Technical Justification of Reactive Power Sizing

1.0 Problem Statement

The focus of this section is to discuss some of the technical considerations of Inclusion I5 in order to better establish the impact of reactive resources on the BES. Inclusion I5 specifically includes in the Definition of Bulk Electric System, Phase 1:

> **I5 -** Static or dynamic devices (excluding generators) dedicated to supplying or absorbing Reactive Power that are connected at 100 kV or higher, or through a dedicated transformer with a high-side voltage of 100 kV or higher, or through a transformer that is designated in Inclusion I1.

Inclusion I5 does not possess a threshold in terms of reactive resource sizing. As a result, all reactive resources are automatically considered to fall within the BES, regardless if their nameplate rating is 1 Mvar or 100 Mvar. This has the potential to lead to many reactive resource islands within the BES, especially within Radial Systems and Local Networks (as defined in Exclusions E1 and E3 respectively), wherein reactive resources are commonly used for voltage control and in some cases for load power factor correction.

As such, the System Analysis and Modeling Subcommittee (SAMS) were tasked with consideration of an appropriate reactive threshold for including reactive devices as part of the BES.

2.0 Current BES Reactive Power Sizing

Currently, the proposed BES definition does not possess a bright line for determining the size of reactive resources that will be included within the BES. The BES core definition assumes that all reactive devices connected at 100kV and above are included in the BES; Inclusion I5 serves to extend the definition to reactive devices attached through dedicated transformers to the BES, so that devices such as STATCOMs and SVCs will be included, as well as reactive devices connected to the tertiary windings of BES transformers. Exclusion E4 provided an exemption for reactive devices installed specifically for customer reactive support:

> **E4 -** Reactive Power devices owned and operated by the retail customer solely for its own use.

Neither the core definition, nor Inclusion I5, nor Exclusion E4, provides Mvar thresholds.

3.0 Reliability Issues

Reactive support/control is a fundamental consideration in the operation of the BES. Many reactive resources are located on sub-100 kV systems (e.g. the low side of power transformers in sub-transmission or distribution substations), where they can most effectively offset the reactive demands of the load, and where they are often less expensive to install and maintain. While these devices are associated with the load and not necessarily integral to BES operation, the lower resultant current magnitude on the BES not only reduces losses but also supports voltages and frees capability on transmission lines, both of which are benefits to BES reliability. These devices reduce the current requirements on the BES because they supply power factor compensation. However; they are associated with the load and are not an integral in the operation of the BES.

There are, of course, reactive resources connected at a variety of voltage levels whose primary function is to provide reactive support and voltage control, and which then have a direct impact on the reliable operation of the BES.

4.0 Technical Alternatives Considered in Selecting a Mvar Threshold

A few alternative approaches were pursued. These include:

- Mimicking the typical reactive output of a 20MVA machine (one of the Phase 1 BES generator bright line criteria).
    - Reason for considering this approach: Currently, there is a 20 or 75 MVA threshold for inclusion of generation resources depending upon individual unit or aggregate nameplate capacity respectively. A similar approach could be taken for reactive resources; by examining the reactive capability of a 20 MVA generator, say 0.8 per unit nameplate at maximum capacity, a value of 12 Mvar could be selected. Alternatively, if the range of typical reactive output is considered, say at 0.85 power factor, a value of 10.5 Mvar could be selected.
    - Reason for disregarding this approach: Without a clear technical justification for the generator threshold, and considering potential inconsistencies between the two given that generators and reactive devices have different primary objectives, extending this criteria to reactive resources does not have sound technical basis. Furthermore, reactive resources are not installed for the same reason as generation (i.e., providing active power and earning income) and are typically only installed as required for support of reliable power system operation.
- Determining a number based on the reactive devices presented in modeling cases.

- Reason for considering this approach: This approach has the advantage that, for devices that might be installed with the sole intent of supporting local load power factor, these reactive devices would be netted into the load.
- Reason for disregarding this approach: As with the previous technical consideration, simply knowing the distribution of sizes among reactive devices does not provide technical justification for the selection of a threshold. However, if a threshold of 10.5 Mvar were selected to correspond to the generator threshold, the ERAG 2010 modeling case shows that roughly 5% of the total number of reactive devices directly connected at 100 kV and above are rated less than 10.5 Mvar. Because this represents a very small number of devices, and the nature of the support that these reactive devices provide to the BES depends on their location in the system, applying the BES exception process to exclude a subset of these devices on a case-by-case basis is preferable to providing blanket exclusion.

