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SCOPE

This document is the ATC system Planning Criteria. These criteria define system performance requirements. Consideration is given to ensure a safe and reliable transmission system. These criteria address customer expectations and compliance with NERC standards. These criteria apply to the ATC transmission system operated at 69-kV and above.

This document may be revised from time to time in response to changes in industry standards, new system conditions, new technologies and new operating procedures, as appropriate. The criteria described below will be subject to change at any time at ATC's discretion. Situations that could precipitate such a change could include, but are not limited to, new system conditions, extraordinary events, safety issues, operation issues, maintenance issues, customer requests, regulatory requirements and Regional Entity or NERC requirements.

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CAUTION: Any hard copy reproductions of this specification should be verified against the on-line system for current revisions.

- 1. System Performance Criteria.....3
 - 1.1 Steady State Assessments Overview.....3
 - 1.1.1 Normal Intact Conditions (P0 Contingency)4
 - 1.1.2 Single Contingency Conditions (P1 and P2 Contingencies)4
 - 1.1.3 Multiple Contingency Conditions (P3 through P7 Contingencies)7
 - 1.1.4 Extreme Disturbance Events (TPL-001-4 Table 1 Steady State Events)8
 - 1.1.5 Planning Horizon Steady State Voltage Stability8
 - 1.1.6 General Steady State Performance Criteria^{1,2}9
 - 1.1.7 Contingency Definitions 11
 - 1.2 Dynamic Stability Assessments Overview..... 13
 - 1.2.1 Large Disturbance Stability Performance Assessment..... 13
 - 1.2.2 Angular Oscillation Damping..... 15
 - 1.2.3 Extreme Disturbance Events (NERC Standard TPL-001-4 Table 1 Stability Extreme Events) 16
 - 1.3 Voltage Flicker 16
 - 1.4 Harmonic Voltage and Current Distortion..... 17
 - 1.5 Under-Frequency Load Shedding 19
 - 1.5.1 Island Identification..... 19
 - 1.5.2 Frequency Performance Assessment Criteria 20
 - 1.5.3 Volts Per Hertz Assessment Criteria..... 20
 - 1.6 Generating Facility Power Factor and Voltage Regulation..... 21
 - 1.6.1 Power Factor 21
 - 1.6.2 POI Voltage 22
- 2. Variations on ATC Planning Criteria 23
- 3. Administration 23
 - 3.1 Review 23
 - 3.2 Retention 23
- 4. Revision History 24

1. SYSTEM PERFORMANCE CRITERIA

System performance over a ten year planning horizon will be assessed at least annually. Such assessments will involve steady state simulations and, as appropriate, dynamic simulations.

1.1 Steady State Assessments Overview

Steady state assessments include the consideration of the following system load conditions.

- 1) Summer peak
- 2) Summer 90/10 proxy peak
- 3) Summer off-peak
- 4) Winter peak
- 5) Fall/spring off-peak
- 6) Light load
- 7) Minimum load

At a minimum, two of the first three load conditions or similar models will be assessed in all long-range planning studies. The last four load conditions may be considered when more detailed analyses are being conducted of specific alternatives developed to solve a particular problem.

The steady state load conditions have the following general applications.

- 1) **Summer peak** - Used to determine summer peak load serving and regional supply limitations, including voltage security assessments.
- 2) **Summer 90/10 proxy peak** - Used considering the P1 and P2 Contingencies (loss of single element) analysis to help us determine whether extreme weather conditions may require unusual measures to meet unexpected load. The 90/10 proxy forecast will be used to help prioritize and stage projects but it will not necessarily be used as the sole reason to justify projects or required in service dates.
- 3) **Summer off-peak** - Used to evaluate Contingencies where transmission equipment may be intentionally outaged at appropriate load levels in addition to assessing system biases or high system imports into the ATC system.
- 4) **Winter peak** - Used to determine winter peak load serving limitations.
- 5) **Fall/spring off-peak** - Used to evaluate Contingencies where transmission equipment may be intentionally outaged at appropriate load levels to identify seasonal regional transfer impacts.
- 6) **Light load** - Used to study the possibility of high voltages on the power system, impact of capacitor switching, and potential equipment overloads near base load power plants due to reduced local demand at light load levels. The light load case represents many more hours in the year than the minimum load model.

- 7) **Minimum load** - Used to review the expected voltage range at distribution interconnection points and for determination of adequate voltage control at minimum load levels. Typically the highest bus voltages will occur with an intact transmission system during minimum load conditions.

Steady state performance assessments incorporating Operating Guides are done to identify potential transmission system vulnerabilities over a reasonable range of future scenarios.

The steady state system performance criteria to be utilized by ATC for its assessments shall include the following conditions.

(Applicable NERC Standard: TPL-001-4, R2.1, R2.2, and R3)

1.1.1 Normal Intact Conditions (P0 Contingency)

No transmission element (BES and 69-kV transmission circuits, transformers, etc.) should experience voltage levels outside of applicable voltage limits or loading in excess of its applicable normal thermal ratings for P0 Contingency conditions. This criterion should apply for a reasonably broad range of forecasted system demands and associated generation dispatch conditions.

The Normal Intact Conditions shall include the following additional considerations.

- 1) The normal voltage limit range is typically 95 percent to 105 percent of nominal voltage for P0 Contingency conditions. Such measurements shall be made at the high side of transmission-to-distribution transformers. Voltage levels that differ from this range will be considered, if they are acceptable to the affected transmission customer or needed to address specific ATC equipment limitations. Exceptions for certain interconnected entities are evaluated accordingly (e.g., agreements implemented for NERC standard NUC-001). All voltage limits should be met with the net generator reactive power limited to 90 percent of the reported maximum reactive power capability.
- 2) The steady state voltage as noted in Section 1.1.4 below should be stable at all ATC buses for normal intact system configurations and for a reasonably broad range of forecasted system demands and associated generation dispatch conditions.

1.1.2 Single Contingency Conditions (P1 and P2 Contingencies)

No transmission element should experience any of the following system conditions¹:

- voltage levels outside of applicable voltage limits,
- loading in excess of its applicable thermal emergency ratings, and

¹ For Categories where load curtailment is acceptable, short duration exposure to potential post-contingency overload, or high or low post-contingency voltage represents an acceptable risk assuming system adjustment within that short period of time can eliminate the exceedance. The applicable short duration timeframe will be situation dependent and may need to be reviewed with Asset Planning & Engineering. Refer to the table in Section 1.1.6 regarding the utilization of load curtailment in planning studies.

- post-Contingency voltage deviation (percent change of actual pre-Contingency and post contingency steady state voltage) of greater than 10%.

