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Procedures for Validation of Powerflow and Dynamics Cases

Procedure for Validation of Power System Steady-State Case

Introduction

Steady-state models of the power system (often called powerflow cases) form the foundation of technical studies of the system. Because of this importance, these cases need to be periodically compared (benchmarked) to measured quantities and operational practices of the power system. Such a comparison validates that the power system case closely resembles actual operating conditions. The comparison also identifies data errors and parameters that cause mismatch. These can then be corrected or adjusted so that cases more closely match the actual conditions.

Powerflow Case – a collection of steady state models for system topology, load, generation, dispatch, and interchange that constitute a snapshot of expected system performance for the selected set of operating

The primary means of validating a particular powerflow case is to use that case to recreate system conditions for a specific point in time (a snapshot) in the past. To the extent practical, power system conditions for the selected time should be similar to the conditions that the case is intended to represent. Generation dispatch, loads, network configuration, and operational characteristics of the case are adjusted to match the conditions that actually existed at that time. The case is then solved and compared to measurements of the power system that were taken at that time. Some aspects of the powerflow case, such as individual equipment limitations, cannot be validated by this procedure and require instead individual data verification.

Only cases representing the currently existing ("as-built") system can be directly validated. Cases that are intended to represent the system in the future should contain the same component representations as the most recently validated model, unless there is a specific reason for the data to be different (i.e., a planned upgrade or system topology change), representing the cumulative planned changes to the system from the time of the validated near-term model through the timeframe intended to be represented by the case.

Routine Tests

Powerflow cases should be tested for data errors prior to use. These checks are normally done as part of the case assembly process. There are a number of possible data inconsistencies that can be found by performing a set of rule checks on a case, including (but not limited to):

- Maximum limit less than minimum limit
- Quantities outside of limits
- Transformer voltage control range smaller than transformer tap step (results in endless hunting in powerflow solution)
- Conflicting voltage set points from multiple regulating devices

The ERAG Multi-regional Modeling Working Group (MMWG) Procedural Manual, WECC Data Preparation Manual, and ERCOT Steady State Working Group (SSWG) Procedural Manual each include a series of tests to detect erroneous powerflow data.

Powerflow cases should be routinely tested against dynamics data by initializing the combination of the powerflow case and the corresponding dynamics data set. Errors that occur in the initialization may be a result of erroneous powerflow data.

Aspects of the Model Validation Process

In general, a powerflow system model is validated by comparing with observed conditions on the power system. This comparison is done by adjusting the generation dispatch and status of equipment in the model to match a particular point in time. The real and reactive system loads in the model also need to be adjusted to reasonably match state estimator load data and/or observed power flows for the same point in time.

Since study cases typically represent conditions in the future, a direct comparison to measured data will of course not be possible. Instead, for these cases, the corresponding case from the previous year is benchmarked. Any case corrections which are revealed by the model validation process are then transferred to the current year’s case.

As part of the powerflow case validation process, a specific time in the past is chosen for benchmarking. The power system conditions for that time should, to the extent practical, be similar to the conditions that the case is intended to represent. For example, a time of peak load during the summer of 2010 would be a possible choice for validating a summer peak model.

After a suitable time is chosen, the case being validated is adjusted to match the conditions for the selected time. Some topological adjustments may also be needed. The case is then solved and compared against power system measurements from the selected time. Details of how to perform this adjustment and comparison are described in Procedure 3, *Procedure for Assembly of a Power Flow and Dynamics Model for a Specific Time.*

If the case (with the adjustments described above) reasonably matches the measured quantities, the comparison validates the aspects of the models listed below. Some of these data represent physical characteristics of equipment, while others approximate operational practices.

- Transmission Network model
  - Line impedance, charging
  - Transformer impedance, tap position
  - Reactive shunt and series device size (for in-service elements) and operating status
- Generator
  - Reactive power output
  - Voltage schedules
- Load model
  - Total system load, bus load and load distribution
  - Real and reactive power
  - Power Factor for given time of day, season, and load level

Aspects of the case that represent projected quantities for future cases cannot be validated using this procedure. Such quantities include expected real and reactive power flows, expected load level, and projected generation dispatch.

Individual Data Verification

Some of the data in power flow models describe characteristics of the equipment that are not observable from a snapshot of power system measurements. Such data cannot be validated by the comparison of the power flow solution to system data and include, but are not limited to:

- Transmission circuit and transformer ratings

- Generator real and reactive limits
    - Generator available reserves
- Generator mode (base load or frequency responsive, AGC or non-AGC)
- Voltage regulation procedure and target voltage profiles (generators, transformers with LTC, shunt devices)

These data require validation through field testing and/or knowledge regarding operational practices (NERC standards MOD-024 and MOD-025, for testing generator real and reactive capability respectively, are currently under development).

Procedure for Validation of Power System Dynamics Cases

Introduction

Beyond the need for analyses of the steady-state behavior of the power system, it is crucial that the dynamics behavior of the system be analyzed as well. Power system dynamics cases form the foundation of those technical studies of the power system. Because of this importance, the simulated response of the power system obtained from these cases needs to be periodically compared to observed transient behavior of the power system. Such a comparison can only be practically performed for recorded system performance from system disturbances.

