Real-Time Algorithms for Control of Transmission and Distribution Networks

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Smart Grids and Computing

- Smart grids generate large amounts of measurements whose timely processing and utilization can be used to improve efficiency and reliability.
- Intermittent energy sources (wind, solar) increase supply uncertainties.
- Real-time processing of large amount of information and implementation of forecasting and control algorithms increase the system resilience, efficiency, and reliability.

Real-Time Problems

The meaning of real time (from milliseconds to hours) depends on a particular problem or application.

Examples of problems:

- State Estimations
- Power Flow Computations
- Stability Analysis
- Weather, Load and Price Forecasting
- Voltage Control
- System Reconfiguration
- Unit Commitment
- Economic Dispatch

Transmission systems

- State Estimation
- Power Flow Calculations
- Stability Analysis Problems

Solving these problems involves solving linear equations

$$AX = B$$

for problems with from 10K to 64K variables.

In order to get practically important results, the system of equations with 10K variables should be solved within 1-2 cycles (16-32 milliseconds).

The vision for importance of such calculation was presented in the article by B. Fardanesh, Future Trends in Power System Control, *IEEE Computer Applications in Power*, 2002.

Transmission Systems

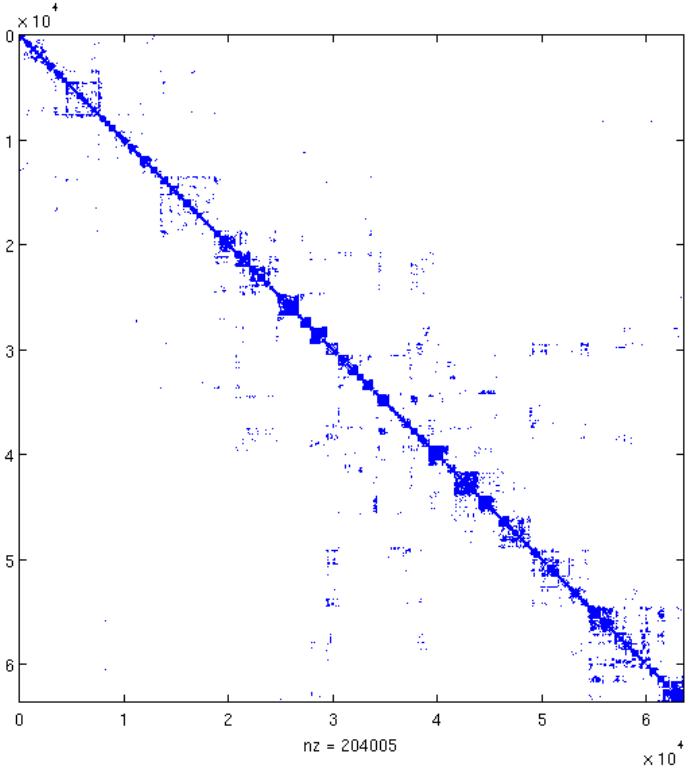
- In 2013-2014, a team from SBU and NYPA conducted a study *Enhances Power System Operation and Control via High Performance Computed* sponsored by NYSEDA; Program Manager: Michael Razanousky.

- In addition to the speaker, the team consisted of Bruce Fardanesh, Deepak Magaral (NYPA), Roman Samulyak (SBU/BNL), George Stefopoulus (NYPA), and SBU graduate students.

Transmission Systems

- In general, solving a linear equation with n variables requires $O(n^3)$operations (by Gaussian eliminations) , which is an astronomical number for $n \geq 10{,}000$.
- Other methods: Strassen ($O(n^{2.807})$ operations) and Coppersmith and Winograd ($O(n^{2.376})$ operations, but this method is impractical).
- However, in our case the matrix A is sparse.

Sparsity structure of Y-bus matrix



Algorithms and Software

Two types of Algorithms

- Exact (LU decomposition).
- Approximate/Iterative (Krylov subspace methods: GMRES /Generalized Minimal Residual Method).

Software

- SuperLU: Linear equation solvers based on LU decomposition algorithms.
- PETSC preconditioned iterative solvers, in particular GMRES with Jacobi preconditioning.
- LSQR / LSMR solvers for over- / under-determined systems.