This criterion is applicable for the following individual Contingencies at appropriate load levels: P1, P2, and maintenance outage (planned single element outage excluding buses and breakers) followed by a P1 Contingencies. This criterion should be applied for a reasonably broad range of forecasted system demands and associated generation dispatch conditions. Refer to the table in Section 1.1.6 regarding the utilization of load curtailment in planning studies. Field switching may not be considered as acceptable measures for achieving immediate overload relief for breaker-to-breaker Contingencies.

For restoration after breaker-to-breaker Contingencies, field switching, Load Tap Changer (LTC) adjustments, Operating Guides and/or generator redispatch may be considered as acceptable measures to bring element loading or voltage levels within applicable ratings or limits during restoration. The transmission element loading or voltage should be brought within the applicable ratings or limits and their associated timeframes¹

For assessments conducted using applicable Midwest Reliability Organization (MRO) and ReliabilityFirst (RF) region-wide firm load and interchange levels (i.e. no market or non-firm system bias), generator real power output should not be limited under P1 and P2 (excluding P2.2 HV, P2.3 HV, and P2.4) Contingencies.

The Single Contingency Conditions shall include the following additional considerations.

- 1) For Categories where load curtailment is unacceptable, system design should ensure that element loading can be adjusted to provide acceptable system performance within 30 minutes or any Interconnection Reliability Operating Limit Tv^2 (IROL Tv), whichever is less. Temporary excursions above the applicable thermal emergency ratings are acceptable if a Special Protection System (SPS) will reduce loadings automatically (i.e. no manual intervention) to acceptable loading levels in the applicable timeframe. The acceptable loading levels after SPS operation cannot exceed the applicable thermal emergency ratings. The applicable timeframe is determined by the type of limitation that will occur if left unmitigated (e.g., clearance limitation may take several minutes whereas exceeding a relay trip setting may result in an essentially instantaneous trip).
- 2) Under applicable P1, P2, and maintenance outage (planned single element outage excluding bus and breaker) followed by a P1 Contingencies; at appropriate load levels, the temporary acceptable voltage level must be within the applicable voltage limits¹. The acceptable temporary voltage range is typically 90 percent to 110 percent of the system nominal voltage. Voltage levels that differ from this range will be considered, if they are acceptable to the affected transmission customer or needed to address specific ATC equipment limitations. Voltage levels more restrictive than this range will be considered to address specific equipment

² The maximum time that an Interconnection Reliability Operating Limit can be violated before the risk to the interconnection or other Reliability Coordinator Area(s) becomes greater than acceptable. Each Interconnection IROL Tv shall be less than or equal to 30 minutes (from NERC Glossary of Terms).

limitations. Exceptions for certain interconnected entities are evaluated accordingly (e.g., agreements implemented for NERC standard NUC-001).

For Categories where load curtailment is unacceptable, load shedding or field switching is not an acceptable measure for achieving immediate voltage restoration for breaker-to-breaker Contingencies. However, for full or partial restoration of load after the event, field switching, LTC adjustments, Operating Guides and/or generator redispatch may be considered as acceptable measures to bring voltage levels within appropriate limits. The applicable voltage limits are screened with the net generator reactive power limited to 90 percent of the maximum reactive power capability. For Categories where load curtailment is acceptable, consideration may be given to operating procedures that are designed to shed a minimum amount of load. Refer to the table in Section 1.1.6 regarding the utilization of load curtailment in planning studies.

- 3) For Categories where load curtailment is unacceptable, system design should ensure that voltage levels outside of any IROL can be restored provide acceptable system performance within 30 minutes or any IROL T_v , whichever is less. These voltage limits are screened with the net generator reactive power limited to 90 percent of the applicable maximum reactive power capability. Temporary voltage excursions outside the range of applicable high and low voltage limits are acceptable if a Special Protection System (SPS) or control of shunt compensation will automatically (i.e. no operator intervention) restore system voltage to temporary acceptable voltage levels within the applicable timeframe. The applicable timeframe will be situation dependent and may need to be reviewed with Asset Planning & Engineering.
- 4) The steady state voltage should be stable at all ATC buses for applicable P1, P2, and maintenance outage (planned single element outage excluding bus and breaker) followed by a P1 Contingencies; at appropriate load levels, for a reasonably broad range of forecasted system demands and associated generation dispatch conditions.
- 5) No NERC Cascading should occur for applicable P1, P2, and maintenance outage (planned single element outage excluding bus and breaker) followed by a P1 Contingencies. ATC uses the following definitions.

NERC Cascading - A cascading outage has occurred and a Total Load at Risk exceeded ATC's IROL threshold of 1000 MW to restore the system within normal limits.

Total Load at Risk is defined as the sum of the following four types of load loss, which are identified in steady-state analyses.

- 1) Consequential Load Loss (NERC definition)

NERC definition is "All Load that is no longer served by the Transmission system as a result of Transmission Facilities being removed from service by a Protection System operation designed to isolate the fault". Basically, it is the load that is outaged as a result of automatic fault protection for an event-based contingency. It

excludes load that is immediately restored via automatic switching to adjacent substations.

2) Interruptible load loss due to other automatic controls

Load that is outaged by other automatic controls for an event-based contingency based on a documented agreement between ATC and the Load-Serving Entity. The end-use customer must make the load available for curtailment to the Load-Serving Entity via contract or agreement.

3) Subsequent cascading load loss

Load that is outaged as a result of subsequent element-based outages during the remaining cascading tier analysis. This type of load loss is a result of either voltage sensitive load tripping when load buses are below 0.8 p.u. or load islanding due to lines/transformers tripping. The 0.8 p.u. load tripping threshold is used as a proxy to simulate the response of voltage sensitive load. The response of voltage sensitive load refers to the tripping of the load due to intrinsic voltage protection mechanisms that manufacturers build into their equipment.

4) Non-Consequential Load Loss (NERC definition)

NERC definition is “Non-Interruptible Load loss that does not include: (1) Consequential Load Loss, (2) the response of voltage sensitive Load, or (3) Load that is disconnected from the System by end-user equipment.” It represents the non-interruptible load shed that may need to be performed by manual or automatic controls to restore the ATC system to be within emergency limits and the additional load curtailment that may need to be performed by manual or automatic control to restore the ATC system to be within normal limits.

1.1.3 Multiple Contingency Conditions (P3 through P7 Contingencies)

No transmission element should experience either of the following system conditions¹:

- voltage levels outside of applicable voltage limits or
- loading in excess of its applicable thermal emergency ratings.

This criterion is applicable for applicable P3 through P7 Contingencies. This criterion should be applied for a reasonably broad range of forecasted system demands and associated generation dispatch conditions. Overload relief methods may include supervisory controlled or automatic switching of circuits, or generation redispatch. Refer to the table in Section 1.1.6 regarding the utilization of load curtailment in planning studies. The transmission element loading or voltage should be brought within the applicable ratings or limits and their associated timeframes¹.