Preferably, these comparisons should be done for a number of system perturbations in order to provide a better calibration of the dynamics modeling and control parameters in the dynamics cases. Setting such parameters from a single test may provide good performance prediction for the test conditions, but the tested elements are constantly subjected to several different types of dynamic events.

> **Dynamics Case** – a collection of dynamics models used in conjunction with a powerflow model to perform a transient stability analysis of system performance.

Models are included for system elements such as, generation (including exciters, governors, power system stabilizers, current compensators, etc.), dynamic system control devices such as static var compensators (SVCs), flexible ac transmission system (FACTS) devices, DC terminal equipment and their controls, and dynamic loads such as motors and discharge lighting. Frequently, some system protection elements are also modeled such as system integrity protection schemes (SIPS), also known as special protection systems (SPS) or remedial action schemes (RAS). Also, for some studies, system protection for circuits, and relays for under-frequency or under voltage load shedding are modeled.

This procedure provides a sequence of steps for validating a power system dynamics case. The primary means of validation is to verify that the case can simulate the dynamic response of the power system with reasonable accuracy when compared to an actual system dynamic event. A comparison of dynamic data recordings of a disturbance with the simulation of the disturbance is the principal method of verification. A variety of types of disturbances – generation loss, faults, and line trips – can test different aspects of the model, such as voltage response, frequency response, and oscillatory behavior.

Routine Tests

After assembly, any power system dynamics case should be subjected to some basic functional testing before it is used for any study:

- No-fault test (no-disturbance test) – all system states should remain constant for an indefinite period of time (test is typically run for 20 seconds).
- Ring down test – disturbance in which system is perturbed without topological changes and should return to its initial state (test is typically run for 60 seconds).

Comparison with Dynamic Data Recordings

Initial Models and Information

To compare the response of an interconnection-wide dynamics case to dynamic data recordings, construction of a compatible power flow case of the power system conditions prior to the disturbance is necessary (see Procedure 3, *Procedure for Assembly of a Power Flow and Dynamics Model for a Specific Time*). The element identification in this powerflow case must be aligned with the corresponding dynamics model data for each component in the dynamics case.

Next, a particular system disturbance is selected. Certain data regarding the disturbance is required for validating a system dynamics case, including a) sequence of events, and b) the location and equivalent positive sequence impedance of any faults that occurred.

Using the combination of the aforementioned powerflow model and corresponding dynamics data, a simulation of a particular disturbance may be performed. Traces of the simulation results can be compared with dynamic data recordings, as shown below.

Quantities for Comparison (recorded Disturbance Monitoring Equipment (DME) data)

- Bus frequency
- Bus voltage magnitude and (where available) angle
- Generator real and reactive output
- Line and transformer flows – real and reactive
- Static and dynamic VAR devices reactive output and voltage
- DC lines active power, terminal voltage and reactive power consumption

Aspects of Comparison

- Oscillations – frequency, damping, initial amplitude
- Initial and final state
- Minimum and maximum values
- Rates of change
- Comparison of simulation and recorded data plots for data described above

Model Data Collectively Validated By This Process (i.e., parameters that may cause mismatch between simulation results and measurements)

Comparisons between simulation results from the model and measured dynamic data provide an indication of the collective validity of a large set of component dynamics models (both their structures and their parameters), including in particular:

- Generator
  - Status of exciter
  - Status of PSS
  - Status of governor
  - Control parameters (gains, feedback time constants, etc.)
  - Machine characteristics (inertia, time constants)
- Load model
  - Real and reactive power under dynamic conditions

- Transmission Network model
  - Reactive shunt dynamics models (automatic shunt switching)

It is difficult to provide clear guidelines as to which dynamics model parameters have the largest impact on a mismatch between the simulated and recorded responses for a particular quantity in a given disturbance. In many cases, a mismatch at a particular location identifies a need to individually validate the dynamics models of the system components in that vicinity. Availability of more data from multiple locations makes it possible to narrow down the location of the problematic component models.

Procedure for Assembly of Powerflow and Dynamics Cases for a Specific Time

Introduction

Validation of powerflow and dynamics cases requires the assembly of a powerflow case that represents system conditions at a specific time. Such case assembly is also critical in performing forensic analysis of disturbances on the power system.

This procedure provides a sequence of steps for building a dynamics-compatible steady-state case that represents system conditions at a specific time. The procedure is based on re-dispatching an existing dynamics-compatible powerflow case to match the desired system conditions. An alternate approach is the capturing of a state-estimator powerflow case for a specific time, and then adding dynamics data. That process is very useful for event replication, but does not allow validation of the off-line study cases or their modeling elements.

