-Ahead Dynamic Simulation: This is a look-ahead dynamic simulation software system that incorporates high performance parallel computing technologies, significantly reduces the solution time for each transient simulation case, and brings the dynamic simulation analysis into on-line applications to enable more transparency for better reliability and asset utilization. It takes the snapshot of the current power grid status, functions in parallel computing, dynamically simulates, and outputs the transient response of the power system in real time.

ESIOS (Electric System Intra-Hour Operation Simulator): This program models the power system's generator capabilities, real-time dispatch (RTD), automatic generation control (AGC) functions, and operator actions to balance system generation and load. Actual dispatch of AGC generators and control performance under various renewable penetration levels can be assessed by running ESIOS. The results provide system operators with more insight on what to expect with different amount of renewable generation in the system. The program 1) performs RTD and AGC simulation for production cost assessment and control performance evaluation for power system operational and planning studies; 2) contains an operator action model that mimics manual actions to maintain system reserves; 3) includes real-time forecasts of variable renewable generation and load; and 4) uses hourly generation schedules that can be produced by many existing tools as inputs, based on which RTD and AGC are performed on participating generators.

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About PNNL

Interdisciplinary teams at Pacific Northwest National Laboratory advance science and technology to understand our world and address America's most pressing problems in energy, the environment, and national security. Founded in 1965, PNNL employs 4,400 staff and has an annual budget of more than $1 billion. It is managed by Battelle for the U.S. Department of Energy's Office of Science.

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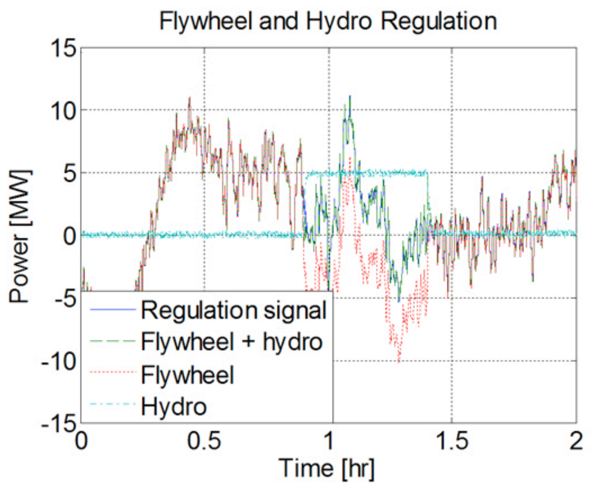


Sample Hybrid Energy Storage System Configuration

Hybrid Storage Conroller/Optimizer: This is an optimizing controller for a hybrid energy storage system that coordinates the operation of fast and slow generation units. The controller allocates the control signal between the slow unit and fast unit so that the slow unit responds to the low-frequency variations and the fast unit responds to the high-frequency variations. In addition, the storage unit operates close to its optimal rated output, maintains certain charge levels, or at a depth-of-discharge favorable to prolong its lifetime. Furthermore, the hybrid system is able to provide energy and ancillary services similar to those provided by a conventional generator. The algorithm also determines the optimal percentages of bids from power capacities into energy and ancillary service markets to provide energy arbitrage/peak shaving, intra-hour balancing and other payable services that will maximize the life cycle revenue of the hybrid energy storage system. See more online.

Model Validation for Optimized PMU Placement: This tool provides an innovative sensitivity approach to identify which parameters are important and need to be calibrated and how to optimally place Phasor Measurement Units (PMUs) to improve dynamic observability of the power grid. The Extended Kalman Filter (EKF) technique is used to perform dynamic state estimation and parameter calibration using measurement data from PMUs. The benefit of this technique is to allow a dynamic view of the power system constructed, providing the opportunity to assess dynamic stability and perform reliability and economic analysis in real-time.

CELL Methodology for PMU Data Analysis: This tool is designed to monitor and detect power system dynamics, and predict system future security trend, based on the characteristic ellipsoid (CELL) method. The tool uses real-time synchronized phasor measurements to identify the timing, types and locations of dynamic events in a power grid. The CELL, defined as a minimum-volume-enclosing ellipsoid, contains the most recent part of the system trajectory in a multidimensional space of phasor measurements. The shape, orientation, volume, and change rate of the CELL indices can eventually provide a new perspective on system status and dynamic behaviors. Motions of a power system, as well as dynamic events and their properties, can be identified by analyzing the time-domain indices of the CELL, such as volume, change rate of volume, eccentricity, and projections of its axes. Decision trees (DTs) provide a link between the CELL's characteristic indices and system dynamic behaviors, and are used to detect disturbances and their properties.