  It's also understood that the interconnection modeling cases may not give an exact picture of all reactive resources, due to equivalencing and load-netting within the model, and therefore the cases may be reliable sources of data for obtaining these numbers. Furthermore, it can be argued that even load-netted reactive devices could have a significant impact on BES reliability if placed in to or out of service inappropriately.

  A bright line threshold using the above approaches proved undesirable.

5.0 Technical Justification Recommendation

The SAMS agree that devices included in Inclusion I5 are installed to support the BES and therefore should be included. A threshold of zero Mvar for exemption is recommended since reactive devices of all sizes can be installed for the purpose of meeting the TPL standards. A zero-Mvar threshold would ensure that all reactive resources are included. It would then be possible to exclude reactive resources at 100 kV or higher by way of the BES exception process in the rules of procedure.

Exception E4 provides for exclusion of end-customer-owned devices. Reactive resources that do not fall within this exception tend to be installed for voltage control purposes. Reactive resources used for voltage control are of primary concern in terms of BES reliability, regardless of the resource size.

Inclusion I5, in its current state, provides an inherent bright line distinction between devices installed to support the BES and devices installed at lower voltages to provide the reactive component of the load (e.g., power factor correction). Inclusion I5 includes any reactive resource directly connected at 100 kV or above, regardless of its design, configuration of its connecting facility, or its planned operation. Proposing a non-zero MVAR threshold for exemption would be adding unnecessary complexity to the current bright-line inclusion. The current wording of Inclusion I5 in tandem with Exclusion E4 provides clear guidance on what is and is not integral to BES reliability.

Technical Justification of Reactive Power Sizing

1.0 Problem Statement

The focus of this section is to discuss some of the technical considerations of Exclusion E3 in order to better establish the impact of a local network (LN) on the BES. Exclusion E3 specifically excludes in the Definition of Bulk Electric System, Phase 1:

> **E3** - Local networks (LN): A group of contiguous transmission Elements operated at or above 100 kV but less than 300 kV that distribute power to Load rather than transfer bulk power across the interconnected system. LN's emanate from multiple points of connection at 100 kV or higher to improve the level of service to retail customer Load and not to accommodate bulk power transfer across the interconnected system. The LN is characterized by all of the following:
>
> a) Limits on connected generation: The LN and its underlying Elements do not include generation resources identified in Inclusion I3 and do not have an aggregate capacity of non-retail generation greater than 75 MVA (gross nameplate rating);
>
> b) Power flows only into the LN and the LN does not transfer energy originating outside the LN for delivery through the LN; and
>
> c) Not part of a Flowgate or transfer path: The LN does not contain a monitored Facility of a permanent Flowgate in the Eastern Interconnection, a major transfer path within the Western Interconnection, or a comparable monitored Facility in the ERCOT or Quebec Interconnections, and is not a monitored Facility included in an Interconnection Reliability Operating Limit (IROL).

The intent of defining a LN is provide an exemption for transmission systems that solely support local distribution service, and that are not planned, designed, nor operated to benefit, to support the balance of, or to provide transfer capability for the interconnected BES. The design and operation of a LN is intended to be such that, at the points of connection to the BES, their effect on the BES is similar to that of a Radial System (i.e., as in Exclusion E1), particularly in regard to the fact that power flow always moves in a direction that is from the BES into the LN. Any distribution of parallel flows into the LN from the BES, as governed by the fundamentals of parallel electric circuits, is negligible, and, more importantly, is overcome by the load served by the LN, thereby ensuring that the net actual power flow direction will always be into the LN at all interface points. Furthermore, as the presence of a LN is not to support the operability of the interconnected BES, the separation of a LN shall not diminish the reliability of the BES.

In other words, a LN can effectively be treated in the same way as a Radial System but with multiple feeds in to enhance reliability, and as such the characteristics of a LN should match as closely as possible to those of a Radial System.

The requirement in Exclusion E3 states that "power only flows into the LN," which can be interpreted as meaning that no power will flow out of any connection point of the LN, at any time. While LNs may not normally have power flow through them (e.g., they are not permitted to wheel power) in normal or single contingency conditions, the potential exists and persists that parallel power flows through a LN could result following multiple contingencies.

The question also arises as to whether there should be a distinction between active and reactive power flow; does the limitation that "power only flows into the LN" also imply that reactive power is absorbed by the LN at all points of interconnection and at all times?

With regard to these issues, the SAMS was tasked with providing a threshold for permissible flow out of a LN, along with an appropriate duration and associated system conditions. Specifically, the problem statement given to the SAMS from the Definition of BES Standard Drafting Team states:

> "It is anticipated that the technical justification will consist of interconnection-wide studies which target the surrounding BES Elements at the connection points of the subject LN. The studies would utilize the criteria currently established within the definitions of Adequate Level of Reliability[1] and Adverse Reliability Impact[2], to determine the appropriate values for the thresholds associated with the potential power flow out of the LN. The final analysis should indicate the amount of acceptable parallel flow through a LN where a loss of the LN or portions of the LN would not result in a reduction of the reliability of the surrounding interconnected Transmission network."

