

System Operating Limit Definition and Exceedance Clarification

The NERC-defined term System Operating Limit (SOL) is used extensively in the NERC Reliability Standards; however, there is much confusion with – and many widely varied interpretations and applications of – the SOL term. This whitepaper describes the Standard Drafting Team’s (SDT) intent with regard to the SOL concept and brings clarity and consistency to the notion of establishing SOLs, exceeding SOLs, and implementing Operating Plans to mitigate SOL exceedances.

System Operating Limit Definition Clarification:

As stated in the NERC Glossary of Terms Used in Reliability Standards, a SOL is defined as the value (such as MW, MVar, Amperes, Frequency or Volts) that satisfies the most limiting of the prescribed operating criteria for a specified system configuration to ensure operation within acceptable reliability criteria. SOLs are based upon certain operating criteria. These include, but are not limited to:

- Facility Ratings (Applicable pre- and post- Contingency equipment or Facility ratings)
- Transient Stability Ratings (Applicable pre- and/or post-Contingency Stability Limits)
- Voltage Stability Ratings (Applicable pre- and/or post- Contingency Voltage Stability)
- System Voltage Limits (Applicable pre- and post-Contingency Voltage Limits)

The concept of SOL determination is not complete without looking at the approved NERC FAC standards FAC-008-3, FAC-011-2, and FAC-014-2:

1. The purpose of approved FAC-008-3, which is applicable to both Generation and Transmission Owners, is to ensure that Facility Ratings used in the reliable planning and operation of the BES are determined based on technically sound principles. A Facility Rating is essential for the determination of SOLs. The standard requires both Generation Owners and Transmission Owners to have a documented Facility Rating that respects the most limiting applicable Equipment Rating of the individual equipment that comprises that Facility. The scope of the Ratings addressed shall include, as a minimum, both Normal and Emergency (short-term) Ratings (approved FAC-008-3, Requirement R3, part 3.4.2). A 24-hour continuous rating is an example of a Normal rating; however, rating practices vary from entity to entity and may include ratings that vary with ambient temperature. Typical Emergency (short-term) Ratings have a finite duration of less than 24 hours (e.g., 4 hours, 2 hours, 1 hour, 30 minutes, or 15 minutes).

2. The purpose of approved FAC-011-2, which is applicable to Reliability Coordinators, is to ensure that SOLs used in the reliable operation of the BES are determined based on an established methodology or methodologies. Approved FAC-011-2, Requirement R2 requires that the Reliability Coordinator's SOL Methodology include a requirement that SOLs provide a certain level of BES performance for the pre- and post-Contingency state. Specifically:

Pre-Contingency: Acceptable system performance for the pre-Contingency state is characterized by the following:

- a. The BES shall demonstrate transient, dynamic, and voltage Stability.
- b. All Facilities shall be within their applicable Facility Ratings and thermal limits.
- c. All Facilities shall be within their pre-Contingency voltage limits.
- d. All Facilities shall be within their Stability limits.

Post-Contingency: Acceptable system performance for the post-Contingency state for single Contingencies is characterized by the following (approved Reliability Standard FAC-011-2, Requirement R2, part 2.2):

- a. The BES shall demonstrate transient, dynamic, and voltage Stability.
 - b. All Facilities shall be within their applicable Facility Ratings and thermal limits.
 - c. All Facilities shall be within their post-Contingency voltage limits.
 - d. All Facilities shall be within their Stability limits.
 - e. Cascading or uncontrolled separation shall not occur.
3. Approved FAC-011-2 Requirement R3, Part 3.1 also ensures that the Reliability Coordinator's methodology for determining SOLs includes a description of the study model, which at a minimum must include at least the entire Reliability Coordinator Area as well as the critical modeling details from other Reliability Coordinator Areas that would impact the Facility or Facilities under study as well as the level of detail of system models used to determine SOLs which is shown in approved FAC-011-2, Requirement R3, Part 3.4. The requirements within approved FAC-011-2, when combined with the BES Exception Process which is designed to bring impactful facilities into the BES, ensure that all facilities that can adversely impact BES reliability are either designated as part of the BES or otherwise incorporated into planning and operations studies.

4. Approved FAC-014-2, Requirement R2 requires that Transmission Operators establish SOLs for their portion of the Reliability Coordinator Area that are consistent with its Reliability Coordinator's SOL Methodology.

