Introduction to Smart Grids*

*SMART GRID
Fundamentals of Design and Analysis
by James Momoh, 2012

CHAPTER 4:

STABILITY ANALYSIS TOOLS FOR SMART GRID

INTRODUCTION

Electric power networks worldwide have expanded to accommodate more generation, RER, and control devices.

So the physical and technical consequences resulting from weaknesses in generation, transmission, and distribution will become more costly to society and the environment.

STRENGTHS AND WEAKNESSES OF EXISTING VOLTAGE STABILITY ANALYSIS TOOLS

The characteristics listed here are inherent in the analytic tools for the smart grid:

- Robustness: Persistence of a system's characteristic behavior under perturbations or conditions of uncertainty.
- Scalability: Ability of a system, network, or process to accommodate growing amounts of work; ability to be enlarged to accommodate growth.
- Stochasticity: Time development (be it deterministic or essentially probabilistic) that is analyzable in terms of probability.
- Predictivity: Rigorous, often quantitative, forecast of what will occur under specific conditions.
- Adaptability: System can adapt its behavior according to changes in its environment or in parts of the system itself.
- Online real - time data acquisition: Instantaneous acquisition of data.

Other suitable tools and techniques include:

WAM (**Wide Area Monitoring)** ***techniques****:*

measurements of voltage, angle, frequency, control series, and available resources for load state conditions; data is usually assumed or computed for static model with advent of GPS importance; new advances in the design of PMUs, smart meters, state estimation (SE), and FIDR monitor and control data for assessing stability, mitigating volatility, and achieving high-order efficiency and reliability.

Other suitable tools and techniques include:

Phasor Measurement Unit: PMUs are high - speed, time - synchronized digital recorders that measure voltage, current, and frequency on the transmission system, and calculate voltage and current magnitudes, phase angles, and real and reactive power flows. PMU data can be applied to the following:

1. Asset management
2. Voltage stability
3. Angle stability assessment
4. Designing optimum controls

Smart Meters:

Two - way electronic communication meter or other device measuring electricity, natural gas, or water consumption.

Old and New Grid Methodology

Methodology	Old Grid	New Grid
Model load	Static	Dynamic
Resources	Deterministic	Stochastic
FACTS devices and controls	Specified	Adaptive
Risk management	Deterministic	Random
Protection platform	Defined	Adaptive

VOLTAGE STABILITY ASSESSMENT

Voltage stability has many definitions.

It is a **fast phenomenon** for engineers involved with the operation of induction motors, air conditioning loads, or HVDC links.

it is a **slow phenomenon** (involving, for example, mechanical tap changing) for others.

Voltage instability or collapse is a dynamic process.

The term stability as used here implies that a dynamic system is being discussed. A power system is a dynamic system.

In contrast to rotor angle (synchronous) stability, the dynamics involve mainly the loads and the means for voltage control. Voltage stability is alternatively called load stability.

VOLTAGE STABILITY AND VOLTAGE COLLAPSE

Voltage stability has often been viewed as a **steady - state** viability problem suitable for static analysis techniques.

The ability to transfer reactive power from production sources to consumption sinks during steady operating conditions is a **major aspect of voltage stability.**

A power system in a given operating state and subject to a given disturbance undergoes ***voltage collapse*** if postdisturbance equilibrium voltages are prespecified acceptable limits in a significant part of the system.

Voltage collapse may be total (blackout) or partial.

Sequence of events leading to a voltage collapse

- The power system is experiencing ***abnormal operating conditions*** with ***large generating units*** near the load centers being ***out of service***. Some EHV lines are heavily loaded and reactive power resources are low.
- A heavily loaded line is lost which causes additional loading on the remaining adjacent lines. ***This increases the reactive power losses*** in the lines (Q absorbed by a line increases rapidly for loads above surge impedance loading), **causing a heavy reactive power demand** on the system.
- Immediately following the loss of the line, a considerable ***voltage reduction occurs*** at adjacent load centers **due to the extra reactive power demand**. ***This causes a load reduction***, and the resulting reduction in power flow through the lines should have a stabilizing effect. However, the generator AVRs quickly resolve terminal voltages by increasing excitation. The resulting additional reactive power flow through the inductances associated with generator transformers and lines ***increases the voltage drop*** across each of these elements.

Classification of Voltage Stability

The three categories of voltage problems are:

1. Primary phenomena ***related to system structure***: Reflect the autonomous response of the system to reactive supply/ demand imbalances.
2. Secondary phenomena **related to control actions**: Reflect the counterproductive nature of some manual or automatic control actions.
3. Tertiary phenomena **resulting from interaction of the above**.