Beyond the lack of consideration for an allowable flow through a LN (especially in consideration of multiple contingencies), the SAMS discussed that the BES definition would greatly benefit from a bright-line distinction for the maximum allowable size (i.e., load limit) of a LN, and in such a way that a system cannot be subdivided into multiple adjoining LNs. In

[1] From the NERC Glossary of Terms, *Adverse Reliability Impact*: "The impact of an event that results in frequency-related instability; unplanned tripping of load or generation; or uncontrolled separation or cascading outages that affects a widespread area of the Interconnection."

[2] Currently under development for inclusion in the Glossary of Terms, *Adequate Level of Reliability*: "The intent of the set of NERC Reliability Standards is to deliver an Adequate Level of Reliability defined by the following bulk power system characteristics:

- The system is controlled to stay within acceptable limits during normal conditions.
- The system performs acceptably after credible contingencies.
- The system limits the impact and scope of instability and cascading outages when they occur.
- The system's facilities are protected from unacceptable damage by operating them within facility ratings.
- The system's integrity can be restored promptly if it is lost.
- The system has the ability to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components."

other words, multiple LNs should not be directly tied to one another, nor should LNs be embedded or nested within one another. If large amounts of load are not properly taken into account across an interconnection due to exclusion as LNs, then significant impacts to BES reliability, including frequency stability issues and system operating limit violations, could result in the instance of total LN load shed or restoration.

2.0 Current Application of Power flow out of Local Network

Prior to the adoption of the Phase 1 BES definition, there were significant regional differences in both the definition of BES and its application that may have permitted exclusions for portions of a load-serving transmission network. The Phase 1 definition Exclusion E3 for Local Networks is intended to standardize this exclusion for systems that are often referred as "load pockets," along with the transmission elements that connect them, assuming that the transmission elements are all operated at voltages of at least 100 kV but less than 300 kV, and the underlying generation inclusions and exclusions are met.

3.0 Reliability Issues

The SAMS believes that the 300 kV ceiling for qualification as a LN (and subsequently non-BES) element is appropriate and reasonable, being consistent with the distinction between Extra High Voltage and High Voltage applied in the NERC Board of Trustees approved Reliability Standard TPL-001-2, and since Extra High Voltage networks are generally designed for bulk power transfer and not serving load.

The interaction between a LN and the BES needs to be considered. Of primary concern to the SAMS is that providing a blanket exclusion for a LN of potentially unlimited size could lead to the exclusion of very large networks, which would compromise the reliability of the BES; as hyperbolic examples, large urban networks such as found in San Francisco, Chicago and Atlanta could be excluded. The loss of such large networks could have far-reaching interconnection-wide system impacts. The definition does not provide a bright line as to the amount of load that can be severed by a LN.

4.0 Technical Alternatives Considered for Defining Acceptable Flow out of a LN

Some alternatives were explored by the SAMS for determining what the maximum allowable outward or parallel flow through a network might be acceptable for a LN. The alternative with the strongest technical basis considered was:

4.1. Using generation limits set forth elsewhere in the BES Phase 1 definition.

- Reason for considering this approach: Applying a limit on outward flow from a LN corresponding with the 75 MVA embedded generation maximum would provide consistency with the Radial System Exclusion E1.
- Reason for disregarding this approach: Unlike Radial Systems where the outward flow will always occur at a single point of connection to the BES, permitting

outward flow of generation at any terminal of the LN, without knowing or considering the internal conditions within the LN, may lead to unpredictable impacts to the overlying BES. Furthermore, without a clear technical justification for the generator threshold, extending this threshold to LN does not have a sound technical basis.

4.2 Using outage transfer distribution factors (OTDF) to define a threshold.

- Reason for considering this approach: Outage transfer distribution factors (OTDF) represent the percentage of a power transfer that flows through the monitored facility for a particular transfer when the contingency facility is switched out of service. In relation to an LN, the monitored facilities would include the terminals of the LN, and the contingency facilities would include BES elements in parallel with the local network. The Flowgate Methodology described in MOD-030-2 sets a threshold for OTDF of 5%, in conjunction with other criteria, for including a monitored facility as a Flowgate; in a similar fashion, an OTDF 5% or less could be selected as a reasonable threshold for defining the permissible flow through a LN upon BES contingency, and subsequently determining a reasonable amount of flow out of a LN.
- Reason for disregarding this approach: While computation of OTDF and related factors are commonplace calculations and well-understood, such factors do not necessarily form a "bright line" for exclusion from the BES; the permitted MW flow computed OTDF will depend on the contingency element, and will be heavily dependent upon system conditions. Appropriate system conditions and contingencies would need to be specified, complicating the definition and supporting analysis, and potentially leading to inconsistencies in application.

