U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability

Advanced Grid Modeling 2014 Peer Review

Stochastic Analysis for Power Grid Operation and Planning

Yuri V. Makarov

Pacific Northwest National Laboratory

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Vision: Building a new generation of probabilistic approaches and tools for a changing power system

- Random impact on power systems is increasing dramatically. Modern power systems gradually are transforming into a huge stochastic machine.
- Random forces include variable generation, system load, component outages, demand-side control, cogeneration, and market.
- They modify the system behavior, dispatch, and exchanges of energy.
- The existing deterministic practices in utility control rooms are based on established dispatches and flow patterns, a few “typical” stresses, and known congested paths.
- They are becoming increasingly inadequate for the growing uncertainty problem.
- This gap could result in more frequent and more significant system failures and inefficiencies.
- Some existing probabilistic approaches are addressing only parts the overall uncertainty problem, and provide partial solutions.
- A new generation of probabilistic methods, reliability and performance criteria, tools, and business practices is very much needed – THIS IS THE OBJECTIVE OF THIS PROJECT.

Outline

- Project purpose
- Significance & impact
- Technical approach and technical accomplishments

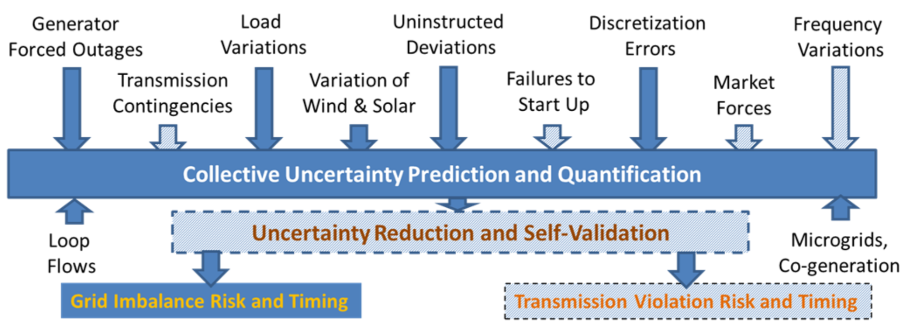
Project Purpose

- To develop a concept and methodologies for real-time and offline power system analytics, representing a power system as a stochastic machine.
- Develop and test new uncertainty quantification methods and tools:
  - Multi-source, multi-variant geographically distributed uncertainty model
  - Characterize prevailing system motions by limited number of principal directions
  - Quantify probabilistic limits along PCA coordinates
  - Explore opportunities for statistical separation of fast and slow system motions and their prediction
  - HPC applications
  - Transmission system uncertainty quantification tool
  - Support transition from deterministic to probabilistic methods in planning and operations

Significance & Impact

- Risk-based soft constraints for system dispatch, unit commitment and energy imbalance markets
- Better utilization of transmission without compromising reliability
- Predictive/preventive control based on probability, and
- Better uncertainty quantification and improved forecasting

Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model

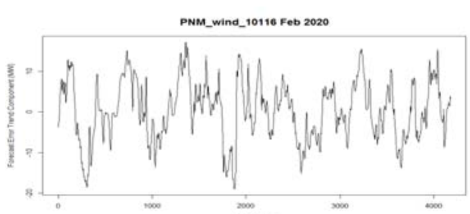


- Identify and represent uncertainties in load and wind generation forecast errors for power system planning and operations
- Reduce such uncertainties through exploratory data analysis such as principal component analysis, signal decomposition, time series forecasting

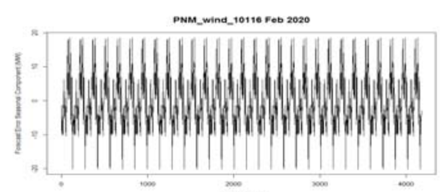
Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model

- Data: load, wind generation, and their forecast at 39 WECC zones
- Forecast errors are generated for statistical analyses, error reconstruction and/or prediction
- Approaches:
  - Seasonal autoregressive integrated moving average (ARIMA)
  - Integrated ARIMA with Cholesky decomposition to honor the cross-correlation matrix of the forecast errors across the 39 WECC zones

