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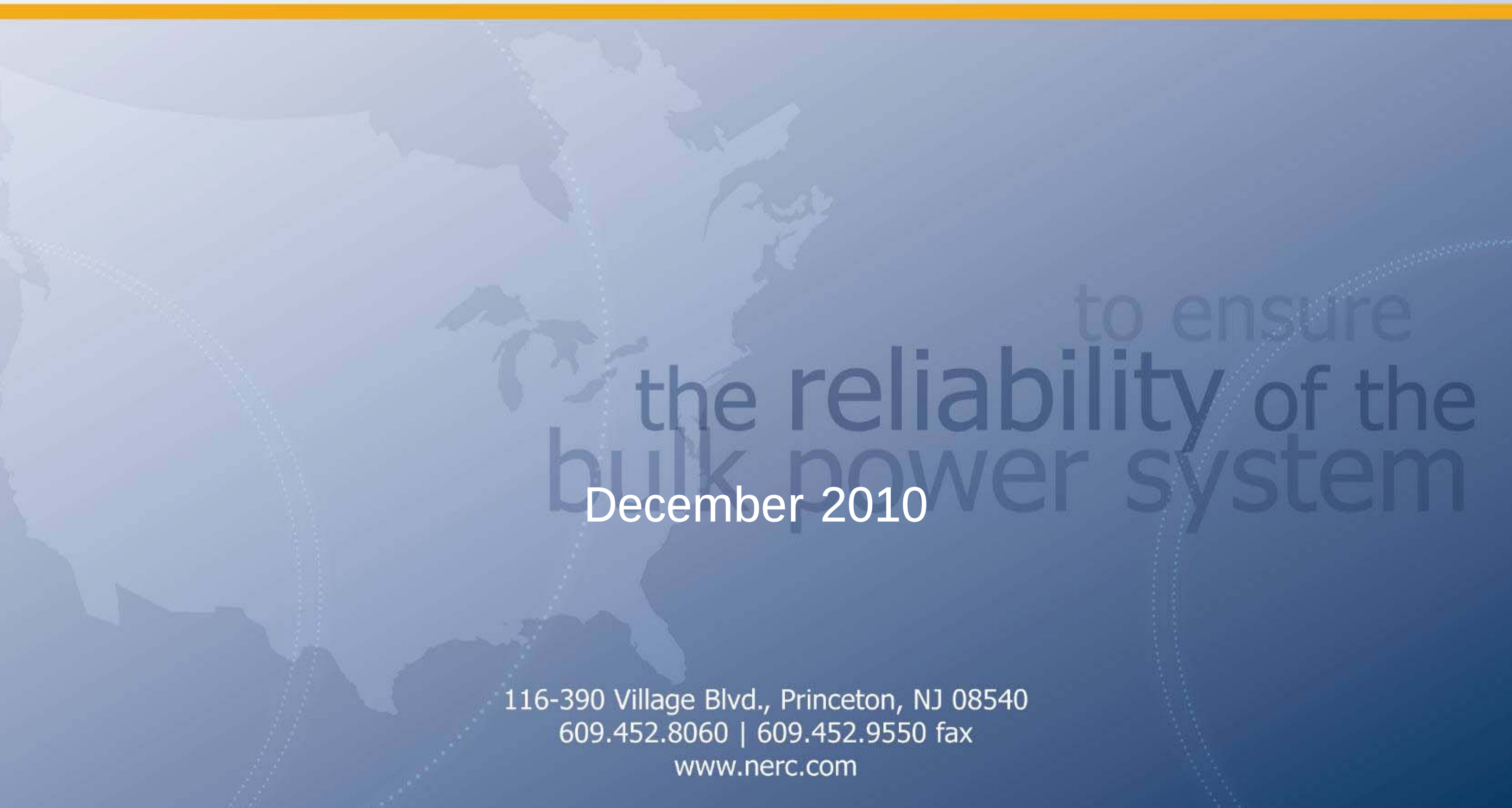
Power System Model Validation

A White Paper by the NERC Model Validation Task Force of the Transmission Issues Subcommittee



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Abstract

Models form the basis for most power system studies; thus, power system model validation is an essential procedure for maintaining system security and reliability. The procedure may be viewed as a "top-down" approach to model verification; comparisons with measured data indicate the quality of the overall model. Analysis of the differences demonstrates which subsystem component models need to be revalidated. Numerous examples are presented to illustrate the use and importance of system model validation.

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Table of Contents

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Executive Summary

Model construction and validation are important tasks that form the foundation of all power system studies. Periodic system model validation is necessary to ensure that the power system models are accurate and up to date. These tasks need to be performed regularly in order to keep up with ongoing changes and additions to the power system. Disturbances present great opportunities for model verification and identification of necessary model improvements. The WECC model validation experience illustrates that a commitment to model validation results in system models that more accurately replicate system events.

The following is a summary of the recommendations of this paper.

1. **The Industry should make periodic model validation and benchmarking an integral part of off-line study model maintenance.** The Planning Committee should assign the TIS or MVTF to produce a SAR for including this practice in the MOD standards.

   Discussion – *Modeling should be updated and validated every time there is a significant change to system topology; generators or their governor, exciters, power system stabilizers, etc.; or system equipment that include active controls that could affect system performance. Further, the industry should take advantage of any opportunity to validate powerflow and dynamics models against actual system performance during a variety of system conditions, particularly during system disturbances. The goal of that validation should not be to mimic just one response but rather to provide the best match of response to a number of system conditions.*

2. **The Industry should validate operational planning (offline) models by comparing them with models developed from real-time data. This will require improvements and standardization of the process for developing powerflow models from real-time data. The Planning Committee should assign the MVTF to develop guidelines for creating powerflow models and compatible dynamics cases from real-time systems.**

   a. **The Industry should proceed to move toward a "node-breaker" model for all powerflow and dynamics cases and analyses.**

   b. **Individual system equipment (transmission lines, breakers, generators, SVCs, etc.) must be universally identifiable between the EMS, state estimators, powerflow cases, and dynamics data sets to ensure proper "mapping" between the various programs and computing platforms.**

   Discussion – *Both powerflow models and dynamics models should be periodically benchmarked against actual system conditions. To do so, the powerflow model must first be adjusted to mimic the measured system conditions. That process requires accounting* *for system topology conditions, including open breakers, abnormal switching configurations, etc. That often requires re-modeling stations into node-breaker topology from the normal powerflow bus-line configuration. That process is often manpower intensive (much of this is still done manually), prone to errors, and very time consuming.*

Moving to a node-breaker representation of stations would eliminate that step, only requiring the collapsing of the station into bus-line configuration 'under the hood' of the powerflow program to reduce the number of zero-impedance branches. It is understood that as part of that changeover, there is a need to have a method for universally identifying individual pieces of equipment for ease of using their unique properties and characteristics between programs, applications, and computing platforms.

Further, in order for the powerflow to be used as the starting point for dynamics verifications, experience shows that the powerflow base case must be reasonably close to the actual system conditions in order to properly match the dynamics simulation results to actual system dynamic performance. Although some current EMS and state estimators are capable of outputting a powerflow model, the bus names, bus numbers, and equipment designations are not compatible with commonly-used dynamics data sets.

3. **The Planning Committee should act to promote the standardization of functional requirements for powerflow and dynamics programs, including data exchange formats, by assigning the TIS or MVTF to take the lead on this effort.**

   Discussion – *While addition of new models to program libraries is always encouraged, the addition of features requested by a few users should not impose a hardship on the remainder of the user community. A working group is needed to develop industry consensus on the program features and associated file formats that should be included in software whose input depends on the exchange of data between different companies in the industry. This should be a collaborative effort with the IEEE Power and Energy Society (PES).*

4. **The Planning Committee should act to resolve issues that impede the free flow of information for model validation to parties responsible for planning and operating the interconnected power system by assigning the MVTF to take the lead in this effort.**

   Discussion – *If existing agreements are inadequate to cover the data confidentiality issues, then new agreements need to be worked out among all of the entities involved – utilities, generator owners, NERC, etc. In particular, the Industry should review how generators are treated during the interconnection process and ensure that future data can be used in the modeling of the Bulk Electrical System. Existing generator data is also needed. Data sharing, security, and proprietary issues are separate yet related issues. They all address an underlying problem: availability of needed model data to* *parties who need the information to build an accurate system wide model. These are complex issues affecting many stakeholders.*

5. **The NERC MOD standards on powerflow and dynamics data (MOD-010 through MOD-015) should be improved and strengthened. The Planning Committee should assign the TIS or MVTF to develop a list of suggested improvements for a Standards Authorization Request (SAR).**

   Discussion – *The current standards lack specificity in many areas. In particular, if a new device cannot be modeled, it should not be interconnected. All devices and equipment attached to the electric grid must be modeled to accurately capture how that equipment performs under static and dynamic conditions. Models provided for equipment must be universally usable and shareable across the interconnection to allow for analysis of performance interaction with other equipment. Such models cannot be considered proprietary.*

6. **Requirements and procedures should be included in the standards for retention of power system powerflow and dynamics data following a system event.**

   Discussion – *The requirements should include specifications for type of data and length of time for retention. These procedures should also address the capture of adequate pre-event data, including specifications for data quality and the pre-event time interval. Several NERC standards are attempting to specify adequate retention periods.*

7. **The Planning Committee should act to foster improved time synchronization and time stamping for DMEs, EMS, and SCADA data by assigning the MVTF to support the standards development efforts.**

8. **The Planning Committee should act to develop training for implementing the more vigorous model validation processes described in this paper by assigning the effort to the MVTF.**

   Discussion – *The initial implementation activities could occur at about the time reputable organizations such as IEEE are projecting large numbers of the experienced electrical industry work force will be retiring, thus further challenging all organization levels to maintain adequate staffing. Policy makers and organizations performing model validation should give careful consideration to these staffing issues. Many of the activities associated with model validation require training, experience, and skill – qualities which take time to develop.*

9. **The Planning Committee should act to promote the development and use of model validation tools by assigning the effort to the MVTF.**

Discussion – *Tools need to be developed to assist in validating models (e.g., feature specification, model parameter sensitivity, and model parameter estimation, with screening of data for appropriate values).*

10. **The Planning Committee should work with the IEEE PES to promote the development of more efficient and robust powerflow solution algorithms to improve the speed of calculations and improve the reliability of solution convergence for contingency analyses.**

1. Introduction

Models are the foundation of virtually all power system studies. Calculation of operating limits, planning studies for assessment of new generation and load growth, performance assessments of system integrity protection schemes (SIPS) – all of these studies depend on an approximate mathematical representation of the transmission, generation, and load. Yet the performance of these models is not regularly compared against actual measured power system data – i.e., the models are not routinely validated. If a particular model does not represent significant observed phenomena on the power system with reasonable accuracy, then how can one have confidence in studies derived from that model?

