

PJM Sub-Transmission Modeling Position Paper

Final Draft

DRAFT

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Executive Summary

Introduction

PJM modeling guidelines and principles are designed to support the NERC Bulk Electric System (BES) definition and the associated corollary recommendations on Facilities under 100 kV¹. This white paper clarifies PJM policy for including sub-transmission facilities in the EMS model (less than 100 kV).

Recent NERC² and PJM³ reports, which made similar recommendations concerning low voltage facilities, initiated a review of sub-transmission facility modeling at PJM. The discussion section of this paper details PJM's approach to mitigating the issues identified regarding sub-transmission modeling including the need to work closely with PJM TOs. Upon request, there is additional reference material related to these reports. Modeling decisions are subject to PJM model management department (MMD) staff approval, based on known criteria, historic decision trends, and future direction considerations.

Modeling considerations

Using telemetered information provides periodic breaker/switch status updates, creating a dynamic model to derive current topology. An accurate 'picture' of current loading throughout the system is then developed using State Estimation (SE) algorithms predicated upon the system topology and telemetered generation, line and transformer flows. Since incorrect or incomplete breaker/switch status and/or inaccurate or insufficient flow information can compromise the SE solution, it is very important for Transmission Owners (TOs) to provide appropriate status and loading information for processing. To maintain a secure system, State Estimator results are provided to the Security Analysis (SA) algorithms to simulate thousands of contingencies. Any security violations identified from the simulations - thermal or voltage - are displayed to dispatchers. Dispatchers are then responsible for implementing corrective strategies, as required, to ensure reliable and economic operation.

The analytical tools used for the simulations are expected to produce results for the SE and SA every minute of the day. Maintaining this requires a robust and well-tuned model. In addition, since increasing the size of the model can lend toward lengthening the time to solve each of the simulations. PJM staff members will model BES facilities and apply engineering judgment to model the non-BES facilities appropriately. For a thorough discussion of the engineering judgments used, see Manual 03A. Principally, engineering judgment is used to maintain high performance and throughput of the SE and SA solutions. PJM models are intentionally kept to the minimum size possible to achieve acceptable solution results (SE & SA). The solution must be achieved quickly and reliably (good numerical stability over varying operating conditions) to provide operators with high-quality, near real-time information. Representatives for each TO staff shall provide analysis and justification of all requested sub-transmission facilities and coordinate modifications of BES with PJM MMD staff.

PJM models and monitors the impact of all PJM member facilities designated as part of BES, including sub-transmission elements of the system. PJM incorporates detailed models of non-BES, sub-transmission facilities which have a significant impact on flows and voltages on BES facilities. TO staff is expected to identify sub transmission facilities that affect BES in a significant manner resulting in coordination with PJM staff to determine if additional modeling is required. Examples of the types of sub-transmission facility models included in the PJM EMS model are cited in this paper. PJM staff members work with TO representatives to ensure that appropriate modeling techniques are employed to produce accurate SE and SA results.

¹ BES Policy on Sub-Transmission (under 100 kV) Facilities White Paper. (<http://www.nerc.com/pa/RAPA/Pages/BES.aspx>)

² NERC report Arizona-Southern California Outages on September 8, 2011 (recommendations 3, 6, 9, 27).
<http://www.nerc.com/pa/rm/ea/Pages/September-2011-Southwest-Blackout-Event.aspx>

³ PJM report on Technical analysis of Operational events and Market Impacts during the September 2013 Heat Wave. (<http://www.pjm.com/~media/documents/reports/20131223-technical-analysis-of-operational-events-and-market-impacts-during-the-september-2013-heat-wave.ashx>)