Some have interpreted the language in approved FAC-011-2, Requirement R2 to imply that the objective is to perform prior studies to determine a specific MW flow value (SOL) that ensures operation within the criteria specified in approved FAC-011-2, Requirement R2 sub-requirements, the assumption being that if the system is operated within this pre-determined SOL value, then all of the pre- and post-Contingency requirements described in approved FAC-011-2, Requirement R2 will be met. The SDT believes this approach may not capture the complete intent of the SOL concept within approved FAC-011-2, which is both:

1. Know the Facility Ratings, voltage limits, transient Stability limits, and voltage Stability limits, and
2. Ensure that they are all observed in both the pre- and post-Contingency state by performing a Real-time Assessment.

SOLs are based on Normal and Emergency (short-term) Facility Ratings, voltage limits, transient Stability limits, and voltage Stability limits – any of which can be the most restrictive limit at any point in time pre- or post-Contingency. For example, if an area of the BES is at no risk of encroaching upon Stability or voltage limitations in the pre- or post-Contingency state, and the most restrictive limitations in that area are pre- or post-Contingency exceedance of Facility Ratings, then the thermal Facility Ratings in that area are the most limiting SOLs. Conversely, if an area is not at risk of instability and no Facilities are approaching their thermal Facility Ratings, but the area is prone to pre- or post-Contingency low voltage conditions, then the voltage limits in that area are the most limiting SOLs.

It is important to distinguish operating practices and strategies from the SOL itself. As stated earlier, the SOL is based on the actual set of Facility Ratings, voltage limits, or Stability limits that are to be monitored for the pre- and post-Contingency state. How an entity remains within these SOLs can vary depending on the planning strategies, operating practices, and mechanisms employed by that entity. For example, one Transmission Operator may utilize line outage distribution factors or other similar calculations as a mechanism to ensure SOLs are not exceeded, while another may utilize advanced network applications to achieve the same reliability objective.

In order to ensure an SOL is not exceeded, the following SOL performance must be maintained:

1. **Facility Ratings:**

In the pre- and post-Contingency state, operate within Facility capability by utilizing Normal and Emergency (short-term) Ratings, as applicable, within their associated time parameters.

2. **Voltage Limits:**

In the pre-Contingency state, operate within normal voltage limits. In the post-Contingency state, operate within applicable emergency voltage limits.

3. **Transient Stability Limits:**

Transmission Operators establish SOLs to prevent intra-area instability, inter-area instability, or tripping of Facilities due to out-of-step conditions. Transient Stability limits are typically defined as the maximum power transfer or load level that ensures critical transient reliability criteria are met. Calculated flows must be maintained within appropriate pre- and/or post-Contingency limits.

4. **Voltage Stability Limits:**

Transmission Operators typically stress Transmission Paths/Interfaces or load areas to the reasonably expected maximum transfer conditions or area load levels to determine whether steady state voltage Stability limits exist. Voltage Stability limits are typically defined as the maximum power transfer or load level that ensures voltage Stability criteria are met. Calculated flows must be maintained within appropriate pre- and/or post-Contingency limits.

System Operating Limit Exceedance Clarification:

The combination of requirements contained within the approved FAC and proposed TOP standards, as well as the use of defined terms contained within those standards such as Operational Planning Analysis, Real-time Assessment, and Operating Plans when executed properly result in maintaining reliable BES performance. Specifically,

1. Approved FAC standards require clear determination of Facility Ratings and describe acceptable system performance criteria for the pre- and post-Contingency state.
2. Proposed TOP-001-3, Requirement R13 requires that a Transmission Operator perform a Real-time Assessment at least once every 30 minutes.
3. Proposed TOP-002-4, Requirement R2 requires that each Transmission Operator have an Operating Plan to address potential SOL exceedances identified as a result of its Operational Planning Analysis.
4. Proposed TOP-001-3, Requirement R14 requires the Transmission Operator to initiate Operating Plan(s) to mitigate SOL exceedances.

Facility Rating Exceedance

Facility Rating exceedance is a function of the available limit set and the magnitude of pre- or post-Contingency flows in relation to those limits as observed in Real-time monitoring or Real-time Assessments. Figure 1 illustrates an SOL Performance Summary for Facility Ratings.