Model validation and benchmarking were identified in the recommendations of the U.S. Canada Power System Outage Task Force and NERC following the August 14, 2003 blackout in the northeastern United States and eastern Canada. Many months of work were needed to develop the powerflow model used to study the outage. However, despite the recommendations made in the US-Canada report, the time and effort required has changed little since that event to develop a system model for post-event analyses from real-time power system conditions and data.

The purpose of this paper is to call attention to the importance of proper system model validation, to explore the state of current model validation practices with some examples, and to propose improvements to the process of system model validation.

2. Overview of Power System Models

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In modeling a large power system, such as the western or eastern interconnection in North America, there are several categories of models that need to be developed:

1. Transmission System: This includes transmission lines, power transformers, mechanically switched shunt capacitors and reactors, phase-shifting transformers, static VAR compensators (SVC), flexible AC transmission systems (FACTS), and high-voltage dc (HVDC) transmission systems. The models often include equipment controls such as voltage pick-up and drop-out levels for shunt reactive devices.
2. Generating Units: This includes the entire spectrum of supply resources – hydro-, steam-, gas-, and geothermal generation along with rapidly emerging wind and solar power plants. There is an imminent need for modeling distributed generation (e.g., solar, micro-turbines, fuel-cells, etc.).
3. Load: Representing the electrical load in the system, which range from simple light-bulbs to large industrial facilities.

2.1 Steady-state Models

Each of the above categories of components (transmission elements, generators, and load) can be represented by a steady-state model. For transmission lines, transformers, and shunt capacitors/reactors, model development is accomplished by an accurate calculation of the impedances, ratings, and other parameters that will be incorporated into the full steady-state network model. FACTS and HVDC have steady-state model structures that can vary with the vintage of technology of the device being modeled and the operating mode of the device. For generation, steady-state models represent real and reactive power capability and voltage control at either the generator terminal bus or a nearby high-voltage bus. These models should use data, including in particular the generator reactive capability, that have been validated through field tests or empirical evidence. Load is typically represented as constant real and reactive power; constant current and constant impedance loads are also sometimes represented in steady-state models.

The individual component models are then combined into a complete system model for representing steady-state behavior of an entire interconnection. This model is known as the "powerflow" model. Powerflow models of transmission systems usually represent only positive sequence quantities. For some studies, remote parts of a large interconnection sufficiently distant from the locations of interest are represented using reduced-size models known as "equivalents."

2.2 Dynamics Models

Models that represent the dynamics of components can also be developed for each of the categories of equipment listed above. For stability studies, the characteristics of concern typically have time constants in the range of a few tens of milliseconds to many seconds. Thus, in this context, the dynamics models represent the behavior of power plants and their controls, certain components of loads, power electronic transmission devices (i.e., FACTS and HVDC), and, for some studies, on-load tap changers, PLC controls on shunt devices, remedial action schemes, and other similar control devices. The components in the powerflow model need to be matched with their corresponding dynamics models.

FACTS and HVDC dynamics models need to represent all of the phenomena that are significant for power system studies. The determination of “significant” phenomena can vary with the type of study being performed and the portion of the power grid being studied. Power system engineers need to work closely with the equipment vendors upon commissioning to obtain a validated model based on comparisons with observed dynamic performance for each such device.

Historically, load has been represented in dynamics studies with a static ZIP model, which consists of a combination of constant impedance (Z), constant current (I), and constant power (P) elements. Typically, the real power of load is modeled as constant current and the reactive power is modeled as constant impedance. A process known as load “conversion” transforms the (usually) constant power load models in a steady-state powerflow model into the selected composition for a dynamics model prior to any dynamics simulations. However, static load models are increasingly viewed as inadequate for representing loads in dynamics studies, particularly with increased penetration of air conditioning and power electronics. Dynamic load models are needed to model many crucial dynamic phenomena of the loads. Motor load models are both dynamic and readily available, but newer load models are needed to represent certain phenomena such as air-conditioner motor stalling. To represent in a system-wide model, an aggregated static/dynamic model from a component based approach using data on customer types and categories at substations is a means of obtaining a first estimate of load composition. Such work would have to be done at multiple times of the year, e.g., summer peak, winter peak, fall, and light load.

2.3 Short Circuit Models

Steady-state network models are also used for short circuit studies. These models include negative sequence and zero sequence network data in addition to positive sequence data.

2.4 Models for Operating Studies vs. Planning Studies

Models are used in both operating studies for setting real-time power transfer limits and planning studies for analyzing conditions some time – possibly many years – in the future. Planning system models cannot be validated directly against power system measurements; however, the portions of the planning model that represent existing facilities which are not expected to change should match the corresponding portions in a validated operations model.

3. Examples of the Importance of Model Validation

Grid planning and operating decisions are based on the results of power system simulations. These simulations rely on power system models to predict system performance during anticipated disturbance events. Both technical and commercial segments of the industry must be confident that the dynamic simulation models, including all of their data, are accurate and up to date. Optimistic models can result in grid under-investment or unsafe operating conditions and ultimately widespread power outages, such as occurred in the summer of 1996 in the Western Interconnection. On the other hand, pessimistic models and assumptions can result in overly conservative grid operation and under-utilization of network capacity. Pessimistic models can also lead to unnecessary capital investment, thereby increasing the cost of electric power. Therefore, realistic models are needed for ensuring reliable and economic power system operation.

Model validation needs to be done on a regular basis. There will always be evolving changes in the characteristics of the power system over time, particularly with respect to loads. Unforeseen interactions can also occur when new control strategies are implemented through the addition of novel devices and technologies. The models must therefore be checked periodically to ensure that trends in the power system which can affect reliability are captured in system studies.

To predict power system performance, one must be able to model correctly all aspects of the system performance. In order to model system performance, one must understand the system’s behavior and assumptions that go into model development. To understand system behavior, one must observe, measure and analyze its actual behavior. Observation, measurement, and analysis of multiple system events provide the best opportunity for system model validation.

3.1 1996 Western Interconnection Outages

Two major disturbances occurred in the Western Interconnection in the summer of 1996: one on July 2 and another on August 10. When planning engineers attempted to reproduce both events in simulations, there was no match between the simulations and the actual disturbance recordings [1], as shown in Figure 3.1. The failure of the simulations to correlate, even remotely, with the actual disturbance data was alarming for utilities and grid operators in the West, since many of the critical paths are stability limited, and the models are used for setting their operating transfer limits. Following the outages, the operating transfer capability of the California-Oregon Intertie was derated from 4,800 MW to 3,200 MW, and the transfer capability of the Pacific HVDC Intertie was derated from 3,100 MW to 2,000 MW. Successful completion of model validation studies was one of the key requirements for the restoration of the intertie ratings.

The August 10, 1996 event was a complex disturbance that included voltage collapse, growing power oscillations, and loss of generation. The lessons learned from the validation studies had a monumental impact on how the studies are done:

1. A major revision of the generator model dynamic database was required. Following the outage, WSCC required that all generators larger than 10 MW be tested for the purpose of model data verification. The benefits achieved by the Western model validation program are indisputable [2]:
    - The first benefit was from the simple fact of having experienced staff visit power plants to review the correlation between dynamic models used to represent them and the actual equipment. There were cases where inappropriate models were used to represent generating controls, e.g., a static excitation system was represented by a rotating DC exciter model. There were cases when pieces of equipment were modeled that were out of service, such as Power System Stabilizers.
    - Model data was improved significantly in many cases, as demonstrated by a number of before-and after-test examples. Excitation system models were the most improved, particularly for older analog controls.
    - Improved generator control tuning was a positive “side effect” of the testing program. Having an experienced engineer with appropriate instrumentation on site presented a great opportunity to correct poorly tuned controls or detect and repair malfunctioning equipment.
2. Correct representation of generator reactive power capabilities was identified as one of the key modeling issues. All generators larger than 10 MVA were required to test and demonstrate their reactive capabilities. An effort was made to test and document settings of over-excitation limiters. Effects of plant-level controls on generator reactive power output need to be recognized in the post-transient time frame.
3. Modeled governor response was found to be optimistic in the validation studies. A significant portion of thermal generation had to be represented as lacking frequency response in order to match the frequency profile in simulations with reality. A governor “blocking” recommendation was put in place for operational and planning studies. Blocking thermal governor response also affected damping of the inter-area oscillations. (See also section 3.3.)