Summary of proposed sub-transmission modeling policy

1. BES sub-transmission facilities
 - a. Adapt PJM's current processes and procedures for modeling of BES elements to align with the current NERC BES definition and corollary recommendations on modeling lower voltage elements of the system.³
 - b. Prepare initial BES data to denote BES elements of the system
 - i. PJM to modify Tariff Facility 'form' adding flag to indicate that an element is part of the BES.
 - ii. TOs perform an initial review of existing systems to assess what is to be included or excluded to the current list of BES elements and provide necessary documentation to NERC.
 - iii. TOs review existing systems to identify areas of existing systems operated between 50 and 100 kV. Facilities under 50 KV are deemed to not warrant modeling⁴.
 - iv. If facilities between 50 kV and 100 kV are 'networked', providing alternate flow paths to higher voltage equipment, TOs are to provide modeling details to PJM for joint assessment to determine if the system should be in the PJM EMS model. Assessment includes analysis provided by TO staff.
 - v. TOs provide data to populate the 'BES flag' as an extension of the annual process to update the Tariff Facilities posted on the PJM web site (<http://www.pjm.com/markets-and-operations/transmission-service/transmission-facilities.aspx>).
 - vi. PJM will integrate approved changes into appropriate manuals.
2. Ongoing maintenance
 - a. For facilities between 50 and 100 kV that provide alternate paths which absorb (divert) significant flow from (to) higher voltage equipment, when simulating outage conditions:
 - i. Consult with PJM to determine best course of action (outage may be deferred).
 - b. TO staff to provide modeling details and analysis to PJM if warranted (i.e. if critical for extended outages).
 - c. Modify RTEP and EMS Model Update data gathering requests so TO's can identify additions/deletions to the BES.
 - d. Incorporate audit of BES flag into annual PJM Tariff Facility Update process
 - e. TOs should identify SA contingency simulations impacted by automatic load transfer schemes and work with PJM representatives to re-allocate load if appropriate using recently developed features of the PJM EMS.
 - i. For non-BES facilities that are expected to impact on BES facilities (e.g., due to expected load shifts and load transfers, etc.) There are two options: 1) provide reallocation percentage values of loading and specifics for building contingencies; or, 2) provide detailed modeling information which includes voltage considerations.

⁴ NERC technical guide for low voltage facilities loop threshold,
<http://www.nerc.com/pa/RAPA/BES%20DL/BES%20Exception%20Evaluation%20Guideline%202-4-14%20REMG%20App.pdf>

Discussion of Sub-Transmission modeling issues

Operational events in the 2013/2014 timeframe within the PJM RTO, as well as, events within the North American electric utility industry, coupled with publication of the revised NERC Bulk Electric System (BES) definition formed the basis for a review of sub-transmission modeling practices at PJM. This white paper's objective is to clarify PJM modeling practices, process, roles and responsibilities, along with criteria for EMS modeling of sub-transmission facilities.

This discussion has four categories; 1) TO and PJM staff responsibilities; 2) Modeling concepts and methods; 3) Considerations for sub-transmission modeling; and, 4) Examples of EMS Sub-Transmission modeling.

Discussion of TO and PJM staff responsibilities

TO Staff responsibilities-to address revised BES definitions

NERC assigns each TO responsibility for evaluating what elements are included in the BES and notifying NERC of any exceptions. To ensure that BES and non-BES elements are modeled by PJM, TOs must also notify the Model Management Department (MMD) by e-Mailing the PJM distribution group: DMS.Officers@pjm.com.

The evaluation is an ongoing process starting in 2014 and is expected to be fully implemented by December 2015. TOs are expected to review their systems and identify BES elements per the NERC definition. It is anticipated that most, if not all, BES facilities have been previously identified. TOs should note that PJM requested information concerning BES elements as part of the annual Tariff Facility Update process which began July 25, 2014.

Once notified that additional sub-transmission facilities are to become part of the BES, PJM staff will review the request. To perform this evaluation TOs must provide a diagram of the area, complete modeling details (connectivity, breakers, switches, impedances, transformers details, load information, generation, shunt devices, etc.). PJM requires telemetered MW/MVAR pairs for line flows and either loads or transformers (may also require tap information) in addition to status points to support near real-time automatic evaluations of connectivity⁵. Consequently, TOs shall denote available telemetry for the elements to be modeled.

The information is to be provided via the eDART Network Model tools, similar to all other data submissions for the EMS model for review by the designated PJM MMD staff member. The data should also be provided through routine mechanisms to PJM planners. It is imperative that modeling information be complete, timely and clear to facilitate the PJM process for both planning and operation divisions staff. Maintaining models of the system is an ongoing process. TOs are responsible for identifying future BES facility additions/deletions as part of the RTEP and EMS Model quarterly update processes.

Representatives for each TO shall provide justification and analysis of all requested sub-transmission facilities and coordinate modifications of BES with PJM MMD staff.

TO Staff responsibilities- ongoing sub-transmission modeling considerations

TOs shall evaluate contingencies used by PJM to simulate outages to determine if load re-allocations are a better alternative. To redistribute loads, TOs shall provide information to PJM regarding the appropriate simulation of the re-allocated load(s) (i.e., percentages of the distribution and location).