These proposed alternatives were discarded because each alternative would be the source of potential confusion for the already established bright line criteria.

5.0 Technical Justification Recommendation

The SAMS recommend that two core components of Exclusion E3 be adjusted. When these changes are applied in conjunction with the definition, the concept of a Local Network is preserved, without confusing the bright line distinction between a LN and the BES. The first of these adjustments is related to item b, with changes in bold:

a. **Active** power flows only into the LN **from every point of connection to the BES for the system as planned and single contingency[3] operation**, and the LN does not transfer energy originating outside the LN for delivery through the LN to the network

[3] *Single Contingency* is used in the same context as it is applied in the TPL-001-2 Standard; i.e., the loss of a single generator, transmission circuit, transformer, or shunt device, or the loss of a single pole of a DC line.

If power flows out of the network at any interconnection point at under normal or single contingencies, then at least some portion of the LN is being used to transfer power for the overlying network. The portions of a proposed LN that allow parallel flow through must be removed from the LN, and the remaining portions of the proposed LN should be further studied to ensure that they do not participate in such flows.

The SAMS also considered specifying that both active and reactive power must flow into the LN. The "**Active** power" clarification is recommended to align with the SAMS recommendation on Inclusion I5 for an appropriate reactive device threshold; if all reactive devices directly to the BES are included in the BES definition, then their impact to BES reliability will be accounted for independently of the application of Exclusion E3. In this way, the SAMS accepts that some reactive power may be delivered by a LN to the BES as conditions internal to the LN change in the same way that, under some conditions, reactive power may be delivered to the BES by a load-serving distribution network.

Limiting the study of a proposed LN for "the system as planned", i.e., over the planning horizon, would permit some outward flow of MW or Mvar during conditions not otherwise considered normal, such as during maintenance.

The "single contingency" verbiage was added for clarity. The intent would be to study single contingencies on the BES outside of the LN, and monitor for any outward flow. The expectation of performance for multiple contingencies is much more difficult to define, as the study of multiple contingencies requires closer examination of credible contingencies; furthermore, the existing Reliability Standards call for the system to be operated to N-1 conditions, so enforcing a single contingency requirement would imply that the definition of LN would hold under NERC mandated operating conditions.

The single contingency load flow test is not to be a burden to administer. First contingency analysis is required to be performed annually as part of the TPL requirements. The purpose of basing the determination on the planning horizon is to preserve the bright-line so that the facilities can be characterized as they are planned to be operated, and avoids the need to constantly reclassify elements in light of the myriad of operating conditions that may occur on the system.

Under any definition, Local Networks will still need to be modeled to an adequate level to support any required studies and analysis.

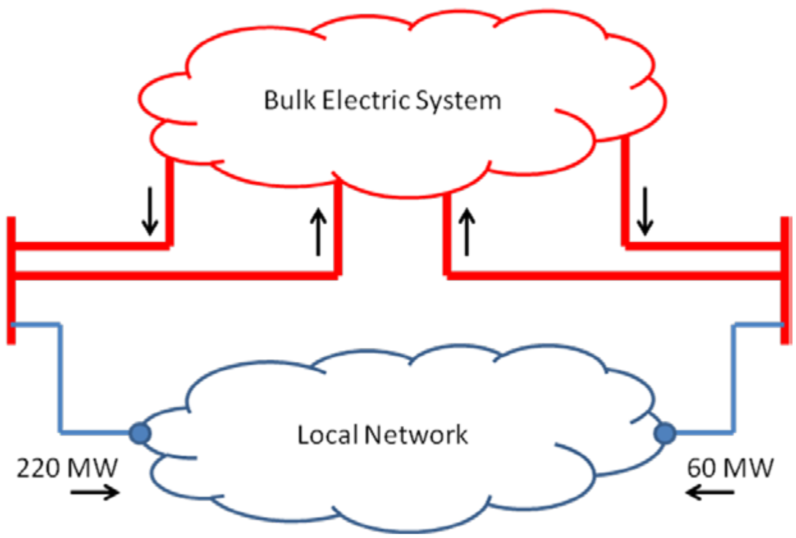
The second adjustment recommended by the SAMS is the addition of a gross load limit in the form of an item d:

d) The gross load served by the Local Network is less than 300 MW.