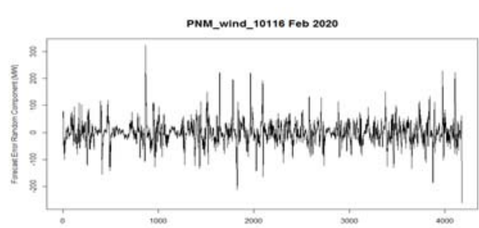
Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model



trend



seasonal

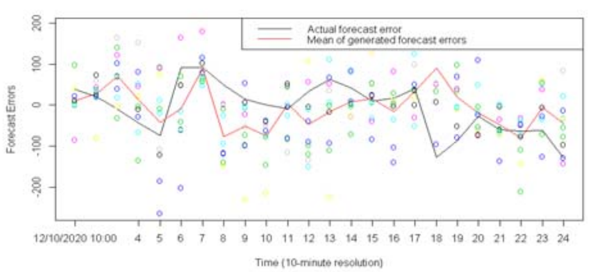


noise

Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model

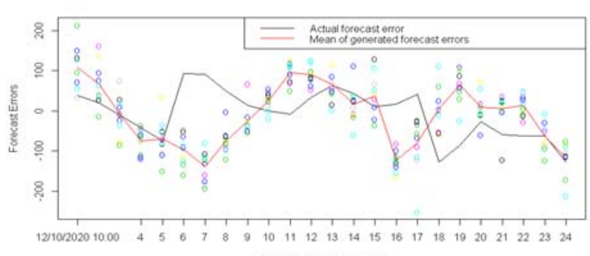
- For the need of the transmission tool development and separation of fast/slow system motions, short-term load and wind forecast errors are simulated
- Given a time instant and 4 hours' forecast error data prior to the time instant (i.e., 24 data points at 10 minute resolution), 200 realizations of different possible forecast errors for the next 4 hours (24 data points) are generated using a sequential Gaussian simulation (SGS) method
- Principal component analysis (PCA) is also implemented to generate the simulated data with reduced uncertainty bounds

Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model



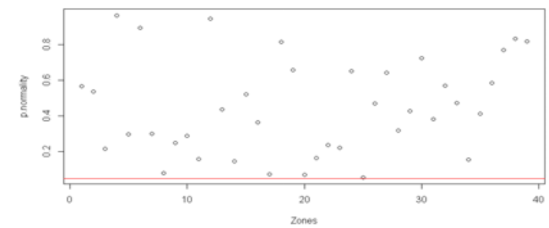
10 sets of simulated load forecast errors for zone 1 using the SGS approach

10 sets of simulated forecast errors for zone 1 using the SGS+PCA approach



Develop an integrated multi-source, multi-variant geographically distributed power system uncertainty model

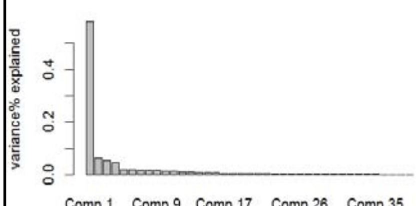
- Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test is conducted to check the stationarity of the generated time series of forecast errors
- The null hypothesis[1] that a time series is stationary will be rejected if the test P-value is smaller than a threshold (e.g., 0.05)
- Shapiro-Wilk test of normality is performed to test the normality of the generated short-term predictions of forecast errors[1]



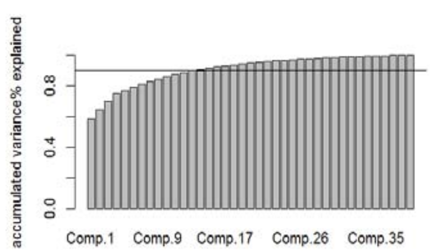
[1]Similar to the KPSS test, the null hypothesis that the test time series is normal will be rejected if the test P-value is smaller than a threshold (e.g., 0.05).