Hardware

- ***Cluster of Intel Xenon X5650 @ 2.67 GHz processors***

  Did not produce good results compared to single CPU because of data communication delays.

- ***Graphics Processing Units*** (GPU) hardware ***NVIDIA Tesla K20X***

  Demonstrated better results than single CPUs.

- ***Intel®Many Integrated Core Architecture (Intel® MIC Architecture*** *or* ***Intel-Phi card)***

  Demonstrated the best results.

Conclusion on linear solvers for power transmission problems

- The following table demonstrates some of the results of the study (in sec):

Matrix Size	Single CPU	Multiple CUP	Single GPU
10K	0.077	0.014	0.051
64K	0.464	0.070	0.267

Conclusion: contemporary computing technology reached the level when solving transmission control problems in real time is possible.

Placing additional PMU to accelerate calculations

- We also conducted a preliminary study the Phasor Measurement Unit (PMU) allocation problem to accelerate power flow calculation.
- By placing a relatively small number of additional PMUs, it is possible to significantly reduce the computational time.
- The solution of the PMU allocation algorithm is based on solving the graph partition problem for the transmission network.

Algorithms for Distribution Networks

- This part of the work is mostly based on some of the results from the project Long Island Smart Energy Corridor funded by DOE (Program Manager: Tom George) to LIPA, SUNY Farmingdale, 2010-2015 and SBU and partly on the results of previous projects on load forecasting with LIPA (Engineer/Manager: Janos Hajagos) and with NYISO (Engineer/Manager: Arthur Maniaci).

Distribution Networks

- As the part of LI Smart Energy Corridor Project, additional measurement, recording, communicating, and control equipment was installed at certain distribution substations and feeders.
- These installations included:
  - 3-phase measurements, recording, and communication devices, at substations, feeders, ASUs, and capacitor banks.
  - Replacement of customer meters with AMIs.
  - Installation of additional capacitor banks and updating control capabilities of existing capacitor banks.

Distribution Networks

- These installations allowed us to develop algorithms for control of distribution networks.
- In particular, the following two problems have been studied:
  - Feeder reconfiguration.
  - Voltage control.
- In this talk we concentrate on Feeder Configuration:

- *E.A. Feinberg, J. Hu, K. Huang, "A Rolling Horizon Approach to Distribution Feeder Reconfiguration with Switching Costs," (J. Hu, and K. Huang), Proceedings of the Second IEEE International Conference on Smart Grid Communications, Brussels, Belgium, 17-20 October 2011, pp. 357-362*

Feeder Reconfiguration

- **Objective**:
  - Improve distribution network performance by altering/modifying the topological structure of distribution feeders (via opening/closing tie and sectionalizing switches).
- **Advantages of feeder configuration:**
  - improve network load balancing.
  - reduce power losses.
  - prevent service disruption in case of power outage.

Rolling Horizon Approach

- Ideally, this can be solved by the dynamic programming (backward iteration) algorithm when the model parameters are known in advance and do not change with time. However, in reality
  - The planning horizon L should be sliding.
  - The model parameters are stochastic and change in time.
  - The current $I_{i,h}$ depends on the loads and network configuration.
  - Load forecast error increases with the horizon length L.

Rolling Horizon Algorithm

- **Use the rolling-horizon approach to solve the feeder reconfiguration problem in an online manner**
  - at each time *t*, assume the load forecast over the next *H* time units is available.
  - use the forecast information to compute/estimate the current flow on all load section over the next *H* periods.
  - use dynamic programming to obtain the optimal switching policy w.r.t. the fixed *H*-horizon problem:

$$\min \; G_t := \sum_{h=t}^{t+H-1} \left(\sum_{i=1}^{N} | I_{i,h} |^2 \, R_i + C \cdot S_h \right)$$

subject to voltage, transfer capacity, and network constraints

  - apply the initial switching action specified by the policy at time *t;* repeat the above procedure for *t=t+1*.

Feeder Reconfiguration: additional comments

- CYME was used to make power flow calculations.
- 2%-10% loss reduction was achieved in computational examples as compared with alternative comparison approaches.
- Network reconfiguration can be used in response to bad weather conditions.