

Dynamic paradigm for future power grid operation

Zhenyu Huang

Pacific Northwest National Laboratory, Richland, WA 99352

Email: zhenyu.huang@pnl.gov

Abstract: For future power grids with intermittent renewable sources and responsive loads, it is essential to establish a dynamic operation paradigm in contrast to today's operation built on *static* state estimation. Recent development in phasor technology makes estimating dynamic states possible with high-speed time-synchronized measurement data. *Dynamic* state estimation provides a full dynamic view of a power grid that further enables real-time *dynamic* simulation and *dynamic* contingency analysis. These three functions form an integrated new paradigm and provide a complete picture of the current, future, and potential dynamic states of a power grid.

1. Introduction

The electric power grid has been evolving over the past 120 years from a single power line to today's large networks. The evolution will continue at an accelerated speed. In the next 10–15 years, more than 15% of electricity will come from intermittent renewable sources, and more than 15% of loads will actively respond to grid situations and incentive signals. President Obama calls for “80 percent of electricity comes from clean energy sources by 2035” in his State of the Union speech. This results in emerging stochastic behaviors and dynamics the grid has never seen nor been designed for. To operating such a dynamic grid with sufficient reliability and efficiency is a challenge. For future power grids, it is essential to establish a dynamic operation paradigm in comparison to today's operation built on *static* state estimation.

2. Dynamic State Estimation

State estimation, as a central function in power grid operations, generates critical inputs for other operational tools. Any deficiency in the state estimation process propagates through the operational tools and has a direct impact on how the system is operated. Traditional state estimators receive telemetered data from a supervisory control and data acquisition (SCADA) system in the time interval of several seconds. The telemetered SCADA data is used in conjunction with an assumed steady-state system model, to generate a best-fit estimate for a set of static state variables, that is, bus voltages and phase angles. Since the estimation of the system states is based on a steady-state system model, only the *static* state characteristics of the grid are reflected. The result of computing only the static state variables is that the state estimator generates a series of snapshots of the system conditions in which the dynamic transition between the snapshots is not considered.

Recent development in phasor technology makes estimating dynamic states (e.g., rotor angle and generator speed) possible with high-speed, time-synchronized measurement data. It is otherwise not possible with SCADA measurements because of the low sampling rate. Phasor measurement units (PMUs) with a typical sampling rate of 30 samples per second currently have the ability to capture the vast majority of high-energy dynamics in power grids and thus enable *dynamic* state estimation. Dynamic state estimation provides a full dynamic view of a power grid, which further enables real-time dynamic simulation and dynamic contingency analysis.

3. Look-ahead Dynamic Simulation

Power grid dynamic simulation solves a set of differential algebraic equations to predict the dynamic trajectory of a power grid. Combined with fast dynamic state estimation, dynamic simulation can be calibrated continuously with up-to-the-second system information. This concept of combining dynamic state estimation and dynamic simulation enables a dynamic view of the current and predicted future status of the grid. Dynamic simulation is expected to run much faster than real time, so a skilled operator can “look ahead” and anticipate developing problems in the grid.

4. Dynamic Contingency Analysis

In addition to current and future status of a power grid, it is equally important to know the potential status in the situation of loss of one or more grid components (i.e., contingencies), so operational plans can be made ahead of time for the grid to respond and sustain the contingencies. Traditional contingency analysis is based on a steady-state power grid model and static state estimation input. It needs to be extended to include dynamic information. Dynamic contingency analysis can be naturally built on the capabilities of dynamic state estimation and real-time dynamic simulation. Each dynamic contingency is a dynamic simulation case with initial conditions determined by dynamic state estimation.

5. Summary

Figure 1 shows the three dynamic analysis functions for future power grid operations. The three functions form an integrated new paradigm and provide a complete picture of the current, future, and potential dynamic states of a power grid.

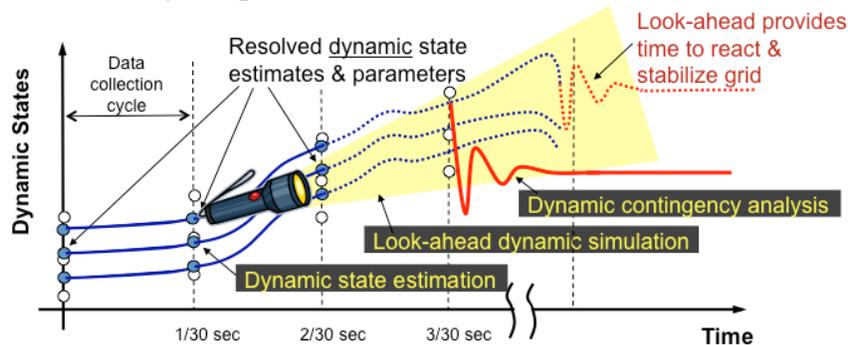


Figure 1. Integrated dynamic paradigm for future power grid operation enabled by dynamic state estimation, look-ahead dynamic simulation, and real-time dynamic contingency analysis.

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