SOL Performance Summary

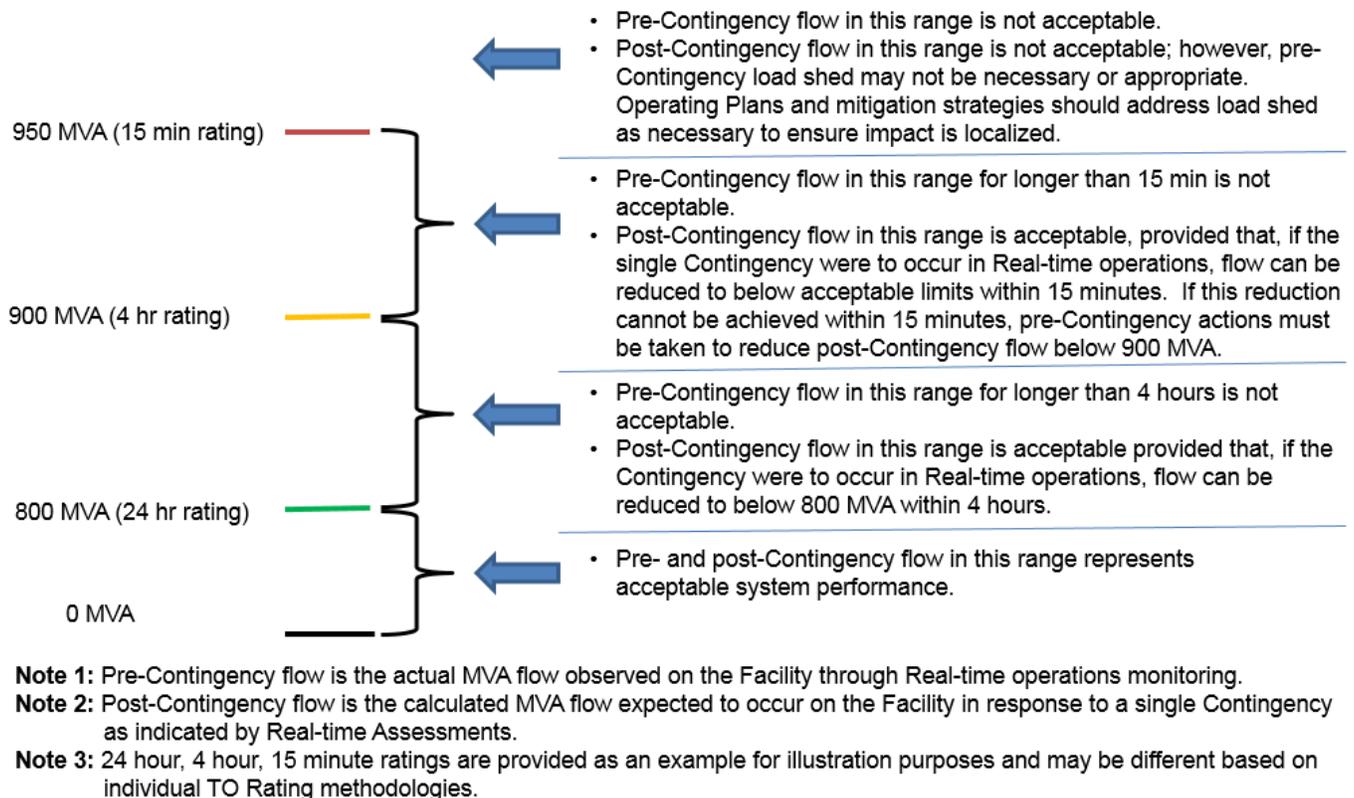


Figure 1. Facility Rating System Operating Limit Performance Summary

In cases where post-Contingency flow exceeds the highest available Facility Rating as shown in Figure 1, Transmission Operators are expected to take pre-Contingency action to relieve the condition (including redispatch, reconfiguration, and making adjustments to the uses of the transmission system); however, the operating condition may not warrant shedding load pre-Contingency to relieve the condition. Pre-Contingency Load shed is generally utilized as a last resort in conditions where the next Contingency could result in Cascading or widespread instability. An entity's Operating Plan is expected to define when it is appropriate to shed Load pre-Contingency versus post-Contingency while ensuring the BES remains N-1 secure.

Steady State Voltage Limit Exceedance

SOL performance for steady state voltage limits is determined through Real-time Assessments. Normal and emergency voltage limits are expected to respect any voltage limitations specified in the Transmission

Owner's or the Generation Owner's Facility Ratings Methodology per approved FAC-008-3. Normal voltage limits are typically applicable for the pre-Contingency state while emergency voltage limits are applicable for the post-Contingency state. SOL exceedance with respect to these voltage limits occurs when either actual bus voltage is outside acceptable pre-Contingency (normal) bus voltage limits, or when Real-time Assessments indicate that bus voltages are expected to fall outside acceptable emergency limits in response to a Contingency event. Real-time Assessments should recognize the impact of auto-reactive devices and whether or not those devices are sufficient for maintaining voltages within acceptable limits pre- or post-Contingency.

Stability Limit Exceedance

Transient and voltage Stability limits can be determined through prior studies, or they can be determined in Real-time.