Powerflow Case Assembly

First, a suitable powerflow case is selected. If system dynamics models are to be validated, the powerflow case must be dynamics compatible. Next, a snapshot of power system conditions for a specific time needs to be assembled. The snapshot consists of the entire set of recorded power system data for the specific time selected:

- Buses
  - Voltage magnitude (measured)
  - Voltage angle (if available)
- Generators
  - Generator status
  - Real power output (gross)

  - Reactive power output (gross)
  - Control mode (voltage control, power factor control)
  - Voltage setting (if on voltage control)
  - Voltage regulation point (local or remote, if on voltage control)
  - Station service load
- Loads
  - Measured real power at available granularity
  - Measured reactive power
- Transmission Network
  - Breakers and disconnect switches (may result in split buses)
    - Status
  - Transmission lines
    - Line status
    - Real power flow (measured)
    - Reactive power flow (measured)
  - Transformers
    - Transformer status
    - Real power flow (measured)
    - Reactive power flow (measured)
    - Fixed-tap transformer tap positions
    - ULTC transformers
      - Tap position
      - Voltage setting
    - Phase-shifting transformers
      - Angle position
      - MW setting
  - Reactive shunt elements (Capacitor, Reactor)
    - Status

    - Size of each individual switchable group
    - Voltage thresholds for switching
  - Reactive series elements (Capacitor, Reactor)
    - Status
    - Size of each individual switchable element
  - Static VAR systems and fast-switched shunt devices
    - Reactive output
    - Voltage setting
    - Status of all controlled shunts
  - DC converters
    - AC real power flow
    - AC reactive power flow
    - DC current
    - DC voltage
    - Power, current, or DC voltage schedule
    - Firing angles
    - Harmonic filter statuses
    - Control modes
  - Other devices present in system model

- Wide-Area Control
  - Area interchange totals
  - Interface flows

For a dynamics case validation, additional snapshot data is needed:

- Generators
  - AVR operating mode
  - PSS status
  - Governor operating mode

Transfer Input Data to Case

The following items from the snapshot data are transferred directly into the steady-state powerflow case (state estimators may be a suitable source for this data):

- Generators
    - Real power output
    - Reactive power output or voltage setting
    - Control mode (voltage control, power factor control)
    - Voltage regulation point (local or remote, if on voltage control)
    - Status
- Loads
    - Measured real power at available granularity
    - Measured reactive power
- Transmission Network
    - Network topology
        - Device statuses
            - Transmission lines
            - Breakers (may result in split buses)
            - Reactive shunt elements (Capacitor, Reactor)
            - Reactive series elements (Capacitor, Reactor)
        - Fixed-tap transformer tap positions
        - ULTC transformers – tap position or voltage setting
        - Phase-shifting transformers – angle position or MW setting
    - Static VAR systems and fast-switched shunt devices – reactive output or voltage setting
    - DC lines – active power flow
    - Other devices present in system model
- Wide-Area Control
    - Area interchange totals

After this data is inserted into the case, a powerflow solution is performed. In order to obtain convergence, it may be necessary to temporarily relax some constraints (such as VAR limits) and/or solution parameters, particularly if the system conditions being modeled are significantly different from the conditions contained in the original powerflow case. A subsequent solution with more stringent constraints and tolerances should then be successful.

Key quantities in the solved powerflow case are then compared against observed system conditions and data in the system snapshot. Exact matches for flows and voltages should not be expected. However, it is desired to replicate the voltages and flows to the greatest extent possible. As a starting point, modeled flows should be targeted to be within ±10% of measured, and modeled voltages should be within ±3 % of measured (these will be refined through experience). Limitations of system SCADA measurements and potentials for error in measurement must be recognized.

Quantities for Comparison

- Real power output of system slack and area slack machines
- Generator reactive output and voltage
- Line and transformer flows – real and reactive
- Interface flows – real and reactive
- ULTC transformer tap position and voltage
- Phase-shifting transformer angle position and MW and Mvar flows
- Bus voltages
- Bus voltage angles (where available)
- Static VAR devices reactive output and voltage
- DC lines terminal voltage, MW flows, and reactive power consumption

If the comparison is unsatisfactory, there are two basic causes. First, the measured power system data may have significant errors. Second, there are a number of data in the power flow model that can cause the comparison to fail, including but not limited to:

- Incorrect transmission network model values
    - Line impedance, charging
    - Transformer impedance, fixed tap position
    - Reactive shunt devices size
    - Reactive series devices size

- Incorrectly split across buses
- Load distribution on each of the buses across the system may differ significantly from the actual system conditions.
- The power factors on each bus in the original case may differ significantly from the actual power factors for the system conditions.
- Spurious (non-existent) transmission elements in the source case

Engineering judgment and knowledge is used to identify faulty powerflow modeling parameters. After identifying and correcting such errors in the powerflow model data, the powerflow is re-solved and the comparison process is repeated. Detailed examination of these parameters must be performed during each comparison, and several bus-by-bus adjustments to load and power factor may be required to obtain a good correlation to the observed system voltages and flows.

When the comparison is deemed satisfactory, the resulting powerflow solution is an acceptable representation of the system conditions at the selected time. After the powerflow model is assembled, it can be used to initialize a dynamics simulation, since the dynamics model data for each of the components will correspond with the powerflow case.