The Multiple Contingency Conditions shall include the following additional considerations.

- 1) Under applicable P3 through P7 Contingencies, the temporary acceptable voltage level must be within the applicable voltage limits¹. The acceptable temporary voltage range is typically 90 percent to 110 percent of the system nominal voltage. Voltage levels that differ from this range will be considered, if they are acceptable to the affected transmission customer or needed to address specific ATC equipment

limitations. Voltage levels more restrictive than this range will be considered to address specific equipment limitations. Exceptions for certain interconnected entities are evaluated accordingly (e.g., agreements implemented for NERC standard NUC-001). Methods of restoration to normal voltage range may include supervisory control of the following: capacitor banks, LTCs, generating unit voltage regulation, generation redispatch, or line switching. Refer to the table in Section 1.1.6 regarding the utilization of load curtailment in planning studies. The applicable voltage limits should be met with the net generator reactive power limited to 90 percent of the applicable maximum reactive power capability.

For Categories where load curtailment is acceptable, consideration may be given to operating procedures that are designed to shed a minimum amount of load.

- 2) The steady state voltage should be stable at all ATC buses for applicable P3 through P7 Contingencies for a reasonably broad range of forecasted system demands and associated generation dispatch conditions.
- 3) No NERC Cascading should occur for applicable P3 through P7 Contingencies.

1.1.4 Extreme Disturbance Events (TPL-001-4 Table 1 Steady State Events)

- 1) The NERC Steady State Extreme Events that are expected to produce more severe system impacts should be evaluated to determine potential system impacts and vulnerabilities. If widespread Cascading may occur, then an evaluation of possible actions that would reduce the likelihood or mitigate the consequences of the extreme event should be performed.
- 2) Transmission elements that experience loading in excess of applicable thermal emergency ratings for applicable NERC TPL-001-4 Table 1 Steady State Contingencies should be evaluated in accordance with ATC cascading tripping thresholds to determine the consequence of the contingent event.

1.1.5 Planning Horizon Steady State Voltage Stability

The transmission system is required to be voltage stable for all P0 through P7 Contingencies. The transmission system is further required to respect a minimum margin to short-term, steady state voltage instability for P0 through P7 Contingencies, except for P3 and P6 Contingencies. A 5 percent real power margin to voltage instability, based on the most limiting post-Contingency real power flow, is the minimum requirement and is chosen to reflect uncertainties in load forecasting and modeling as well as to provide a reasonable reliability margin. Additional margin may be required in some situations. In addition to the 5 percent margin, a Control Point will be defined for all voltage stability flowgates and respected in all Planning analyses. The Control Point is the flow threshold where mitigation actions are initiated.

Steady state voltage stability assessments are performed on a selective basis using engineering judgment. Otherwise, acceptable steady state voltage stability is assumed to exist. If analysis determines steady-state voltage instability, requiring the need for voltage stability flowgates, then the following definitions are applied.

- The Power-Voltage (P-V) curve nose is the transfer point where the maximum real power interface flow occurs. Therefore, if there is no inflection point at the maximum transfer level on the P-V curve, then the last solved point will be used as the P-V curve nose.
- If an Interconnection Reliability Operating Limit (IROL) is determined to exist, then the IROL is defined as the pre-Contingency real power flow that results in the post-Contingency P-V curve nose.
- The System Operating Limit (SOL) is defined as the pre-Contingency real power flow that results in the post-Contingency real power flow that is 95 percent of the post-Contingency P-V curve nose.
- If the calculated SOL occurs at a point on the P-V curve that results in a low voltage violation at the critical bus, then the SOL is reduced to the maximum pre-Contingency real power flow that does not result in a voltage violation at the critical bus. The critical bus is the bus that is most voltage-sensitive to the power transfer.
- If the SOL is unstable with a P3 or P6 Contingency, then the SOL is reduced to the maximum pre-Contingency real power flow that is stable post-contingency (i.e., the post-P3 or P6 Contingency real power flow relating to the SOL must be less than the post-P3 or P6 Contingency P-V curve nose).
- The Control Point is defined as the pre-Contingency real power flow that is 98 percent of the SOL.

Voltage stability analysis must demonstrate that the nose of the post-Contingency P-V curve occurs at a voltage that is less than or equal to the applicable bus low voltage limit as coordinated with the applicable Planning Coordinator and/or by any applicable Transmission Owner(s) (e.g., the MWEX limitation of 95 percent of nominal voltage at the Arrowhead4 230-kV bus) to assure adequate system voltage stability and reactive power resources for P0 through P7 Contingencies.

System design as planned for all Planning Events should ensure that exceeding any steady state voltage stability IROL can be mitigated within 30 minutes or any IROL Tv, whichever is less.

1.1.6 General Steady State Performance Criteria^{1,2}

Event	Voltage Level ³	Voltage limits ⁴ (per unit)		Thermal Ratings	Loss of Firm Transmission Service	Loss of Non-Consequential Load	Event
		Min	Max				
P0	All	0.95	1.05	Normal	0	0	P0
P1.1-1.5	HV, EHV	0.90	1.10	Emergency ⁷	0 ⁵	0 ⁶	P1.1-1.5
	Non-BES				0	0	
P2.1	HV, EHV				0 ⁵	0 ⁶	P2.1
	Non-BES				0	0	
P2.2&2.3	EHV				0 ⁵	0	P2.2&2.3

	HV, Non-BES				Allowed	Allowed	
P2.4	All				Allowed	Allowed	P2.4
P3	HV, EHV				0 ⁵	0 ⁶	P3
	Non-BES				Allowed	Allowed	
P4.1-4.5	EHV				0 ⁵	0	P4.1-4.5
	HV, Non-BES				Allowed	Allowed	
P4.6	All				Allowed	Allowed	P4.6
P5.1-5.5	EHV				0 ⁵	0	P5.1-5.5
	HV, Non-BES				Allowed	Allowed	
P6.1-6.4	All				Allowed	Allowed	P6.1-6.4
P7.1&7.2	All	0.90	1.10		Allowed	Allowed	P7.1&7.2

Table Notes:

1. Generator reactive capability is reduced to 90 percent of the reported capability.
2. Due to uncertainties in study assumptions, assuring Steady State voltage stability for Planning Events requires adequate margin. To accomplish this, ATC requires planning the system to a control point that is 98% of a voltage stability SOL. This SOL is a pre-contingent real power flow that provides a minimum 5 percent real power margin from the post-Contingency P-V curve nose as defined in Section 1.1.5.
3. Steady State voltage stability is 10 percent from the nose of the P-V curve.
4. 'All' is defined as ATC owned equipment at any voltage level. 'EHV' is defined as, 300-kV and above, ATC owned equipment at 'HV' is defined as ATC owned equipment strictly less than 300-kV and greater than or equal to 100-kV. 'Non-BES' is defined as ATC owned 69-kV through 99-kV equipment.
5. These are the typical voltage limits. Voltage levels at specific buses may vary from these values based on specific transmission customer or ATC equipment considerations.
6. Footnote 9 in TPL-001-4

An objective of the planning process should be to minimize the likelihood and magnitude of interruption of Firm Transmission Service following Contingency events. Curtailment of Firm Transmission Service is allowed both as a System adjustment (as identified in the column entitled 'Initial Condition') and a corrective action when achieved through the appropriate re-dispatch of resources obligated to re-dispatch, where it can be demonstrated that Facilities, internal and external to the Transmission Planner's planning region, remain within applicable Facility Ratings and the re-dispatch does not result in any Non-Consequential Load Loss. Where limited options for re-dispatch exist, sensitivities associated with the availability of those resources should be considered.