TOs shall coordinate with PJM staff on an ongoing basis to identify modeling updates to be applied in the PJM EMS to ensure that models are appropriate when simulating outage conditions.

⁵ See PJM Manuals M1, Control Center and Data Exchange Requirements, and M3A Energy Management System (EMS) Model Updates and Quality Assurance, et al.

Representatives for each TO shall provide justification and analysis of all requested sub-transmission facilities and coordinate modifications with PJM MMD staff.

Detailed examples of sub-transmission facilities in the PJM EMS model are listed in in this white paper. TO staff shall review these examples, understand them fully, and follow-any guidelines cited in their efforts to submit modeling of sub-transmission facilities.

PJM Staff responsibilities- to address revised BES definitions

PJM expects to work with TOs to fulfill the initial review and maintain the BES element list going forward. To assist with maintaining the data, PJM will incorporate a review of BES facilities as part of the annual review of Tariff Facilities by adding a new flag to the posted Tariff Facility data.

PJM expects to collect the initial, full set of model data to identify BES elements and expand the PJM list as required as part of the Spring 2015 quarterly update process. As part of the ongoing model update process, any modifications to the model and BES element list should be included as part of the EMS quarterly Model Update or RTEP processes, respectively.

PJM Staff responsibilities- ongoing sub-transmission modeling considerations

Data requirements for EMS models shall adhere to the discussion at the May 2014 Data Management Subcommittee (DMS) meeting Agenda item 6, titled "Network model 101". The sub-transmission data submission shall include justification for inclusion in the EMS model and indicate if the facilities are to be considered BES elements. Staff members of PJM's Systems Operations and Systems Operations Support may be involved in various aspects of the modeling effort.

The need to expand the model, particularly to incorporate sub-transmission elements, can be identified through the PJM outage assessment process (see PJM Manual 38). If PJM staff initiates the request, coordination with the TO staff is imperative to: 1). Gain the TO's acceptance; 2). Facilitate required NERC notifications; and, 3). Prepare complete, timely and clear modeling data. PJM staff shall work with TOs to ensure that all concerned have a common and full understanding of any modeling changes required. NERC regions have ultimate responsibility and approval for designating equipment as BES or non-BES. Any non-BES nominated sub-transmission facility additions to the PJM EMS model will be addressed on a case-by-case basis and shall be approved by the MMD manager or his designee following the procedure documented in PJM Manuals ⁵.

The cited examples of sub-transmission facility modeling are typically driven by actual operational experience and engineering assessment/experience.

To facilitate stakeholder review and acceptance, PJM staff will update Manual 3A, adding a section on sub-transmission facility modeling. This section will outline the policy, practices and responsibility for this modeling.

Modeling consistent with existing concepts and methods

Since sub-transmission systems are dependent upon the bulk electric transmission system, good Industry practice dictates the relevant models incorporate modeling concepts consistent with current BES practices. To the extent possible, PJM will enhance current model requirements and update processes to support sub-transmission modeling where appropriate. Note that this approach also accommodates modeling non-BES, sub-transmission elements if necessary.

Although NERC specifically assigns responsibility for identifying BES elements to TOs, this information is essential for PJM's system operation. PJM proposes to work with TOs to complete these assessments and has concluded that PJM's current modeling processes and procedures can be modified and expanded, as needed, to meet requirements (see PJM Manual 3A and Manual 3). To support this effort, it is imperative that TOs:

- Engage in assessing their existing systems
- Understand and apply the NERC BES Definition
- Provide input to PJM, as well as, NERC and its regional entities (i.e. RFC & SERC)

Note that most, if not all, BES facilities are already modeled and monitored by PJM.

While the NERC report on Arizona – Southern California outages on September 8, 2011² provided insights into the need for sub-transmission facility modeling and suggested that each ISO / RTO / Regional controlling entity specify practices and criteria for modeling sub-transmission facilities in their EMS, the report made no specific recommendations regarding sub-transmission modeling practice or criterion. An internal PJM report on Technical analysis of Operational events and Market Impacts during the September 2013 Heat Wave³, endorsed this NERC report and specifically recommended that a task force be established to more clearly define PJM EMS modeling requirements for sub-transmission (under 100 kV) facilities. This white paper supports that recommendation.