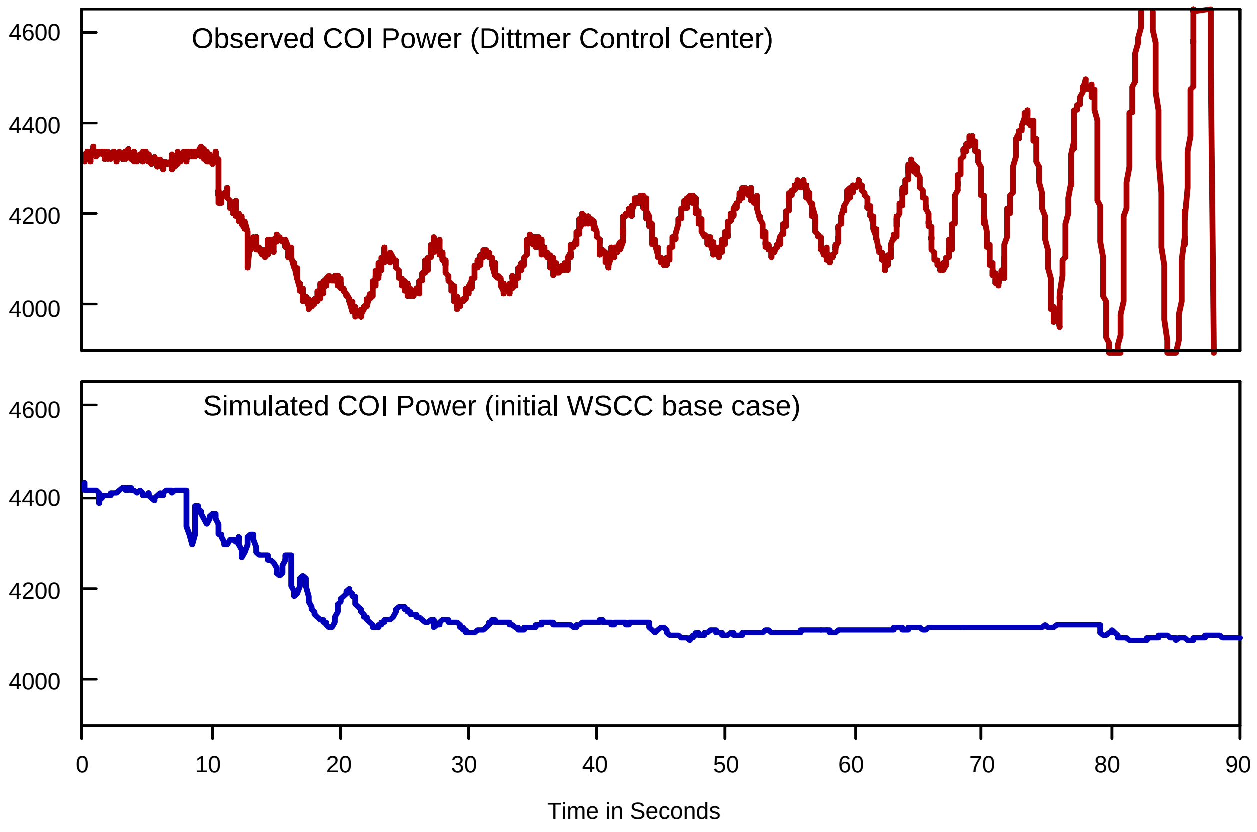

Figure 3.1 — Comparison of Observed System Response During August 10, 1996 Disturbance with Response Using Models Then in Use.

4. Controls of the Pacific HVDC Intertie (PDCI) were a major contributing factor to voltage collapse and growing oscillations. A true multi-terminal HVDC system model was developed, and detailed control models were developed for PDCI. Following the event analysis, control modifications were implemented to improve DC performance with respect to the grid [3].

5. Automatic Generation Controls played a negative role in the 1996 disturbance by replacing lost generation with increased generation in places farther away from the intertie, thereby increasing the system stress, and eventually resulting in instability. The effects of AGC action in a mid-term dynamic time frame need to be acknowledged.

6. Finally, the study recognized the need to represent the dynamic component of the load. Motor load had to be added to the case to get better agreement between simulation and reality for oscillation damping and voltage collapse.

It took nearly a year to build the initial powerflow model and six additional months of modeling work before the validation studies could match the actual disturbance well. Similar modeling changes were later applied to the July 2, 1996 validation case.

3.2 August 2000 Western Interconnection Oscillation Event

The Western Interconnection experienced a poorly damped oscillation on August 4, 2000. The event presented a great opportunity for model validation. Several modeling changes had to be put in place to replicate the event; the most notable was revision of power system stabilizer data. The event also presented an opportunity to test the motor load modeling assumptions that were derived from the 1996 disturbance studies. For simplicity of implementation, induction motor models were added uniformly to the high side buses across the Western Interconnection. The percentage of the motors was adjusted to get a good match for the North-South oscillations for August 10, 1996 and August 4, 2000 events. The model was recognized as "interim" and was used to address critical operation issues related to damping of power oscillations on the California-Oregon Intertie [4]. It was also recognized that a more comprehensive model is needed, and the Western Electricity Coordinating Council (WECC) accordingly formed the Load Modeling Task Force to develop and implement a composite load model.

3.3 WECC Frequency Response Reserve

By the early 2000s, WECC had a large record of under-frequency events in the Western Interconnection. Two observations were obvious:

- The simulated frequency dip was less than the observed dip for the same amount of generation lost.
- The simulated power pick-up on California-Oregon Intertie was not as large as the observed pick-up.

Since voltage stability of several transmission paths is affected by the distribution and amount of governor response, the discrepancy between simulated and actual governor responses again raised concerns about the safety of operating limits on major transmission paths.

A sequence of system tests was conducted in May 2001 as part of a WECC effort to establish a Frequency Responsive Reserve (FRR) Standard. Automatic Generation Control was disabled throughout the entire Western Interconnection so that pure governor response could be recorded. The tests included planned generation drops at Grand Coulee and Hoover dams.

The tests revealed that a large portion of thermal generation in the southern part of the Western Interconnection is operated "baseloaded," i.e., non-responsive to under-frequency events. The analysis also revealed a wide use of load controllers that allow initial response to under-frequency but quickly withdraw the response and return back to their setpoint.

WECC used historic synchrophasor and SCADA data to determine units which a) normally operate under governor control, b) are normally on load control, and c) are normally baseloaded. These operating practices were reflected in the study cases. Several validation studies were performed for large generation outages that occurred in 2002 to validate the over-all system performance, with specific attention to system frequency, power pick-up on major paths, and damping of inter-area oscillations.

The governor modeling recommendation had a huge impact on the studied transfer capability of major paths in the Western Interconnection. Results of this modeling work fueled the development of Frequency Responsive Reserve standards by WECC.

3.4 August 14, 2003 Eastern US-Canada Blackout

The blackout that affected the northeastern United States and Ontario on August 14, 2003 was comparable to the legendary 1965 blackout. Fifty million people and 61,800 MW of load were affected. A major part of the analysis of the blackout depended on the construction of a powerflow model of system conditions preceding the disturbance. The effort required to build this model was extensive (thousands of hours). The model was used to reconstruct the sequence of events and determine the causes and impacts of each of the individual events that took place. Construction of the model also revealed that the system models then in use underestimated reactive power load.

The recommendations from the studies of the blackout included model validation and benchmarking. Recommendation 24 of the U.S.-Canada Power System Outage Task Force was to “Improve quality of system modeling data and data exchange practices.” This recommendation included a statement that the “regional councils are to establish and begin implementing criteria and procedures for validating data used in powerflow models and dynamic simulations by benchmarking model data with actual system performance.” NERC also issued recommendations as a result of the August 14, 2003 blackout, many of which corresponded to the Task Force recommendations. NERC Recommendation 14 was to “Improve System Modeling Data and Data Exchange Practices.” The full recommendation stated that “The regional reliability councils shall within one year establish and begin implementing criteria and procedures for validating data used in powerflow models and dynamics simulations by benchmarking model data with actual system performance. Validated modeling data shall be exchanged on an inter-regional basis as needed for reliable system planning and operation.”

3.5 June 14, 2004 Westwing Event

A major disturbance occurred on June 14, 2004, when several protection relay failures resulted in a fault lasting longer than 30 seconds and the trip of three Palo Verde nuclear units. The simulations of the event reproduced the system frequency and power pick-up on major paths reasonably well. However, the validation study could not reproduce reactive power output from Palo Verde generators during the depressed voltages. The model was showing nearly 50% higher reactive power response than actual. Independently, BPA compared measured and simulated reactive capabilities for large hydro-power plants. Almost uniformly, the model was showing much greater reactive power output for a given set of boundary conditions (stator voltage, field current and active power). Such misrepresentations have a major impact on studies related to fault-induced delayed voltage recovery (discussed next), when machines can be forced to their excitation limits. The issue was attributed to the treatment of machine saturation by the simulation programs.

3.6 Fault-Induced Delayed Voltage Recovery

Fault-Induced Delayed Voltage Recovery (FIDVR) (refer to TIS Technical Reference Document on the subject[10]) is the phenomenon of a voltage condition initiated by a transmission fault and characterized by stalling of induction motors, initial voltage recovery after the clearing of a fault to less than 90% of pre-contingency voltage and slow voltage recovery of more than 2 seconds to expected post-contingency steady-state voltage levels. Multiple FIDVR occurrences have been observed in Southern California, Florida, and the southeast United States since the late 1980s. The phenomenon is related to stalling of motor loads, especially residential single-phase air-conditioners, in the area close to the fault. A severe FIDVR event may compromise safe operation of the grid.

The simulations of these events show instantaneous post-fault voltage recovery when using the WECC “interim” load model that has a percentage of induction motor models [4]. Studies conducted by Southern California Edison (SCE) and Florida Power and Light (FPL) concluded that:

- Three-phase motor models did not reproduce the air-conditioner stalling phenomenon during the simulated events. A hybrid modeling approach was developed by SCE and FPL engineers in which the load is modeled as being in one of two states: running or stalled. A three-phase motor model is used to represent the running state. When the voltage drops below a designated stalling voltage (generally around 60%), the motor model is replaced with a constant impedance representing a stalled motor [7]. This approach was later enhanced by the Electric Power Research Institute (EPRI) working with Arizona Public Service (APS) [11].