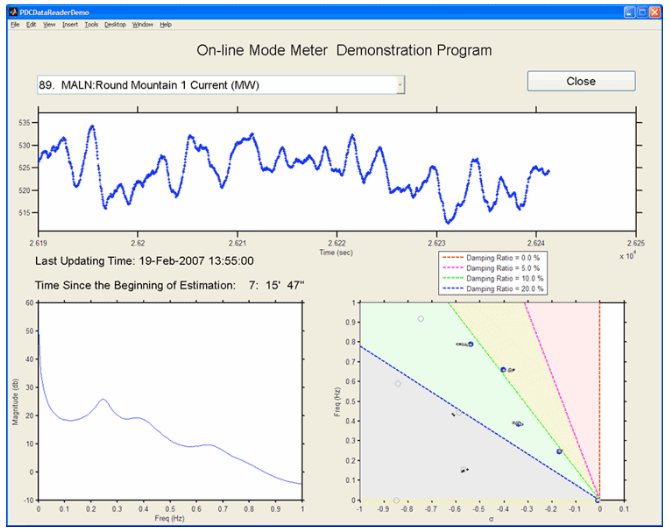
Renewables Integration Suite: Three related tools were developed to aid in the integration of renewable resources on the grid. Originally developed for the California independent system operator (CAISO), these tools are available for licensing to other independent system operators (ISO) and balancing authorities. The first tool is a method to analyze the impact of integrating wind generation on the regulation and load following requirements. The methodology developed is based on a mathematical model of the ISO's actual scheduling, real time dispatch, and regulation processes and their timelines. Minute-to-minute variations and statistical interactions of the system parameters involved in these processes are depicted with sufficient details to provide a robust and accurate assessment of the additional capacity, as well as ramping and ramp duration requirements that the ISO's regulation and load following systems are expected to face with the additional wind generation. The second tool is a method for predicting day-ahead regulation requirements. This tool has been developed to estimate needed procurement of upward and downward regulation reserve by the ISO in terms of capacity, ramp rate and ramp duration for each operating hour of the next day. Based on a scientific approach that uses a pre-specified level of confidence, the estimate minimizes procurement requirements without compromising reliability and mandatory control performance standards. The third tool is a probabilistic analysis of forecast errors and how to incorporate them into the determination of capacity, ramp rate, and ramp duration. The software uses actual historical data for day-ahead analysis and simulated data for hour-ahead and real-time analysis.


PNNL has developed a forecasting methodology to reduce the costs and risks associated with operating a power system with high penetration of renewable resources.

Net Interchange Forecasting and Error Prediction: This technology involves a short-term prediction methodology (with minutes to hours in lead time) for power system states while quantifying the uncertainty of its prediction. Motivated by the challenges of increasing uncertainty and variation introduced into the power system by variable generation, PNNL has developed a forecasting methodology to reduce the costs and risks associated with operating a power system with high penetration of renewable resources. This tool incorporates multiple prediction methods, such as regression methods and machine learning methods and then applies a Bayesian model averaging based ensemble approach for summarizing the prediction results and establishes a model structure for predicting net interchange schedule as a user case. Further, this tool includes a sensitivity-based smart sampling method reducing uncertainty in generating state prediction. Sensitivity-based smart sampling is a method that first performs sensitivity analysis to identify the most important uncertain model parameters. The next step then applies the high-order sampling method on the most important uncertain model parameters to achieve fast uncertainty quantification with high accuracy. This supports both estimating the prediction value, while at the same time quantifying the confidence interval of the prediction value in the statistical framework. See more online.

FTR Parallel Solver: Financial Transmission Rights (FTRs) help power market participants reduce price risks associated with transmission congestion. FTRs are issued based on a process of solving a constrained optimization problem with the objective to maximize the FTR social welfare under power flow security constraints. Security constraints for different FTR categories (monthly, seasonal or annual) are usually coupled and the number of constraints increases exponentially with the number of categories. Commercial software for FTR calculation can only provide limited categories of FTRs due to the inherent aforementioned computational challenges. This tool is a novel Non-linear Dynamical Solver (NDS) to solve the optimization problem and the performance is benchmarked against widely used linear programming (LP) solvers like CPLEX™. Furthermore, the NDS based solver can be easily parallelized while exploiting the data structure of the revised formalism to avoid backfill of coupled blocks and simultaneously reducing computational complexity.

Mode Meter Expert System: Electromechanical oscillation modes carry important information about power system stability. This tool provides an optimized output of three algorithms for on-line identification of power system modes based on measurement data in real time. These mode meter algorithms were separately developed at Montana Tech, the University of Wyoming, and PNNL, and the expert system was co-developed by all three institutions. This is a measurement-based tool for on-line power system mode monitoring which provides time for remedial action when a power system approaches some unstable conditions, and thus enhances the reliability of power system operation.



This graphic shows the mode meter tool developed by PNNL that uses real-time streaming synchrophasor data to predict grid instability.