Characterize prevailing system motions by limited number of principal directions

- Load and wind generation and their forecasts are spatially and temporally correlated across the study zones (in our study, there are 39 zones altogether)
- PCA can help characterize the system motion similarity and express the overall behavior in a much lower dimensional subspace



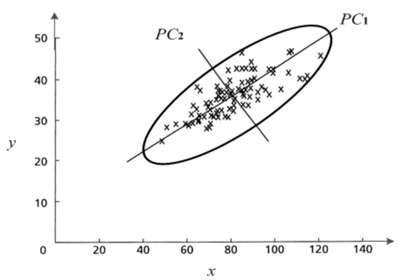
Percentage of total variance in original data that is explained by each principal component



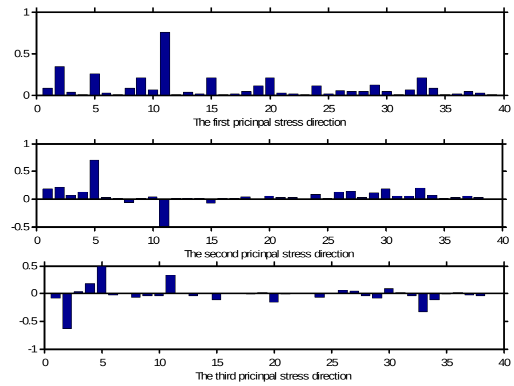
Accumulated percentage of total variance in original data that is explained by the principal components

Characterize prevailing system motions by limited number of principal directions

- Principal component analysis (PCA) is applied
- It helps to determine several most probable statistically independent and orthogonal stress directions
- Wind/solar intermittent sources introduce uncertainties to power system motion



Demonstration of PCA concept the two dimensional space

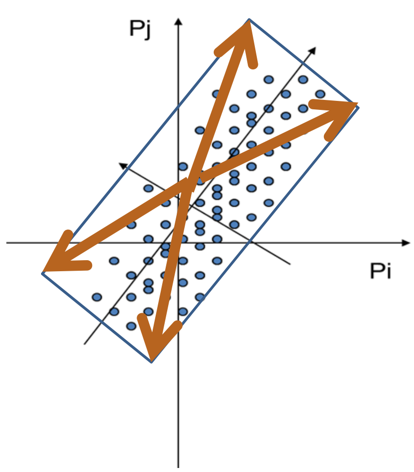


Principal stress direction in the 39 dimensional space

Stress directions-increment of active power in WECC with 39 zones in the time interval between 8 and 9 clock in Jan.

Develop uncertainty quantification and minimization methods for principal components

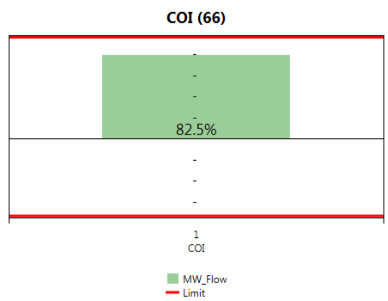
- Quantify security limits along "modal" coordinates.

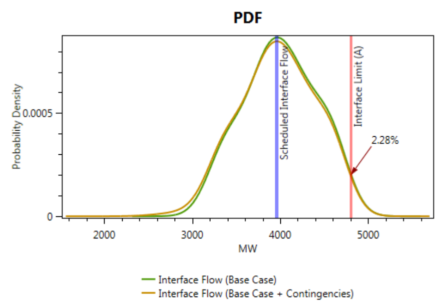


- They can be tried "independently" to find a suitable security boundary approximations

Develop uncertainty quantification and minimization methods for principal components

- Variable generation and load can skew the transmission flows beyond the limits
- Generation re-dispatch can be planned with stochastic methodologies using PTDFs





Develop uncertainty quantification and minimization methods for principal components