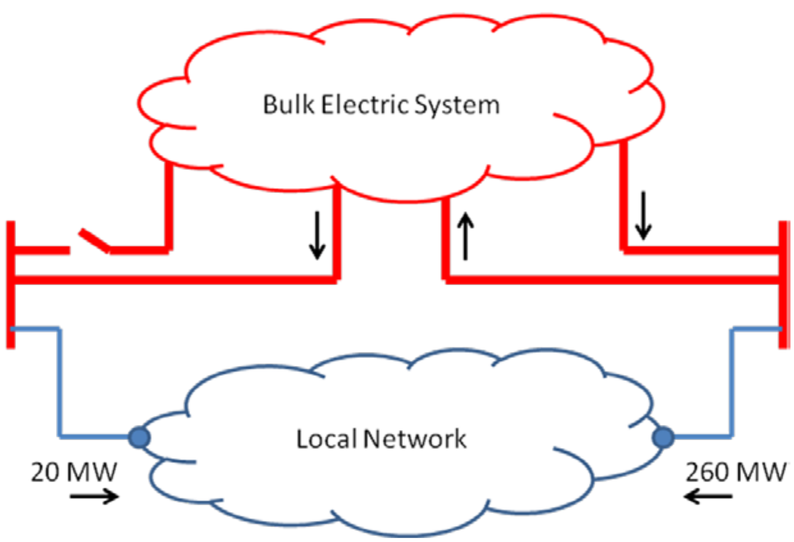
The limit of 300 MW was selected based on surveys of the typical size of tapped and radial load, and for consistency with other established reporting norms. For example, DOE OE-417 requires reporting within 1 hour for "Uncontrolled loss of 300 Megawatts (MW) or more of firm system loads for more than 15 minutes from a single incident."

Even for zero outward power flow as allowed in the LN definition, this 300 MW load limit could entail a change in flow on the terminals of the overlying BES of up to 300 MW (i.e., a 300 MW swing between two terminals of the LN). A very simple illustration is provided follows, based on an actual network. Higher voltage networks and the BES are depicted in red, and a lower voltage network to be considered as a LN in blue.

Under normal operating conditions, say that a two-terminal LN is receiving 220 MW on its western terminal and 60 MW on the eastern one:



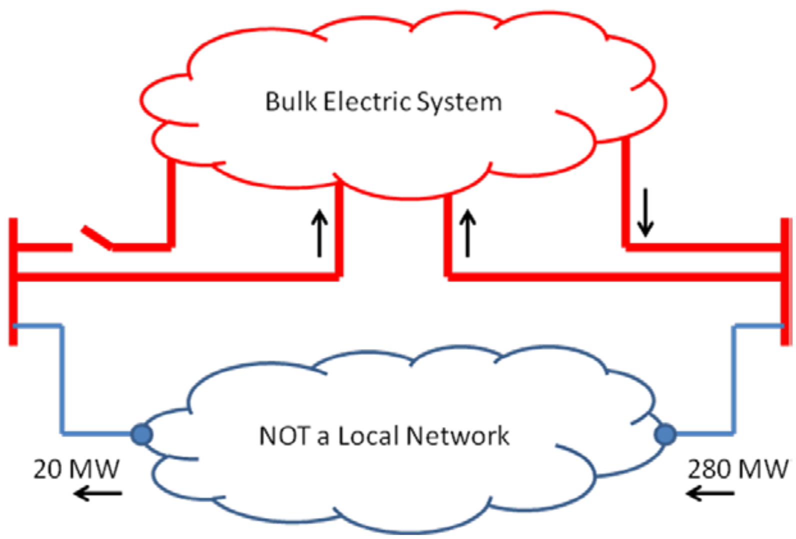
For a single BES contingency, the flow into the LN shifts by from west to east by 200 MW, so that the LN is now receiving 20 MW on its western terminal and 260 on its eastern one:



The 200 MW shift would be reflected in the BES, and would be picked up by one of BES transmission lines on the eastern side of the system; this change could represent a substantial increase in loading for the affected line.

If a gross load limit was not placed on the size of the LN, then such a shift could be much larger, and the resultant impact to the BES could be significant. In a similar vein, consideration also may need to be given to limiting the size of a Radial System (identified in Exclusion E1) since the total loss of load in the Radial System could have a similarly significant impact to the BES depending on its location in the system.

Now consider the same system, but as a result of conditions within what was previously considered a LN (for example, non-BES generation dispatch and shifting load), the power now flows through the lower voltage system:



In this case, the lower voltage system is not a LN since it is supporting flow through to the BES.