Analysis Techniques for Dynamic Voltage Stability

It is only recently that the effects of system and load dynamics have begun to be investigated in the context of voltage collapse. The dynamics considered as fast and slow dynamics:

Fast dynamics,

1. Machine and excitation system dynamics including power system stabilizer (PSS)
2. Load dynamics
3. Dynamics of SVC controls and FACTS devices

Slow dynamics,

4. Tap - changer dynamics
5. Dynamics due to load frequency control, AGC.

OPTIMIZING STABILITY CONSTRAINT IN PREVENTIVE CONTROL OF VOLTAGE STABILITY

The controllable reactive power sources;

- generators
- shunt reactors
- shunt capacitors
- on load tap changers of transformers (OLTC).

Generators can **generate or absorb reactive power** depending on the excitation. When overexcited they supply the reactive power, and when under - excited they absorb reactive power. The automatic voltage regulators of generators can continually adjust the excitation.

Reactors shunt capacitors and **OLTCs** are traditionally **switched on/off** through circuit breakers on command from the operator.

ANGLE STABILITY ASSESSMENT

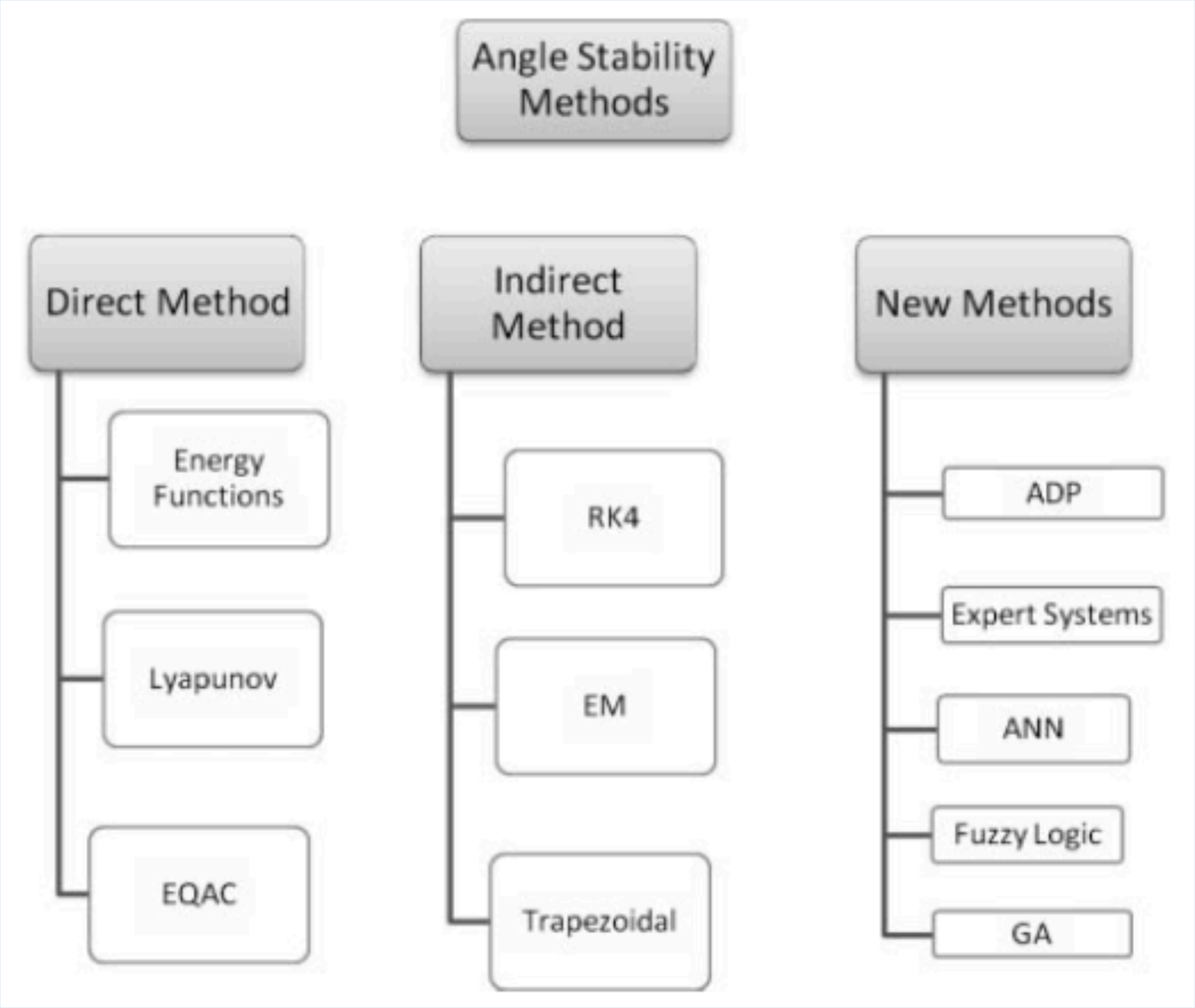
Transient stability studies of a typical 500-bus, 100-machine system require an hour of run time, even for a single contingency.