- Multiple interfaces can have violations
- Area generations can be uniformly scaled to alter interface flows
- Linear approximation of PTDFs on power transfer for every change in area generation
- Solve

$$\Delta F_i^{low} \leq \sum PTDF_{ij} \Delta P_j \leq \Delta F_i^{high}$$

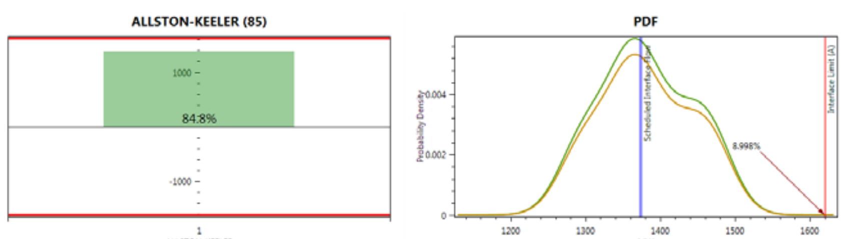
- Where
  - ΔF_i - change in interface flow for 'i'th interface
  - $PTDF_{ij}$ - power transfer distribution factor that represents change in interface flow for 'i'th interface due to generation change in 'j'th area.
  - ΔP_j - change in area generation for 'j'th area.

Develop uncertainty quantification and minimization methods for principal components

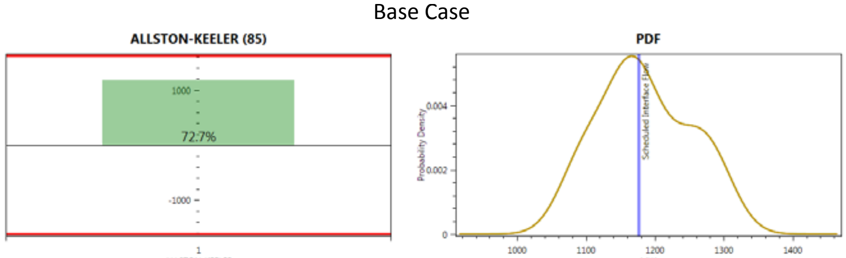
- Finite probabilities of violations observed for few interfaces due to intermittent generation uncertainties.

Number	Interface_Name	Base case transfer (MW)	ΔF_low	ΔF_high
85	ALLSTON-KEELER	1374.379	-2580	-180
45	CA INDEPENDENT - MEXICO (CFE)	-413.79	56	764
16	IDAHO - SIERRA	-272.629	20	700
60	INYO - CONTROL 115 KV TIE	-48.877	1	95
75	MP-SL	-374.247	280	1500
26	PATH 26	2526.669	-3600	-1000

Develop uncertainty quantification and minimization methods for principal components

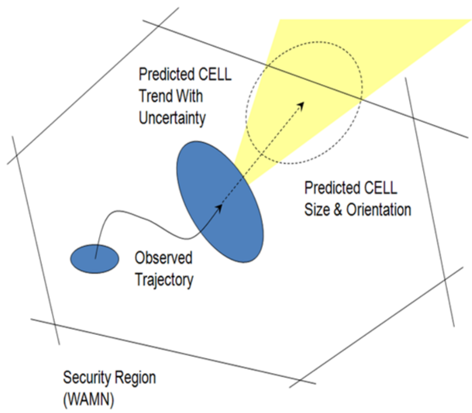


Base Case



Updated Case with Computed Generation Redispatch

Explore opportunities for statistical separation of fast and slow system motions and their prediction



- Ultimate objective: Develop predictive capability to detect system insecurities ahead of time
- Characteristic ellipsoid (CELL) ideas can be used for this purpose

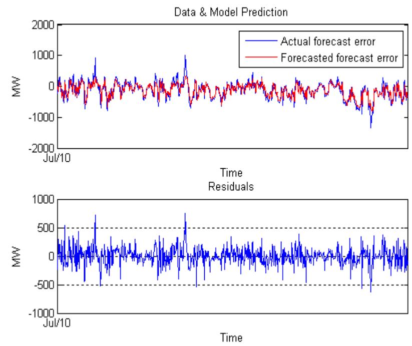
Explore opportunities for statistical separation of fast and slow system motions and their prediction