7. Footnote 12 in TPL-001-4

An objective of the planning process is to minimize the likelihood and magnitude of Non-Consequential Load Loss following planning events. In limited circumstances, Non-Consequential Load Loss may be needed throughout the planning horizon to ensure that BES performance requirements are met. However, when Non-Consequential Load Loss is utilized under footnote 12 within the Near-Term Transmission Planning Horizon to address BES performance requirements, such interruption is limited to circumstances where the Non-Consequential Load Loss meets the conditions shown in Attachment 1. In no case can the planned Non-Consequential Load Loss under footnote 12 exceed 75 MW for US registered entities. The amount of planned Non-Consequential Load Loss for a non-US Registered Entity should be implemented in a manner that is consistent with, or under the direction of, the applicable governmental authority or its agency in the non-US jurisdiction.

8. Emergency Ratings are based on two different time durations: Long-Term and Short-Term. Steady-State thermal loading for ATC facilities must be within the Long-Term emergency rating for all Planning Events in this table that do not allow non-consequential load loss. For Planning Events that allow Non-Consequential load loss, Short-Term emergency ratings may be applied to allow time for post-contingent, manual mitigation (as permitted by NERC standards, such as load shedding) to restore facility loading within Long-Term emergency ratings.

1.1.7 Contingency Definitions

Event Category	Initial Condition	Fault Type	Event
P0	Normal System	N/A	None
P1	Normal System	3Φ	Loss of one of the following: 1. Generator 2. Transmission circuit 3. Transformer 4. Shunt device
		SLG	5. Single pole of a DC line
P2	Normal System	N/A	1. Open line section w/o fault
		SLG	2. Bus section fault 3. Internal non-bus-tie breaker fault 4. Internal bus-tie breaker fault
P3	Loss of generator unit followed by system adjustments	3Φ	Loss of one of the following: 1. Generator 2. Transmission circuit 3. Transformer 4. Shunt device
		SLG	5. Single pole of a DC line

P4	Normal System	SLG	Loss of multiple elements caused by a stuck breaker (non-bus-tie) attempting to clear a Fault on one of the following: 1. Generator 2. Transmission circuit 3. Transformer 4. Shunt device 5. Bus section 6. Loss of multiple elements caused by a stuck breaker (bus-tie breaker) attempting to clear a fault on the associated bus
P5	Normal System	SLG	Delayed Fault clearing due to the failure of a non-redundant relay protecting the Faulted element to operate as designed, for one of the following: 1. Generator 2. Transmission circuit 3. Transformer 4. Shunt device 5. Bus section
P6	Loss of one of the following followed by System adjustments. 1. Transmission circuit 2. Transformer 3. Shunt device 4. Single DC line pole	3 Φ	Loss of one of the following: 1. Transmission circuit 2. Transformer 3. Shunt device
		SLG	4. Single pole of a DC line
P7	Normal System	SLG	The loss of: 1. Any two adjacent circuit on a common tower 2. Loss of a bipolar DC line

1.2 Dynamic Stability Assessments Overview

The dynamics cases are built to be consistent with the regional dynamics database except for the load modeling, which may consist of appropriate load and motor modeling for voltage stability assessments. Dynamic stability assessments will include consideration of the following system load conditions.

- 1) Summer peak
- 2) Light load

The dynamic load conditions have the following general applications.

- 1) **Summer peak** – This load condition is typically used for voltage stability studies to determine whether system disturbances during peak load conditions cause voltage instability. Also, since the performance of wind generators is more closely linked to system voltage performance, summer peak cases should be considered when assessing the performance of wind generation.
- 2) **Light load** – This load condition is typically used for dynamic stability assessments in order to assess the angular stability of synchronous machines (e.g. fossil fuel generators). Empirically, it is noted that the dynamic performance of synchronous machines is worse in lighter load conditions likely due to lower field excitation current.

Transient and dynamic stability assessments of the planning horizon are generally performed by the System Planning Department to assure adequate avoidance of loss of generator synchronism, prevention of system voltage collapse, and system reactive power resources after a system disturbance based on 20 second simulations.

The transient and dynamic system stability performance criteria to be utilized by ATC for planning purposes shall include the following factors.

(Applicable NERC Standard: TPL-001-4, R2.4, R2.5, and R4)

1.2.1 Large Disturbance Stability Performance Assessment

- 1) For generator transient stability, faults will be modeled on the high side bus at generating plants.
- 2) For generating units with actual “as built” or “field setting” dynamic data, a 0.5 cycle margin will be added to the expected clearing time (ECT) for dynamic Contingency simulations. For generating units with assumed, typical, or proposed dynamic data, a 1.0 cycle margin will be added to the ECT for dynamic Contingency simulations. The ECT margin will only be added to near end protective device for normal clearing faults (i.e. P1, P2, P3, P6 and P7) or it will be only added to the protective device with delayed clearing (i.e. P4 and P5). The total clearing time (ECT + margin) must be equal to or less than the calculated critical clearing time (CCT) from the simulation.
- 3) Generator transient stability will be demonstrated for at least one key Contingency for each applicable P1 through P7 Contingency. Unacceptable transient stability performance occurs when any of the stability assessment criteria are not met.

A. Angular Stability Assessment

- i. Generating unit loses synchronism with the transmission system, unless it is deliberately islanded
- ii. Cascading tripping of transmission lines, tripping of transmission transformers or uncontrolled loss of load
- iii. Poorly damped angular oscillations where acceptable damping is defined in Section 1.2.2 below

B. Voltage Stability Assessment

- i. Transient stability voltage response at applicable Bulk-Electric System (BES) buses serving load shall recover to at least 80% of nominal voltage within 2 seconds after the initiating event is cleared for all P1-P7 Contingencies
- ii. For voltage swings subsequent to fault clearing and the first voltage recovery above 80%, voltage dips at each applicable BES bus serving load for all P1-P7 Contingencies:
 - a. Shall not dip below 70% of nominal voltage for more than 30 cycles continuous, or
 - b. Shall not dip below 80% of nominal voltage for more than 2 seconds continuous.