- It is necessary to model a distribution system equivalent to capture the voltage drop and reactive power losses in the distribution system. The WECC Load Modeling Task Force is completing a multi-year effort on developing and implementing a composite load model [12]. The model was shown to reproduce in principle historic FIDVR events and is now intended for use in voltage stability assessments.

4. Model Validation Process

4. Model Validation Process

The need for power system models has been discussed in the previous sections with several illustrative examples. The models of interest include:

- Operational cases
- Planning cases
- Models for the components that make up the cases
- Data constants associated with the component models

These cases and their constituent component models can be static (i.e., powerflow) or dynamic in nature.

The purpose of model validation is to understand the underlying power system phenomena so they can be appropriately represented in power system studies. The eventual goal is to have a total system model that can reasonably predict the outcome of an event (e.g., a model that would show the growing oscillations in Figure 3.1, even if it did not match exactly); however, to achieve this, one needs to have individual constituents of the system model to also be valid. The process of model validation and the eventual “validity” of the model require sound “engineering judgment” rather than being based on a simple pass/fail of the model determined by some rigid criteria. This is because any modeling activity necessitates certain assumptions and compromises, which can only be determined by a thorough understanding of the process being modeled and the purpose for which the model is to be used.

While models for some individual power system components – e.g., individual power plants, transformers, etc. – are regularly validated, the entire interconnected power system model is not usually taken through a systematic model validation process at present. Validation of the individual component models and associated data first, followed by an extension to system wide model validation, is a logical progression. In validating a model, “engineering judgment” and “generally accepted practices” are applied to:

- Measuring or testing components or systems
- Selecting component models
- Determining component model constants
- Tuning the overall system

In summary, validation means confirming that the simulated response (whether for a component or the overall power system) to a disturbance reasonably matches the measured response to a similar disturbance.

4.1 Steps in Component Model Validation

Presently, in North America, much effort is spent in individual component model validation of generation equipment. One clear example is the effort in WECC for generator model validation and certification [2, 15]. Component level testing can be done either through staged tests [16–19] or on-line disturbance based model validation [20]. Reference [21] presents an example of model validation based on disturbance monitoring for a FACTS device (SVC), while references [22, 23] discuss much work done in developing better load models and component level model validation for load models using laboratory tests. Such component level testing is of course a crucial step and a necessary part of system wide model validation.

For load models, data from distribution feeders can be used to gain valuable insight into which individual model types are needed to form the complete feeder load model. Appropriate model parameters can also be developed from such data. This data can then be compared to the aggregated models developed through the component based approaches to offer a means of refining them and/or helping to identify ranges of potential variation in load composition and parameters for sensitivity studies in planning analysis. Research is still being done in this area. Reference [14] discusses some of the significant challenges one is faced with when dealing with the great variability of load, both in composition and magnitude. Load modeling, perhaps more than any other segment of modeling, illustrates the need for “engineering judgment,” understanding the process being modeled, and the purpose for which the model will be used.

4.2 Steps in System-Wide Model Validation

In contrast to component model validation, systematic system wide model validation, the next logical step, is not done routinely at present. Figure 4.1 shows the process diagram for such system wide model validation.

Powerflow simulation results are compared with time-synchronized recordings of nodal voltages, angles, and key inter-tie flows during equilibrium conditions to ensure the adequacy of system wide powerflow models. Also, the simulated dynamic response to a measured event is compared to dynamic recorded responses of system wide frequency excursions and voltage and power fluctuations at major substations and transmission lines. Parts of the power system model that may require further refinement are thus identified.

Adjusting the conditions in the powerflow model to match the observed conditions of the actual power system is a major task but essential for model validation. The process is essentially a state estimation process, but the number of variables to be estimated is much larger than for EMS state estimators, since the study models being validated contain much more network and machine detail. The model needs to represent the observed power system conditions (i.e., the initial steady-state conditions, which are constituted by the initial powerflow and nodal voltages, etc.) for the moment in time just prior to the event that is used for the validation.

Various aspects of a system powerflow model that need to be matched to a specific event include:

1. network topology (line status (I/S or O/S), general network connections, and impedances):
2. generation dispatch
3. transformer tap position
4. status of switched reactive devices
5. load profile

The degree of success in matching a powerflow model to observed system conditions is an indicator of the validity of the powerflow model. Large unresolved errors in parts of the network (that cannot be attributed to measurement errors) strongly suggest that the system powerflow model itself has errors there.

For a dynamics model, additional characteristics may need to be matched to a specific time, including:

1. load dynamics and composition
2. power plant dynamics

For system dynamics models in particular, the challenge is to modify the simulation model, within reasonable bounds, to capture important features of a disturbance event. The model is tuned through parameters, and this process is one of parameter estimation. Parameters associated with the dynamic models are known with different degrees of confidence. Machine models are known and their parameters are usually available. For any particular event, engineers may need to confirm control settings and potential atypical characteristics that may have been present at the time of the event – but these can be known with some confidence. Other components, such as load models, are not precisely known, and choices for initial load model parameters are made with lower confidence.

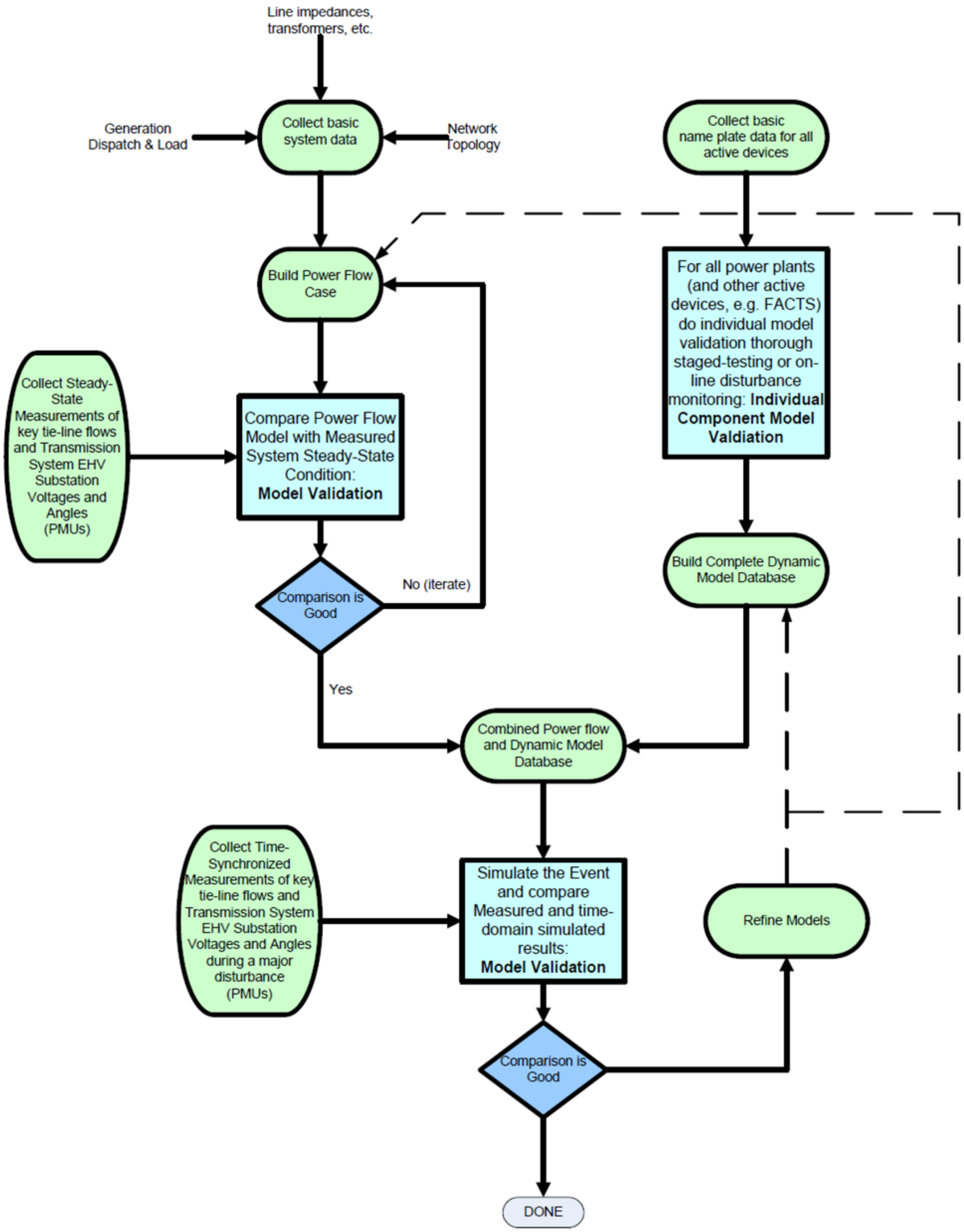

Figure 4.1: Process of system model validation.

A relatively new enabling technology for system wide model validation is phasor measurement units (PMUs). The number of PMU installations in the Eastern Interconnection continues to increase. The North American Synchro-Phasor Initiative (NASPI) effort is also underway to develop a robust data communications infrastructure (NASPInet) to support PMU integration efforts and facilitate an increase in the number of PMUs across North America. A significant surge increase in PMU installations is also expected as a result of the recently awarded DOE grant for phasor technology projects.

PMUs can record both the steady-state behavior and the time-varying response of the power system. Synchronized data can be captured, including major nodal voltages and angles and major tie-line real and reactive powerflows. Then by comparing these measurements to those predicted by our system wide models, the validity, and adequacy of the models can be assessed. Other sources of data for dynamics model validation include digital fault recorders (DFRs) and digital relay data.