- The net load forecasts reflect the system **slow motion**
- The forecast errors capture the **fast motion** of system movement
- The residuals represent **very fast motion** that can be characterized as random noise following Gaussian distribution
- Through reducing forecast errors and system uncertainties, these motions can be separated to predict system moving direction
- Progress:
  - Tested two load forecast methods: regression trees and neutral network
  - Improved the day-ahead regression trees method to train the model every day and further improved to do hour-ahead load forecast
  - The mean average percent error and the standard deviation of the absolute percent error of hour-ahead forecast are greatly reduced

Explore opportunities for statistical separation of fast and slow system motions and their prediction

BPA July 2010

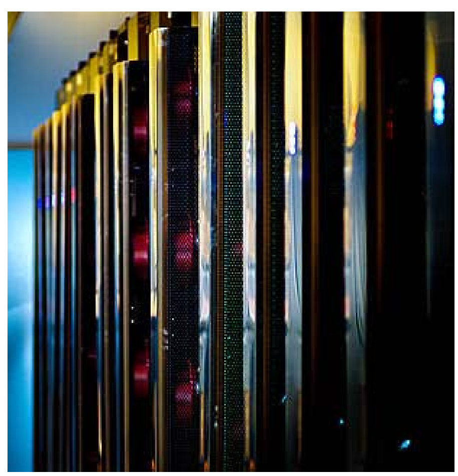
- Applied regression trees to predict hour-ahead load forecast error of Seattle City Light (SCL) and hour-ahead net load forecast error including load and wind of Bonneville Power Administration (BPA)
- A quantile-quantile plot of the residuals against a set of data under standard Gaussian distribution to see their similarity from a Gaussian distribution



- The standard deviation of actual forecast errors is 274.6. The standard deviation of residuals is 159.9. The magnitude and standard deviation of forecast errors are significantly reduced. It indicates that the very fast motions are separated from the fast motions

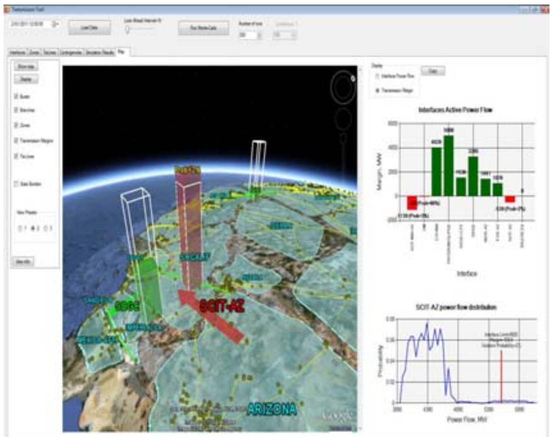
Explore opportunities for high-performance computing to support the project objectives

- Many of the stochastic tasks are naturally parallel
- Near-linear increase in computational speed obtained on PNNL Institutional Computing (PIC) supercomputers
  - Running many copies of executable on PIC
  - Each executable has its own input/output