C. Inverter-Based Resources Stability Assessment

Inverter-based resources refer to generating and energy storage resources that are asynchronously connected to the grid and are either completely or partially interfaced with the transmission system through power electronics.

- i. An inverter-based resource shall not trip for any studied Planning Events, unless it is deliberately islanded. This also applies to single line to ground (SLG) faults for Planning Events that are defined as three phase faults (e.g. certain P1, P3 and P6 events).
- ii. An inverter-based resource's active power and reactive power as measured at the machine bus and bus voltage as measured at the Point-of-Interconnection (POI) shall be positively damped and meet one of the following two criteria:
 - a. Time domain analysis indicates a 50% or greater reduction in oscillation magnitude over the last four oscillation periods.
 - b. Peak-to-peak magnitudes during the last two seconds of the 20 second simulation shall not exceed 3% of their rated values (machine MVA base for active and reactive power and base kV at POI for voltage).

- iii. Inverter-based resources shall not re-enter fault ride-through mode more than once in the time period beginning 6 cycles after the fault clears until the end of the 20 second simulation.
- iv. Inverter-based resources should be designed and configured to continue current injection (active, reactive, or a combination of current) inside the “No Trip Zone” of the frequency and voltage ride-through curves of the currently effective version of PRC-024 unless a reliability study identifies a system need to cease injecting current. Inverter-based resources should be designed and configured to use momentary cessation only outside the “No Trip Zone” if this helps mitigate potential tripping conditions based on interconnection studies. Any use of momentary cessation should be based on equipment limitations or based on reliability studies identifying a system need. Return from momentary cessation upon voltage recovery to within the continuous operation range should occur as quickly as possible with no intentional time delay while maintaining stability.

Exceptions to these criteria (item ii, iii) given within this section may be considered on a case-by-case basis (e.g. for existing inverter-based resources or if NERC provides more specific inverter-based resource performance guidelines before ATC revises these criteria).

- 4) Where needed system reinforcement cannot be implemented in an appropriate timeframe, then a corrective plan must be established in order to respect System Operating Limits and/or Interconnected Reliability Operating Limits. Where appropriate, corrective plans may include generator redispatch, operating guides, and/or Special Protection Systems.

1.2.2 Angular Oscillation Damping

Well damped angular oscillations need to meet one of the following two criteria.

- 1) The generator rotor angle peak-to-peak magnitude is within 1.0 degree or less at the end of the 20 second simulation:
- 2) The generator average damping factor for the last five cycles of the 20 second simulation is 15.0 percent or greater after the switching event.

$$\text{Average Damping Factor (\%)} = \left(\frac{d_1 + d_2 + d_3 + d_4}{4} \right) \times 100$$

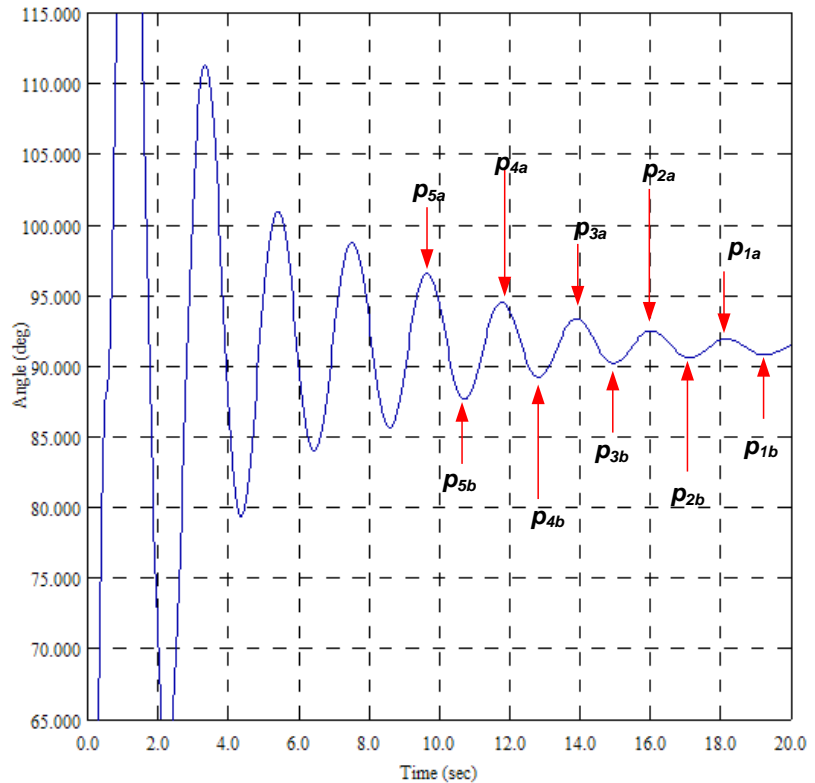
Where:

$d_n = (1 - SPPR_n)$ where $SPPR_n$ (Successive Positive Peak Ratio) is the ratio of the peak-to-peak amplitude of a rotor angle swing (n^{th} cycle back from the 20 second simulation time) to the peak-to-peak amplitude of a rotor angle swing on the previous cycle ($(n+1)^{\text{th}}$ cycle back from the 20 second simulation time).

$$d_4 = 1 - \frac{P_4}{P_5}, \quad d_3 = 1 - \frac{P_3}{P_4}, \quad d_2 = 1 - \frac{P_2}{P_3}, \quad d_1 = 1 - \frac{P_1}{P_2}$$

Example

 Last 5 peak-peak magnitudes:
 1) max = 96.580 time = 9.654
 min = 87.661 time = 10.712
 peak-peak = 8.918
 2) max = 94.526 time = 11.771
 min = 89.222 time = 12.829
 peak-peak = 5.304
 3) max = 93.371 time = 13.904
 min = 90.226 time = 14.962
 peak-peak = 3.146
 4) max = 92.512 time = 16.021
 min = 90.611 time = 17.113
 peak-peak = 1.901
 5) max = 91.941 time = 18.163
 min = 90.811 time = 19.246
 peak-peak = 1.129
 Average Damping (last 5 peak-peak):
 40.347 %
 Ave. Freq. Oscillation (last 5 peak-peak):
 0.470 Hz



$$p_1 = p_{1a} - p_{1b} = 1.129$$

$$d_1 = 1 - (1.129/1.901) = 0.406102$$

$$p_2 = p_{2a} - p_{2b} = 1.901$$

$$d_2 = 1 - (1.901/3.146) = 0.395741$$

$$p_3 = p_{3a} - p_{3b} = 3.146$$

$$d_3 = 1 - (3.146/5.304) = 0.406863$$

$$p_4 = p_{4a} - p_{4b} = 5.304$$

$$d_4 = 1 - (5.304/8.918) = 0.405248$$

$$p_5 = p_{5a} - p_{5b} = 8.918$$

$$\text{Average Damping Ratio} = (d_1 + d_2 + d_3 + d_4) \times 100 / 4 = 40.35\%$$

1.2.3 Extreme Disturbance Events (NERC Standard TPL-001-4 Table 1 Stability Extreme Events)

The NERC Stability Extreme Events that are expected to produce more severe system impacts should be evaluated to determine potential system impacts and vulnerabilities. If widespread Cascading may occur, then an evaluation of possible actions that would reduce the likelihood or mitigate the consequences of the extreme event should be performed.