Therefore, direct methods of stability assessment are attractive alternatives.

It should be noted that a transient stability study is often more than an investigation of whether the synchronous generators, following the occurrence of disturbance, will remain in synchronism, for it can be a general - purpose transient analysis to investigate the quality of the dynamic system behavior.

The transient period of primary interest is the electromechanical transient, usually lasting up to a few seconds in duration.

Angle stability methods



STATE ESTIMATION

Energy management systems (EMS) run in real time to compute and maintain security of operation at minimum cost.

The power system measurements provide information to the SE program for processing and analysis. The functions performed include topology processing which gathers data about breakers and disconnect switches.

State estimation (SE) of voltage and angles are obtained for all busses using the weighted least square (WLS) method. Detection of inaccurate data is obtained from network parameters, tap changing transformers, shunt capacitors, or breakers.

STATE ESTIMATION

Many of the algorithms in use contain problems including:

1. Convergence problem: traditional SE may not converge if the power system state changes faster than the SCADA data
2. Possibility of missing critical data from communication channels
3. System parameter data base with many errors
4. Report changes in system parameters or devices such as breaker, taps, or disconnected switches

SE FOR THE SMART GRID ENVIRONMENT

These attributes are desirable in the development of future SE for smart grid computational tools:

1. PMU - based SE includes the following steps:

   a) Obtain PMU measurements at precisely controlled instants to estimate slow errors

   b) Measure for magnitude and angle of bus voltages (do not have to estimate angle)

   c) Measure the magnitude and angle of current

   d) Detect the state changes to reduce errors in building the bus admittance matrix

   e) Directly compute active and reactive power flows at the substation, or simply use voltage and current phasors to calculate active, reactive, and apparent power

REAL-TIME NETWORK MODELING

Real - time models are built from a combination of snapshots of real - time measurements and static network data.

The real - time measurements consist of analog measurements and the status of switching devices, whereas static network data corresponds to the system ’ s parameters and basic substation configurations.

Hence, the real - time model is a mathematical representation of the network ’ s current conditions extracted at intervals from SE results.

Approach of the Smart Grid to State Estimation

State estimation is an **important tool** for **detecting** and **diagnosing errors in measurement** such as network error and/or device malfunctions.

The technique is **used** in estimating voltage and power flow **errors** as a result of system parameters errors.

WHY THE STATE ESTIMATOR USED ?

Hence, the state estimator is used to build the model for the observable part of the network and optionally to attach a model of the unobservable part. With adequate redundancy level, SE can eliminate the effect of bad data and allow the temporary loss of measurements without significantly affecting the quality of the estimated values.

SE is mainly used to filter redundant data, to eliminate incorrect measurements, and to produce reliable state estimates, although to a certain extent it allows the determination of the power flows in parts of the network that are not directly metered.

Not only will traditional applications, such as contingency analysis, optimal power flow, and dispatcher training simulation, rely on the quality of the real-time network model obtained via SE

DYNAMIC STATE ESTIMATION

The **accuracy** of the state estimator is very **important** because it **feeds** EMS functions, that is, voltage/angle stability, economic dispatch, security analysis, and so on.

Today's power system is clearly **more dynamic** since both load and source vary with the introduction of RER as distributed resources.

A **technique** to address this new dynamic system, **dynamic state estimation** (DSE), is currently being researched.

SUMMARY

In this Chapter several performance tools for incorporation into smart grid design are presented.

The tools included;

- voltage stability
- angle stability
- state estimation

certain terms commonly encountered in stability analysis

Steady-state operating condition

A power system is in a **steady-state operating condition** if all the measured (or calculated) physical quantities describing the operating condition of the system can be considered constant for purposes of analysis.

When operating in a steady-state condition if a sudden change or sequence of changes occurs in one or more of the parameters of the system, or in one or more of its operating quantities, we say that the **system has undergone a disturbance** from its steady-state operating condition.

certain terms commonly encountered in stability analysis

Large disturbance

Disturbances can be **large** or **small** depending on their origin.

A **large disturbance** is one for which the nonlinear equations describing the dynamics of the power system cannot be validly linearized for purposes of analysis.

Large disturbances examples:

- Transmission system faults
- sudden load changes
- loss of generating units
- line switching

certain terms commonly encountered in stability analysis

Small disturbance

If the power system is operating in a steady-state condition and it undergoes change which can be properly analyzed by linearized versions of its dynamic and algebraic equations, we say that a **small disturbance** has occurred.

A small disturbance example:

- A change in the gain of the automatic voltage regulator in the excitation system of a large generating unit

certain terms commonly encountered in stability analysis

Transiently stable

The power system is steady-state stable for a particular a steady-state operating condition if, following a small disturbance, it returns to essentially the same steady-state condition large disturbance, a significantly different of operation. However, if following but acceptable steady-state operating condition is attained, we say that the system is **transiently stable**.