Transient Stability limits are often expressed as flow limits on a defined interface or cut plane that, if operated within, ensures that the system will remain transiently stable should the identified Contingency(s) occur. Transient instability could take several forms, including undamped oscillations, or angular instability resulting in portions of the system losing synchronism.

Though voltage Stability limits can be determined, expressed, and monitored in several ways, the general principle is universal – voltage Stability limits are intended to ensure that the system does not experience voltage collapse in the pre- or post-Contingency state.

SOL exceedance for Stability limits occurs when the system enters into an operating state where the next Contingency could result in transient or voltage instability. Figure 2 depicts a wide-area voltage Stability based SOL that qualifies as an IROL. In this example, SOL (IROL) exceedance occurs when power transfers over the monitored Facility(s) exceeds the P_{IROL} value. Note - A localized voltage collapse may not qualify as an IROL.

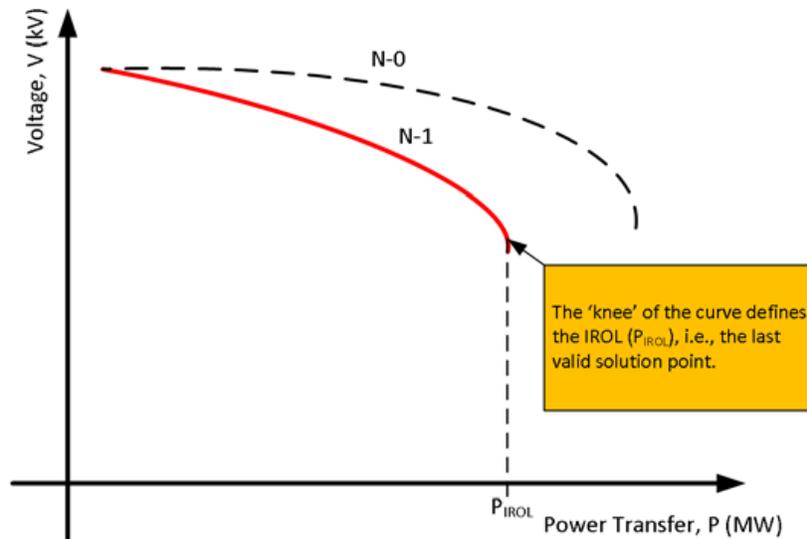


Figure 2. Voltage Stability System Operating Limit Performance Summary

SOL exceedance occurs when acceptable system performance as described in approved FAC-011-2 is not occurring in Real-time operations as determined by Real-time Assessments. In other words, unacceptable system performance as indicated by Real-time Assessments equates to SOL exceedance. An SOL is exceeded when any of the following occur or are observed as part of a Real-time Assessment:

- Actual flow on a Facility is above the Facility Rating for an unacceptable time duration
- Calculated Post-Contingency flow on a Facility is above the highest available Facility Rating
- Actual bus voltage is outside acceptable pre-Contingency (normal) bus voltage limits
- Post-Contingency bus voltage is outside acceptable post-Contingency (emergency) bus voltage limits
- Defined transient or voltage Stability limits are exceeded (techniques for determining and observing Stability limits can vary)

SOL Exceedance and Operating Plans:

When an SOL is being exceeded in Real-time operations, the Transmission Operator is required to implement mitigating strategies consistent with its Operating Plan(s). Operating Plans can include specific Operating Procedures or more general Operating Processes. Operating Plans include both pre- and post-Contingency mitigation plans/strategies. Pre-Contingency mitigation plans/strategies are actions that are implemented before the Contingency occurs to prevent the potential negative impacts on reliability of the

Contingency. Post-Contingency mitigation plans/strategies are actions that are implemented after the Contingency occurs to bring the system back within limits. Operating Plans contain details to include appropriate timelines to escalate the level of mitigating plans/strategies to ensure BES performance is maintained as per approved FAC-011-2, Requirement R2, preventing SOL exceedances from becoming an IROL. Operating Plan(s) must include the appropriate time element to return the system to within acceptable Normal and Emergency (short-term) Ratings and/or operating limits identified above. For example, in Figure 1, operating above the 950 MVA 15 minute limit would be an SOL exceedance for actual flows and may also be an exceedance for projected post-Contingency flows if a communicated post-Contingency load shed plan cannot be implemented in a timely fashion in order to prevent post-Contingency equipment damage and/or non-localized Cascading outages. However, operating between 900 MVA and 950 MVA is not an SOL exceedance unless the associated Operating Plan time parameter is exceeded as explained in Figure 1.

An example Operating Plan is shown in Table 1.