4.3 Making Refinements to the Models

Model refinement during the model validation process for individual component modeling can, to some extent, be automated (see for example [20]). Powerflow component models can generally be validated by direct measurement – for example, transmission line parameters (resistance, reactance, and capacitance) can be verified by using measured voltage, real power, and reactive powerflows from each end of the line. Of course, the accuracy and precision of such measurements is limited. Dynamics model parameters can be selected such that the simulated model response provides a best fit to a measured response according to a suitable error criterion.

For system wide model validation, automation is unlikely to be viable or practical. In such efforts, the focus should be on using engineering judgment and a thorough understanding of the system under study. An example of the use of disturbance monitoring to refine the entire power system model might be a scenario involving the loss of a large generator in the southern part of a system. In this case, one might see from recorded disturbance monitor data that powerflow over a major north-south inter-tie ends up being greater from the north to the south than what is predicted by simulations, providing a hint that perhaps the spinning reserve and primary governing response of units in the north are greater than actually modeled. Having initially identified a group of generating units that require modeling refinements, specific unit(s) with questionable models can be chosen by looking at a comparison of individual unit response to simulated individual unit response for the event. Of course, appropriate digital recordings of individual plant response must be available for the same event (e.g., as discussed in [20]). In this manner, a system model validation process thus helps to identify models that need to be refined. This iterative refinement process is shown by the dotted lines in Figure 4.1.

As illustrated in section 3, the process of simulating actual events may require dealing with several related issues, including:

- Component model selection
- Data management
- Equipment application issues
- Equipment malfunction issues
- Operations and generator dispatch issues

One should exercise caution when addressing these or similar issues during the validation process. The overall power system model may provide simulation results that match the event recordings. However, that does not mean this “validated” power system model is applicable if the system conditions change. Considerable informed judgment should be used when using such finely tuned models.

Recommendation – The Industry should make periodic model validation and benchmarking an integral part of off-line study model maintenance. The Planning Committee should assign the TIS or MVTF to produce a SAR for including this practice in the MOD standards.

Discussion – Modeling should be updated and validated every time there is a significant change to system topology; generators or their governor, exciters, power system stabilizers, etc.; or system equipment that include active controls that could affect system dynamics. Further, the industry should take advantage of any opportunity to validate powerflow and dynamics models against actual system performance during a variety of system conditions, particularly during system disturbances. The goal of that validation should not be to mimic just one response but rather to provide the best match of response to a number of system conditions.

5. Deficiencies in Present Practice

5. Deficiencies in Present Practice

The preceding sections have demonstrated the need for ongoing validation of the models that are used to operate and plan the power system. However, in practice, such validation is not done frequently, for many reasons. The major burden of transferring measured power system data from real-time operating systems to a study model has already been noted. There are other barriers to model validation as well – "hoarding" of data for various reasons, multiple data formats, and incompatible program versions.

5.1 Powerflow Model Construction

The construction of a powerflow model to represent power system conditions prior to a disturbance is a prerequisite for all system model validation cases. This need is present even for studies which do not require powerflow analysis. However, current procedures and data processing systems at utilities, reliability coordination centers, and other managers of real-time system data are not able to perform this task in a timely manner. In order to study the August 10, 1996 WECC oscillation and separation event, a full year was required to construct a powerflow model before any event replication simulations could be performed. Similarly, several months were needed to build a powerflow case for the August 14, 2003 blackout study, and the validity of the resulting case was questionable. The situation has not materially improved since these studies.

5.1.1 Transfer of Real-time Data

Conceptually, much of the task of building a model of powerflow conditions for a specific date and time is simply the transfer of archived real-time data from EMS systems to a separate powerflow model that is being validated. Many quantities, such as generator real power, line statuses, voltage setpoints, statuses of switched reactive devices, and transformer tap positions are direct inputs to the powerflow solution, and hence their values simply need to be taken directly from real-time measurements. At present, however, there are a number of obstacles to this transfer. The real-time EMS systems use power system models that differ considerably in detail and structure from the models used for off-line powerflow and dynamic stability analysis. Linkages between the different models are typically not maintained, and the different models often have incompatible data formats.

Power system models for real-time systems are typically much simpler than the corresponding representations for off-line powerflow and dynamics studies. The real-time system models represent many fewer buses and transmission lines, and individual units at generating plants are sometimes "lumped" into a single unit in the model. Real-time system models, however, usually use a “node-breaker” model for each substation, in which the configuration of the individual breakers is explicitly recognized. Off-line study models normally use a “bus-branch” representation, in which common-voltage elements of an entire substation are modeled as a single bus. Such a model will not inherently recognize three-terminal lines or the splitting of buses that can occur as a result of contingencies. Transferring breaker status information from a real-time node-breaker model to an off-line bus-branch model requires a topology processing step to ensure that any split buses or three-terminal lines are properly recognized and represented in the off-line study model.

Bus branch model to node-breaker conversions require creation and maintenance of a mapping of each station into its constituent elements. However, the converse mapping is merely a reduction of zero-impedance elements into the resultant buses. Therefore, use of a node-breaker model is more advantageous to maintain and keep linked to the system topology used in the EMS.

Some of the quantities in the powerflow model cannot be measured directly and need to be estimated. Real and reactive loads are a prime example. A state estimator is the primary tool for estimating these values; however, as noted above, the state estimator uses a system model that is considerably different (usually much simpler) than the powerflow models which are employed for system studies. Developing a method to transfer state estimator data into a study model may be quite complex and require prorating aggregate loads from the state estimator model across a large number of loads in the study model.

Not all of the measured data are direct inputs into the powerflow solution. Some sets of data, such as generator reactive output and generator terminal voltage, are measured separately, but are in fact dependent on each other in the powerflow solution. Station voltages are also generally dependent on the other powerflow data. For such dependent quantities, it is necessary to use one as a powerflow solution input and verify that the solution matches the other. A weighted least squares error solution, such as calculated by a state estimator, may be needed for the study model solution.

When compiling an interconnection-wide powerflow model, real-time data from different control areas needs to be merged into a single system model. EMS systems often capture data at different sample rates (e.g., three-second, five-second, etc.) than neighboring areas, thus measured flows between systems can yield quite different results simply because of the time that the data was acquired. This makes it very difficult to create an off-line powerflow model for a precise instant in time.

Recommendation – The Industry should validate operational planning (offline) models by comparing them with models developed from real-time data. This will require improvements and standardization of the process for developing powerflow models from real-time data. The Planning Committee should assign the MVTF to develop guidelines for creating powerflow models and compatible dynamics cases from real-time systems.

a. The Industry should proceed to move toward a "node-breaker" model for all powerflow and dynamics cases and analyses.

b. Individual system equipment (transmission lines, breakers, generators, SVCs, etc.) must be universally identifiable between the EMS, state estimators, powerflow cases, and dynamics data sets to ensure proper "mapping" between the various programs and computing platforms.

Discussion – Both powerflow models and dynamics models should be periodically benchmarked against actual system conditions. To do so, the powerflow model must first be adjusted to mimic the measured system conditions. That process requires accounting for system topology conditions, including open breakers, abnormal switching configurations, etc. That often requires re-modeling stations into node-breaker topology from the normal powerflow bus-line configuration. That process is often manpower intensive (much of this is still done manually), prone to errors, and very time consuming.

Moving to a node-breaker representation of stations would eliminate that step, only requiring the collapsing of the station into bus-line configuration 'under the hood' of the powerflow program to reduce the number of zero-impedance branches. It is understood that as part of that changeover, there is a need to have a method for universally identifying individual pieces of equipment for ease of using their unique properties and characteristics between programs, applications, and computing platforms.

Further, in order for the powerflow to be used as the starting point for dynamics verifications, experience shows that the powerflow base case must be reasonably close to the actual system conditions in order to properly match the dynamics simulation results to actual system dynamic performance. Although some current EMS and state estimators are capable of outputting a powerflow model, the bus names, bus numbers, and equipment designations are not compatible with commonly-used dynamics data sets.

5.1.2 Discrepancies with Measured Data

Even after the task of transferring real-time data into a powerflow study model is completed, additional pitfalls remain. As noted above, not all power system quantities that can be measured are independent of each other. For various reasons, the powerflow solution may result in large errors between measured values and the powerflow model values of dependent quantities, such as system voltages. One source is the presence of error in the measurements themselves. Another possibility is the presence of errors in the parameters of the study model, such as line resistance and reactance. Naturally, poor estimates of these values will result in a poor match between the study model solution and actual system conditions. Poor estimates of load power factor in the model are a common source of such discrepancies.

5.1.3 Software Version Issues

Another closely related issue is the continuous change of software versions that are released and supported by software vendors. New software versions have too often been found to be “bug-infested” and unreliable. New program versions also often introduce dialogue, data file format, and other program interface changes that are extremely time-consuming for experienced users. Many users have developed a library of auxiliary tools and files to work with the program. When a new program version is installed, these auxiliary tools are rendered inoperative and a month or more of work is often required to make them usable again. These sorts of ongoing changes to the analysis software wreak havoc with efforts to translate data from EMS and data archive systems.

Recommendation – The Planning Committee should act to promote the standardization of functional requirements for powerflow and dynamics programs, including data exchange formats, by assigning the TIS or MVTF to take the lead on this effort.

Discussion – While addition of new models to program libraries is always encouraged, the addition of features requested by a few users should not impose a hardship on the remainder of the user community. A working group is needed to develop industry consensus on the program features and associated file formats that should be included in software whose input depends on the exchange of data between different companies in the industry. This should be a collaborative effort with the IEEE Power and Energy Society (PES).