1.3 Voltage Flicker

The criteria for acceptable voltage flicker levels are defined by the requirements of regulatory entities in the states in which ATC owns and operates transmission facilities, IEEE recommended practices and requirements, and the judgment of ATC. The criteria are described below.

The following flicker level criteria are to be observed at minimum nominal system strength with all transmission facilities in service. Minimum nominal system strength shall be defined as the condition produced by the generation that is in service in the Minimum load models, minus any generation that is:

- 1) Electrically close to the actual or proposed flicker-producing load
- 2) Could significantly affect flicker levels
- 3) Could reasonably be expected to be out of service under Minimum load conditions

Although the limits described below are not required to be met during transmission system outages, if these limits are exceeded under outage conditions, the flicker producing load must be operated in a manner that does not adversely affect other loads. Planned outages can be dealt with by coordinating transmission and flicker producing load outages. Because operating restrictions during unplanned outages may be severe, it would be prudent for the owner of the flicker producing load to study the effect of known, critical, or long term outages before they occur, so that remedial actions or operating restrictions can be designed before an outage occurs. During outages, actual, rather than minimum nominal, system strength should be considered.

All ATC buses are required to adhere to the following two criteria.

- 1) Relative steady state voltage change is typically limited to 3 percent of the nominal voltage for intact system condition simulations. For new projects, it is also typically limited to 5 percent of the nominal voltage under outage conditions. The relative steady state voltage change is the difference in voltage before and after an event, such as capacitor switching, load switching or large motor starting (not including Contingency events). These events should occur at least 10 minutes apart and take less than 0.2 seconds (12 cycles) to go from an initial to a final voltage level.
- 2) Planning levels are to be limited to a short term perception (Pst) of 0.8 and a long term perception (Plt) of 0.6. Pst and Plt are calculated using the calculation methods outlined in IEEE standard 1453-2015.

1.4 Harmonic Voltage and Current Distortion

In general, it is the responsibility of ATC to meet harmonic voltage limits and the responsibility of the load customers to meet harmonic current limits. Usually, if harmonic current limits are met, then harmonic voltage limits will also be met. The level of harmonics acceptable on the ATC system is defined by state regulations, IEEE Standard 519-2014 (Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems) and the judgment of ATC. The voltage distortion limits and current distortion limits are specified in the Tables 1-4 below.

The observance of harmonic limits should be verified whenever a harmonic related problem is discovered or a new harmonic producing load with a reasonable possibility of causing harmonic problems is connected to the ATC system. The following process is utilized by ATC when managing an existing harmonic-related problem or a new harmonic-producing load:

- 1) Existing problems – When a harmonic related problem is found on the ATC system, it is ATC’s responsibility to determine the source of the harmonics. If harmonic current limits are violated, the source of the harmonics will be required to decrease their harmonic currents to below the limits. If, after the harmonic current has been reduced to an acceptable level, the harmonic voltage is still causing a problem and above specified levels, it shall be the responsibility of ATC to bring the harmonic voltages within limits. If limits are not violated and there is still a harmonic related problem (an unlikely situation), it is the responsibility of the entity experiencing the problem to harden its equipment to the effect of harmonics or reduce the harmonics at their location. An existing violation of these harmonic limits that is not causing any problems does not necessarily require harmonic mitigation.
- 2) New harmonic producing loads – It is the responsibility of any customer wanting to connect a harmonic producing load to the ATC system to determine if the proposed load will violate the harmonic current limits and, if these limits are violated, to determine and implement steps necessary to reduce the harmonic currents to acceptable levels. If harmonic voltage limits are not met after harmonic current limits have been met, it is the responsibility of ATC to determine if the harmonic voltage distortion will cause any system problems and if they will, it is ATC’s responsibility to develop and implement a plan to meet the harmonic voltage limits.

Table 1 – IEEE 519 Voltage Distortion Limits

Bus Voltage at Point of Common Coupling	Individual Voltage Distortion (%)	Total Voltage Distortion (%)
1-kV<V≤69-kV	3.0	5.0
69-kV<V≤161-kV	1.5	2.5
161-kV<V	1.0	1.5

Note 1: These limits should be used as system design values for the “worst case” for normal operation (conditions lasting longer than one hour). For periods lasting less than one hour, these limits may be exceeded by 50 percent.

Note 2: High-voltage systems (>161-kV) can have up to two percent Total Voltage Distortion when caused by a HVDC terminal whose harmonics are attenuated by the time it is tapped by a user.

Table 2 – IEEE 519 Current Distortion Limits for General Systems with Nominal Voltages Between 120-V to 69-kV and All Power Generation Equipment Maximum Harmonic Current Distortion for Odd Harmonics (Percent of I_L)

I _{sc} /I _L	Individual Harmonic Order (%)					TDD
	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

I_{sc} = maximum short circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at PCC

Note 1: Even Harmonics are limited to 25 percent of the odd harmonic limits listed above.

Note 2: Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

Note 3: All power generation equipment is limited to the I_{sc}/I_L<20 limits listed in this table, regardless of actual I_{sc}/I_L.

Table 3 – IEEE 519 Current Distortion Limits for General Systems with Nominal Voltages Between 69.001-kV and 161-kV Maximum Harmonic Current Distortion for Odd Harmonics (Percent of I_L)

Isc/I _L	Individual Harmonic Order (%)					TDD
	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	
<20	2.0	1.0	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4.0
50<100	5.0	2.25	2.0	0.75	0.35	6.0
100<1000	6.0	2.75	2.5	1.0	0.5	7.5
>1000	7.5	3.5	3.0	1.25	0.7	10.0

I_{sc} = maximum short circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at PCC

Note 1: Even Harmonics are limited to 25 percent of the odd harmonic limits listed above.

Note 2: Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

Note 3: All power generation equipment is limited to the I_{sc}/I_L<20 limits listed in this table, regardless of actual I_{sc}/I_L.