Employing a team of industry experts, NERC revised the BES definition (see, www.nerc.com/pa/rapa/pages/bes.aspx) clearly defining what is to be included and excluded. In addition, the NERC team developed a technical guide on modeling of facilities under 100 kV⁴. As part of the NERC BES effort, an exception process was added allowing a request for facilities to be added or deleted to the BES beyond the 'bright line 100 kV test'. Consequently, approved sub-transmission facilities can become part of the BES. The link at <http://www.nerc.com/pa/RAPA/Pages/BES.aspx> shows a summary of the bright line test facilities (defined by the NERC bright line test as $\geq 100\text{kV}$) and the NERC BESnet tool Transmission Owners are to use when making exception requests.

Considerations for sub-transmission modeling

Models are vital to systems that control the Grid, coordinate market activities and feed into the planning division processes. PJM's policies and procedures allow member TOs to nominate facilities to be appropriately modeled and monitored against loading and voltage limits. To ensure that the system is operated reliably and economically, some facilities rated below 100 kV may also need to be modeled. As part of PJM's model update process (annual RTEP and quarterly EMS), TOs are responsible for nominating facilities to be modeled in the PJM EMS, including sub-transmission facilities. PJM staff members work with TOs representatives to model sub-transmission facilities appropriately, subject to PJM approval.

The models serve multiple needs and require significant coordination and communication between TOs and PJM. A robust State Estimator (SE) solution which is accurate, fast and numerically stable, is used to evaluate current conditions. The SE solution provides the base condition for the Security Analysis (SA) function which evaluates the possible impact of thousands of potential contingencies. The SA tool and associated contingencies are also used to perform simulations using the study-mode power flow as input. Results from the SE and SA function are shared with PJM planners for further evaluation, if necessary.

The requirement to ensure a fast, robust SE solution cannot be understated. Any modeling that enhances good numerical stability over varying operating conditions should be considered. Many systems, including for Markets, rely on an almost

100% SE solution rate. The SE solution typically solves in less than 30 seconds, with 15-25 iterations, and the SA completes its assessment in less than 1 minute. Throughput is dependent upon a variety of factors including a robust and well-tuned model. PJM applies engineering judgment to reduce the model where possible. This maintains accurate topology and associated flow and voltage measurements, ensuring a robust model and SE solution. These engineering judgments cited in Manual 3A include the following considerations: transmission constraints, parallel circuitry, tightly coupled facility, solution throughput and integrity, appropriate amount of detail, facility observability, congestion management (including post), tie lines, AGC, Day-Ahead Markets, RTEP related projects, BES reliability and economics, coordination with TO model, electrical closeness, impact on SE solution, operating experience, best analysis to operators for reliability and commercial evaluations, Monitored Priority status, TO ability to validate model, Settlements impact, additional metering to enhance error detection.

Sub-transmission facilities can impact the BES, especially when outages are necessary. In some cases, sub-transmission is used to provide an alternate network path to higher voltage station facilities. In other cases, switching on underlying systems serves to re-allocate load centers. For any sub-transmission facility modeling, a similar set of requirements is needed as has been employed for all BES facilities. Detailed models of sub-transmission shall be managed and maintained consistent with all other elements of the system model which may require additional resource requirements. Expanding the model needs a clearly identified benefit, typically based on operational experience, to warrant the addition of more detailed model (Ex. Enhancing SE and/or SA solution accuracy).

All elements of the EMS model representing PJM owned facilities are assigned a monitored priority (MP). To support this, PJM can require status information on member owned facilities within the PJM footprint. These facilities are typically classified as a Monitor Priority 3 (MP3, or Status only) or 6 (Reliability Non-BES). They may or may not have ratings submitted and are not part of the monitored facilities that impact outage requests. Elements nominated for inclusion into the BES definition are classified by PJM as Monitored Priority 1 (Reliability & Markets); or 2 (Reliability BES). Any facilities that are to be limit checked require ratings. The assessment and determination of the monitored priority assigned to each facility is reviewed on an annual basis by TO staff, and updated as needed in the normal daily operation process.

Additional work is necessary to develop and maintain contingency lists, maintain ratings and track cut-ins of new equipment related to any requested sub-transmission modeling.