5.2 Institutional Issues

Besides the technological challenges to system model validation, there are several institutional issues that impede such efforts as well. These factors are discussed below:

5.2.1 Data Sharing and Security Issues

Data required for disturbance analysis or model validation is owned by many different entities with real or perceived confidentiality and commercial interest. There are legal and procedural issues that make it difficult to gather and distribute essential data among stakeholders. Some of these issues are related to FERC CEII (critical energy infrastructure information) requirements. Others are related to misunderstandings regarding and inconsistencies in procedures that organizations use to comply with CEII requirements. In many instances, it is not even known what data is available. There is skepticism about the validity of many of the reasons for the lack of data sharing.

When electrical power engineers can freely share powerflow data, dynamics data, synchronous phasor measurement data, and state estimator data, they can collaborate to understand system issues and develop solutions to problems. When engineers cannot obtain the necessary data, or have unreasonable barriers placed upon obtaining or discussing the necessary data, progress is blocked. Barriers should be minimal on sharing data between long-term stakeholder collaborators. NERC standards are attempting to address many of these issues for disturbance records.

Recommendation – The Planning Committee should act to resolve issues that impede the free flow of information for model validation to parties responsible for planning and operating the interconnected power system by assigning the MVTF to take the lead in this effort.

Discussion – If existing agreements are inadequate to cover the data confidentiality issues, then new agreements need to be worked out among all of the entities involved – utilities, generator owners, NERC, etc. In particular, the Industry should review how generators are treated during the interconnection process and ensure that future data can be used in the modeling of the Bulk Electrical System. Existing generator data is also needed. Data sharing, security, and proprietary issues are separate yet related issues. They all address an underlying problem: availability of needed model data to parties who need the information to build an accurate system wide model. These are complex issues affecting many stakeholders.

5.2.2 Proprietary Information Issues

Many generator manufacturers, notably wind turbine manufacturers, wish to keep dynamics models of their equipment confidential. As most areas are experiencing a surge in wind penetration, obtaining accurate dynamics model data for wind farms is becoming increasingly difficult if not impossible.

The generator owners provide accurate model data of their systems during the generator interconnection process. This information is critical as it ensures that their power generating systems can be safely incorporated into the electric grid. However, many of these accurate model datasets which are submitted for use in the generator interconnection process cannot be used for any other modeling endeavors due to non-disclosure agreements or pro forma tariff language concerning use of “confidential information.” These generator owners claim that industry sensitive data is contained in their datasets and therefore cannot be divulged to anyone outside the interconnecting utility, i.e., Transmission Owner or interconnection-wide powerflow and dynamic models.

Recommendation – The NERC MOD standards on powerflow and dynamics data (MOD-010 through MOD-015) should be improved and strengthened. The Planning Committee should assign the TIS or MVTF to develop a list of suggested improvements for a Standards Authorization Request (SAR).

Discussion – The current standards lack specificity in many areas. In particular, if a new device cannot be modeled, it should not be interconnected. All devices and equipment attached to the electric grid must be modeled to accurately capture how that equipment performs under static and dynamic conditions. Models provided for equipment must be universally usable and shareable across the interconnection to allow for analysis of performance interaction with other equipment. Such models cannot be considered proprietary.

5.2.3 Preservation of Measured Data

Measured data from digital fault recorders and dynamic disturbance recorders are required for the analysis of system disturbances. Precise sequence of events data is needed as well. Such event data includes records of automatic protection and control actions as well as manual interventions. For a wide area system model validation or disturbance analysis, the various data listed above has different ownership and retention periods. Installed data recorders capture large amounts of data, but not all data captured is significant or needs to be analyzed. By the time an investigating party decides to request the data, the data may not be available due to limited retention periods, even if all the entities owning the data plan to cooperate.

Recommendation – Requirements and procedures should be included in the standards for retention of power system powerflow and dynamics data following a system event.

Discussion – The requirements should include specifications for type of data and length of time for retention. These procedures should also address the capture of adequate pre-event data, including specifications for data quality and the pre-event time interval. Several NERC standards are attempting to specify adequate retention periods.

5.2.4 Data Synchronization

In the past, power system event recordings either were not time stamped or were stamped with a local clock time. Reconstructing events with certainty from multiple recorders with different time stamp references can be a difficult to nearly impossible task. The availability of GPS technology makes possible a consistent time stamp for all recorders, thus facilitating event reconstruction. Some utilities have begun using this technology, but application is not universal. In particular, many of the data needed to establish pre-disturbance steady-state conditions, such as SCADA system data, have much poorer time synchronization and resolution. NERC standard writing efforts to address these issues are currently underway.

Recommendation – The Planning Committee should act to foster improved time synchronization and time stamping for DMEs, EMS, and SCADA data by assigning the MVTF to support the standards development efforts.

5.2.5 Data Format Issues

Data needed for disturbance analysis or model validation comes in a wide variety of formats, adding impediments to the analysis process. Most disturbance data recording requirements in NERC standards require the data to be in the IEEE COMTRADE standard format (IEEE Standard C37.111, 1999). Unfortunately, some unapproved (1991 & 2003) and non-conforming, versions of the COMTRADE format are in use, often making the use of the data from those sources challenging. Data available from EMS systems is often in formats that are different than those used in planning models, which makes the establishment of base conditions in a study model extremely difficult. In addition, models for each control area have varying amounts of detail, and some models of neighboring areas overlap, creating potential problems of disentanglement and inconsistent data.

5.2.6 Personnel Resources

Many organizations may not have a sufficient number of trained personnel with available time to perform these activities. This personnel shortage and the aging of the current knowledgeable workforce have often been cited as a growing problem in the NERC Long-Term Reliability Assessments.

Recommendation – The Planning Committee should act to develop training for implementing the more vigorous model validation processes described in this paper by assigning the effort to the MVTF.

Discussion – The initial implementation activities could occur at about the time reputable organizations such as IEEE are projecting large numbers of the experienced electrical industry work force will be retiring, thus further challenging all organization levels to maintain adequate staffing. Policy makers and organizations performing model validation should give careful consideration to these staffing issues. Many of the activities associated with model validation require training, experience, and skill – qualities which take time to develop.

5.3 Tools for Comparing Models to Measurements

Post-disturbance simulations of events often differ from measurements, and there are few tools to understand the sources of the modeling mismatch and guide the adjustment of simulation parameters to better match observations. Analyses of events are typically treated as custom studies, and much initial work is needed to develop or modify a base model to match pre-event conditions. Then model parameters are manually varied using engineering judgment to align simulations and measurements. It is a laborious and inefficient process and may not achieve a satisfactory match.

Sensitivity models are needed to describe the relation between model parameters and resulting simulations. These sensitivities improve the understanding of the model, and they can be used to guide model adjustments. Parameter estimation is facilitated by the use of explicit sensitivity models, knowledge of model parameters, and confidence in knowing reasonable bounds on parameters values. Such explicit parameter sensitivity models are not currently available in common power system simulation packages. In practice sensitivities are discovered, inefficiently, by repeated simulations conducted manually.

Tools to guide model parameter estimation should include:

- Feature specification – An engineer needs to be able to identify important features to match in the response, including oscillatory characteristics (magnitude, phase, frequency, damping), and extremes of response (min/max excursions in voltage, frequency, power, etc.).
- Sensitivity model – automatic calculation of sensitivities relating parameter values to the specified features.
- Parameter estimation – compute new parameter values using the sensitivity model, contained within model parameter bounds, and weighted by confidence.

This process of parameter estimation requires engineer guidance, but the computations for any particular event could be automated in software.

The use of such tools should lead to the identification of key measurements that are most useful for tuning parameters within a particular region. Then model validation and parameter estimation can be performed efficiently whenever a new event occurs.

Recommendation – The Planning Committee should act to promote the development and use of model validation tools by assigning the effort to the MVTF.

Discussion – Tools need to be developed to assist in validating models (e.g., feature specification, model parameter sensitivity, and model parameter estimation, with screening of data for appropriate values).

5.4 Solution Algorithm Issues

In some cases, a solution algorithm may fail to converge for system conditions that were observed in real-time measurements, hampering model validation. A robust solution algorithm is essential to development of efficient processes to create new powerflow cases. When engineers compile a powerflow case to represent a future system, and also when they compile a powerflow case to represent the system during past disturbances, they need to be able to readily identify issues that keep the powerflow case from solving, and they need robust solutions that efficiently arrive at the solution when a solution exists.

Steady-state powerflow analysis is performed on a routine basis by system planners for reliability assessment. In addition, engineers routinely build powerflow cases of future year scenarios to plan system additions for future years, or build cases to study past disturbances. There are differences in the numerical performance and convergence properties of powerflow algorithms among the various vendors of power system simulation software in the industry - some perform better than others.

Recommendation – The Planning Committee should work with the IEEE PES to promote the development of more efficient and robust powerflow solution algorithms to improve the speed of calculations and improve the reliability of solution convergence for contingency analyses.

6. Conclusions and Recommendations

6. Conclusions and Recommendations

The following is a summary of the recommendations of this paper in the order they appear.

1. The Industry should make periodic model validation and benchmarking an integral part of off-line study model maintenance. The Planning Committee should assign the TIS or MVTF to produce a SAR for including this practice in the MOD standards.
2. The Industry should validate operational planning (offline) models by comparing them with models developed from real-time data. This will require improvements and standardization of the process for developing powerflow models from real-time data. The Planning Committee should assign the MVTF to develop guidelines for creating powerflow models and compatible dynamics cases from real-time systems.
    a. The Industry should proceed to move toward a "node-breaker" model for all powerflow and dynamics cases and analyses.
    b. Individual system equipment (transmission lines, breakers, generators, SVCs, etc.) must be universally identifiable between the EMS, state estimators, powerflow cases, and dynamics data sets to ensure proper "mapping" between the various programs and computing platforms.
3. The Planning Committee should act to promote the standardization of functional requirements for powerflow and dynamics programs, including data exchange formats, by assigning the TIS or MVTF to take the lead on this effort.
4. The Planning Committee should act to resolve issues that impede the free flow of information for model validation to parties responsible for planning and operating the interconnected power system by assigning the MVTF to take the lead in this effort.
5. The NERC MOD standards on powerflow and dynamics data (MOD-010 through MOD-015) should be improved and strengthened. The Planning Committee should assign the TIS or MVTF to develop a list of suggested improvements for a Standards Authorization Request (SAR).
6. Requirements and procedures should be included in the standards for retention of power system powerflow and dynamics data following a system event.
7. The Planning Committee should act to foster improved time synchronization and time stamping for DMEs, EMS, and SCADA data by assigning the MVTF to support the standards development efforts.