Thermal SOL Limit Exceeded	Pre-Contingency (actual) Loading	Post-Contingency (calculated) Loading
Normal (24 hr)	Reconfiguration actions, Redispatch actions, emergency procedures except Load shed consistent with timelines identified in Operating Plan.	Trend – continue to monitor. Take reconfiguration actions to prevent Contingency from exceeding emergency limit consistent with timelines identified in Operating Plan.
Emergency (4 hr)	All of the above plus Load shed only if necessary and appropriate to control loading below 4 hr Emergency Rating consistent with timelines identified in Operating Plan.	Use available effective actions and emergency procedures except Load shed consistent with timelines identified in Operating Plan.
Emergency (15 min)	All of the above plus Load shed to control loading below 15 min Emergency Rating consistent with timelines identified in Operating Plan.	All of the above however, Load shed only if necessary and appropriate to avoid post-Contingency Cascading consistent with timelines identified in Operating Plan.

Table 1. Operating Plan Example

APPLICABLE DEFINITIONS

Real-time Assessment – An evaluation of system conditions using Real-time data to assess existing (pre-Contingency) and potential (post-Contingency) operating conditions. The assessment shall reflect applicable inputs including, but not limited to: load, generation output levels, known Protection System and Special Protection System status or degradation, Transmission outages, generator outages, Interchange, Facility Ratings, and identified phase angle and equipment limitations. (Real-time Assessment may be provided through internal systems or through third-party services.)

Operational Planning Analysis – An evaluation of projected system conditions to assess anticipated (pre-Contingency) and potential (post-Contingency) conditions for next-day operations. The evaluation shall reflect applicable inputs including, but not limited to, load forecasts; generation output levels; Interchange; known Protection System and Special Protection System status or degradation; Transmission outages; generator outages; Facility Ratings; and identified phase angle and equipment limitations. (Operational Planning Analysis may be provided through internal systems or through third-party services.)

Changes made to the definitions of Real-time Assessment and Operational Planning Analysis were made in order to respond to issues raised in NOPR paragraphs 55, 73, and 74 dealing with analysis of SOLs in all time horizons, questions on Protection Systems and Special Protection Systems in NOPR paragraph 78, and recommendations on phase angles from the SW Outage Report (recommendation 27). The intent of such changes is to ensure that Real-time Assessments and Operational Planning Analysis contain sufficient details to result in an appropriate level of situational awareness. Some examples include: 1) analyzing phase angles which may result in the implementation of an Operating Plan to adjust generation or curtail transactions so that a Transmission facility may be returned to service, or 2) evaluating the impact of a modified Contingency resulting from the status change of a Special Protection Scheme from enabled/in-service to disabled/out-of-service.

Operating Plan – A document that identifies a group of activities that may be used to achieve some goal. An Operating Plan may contain Operating Procedures and Operating Processes. A company-specific system restoration plan that includes an Operating Procedure for black-starting units, Operating Processes for communicating restoration progress with other entities, etc., is an example of an Operating Plan.

Operating Process – A document that identifies general steps for achieving a generic operating goal. An Operating Process includes steps with options that may be selected depending upon Real-time conditions. A guideline for controlling high voltage is an example of an Operating Process.

Operating Procedure – A document that identifies specific steps or tasks that should be taken by one or more specific operating positions to achieve specific operating goal(s). The steps in an Operating Procedure should be followed in the order in which they are presented, and should be performed by the position(s) identified. A document that lists the specific steps for a System Operator to take in removing a specific transmission line from service is an example of an Operating Procedure.

Time Horizons

When establishing a time horizon for each requirement, the following criteria should be used:

- **Long-term Planning** – a planning horizon of one year or longer.
- **Operations Planning** – operating and resource plans from day-ahead up to and including seasonal.
- **Same-Day Operations** – routine actions required within the timeframe of a day, but not Real-time.
- **Real-time Operations** – actions required within one hour or less to preserve the reliability of the Bulk Electric System.

Facility Rating – The maximum or minimum voltage, current, frequency, or real or reactive power flow through a facility that does not violate the applicable equipment rating of any equipment comprising the facility.

Normal Rating – The rating as defined by the equipment owner that specifies the level of electrical loading, usually expressed in megawatts (MW) or other appropriate units that a system, facility, or element can support or withstand through the daily demand cycles without loss of equipment life.

Emergency Rating – The rating as defined by the equipment owner that specifies the level of electrical loading or output, usually expressed in megawatts (MW) or Mvar, or other appropriate units, that a system, facility, or element can support, procedure, or withstand for a finite period. The rating assumes acceptable loss of equipment life or other physical or safety limitations for the equipment involved.