Examples of EMS Sub-Transmission modeling

Ex 1: 69 KV Network, in an area surrounded by BES source stations

In some locations there are multiple BES sources supplying a 69 kV network which ties the BES system together. This can impact a fairly large geographical area. Typically the sub-transmission facilities can provide support to the BES under a wide array of situations. Simply using a telemetered load at BES source locations, without recognizing the effects of the sub-transmission network, can prevent PJM dispatchers from observing the same system issues as their member company counterparts (situational awareness). As PJM practice dictates that the 'most conservative' approach be followed, the system may subsequently operate at sub-optimal levels - unless a decision is made to use the TO more detailed model. Based on operational experience, PJM and the TO may opt to include models of the sub-transmission facilities in the area to have a consistent situational awareness in the PJM and TO control rooms.

Similarly, in locations where planned outages will force additional flows on the sub-transmission network diverting flows to other BES facilities, modeling might be required before an outage request is granted.

Ex 2: 69 KV network as backbone modeling considerations

For some company systems, a substantial percentage of its internal EMS model backbone is 69 KV network, requiring an extensive 69 KV model to support an accurate SE solution and calculation of actual flows on BES facilities. PJM can model this sub-transmission in detail with limit checks in place with Monitored Priority 6, Reliability non-BES. Limit checks on these facilities are then customarily performed only as appropriate, or by exception, during outage analysis.

These models are important so that PJM and the corresponding TO observe similar results when simulating various outages. The added detail improves correlation between the TO and PJM models, mitigating the need to defer to more conservative result. Without this additional detail, the PJM dispatchers and REs would not have consistent situational awareness as there would be too many missing elements in the PJM system model.

Ex 3: Sub-Transmission modeling complexities - external company considerations

In some cases, under 100 kV facilities constitute a large portion of the company's 'backbone' system with multiple low voltage connections to neighbors. In these cases, sub-transmission elements of neighboring systems will likely impact SE solution accuracy. If the neighbor is not a PJM member Tie-line accounting will also be impacted and employing a detailed sub-transmission model will improve SE and SA numerical stability and EMS performance.

Some PJM member stations and their loads can also be interspersed among another neighboring company's stations. Modeling of the sub-transmission can be used to address this type of issue.

Ex 4: Tariff review and BESnet example

In the annual tariff facility review, PJM is expanding the spreadsheet to be used for TO responses to identify BES facilities and indicate if a change is required and the reason for the change (see highlighted column). The information provided shall be consistent with exception requests posted via the NERC BESnet tool. The objective is to link the facilities in the current PJM BES list with the BESnet submissions that started after July 1, 2014.

Type in tariff list	Voltage	MP	BES	Reason	NERC BESnet exception	Model Status	Size
Line	69 KV	1	Y	Network	Y	Exist	
XFR	138/69 KV	1	Y	Network Source	Y	Exist	
Line	138	6	N	Radial	N	Exist	
Gen	23/230 KV	1	Y	GSU	N	New	100 MVA
Gen	4/138 KV	1	Y	GSU - Markets	Y	Exist	2 MVA
Line	69 KV	1	Y	Network, Voltage support	Y	New	

All entries tagged for inclusion into the BESnet tool; need to be sent to the PJM staff per Compliance bulletin 014.

Conclusion

This white paper outlines the policy, practices, and implementation strategy for modeling sub-transmission facilities in the PJM EMS model quarterly build process. These practices are drawn from: 1) the proven modeling practices used for BES facilities and 2) the existing methods being practiced for sub-transmission modeling. It contains the roles and responsibilities for both the TO staff and the PJM staff. This white paper outlines proper coordination practices to implement modeling of sub-transmission facilities. Key considerations for all sub-transmission modeling include determining answers to the following questions:

- Does the facility impact a BES facility or is requested to be a BES facility? (appropriate telemetry shall be available)
- Do the proposed non-BES facilities have the same level of available Telemetry as BES facility requirements?
- Are the proposed equipment facilities between 50 KV and 100 kV?
- Is the Security Analysis contingency list impacted?
- Do the TO and PJM staffs commit to maintaining the proposed modeling consistent with PJM practices?

If the answer is “Yes” to all the above questions, then the sub-transmission facilities should be considered for inclusion in the RTEP process and the EMS model quarterly build process, respectively, per TO staff submissions. TO staff are expected to accommodate the existing PJM processes, eDART Network Model submissions, weekly cut-in reporting, annual Tariff facility review, DMS and SOS-T participation for all model inclusions in the EMS model quarterly build process.

Requested sub transmission BES facilities should be indicated by the designated BES facility flag in coordination with the NERC exception process and the NERC BESnet application.