8. The Planning Committee should act to develop training for implementing the more vigorous model validation processes described in this paper by assigning the effort to the MVTF.
9. The Planning Committee should act to promote the development and use of model validation tools by assigning the effort to the MVTF.
10. The Planning Committee should work with the IEEE PES to promote the development of more efficient and robust powerflow solution algorithms to improve the speed of calculations and improve the reliability of solution convergence for contingency analyses.

Appendix A — References

[1] D. N. Kosterev, C. W. Taylor, W. A. Mittelstadt, “Model Validation for the August 10, 1996 WSCC System Outage,” IEEE Transactions on Power Systems, vol. 14, no. 3, pp. 967-979, August 1999

[2] John Undrill, Les Pereira, Dmitry Kosterev, Shawn Patterson, Donald Davies, Robert Cummings, Baj Agrawal, Steve Yang, “Generator Model Validation in WECC,” presented at 2009 Power Engineering General Meeting, Calgary, AB, July 2009.

[3] R. H. Bunch, D. N. Kosterev, “Design and Implementation of AC Voltage Dependent Current Order Limiter at Pacific HVDC Intertie,” IEEE Transactions on Power Delivery, vol. 15, no. 1, pp. 293-299, January 2000.

[4] Les Pereira, Dmitry Kosterev, Peter Mackin, Donald Davies, John Undrill, Wenchun Zhu, “An Interim Dynamic Induction Motor Model for Stability Studies in WSCC,” IEEE Transactions on Power Systems, vol. 17, no. 4, pp. 1108-1115, 2002.

[5] Les Pereira, John Undrill, Dmitry Kosterev, Donald Davies and Shawn Patterson, “A New Thermal Governor Modeling in WECC,” IEEE Transactions on Power Systems, vol. 18, no. 2, pp. 819-829, May 2003.

[6] Baj Agrawal, Dmitry Kosterev, “Model Validation for a Disturbance Event that Occurred on June 14 2004 in the Western Interconnection,” presented at 2007 Power Engineering General Meeting, Tampa, FL, June 2008.

[7] Bradley Williams, Wayne Schmus, Douglas Dawson, “Transmission Voltage Recovery Delayed by Stalled Air Conditioner Compressors,” IEEE Transactions on Power Systems, vol. 7, no. 3, pp. 1173-1181, August 1992.

[8] John Shaffer, “Air Conditioner Response to Transmission Faults”, IEEE Transactions on Power Systems, vol. 12, no. 2, May 1997, pp. 614-621.

[9] Garry Chinn, “Modeling Stalled Induction Motors,” presented at the IEEE Transmission and Distribution Conference, Dallas TX, May 2006.

[10] NERC Transmission Issues Subcommittee, White Paper on Fault-Induced Delayed Voltage Recovery, June 2009.

[11] P. Pourbeik and B. Agrawal, “Hybrid Model for Representing Air-Conditioner Compressor Motor Behavior in Power System Studies,” Proceedings of the IEEE PES General Meeting, to be published, July 2008.

[12] Dmitry Kosterev, Anatoliy Meklin , John Undrill, Bernard Lesieutre, William Price, David Chassin, Richard Bravo, Steve Yang, “Load Modeling in Power System Studies: WECC Progress Update”, presented at 2008 Power Engineering General Meeting, Pittsburgh, PA, July 2008.

[13] P. Pourbeik, P. S. Kundur and C. W. Taylor, “The Anatomy of a Power Grid Blackout,” IEEE Power & Energy Magazine, September/October 2006, pp. 22-29.

[14] CIGRE Technical Brochure on Review of the Current Status of Tools and Techniques for Risk-Based and Probabilistic Planning in Power Systems, March 2010, Prepared by CIGRE WG C4.601 (to be published at www.e-igre.org).

[15] WSCC Control Work Group and Modeling & Validation Work Group, “Test Guidelines for Synchronous Unit Dynamic Testing and Model Validation,” February 1997. (www.wecc.biz)

[16] IEEE Task Force on Generator Model Validation Testing, “Guidelines for Generator Stability Model Validation Testing,” Proceedings of the IEEE PES General Meeting, Tampa, FL, June 2007.

[17] L. N. Hannett and J. W. Feltes, “Derivation of Generator, Excitation System and Turbine Governor Parameters from Tests,” presented at the CIGRÉ Colloquium on Power System Dynamic Performance, Florianópolis, Brazil, 1993.

[18] L. M. Hajagos and G. R. Berube, “Utility Experience with Gas Turbine Testing and Modeling,” Proceedings of the IEEE PES Winter Power Meeting, January 2001.

[19] P. Pourbeik and F. Modau, “Model Development and Field Testing of a Heavy-Duty Gas-Turbine Generator,” IEEE Trans. PWRS, May, 2008.

[20] P. Pourbeik, “Automated Parameter Derivation for Power Plant Models From System Disturbance Data,” Proceedings of the IEEE PES General Meeting, Calgary, Canada, July 2009.

[21] P. Pourbeik, A. P. Bostrom, E. John, and M. Basu, “Operational Experience with SVCs for Local and Remote Disturbances”, Proceedings of the IEEE Power Systems Conference and Exposition, Atlanta, GA, October 29th -November 1st, 2006.

[22] D. Kosterev, A. Meklin, J. Undrill, B. Lesieutre, W. Price, D. Chassin, R. Bravo, and S. Yang, “Load modeling in power system studies: WECC progress update” Proceedings of the IEEE PES General Meeting, Pittsburg, July 2008.

[23] A. M. Gaikwad, R. J. Bravo, D. Kosterev, S. Yang, A. Maitra, P. Pourbeik, B. Agrawal, R. Yinger, and D. Brooks, “Results of Residential Air Conditioner Testing in WECC,” Proceedings of the IEEE PES General Meeting, Pittsburg, July 2008.

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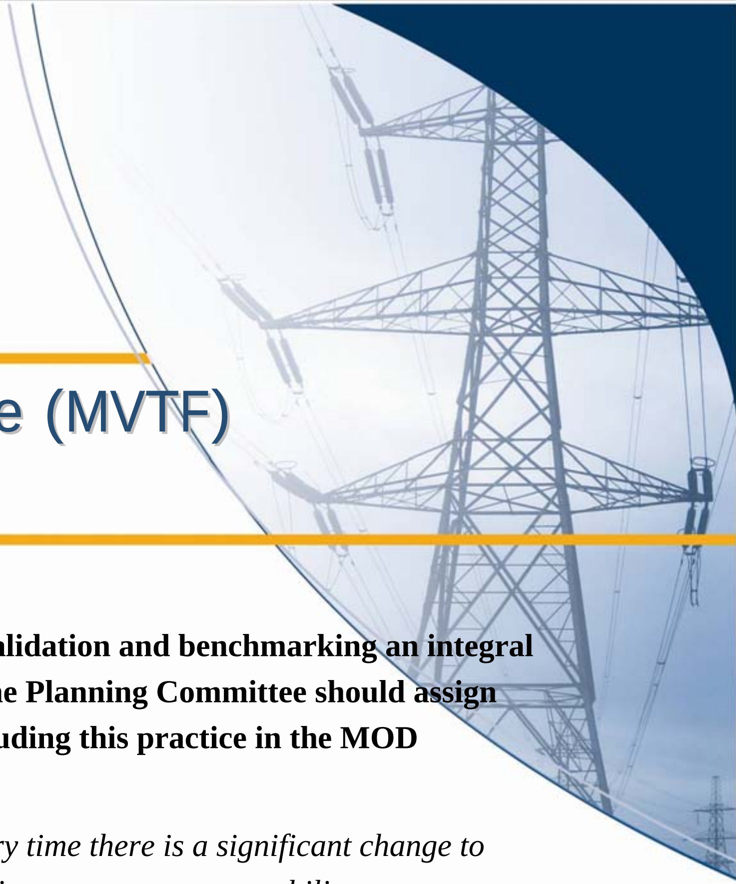
Appendix C — MVTF Work Plan

NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION



Model Validation Task Force (MVTF) Work Plan

1. **The Industry should make periodic model validation and benchmarking an integral part of off-line study model maintenance. The Planning Committee should assign the TIS or MVTF to produce a SAR for including this practice in the MOD standards.**

Modeling should be updated and validated every time there is a significant change to system topology; generators or their governor, exciters, power system stabilizers, etc.; or system equipment that include active controls that could affect system dynamics. Further, the industry should take advantage of any opportunity to validate powerflow and dynamics models against actual system performance during a variety of system conditions, particularly during system disturbances. The goal of that validation should not be to mimic just one response but rather to provide the best match of response to a number of system conditions.

1.1 The MVTF should write a procedure for validation of the power system powerflow case.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: High

The procedure should describe the specific measurements that will be validated in the powerflow model and the data that will be used for the validation. The procedure should also suggest corrective adjustments to be made to the case, if necessary. A trial of the procedure should be performed.

1.2 The MVTF should write a procedure for validation of the power system dynamics model.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: High

The procedure should describe the specific measurements that will be validated in the dynamics model and the data that will be used for the validation. The procedure should also suggest corrective adjustments to be made to the dynamics model, if necessary. A trial of the procedure should be performed.