PNNL's Olympus Supercomputer

Enhance transmission system uncertainty quantification tool

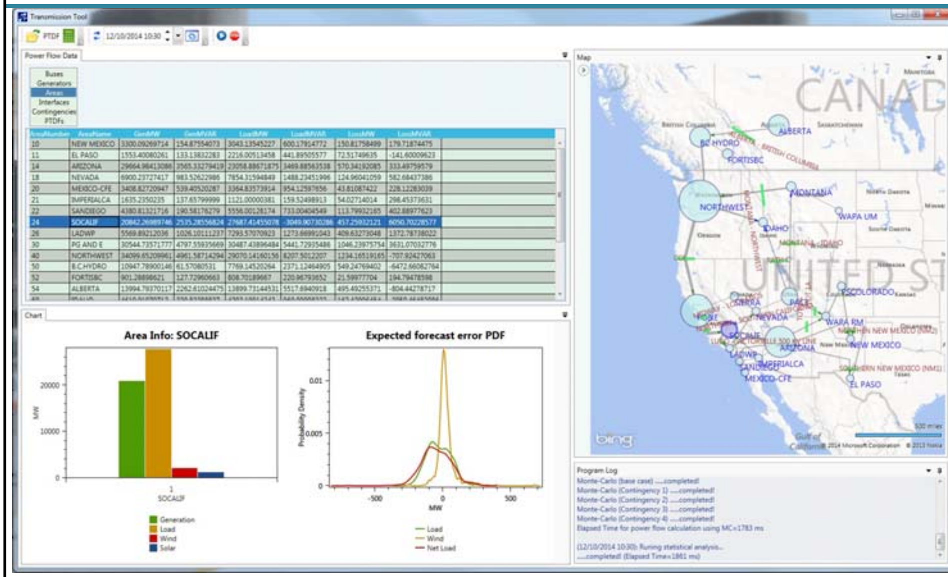


- The work was initially funded by CEC
- A prototype-level tool has been developed
- In this project, we will include California ISO data to evaluate the performance of the transmission tool, analyze the results
- The tool will be tested using California data and perfected to the level of industry-level product

Enhance transmission system uncertainty quantification tool

- Transmission tool analyzes impacts on:
  - Congestion
  - Voltage and transient stability margins
  - Voltage reductions and reactive power margins
- Information provided by the transmission tool includes:
  - Probability of violation of transmission constraints
  - Average and maximum sizes of violations
  - Actually available probability-based security margin
  - Visualization of the transmission impacts
  - Real-time dispatcher alerts, and
  - Advisory information using Google Earth technology

Enhance transmission system uncertainty quantification tool



Conclusion

- We are on track with the project goals and milestones
- Our intention is to build this project on our previous methods, tools, and datasets
- We want to provide usable results within the first year or our work
  - Transmission tool
  - Probabilistic stressing
- The second year of our work will include the development of several important methodologies and tools:
  - Statistical linearization
  - System reduction
  - Stochastic optimization and control
  - Tail events quantification and assessment.
- We are going to create a bridge from academic research to practical probabilistic methods
- We will cooperate with the industry, vendors, and other researchers and contribute to a major change in power system planning and operation area

Acknowledgements/Contacts

Acknowledgements:
Gil Bindewald, DOE-OE Office

Contact:
Yuri Makarov
Pacific Northwest National Laboratory
Phone: 509-372-4195
E-mail: yuri.makarov@pnnl.gov

Back-Up Slides

Project Summary: Stochastic Operation and Planning

PI/PM: Y.V. Makarov, Other key participants: B. Vyakaranam, N. Samaan , P. Etingov, R. Diao , Z. Hou, D. Wu, M. Vallem, Y. Sun, Y. Zhang, S. Wang, H. Huang, M. Morgan

The Stochastic Operation and Planning project addresses the Electric Industry challenge of the imminent uncertainty in the modern power systems and makes a bridge from deterministic to probabilistic methods in planning and operations. The technical approach used by the research team was based on advanced methods for uncertainty quantification, reduction and prediction, principal component analysis (PCA), regression decision tree analysis, Monte Carlo simulations, HPC, and state-of-the-art visualization.

The results to date have been:
1) Unique comprehensive distributed uncertainty model of the WECC system,
2) Uncertainty reduction and predictability of WECC system motions through PCA and ARMA models,
3) Statistical separation of slow, fast and very fast motions in the WECC system helping to improve predictability,
(4) Transmission tool predicting the impact of uncertainty on transmission system, and
(5) Dispatch algorithms based on soft risk- and probability-based constraints.

Future applications could include risk-based soft constraints for system dispatch, unit commitment and energy imbalance markets; better utilization of transmission without compromising reliability; predictive/preventive control based on probability, and better uncertainty quantification and improved forecasting.

The project builds upon multiple previous projects in the renewable integration area funded by DOE, CEC, CAISO, BPA, ISO NE. The proposed next phase of the project includes statistical linearization; system reduction based on statistical methods; stochastic optimization and control, tail events quantification and assessment, and developing a state-of-the-art framework and a roadmap for stochastic planning and operations. In a broader perspective, we propose: Cooperate with industry, vendors, and other researchers and contribute to a major change in power system planning and operations; initiate a nationwide effort for implementing this framework; facilitate continuing education, dissemination, and technology transfer in this area; and create and lead Probabilistic Technology Interest Group (PTIG).