Table 4 – IEEE 519 Current Distortion Limits for General Systems with Nominal Voltages Above 161-kV Maximum Harmonic Current Distortion for Odd Harmonics (Percent of I_L)

Isc/I _L	Individual Harmonic Order (%)					TDD
	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

I_{sc} = maximum short circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at PCC

Note 1: Even Harmonics are limited to 25 percent of the odd harmonic limits listed above.

Note 2: Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

Note 3: All power generation equipment is limited to the I_{sc}/I_L<50 limits listed in this table, regardless of actual I_{sc}/I_L.

1.5 Under-Frequency Load Shedding

Under-frequency load shedding (UFLS) island identification is based on the following criteria. In general, UFLS is designed to arrest declining frequency after an under frequency event. Island identification is the subdivision of the Bulk Electric System (BES) including the ATC transmission system into sub regions. UFLS analysis falls into two categories; frequency performance and dynamic volts per hertz performance.

1.5.1 Island Identification

The identification of UFLS islands is based on the NERC reliability standard PRC-006. The UFLS island identification that ATC uses is based on the following four criteria:

1) Actual Historical Island Event

A UFLS island is identified as a portion of the BES including the ATC transmission system which was an actual historical island event within the past five years.

2) Non-UFLS System Studies

A UFLS island is identified as a portion of the BES including the ATC transmission system which was determined to be an island through non-UFLS system studies.

3) Relay Scheme or a Special Protection System

A UFLS island is identified as a portion of the BES including the ATC transmission system which is planned to detach from the transmission system as a result of the operation of a relay scheme or a special protection system.

4) Large Single Island

A UFLS island is identified as a single island in the MRO area, the RF area, or the Eastern Interconnection that includes the entire ATC transmission system. The island shall be selected by applying the above criteria and coordinating with the criteria of MISO and PJM to verify that all ATC UFLS schemes meet the PRC-006 standard performance requirements when acting together with or without the programs of the BES.

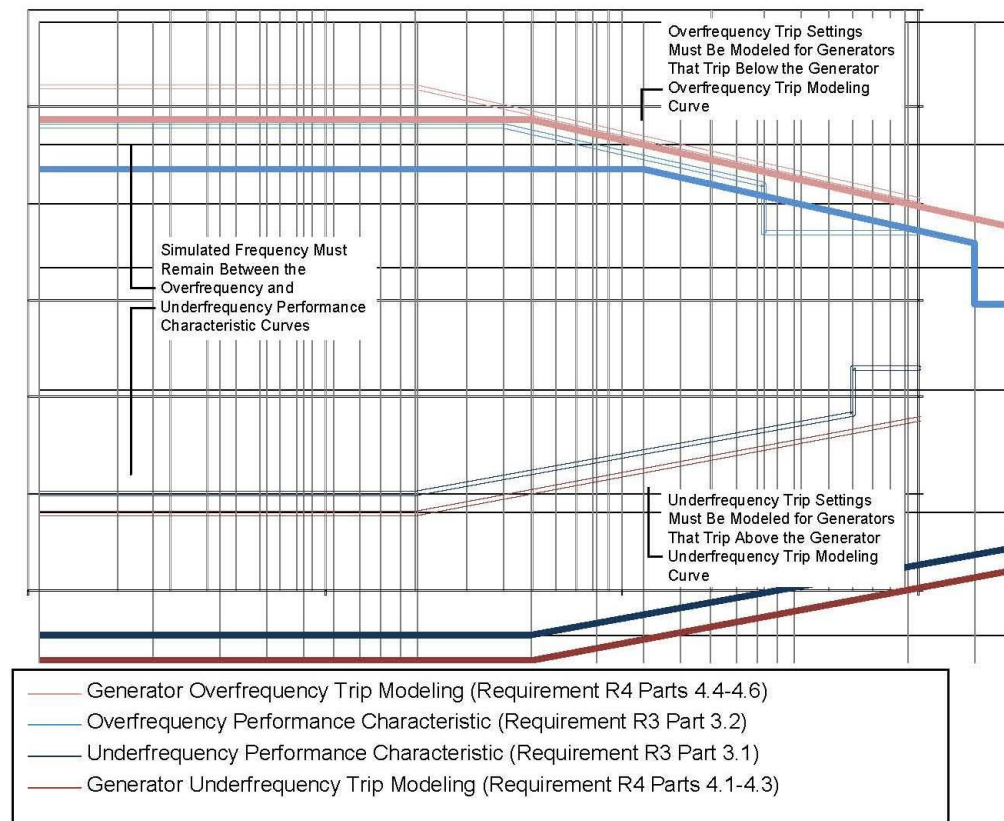
1.5.2 Frequency Performance Assessment Criteria

Transient island frequencies shall remain within the Under-frequency and Over-frequency Performance Characteristic Curves in PRC-006 Standard Attachment 1.

1.5.3 Volts Per Hertz Assessment Criteria

Transient Volts per Hertz values shall not exceed 1.18 per unit for longer than two seconds cumulatively per simulated event, and shall not exceed 1.10 per unit for longer than 45 seconds cumulatively per simulated event at each generator bus and generator step-up transformer high-side bus.

PRC-006-1 – Attachment 1
Underfrequency Load Shedding Program
Design Performance and Modeling Curves for
Requirements R3 Parts 3.1-3.2 and R4 Parts 4.1-4.6



Curve Definitions

Generator Overfrequency Trip Modeling		Overfrequency Performance Characteristic		
$t \leq 2$ s	$t > 2$ s	$t \leq 4$ s	$4 \text{ s} < t \leq 30$ s	$t > 30$ s
$f = 62.2$ Hz	$f = -0.686\log(t) + 62.41$ Hz	$f = 61.8$ Hz	$f = -0.686\log(t) + 62.21$ Hz	$f = 60.7$ Hz

Generator Underfrequency Trip Modeling		Underfrequency Performance Characteristic		
$t \leq 2$ s	$t > 2$ s	$t \leq 2$ s	$2 \text{ s} < t \leq 60$ s	$t > 60$ s
$f = 57.8$ Hz	$f = 0.575\log(t) + 57.63$ Hz	$f = 58.0$ Hz	$f = 0.575\log(t) + 57.83$ Hz	$f = 59.3$ Hz

Figure 1 – Performance Characteristic Curves for UFLS Frequency Performance Criteria

1.6 Generating Facility Power Factor and Voltage Regulation

1.6.1 Power Factor

Power Factor Requirements for Interconnection Generating Units are as follows. ATC’s standard power factor range for synchronous and non-synchronous (e.g., wind turbines, solar) generation is 0.95 leading (when a Generating Facility is consuming reactive power

from the Transmission System) to 0.95 lagging (when a Generating Facility is supplying reactive power to the Transmission System).