1.3 The MVTF should post the procedures developed in Task 1.1 and Task 1.2 for industry comment.

MVTF	Start Date: 2nd Qtr. 2011	End Date: 2nd Qtr. 2011

Priority: High

1.4 The MVTF should prepare a SAR for standards action, if appropriate.

MVTF	Start Date: 2nd Qtr. 2011	End Date: 2nd Qtr. 2011

Priority: High

2. **The Industry should validate operational planning (offline) models by comparing them with models developed from real-time data. This will require improvements and standardization of the process for developing powerflow models from real-time data. The Planning Committee should assign the MVTF to develop guidelines for creating powerflow models and compatible dynamics cases from real-time systems.**
    a. **The Industry should proceed to move toward a "node-breaker" model for all powerflow and dynamics cases and analyses.**
    b. **Individual system equipment (transmission lines, breakers, generators, SVCs, etc.) must be universally identifiable between the EMS, state estimators, powerflow cases, and dynamics data sets to ensure proper "mapping" between the various programs and computing platforms.**

Both powerflow models and dynamics models should be periodically benchmarked against actual system conditions. To do so, the powerflow model must first be adjusted to mimic the measured system conditions. That process requires accounting for system topology conditions, including open breakers, abnormal switching configurations, etc. That often requires re-modeling stations into node-breaker topology from the normal powerflow bus-line configuration. That process is often manpower intensive (much of this is still done manually), prone to errors, and very time consuming.

Moving to a node-breaker representation of stations would eliminate that step, only requiring the collapsing of the station into bus-line configuration 'under the hood' of the powerflow program to reduce the number of zero-impedance branches. It is understood that as part of that changeover, there is a need to have a method for universally identifying individual pieces of equipment for ease of using their unique properties and characteristics between programs, applications, and computing platforms.

Further, in order for the powerflow to be used as the starting point for dynamics verifications, experience shows that the powerflow base case must be reasonably close to the actual system conditions in order to properly match the dynamics simulation results to actual system dynamic performance. Although some current EMS and state estimators are capable of outputting a powerflow model, the bus names, bus numbers, and equipment designations are not compatible with commonly-used dynamics data sets.

2.1 The MVTF should write a procedure for assembling a powerflow and dynamics model that reflects conditions at a specific time in the recent past.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: High

The procedure should describe the data items that will be incorporated into the model and how they will be incorporated.

2.2 The MVTF should draft a proposal for the Industry to institute node-breaker models in all off-line study models.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: Medium

The MVTF should convene a symposium of powerflow, dynamics, and EMS vendors to set goals and timeframe for development of node-breaker planning powerflow and dynamics models. Topology processors may act as a front-end for these programs. The MVTF should also convene an industry symposium on node-breaker modeling and how it will help them meet the proposed TPL standard requirements for analysis.

2.3 The MVTF should propose rule sets for node and element naming and labeling conventions.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: Medium

Program vendors should be included in the development of the conventions. These rule sets should be posted for industry comment. If appropriate, IEEE and/or CIGRE should be engaged to develop naming conventions for facilitating data transfer.

3. **The Planning Committee should act to promote the standardization of functional requirements for powerflow and dynamics programs, including data exchange formats, by assigning the TIS or MVTF to take the lead on this effort.**

   While addition of new models to program libraries is always encouraged, the addition of features requested by a few users should not impose a hardship on the remainder of the user community. A working group is needed to develop industry consensus on the program features and associated file formats that should be included in software whose input depends on the exchange of data between different companies in the industry. This should be a collaborative effort with the IEEE Power and Energy Society (PES).

3.1 The MVTF should write a proposal for use of standard model components in all powerflow and dynamics models.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: High

The proposal should include provision for addition of new models to the standard model list and treatment of unique or unusual facilities.

3.2 The MVTF should draft a proposal for adopting a common data format (maybe CIM) for data transfer between EMS systems and planning models regardless of program vendor.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: Medium

The Industry should move toward a standardized data transfer format for all powerflow and dynamics models.

3.3 The MVTF should work with IEEE and other similar organizations to codify that format as the world standard for data transfer.

MVTF	Start Date: 4th Qtr. 2011	End Date: 3rd Qtr. 2013

Priority: Medium

4. **The Planning Committee should act to resolve issues that impede the free flow of information for model validation to parties responsible for planning and operating the interconnected power system by assigning the MVTF to take the lead in this effort.**

   If existing agreements are inadequate to cover the data confidentiality issues, then new agreements need to be worked out among all of the entities involved – utilities, generator owners, NERC, etc. In particular, the Industry should review how generators are treated during the interconnection process and ensure that future data can be used in the modeling of the Bulk Electrical System. Existing generator data is also needed. Data sharing, security, and proprietary issues are separate yet related issues. They all address an underlying problem: availability of needed model data to parties who need the information to build an accurate system wide model. These are complex issues affecting many stakeholders.

4.1 The MVTF should develop a list of specific problems that are impeding the free flow of model information and recommend corrective actions.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: High

5. **The NERC MOD standards on powerflow and dynamics data (MOD-010 through MOD-015) should be improved and strengthened. The Planning Committee should assign the TIS or MVTF to develop a list of suggested improvements for a Standards Authorization Request (SAR).**

The current standards lack specificity in many areas. In particular, if a new device cannot be modeled, it should not be interconnected. All devices and equipment attached to the electric grid must be modeled to accurately capture how that equipment performs under static and dynamic conditions. Models provided for equipment must be universally usable and shareable across the interconnection to allow for analysis of performance interaction with other equipment. Such models cannot be considered proprietary.

5.1 The Planning Committee should assign the TIS or MVTF to develop a list of suggested improvements for a Standards Authorization Request (SAR).

TIS	Start Date: 3rd Qtr. 2010	End Date: 3rd Qtr. 2010

Priority: High

This recommended action was approved by Planning Committee 6/16/10, and the task will proceed consistent with the standards development plan.

- TIS is drafting a SAR for updating and strengthening standards MOD-010 through MOD-015 incorporating the recommendations of the MVTF white paper, the DCS report, and the IVGTF report.
- The draft SAR will be presented to the PC at their September 2010 meeting.
- The PC approved SAR will be presented to the Standards Committee for inclusion in their work plan.

6. **Requirements and procedures should be included in the standards for retention of power system powerflow and dynamics data following a system event.**

   The requirements should include specifications for type of data and length of time for retention. These procedures should also address the capture of adequate pre-event data, including specifications for data quality and the pre-event time interval. Several NERC standards are attempting to specify adequate retention periods.

6.1 The MVTF should review the requirements for data retention in the standards and Rules of Procedure, and, if appropriate, propose specific language for modifications and/or recommend a SAR for improving those requirements.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: Medium

- This may be better handled through a change to Appendix 8 of the Rules of Procedure.
- The MVTF should proposed specific language for modifications to Appendix 8 of the ROP to be consistent with enabling appropriate forensic analysis of power system events and to enable validation of dynamics and powerflow system models to actual system events. Those proposed changes will follow the procedure for changes to the ROP.

7. **The Planning Committee should act to foster improved time synchronization and time stamping for DMEs, EMS, and SCADA data by assigning the MVTF to support the standards development efforts.**

   Accurate synchronization of recorded power system data is essential for event analysis and model validation.

7.1 The MVTF should work with the DME standards drafting team to codify synchronization and time stamping requirements for DMEs.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2011

Priority: Medium

7.2 The MVTF should draft a proposal for synchronization and time stamping of EMS/SCADA data for discussions with IEEE, CIGRE, etc.

MVTF	Start Date: 4th Qtr. 2010	End Date: 3rd Qtr. 2012

Priority: Medium

The proposal should incorporate time stamping done for CIP.

8. **The Planning Committee should act to develop training for implementing the more vigorous model validation processes described in this paper by assigning the effort to the MVTF.**

   The initial implementation activities could occur at about the time reputable organizations such as IEEE are projecting large numbers of the experienced electrical industry work force will be retiring, thus further challenging all organization levels to maintain adequate staffing. Policy makers and organizations performing model validation should give careful consideration to these staffing issues. Many of the activities associated with model validation require training, experience, and skill – qualities which take time to develop.

8.1 The MVTF should develop and maintain training materials for industry on model validation methods and techniques.

MVTF	Start Date: 2nd Qtr. 2011	End Date: 3rd Qtr. 2012

Priority: Medium

8.2 The MVTF should hold a series of ongoing workshops for hands-on validation training.

MVTF	Start Date: 3rd Qtr. 2012	End Date: 3rd Qtr. 2012?

Priority: Medium

9. **The Planning Committee should act to promote the development and use of model validation tools by assigning the effort to the MVTF.**

   Tools need to be developed to assist in validating models (e.g., feature specification, model parameter sensitivity, and model parameter estimation, with screening of data for appropriate values).

   This recommendation will also be addressed by task 8.1.

10. **The Planning Committee should work with the IEEE PES to promote the development of more efficient and robust powerflow solution algorithms to improve the speed of calculations and improve the reliability of solution convergence for contingency analyses.**

In some cases, a solution algorithm may fail to converge for system conditions that were observed in real-time measurements, hampering model validation. A robust solution algorithm is essential to development of efficient processes to create new powerflow cases. There are differences in the numerical performance and convergence properties of powerflow algorithms among the various vendors of power system simulation software in the industry -some perform better than others.

10.1 The MVTF should investigate developments in more efficient and robust powerflow solution algorithms taking place in IEEE and CIGRE.

MVTF	Start Date: 4th Qtr. 2010	End Date: 4th Qtr. 2015

Priority: Low

The MVTF should search IEEE and CIGRE materials and enjoin any active groups.

Resources needed:

This work plan is based on an MVTF membership of 40-50 people with each person devoting 10% of their available time over the first twelve months.