Static reactive power sources can only be used to make up for losses between the machine terminal and the POI for synchronous machines and losses between the terminal of the machines and the high side of the GSU for non-synchronous machines. All other reactive power to meet the power factor requirement must be provided by continuous and sustainable dynamic sources. Operation across the entire power factor range must be fully dynamic, variable, and capable of sustained indefinite operation.

Static sources can be switched on or off in the range of seconds and provide reactive power in large discrete blocks. Cap Banks are considered static sources of reactive power.

Dynamic sources can provide variable amounts of reactive power in a few milliseconds. Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), Flexible AC Transmission Systems (FACTS), inverters, and synchronous condensers are all considered dynamic sources of reactive power.

The Generating Facility must be capable of maintaining ATC's standard power factor range at all power output levels by providing continuous dynamic reactive power at the following locations:

- a) The Point Of Interconnection (POI) for all synchronous generators

For synchronous machines, the interconnection studies will account for the net effect of all energy production devices and losses on the Customer's side of the POI.

- b) The high-side of the generator step up transformer (GSU) for all non-synchronous generators³

For non-synchronous machines, the interconnection studies will account for the net effect of all energy production devices and losses on the Customer's side of the GSU.

Dynamic reactive power provided by non-synchronous generators must meet the following requirement from FERC order 827 Item 35:

“Non-synchronous generators may meet the dynamic reactive power requirement by utilizing a combination of the inherent dynamic reactive power capability of the inverter, dynamic reactive power devices (e.g., Static VAR Compensators), and static reactive power devices (e.g., capacitors) to make up for losses.”

1.6.2 POI Voltage

The interconnecting generator must be capable of automatically and dynamically maintaining a POI voltage schedule that is specified by the Transmission Operator. Any generator interconnected within the ATC system is expected to maintain a voltage schedule (voltage setpoint) of 1.02 p.u. at its POI, within limits of its reactive capabilities, to facilitate

³ FERC Order No. 827

transmission operations reliability under normal system conditions (system intact) and contingency conditions, unless another voltage level is communicated to the generator by the ATC Transmission Operator (cf. NERC Reliability Standard VAR-001).

2. VARIATIONS ON ATC PLANNING CRITERIA

The ATC transmission system consists of assets contributed by entities within the five Balancing Authorities of the Wisconsin-Upper Michigan Systems. Each of the original asset owners planned their system to separate planning criteria, particularly in regard to transient and dynamic performance. Therefore, as ATC has implemented its own planning criteria, portions of the system may require upgrades to meet the more stringent ATC criteria.

This section of the ATC planning criteria describes the philosophy that will be followed for completing projects in a portion of the system identified as deficient with respect to the ATC planning criteria.

Area does not meet the ATC planning criteria performance requirements.

- 1) Complete projects required for bringing the existing system up to the ATC planning criteria performance requirements with no intentional delay.
- 2) New generator interconnections are not permitted until the ATC planning criteria are met with the addition of the new generator, if the new generator interconnection aggravates the stability condition [A new generation interconnection is deemed to aggravate the stability performance of an area if a change in scope is required to meet the ATC planning criteria. See NERC Standard FAC-002-1 for new generator interconnections].
- 3) Depending on the level of risk associated with the deficiency, special operating procedures (restrictions or guides) may be required to mitigate the risk until the projects are completed. If a new generator interconnection is permitted but still negatively influences the stability condition, the operating restriction may follow a “last interconnected, first restricted” approach.
- 4) Reinforcements to meet ATC Criteria will be reviewed to ensure the risk, cost and benefit are in the best interest of stakeholders. ATC Planning Leadership will have the discretion to determine exceptions to the criteria.

3. ADMINISTRATION

3.1 Review

This document may be revised from time to time in response to changes in industry standards, new system conditions, new technologies and new operating procedures, as appropriate. Annually the need for a full review will be evaluated.

3.2 Retention

The previous version of this document will be retained for at least five years after it becomes retired.

4. REVISION HISTORY

Revision	Author(s)	Manager(s)	V.P.(s) Director(s)	Summary of Changes
14	Connie Lunde, et alia	David Smith, Paul Walter	Ron Snead	Primary – split Criteria and Practices into separate documents, added voltage limit text, modified voltage stability margin text; Details – Summary of Planning Criteria V14 and Practices V1 Revisions document
15	Shane Ehster, et alia	David Smith, Paul Walter	Ron Snead	Primary – Addition of UFLS criteria, added low voltage limit text for the P-V nose, revised Category D generator stability requirements, moved Variations on ATC Planning Criteria section from Assessment Practices document
16	Curtis Roe, et alia	David Smith, Paul Walter	Ron Snead	Revised NERC references to TPL-001-4, revised annual review requirement, added criteria summary table, added maintenance plus in P1, and added TTL specifics
16.1	Curtis Roe, et alia	David Smith, Paul Walter	Ron Snead	Errata
17	Curtis Roe, et alia	David Smith, Paul Walter	Andy Dolan	Added post-Contingency voltage deviation criteria, removed post fault voltage recovery threshold, revised the TTL terminology to cascading trip threshold.
18	Curtis Roe, et alia	David Smith, Paul Walter	Andy Dolan	Updated references to IEEE 1453 and 519; and revised the transient response requirement.
19	Curtis Roe, et alia	David Smith, Paul Walter	Andy Dolan	Added non-BES rows to P1.1-P2.5 and P2.1 contingencies in Table 1.1.6, removed Small Signal Stability criteria, added Section 1.6 Generating Facility Power Factor, and added Section 2 Variations bullet item #4.
19.1	Chengyue Guo	David Smith, Paul Walter	Andy Dolan	Added clarity around voltage limitations.
19.2	Curtis Roe	Paul Walter	Andy Dolan	Revised power factor limit (new limit 0.95 lagging).
19.3	Chengyue Guo, Damien Sommer, Mike Marz, Bob Krueger, et alia	Paul Walter Adam Manty	Andy Dolan	Added sub-section for “Inverter-Based Resources Stability Assessment”, improved languages in Voltage Stability Assessment criteria for clarification and cleaned up stability simulation time descriptions to be consistent
19.4	David Smith, et alia	Tom Dagenais	Andy Dolan	Added note 7 to the “General Steady State Performance Criteria” table in section 1.1.6, to clarify thermal emergency rating
19.5	Chengyue Guo, Damien Sommer, et alia	Paul Walter Adam Manty	Andy Dolan	Enhanced inverter-Based Resources Stability criteria and improved languages in Section 1.2.1.
20	David Smith	--	Andy Dolan	Changed version from 19.5 to 20 to match TYA year
20.1	Joel Berry Chengyue Guo	Adam Manty Paul Walter	Andy Dolan	Revised the Voltage Stability Margin requirement to 5% on a post-contingent basis. Clarified the application of margins on expected clearing times.