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White Paper on Bulk Electric System Radial Exclusion (E1) Low Voltage Loop Threshold

September 2013

RELIABILITY | ACCOUNTABILITY

Project 2010-17: Definition of Bulk Electric System

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Bulk Electric System Radial Exclusion (E1)
Low Voltage Loop Threshold

Background

The definition of "Bulk Electric System" (BES) in the NERC Glossary consists of a core definition and a list of facilities configurations that will be included or excluded from the core definition. The core definition is used to establish the bright line of 100 kV, the overall demarcation point between BES and non-BES elements. Exclusion E1 applies to radial systems. In Order No. 773 and 773-A, the Federal Energy Regulatory Commission's (Commission or FERC) expressed concerns that facilities operating below 100 kV may be required to support the reliable operation of the interconnected transmission system. The Commission also indicated that additional factors beyond impedance must be considered to demonstrate that looped or networked connections operating below 100 kV need not be considered in the application of Exclusion E1.[1]

This document responds to the Commission's concerns and provides a technical justification for the establishment of a voltage threshold below which sub-100 kV equipment need not be considered in the evaluation of Exclusion E1.

> *NOTE: This justification does not address whether sub- 100 kV systems should be evaluated as Bulk Electrical System (BES) Facilities. Sub- 100 kV systems are already excluded from the BES under the core definition. Order 773, paragraph 155 states: "Thus, the Commission, while disagreeing with NERC's interpretation, does not propose to include the below 100 kV elements in figure 3 in the bulk electric system, unless determined otherwise in the exception process." This was reaffirmed by the Commission in Order 773A, paragraph 36: "Moreover, as noted in the Final Rule, the sub-100 kV elements comprising radial systems and local networks will not be included in the bulk electric system, unless determined otherwise in the exception process." Sub-100 kV facilities will only be included as BES Facilities if justified under the NERC Rules of Procedure (ROP) Appendix 5C Exception Process.*

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[1] *Revisions to Electric Reliability Organization Definition of Bulk Electric System and Rules of Procedure*, Order No. 773, 141 FERC ¶ 61,236 at P155, n.139 (2012); *order on reh'g*, Order No. 773-A, 143 FERC ¶ 61,053 (2013).

Executive Summary

The Project 2010-17 Standard Drafting Team conducted a two-step process to establish a technical justification for the establishment of a voltage threshold below which sub-100 kV loops do not affect the application of Exclusion E1. The justification for establishing a lower voltage threshold for application of Exclusion E1 consisted of a two-step technical approach:

- Step 1: A review was performed to determine the minimum voltage levels that are monitored by Balancing Authorities, Reliability Coordinators, and Transmission Operators for Interfaces, Paths, and Monitored Elements. This minimum voltage level reflects a value that industry experts consider necessary to monitor and facilitate the operation of the Bulk Electric System (BES). This step provided a technically sound approach to screen for a minimum voltage limit that served as a starting point for the technical analysis performed in Step 2 of this study.

- Step 2: Technical studies modeling the physics of loop flows through sub-100 kV systems were performed to establish which voltage level, while less than 100 kV, should be considered in the evaluation of Exclusion E1.

The analysis establishes that a 50 kV threshold for sub-100 kV loops does not affect the application of Exclusion E1. This approach will ease the administrative burden on entities as it negates the necessity for an entity to prove that they qualify for Exclusion E1 if the sub-100 kV loop in question is less than or equal to 50 kV. This analysis provides an equally effective and efficient alternative to address the Commission's directives expressed in Order No. 773 and 773-A.

It should be noted that, although this study resulted in a technically justified 50 kV threshold based on proven analytic methods, there are other preventative loop flow methods that entities can apply on sub-100 kV loop systems to address physical equipment concerns. These methods include:

- Interlocked control schemes;
- Reverse power schemes;
- Transformer, feeder and bus tie protection; and
- Custom protection and control schemes.

These methods are discussed in detail in Appendix 4. The presence of such equipment does not alter the criteria developed in this white paper, nor does it influence the conclusions reached. Additionally, the presence of this equipment does not remove or lessen an entity's obligations associated with the bright-line application of the Bulk Electric System (BES) definition.

Radial Systems Exclusion (E1)

The proposed definition (first posting) of radial systems in the Phase 2 BES Definition (Exclusion E1) was: *A group of contiguous transmission Elements that emanates from a single point of connection of 100 kV or higher and:*

- *a) Only serves Load. Or,*
- *b) Only includes generation resources, not identified in Inclusions I2 and I3, with an aggregate capacity less than or equal to 75 MVA (gross nameplate rating). Or,*
- *c) Where the radial system serves Load and includes generation resources, not identified in Inclusions I2 and I3, with an aggregate capacity of non-retail generation less than or equal to 75 MVA (gross nameplate rating).*

Note 1 – A normally open switching device between radial systems, as depicted on prints or one-line diagrams for example, does not affect this exclusion.

Note 2 - The presence of a contiguous loop, operated at a voltage level of 30 kV or less[2]*, between configurations being considered as radial systems, does not affect this exclusion.*

STEP 1 – Establishment of Minimum Monitored Regional Voltage Levels

All operating entities have guidelines to identify the elements they believe need to be monitored to facilitate the reliable operation of the interconnected transmission system. Pursuant to these guidelines, operating entities in each of the eight Regions in North America have identified and monitor key groupings of the transmission elements that limit the amount of power that can be reliably transferred across their systems. The groupings of these elements have different names: for instance, Paths in the Western Interconnection; Interfaces or Flowgates in the Eastern Interconnection; or Monitored Elements in the Electric Reliability Council of Texas (ERCOT). Nevertheless, they all constitute element groupings that operating entities (Reliability Coordinators, Balancing Authorities, and Transmission Operators) monitor because they understand that they are necessary to ensure the reliable operation of the interconnected transmission system under diverse operating conditions.

To provide information in determining a voltage level where the presence of a contiguous loop between system configurations may not affect the determination of radial systems under Exclusion E1 of the BES definition, voltage levels that are monitored on major Interfaces, Flowgates, Paths, and ERCOT Monitored Elements were examined. This examination focused on elements owned and operated by entities in North America. The objective was to identify the lowest monitored voltage level on these key element groupings. The lowest monitored line voltage on the major element groupings provides an indication of the lower limit which operating entities have historically believed necessary to ensure the

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[2] The first posting of this Phase 2 definition used a threshold of 30 kV; however as a result of the study work described in this paper, the Standard Drafting Team has revised the threshold to 50 kV for subsequent industry consideration.

reliable operation of the interconnected transmission system. The results of this analysis provided a starting point for the technical analysis which was performed in Step 2 of this study.

Step 1 Approach

Each Region was requested to provide the key groupings of elements they monitor to ensure reliable operation of the interconnected transmission system. This list, contained in Appendix 1, was reviewed to identify the lowest voltage element in the major element groupings monitored by operating entities in the eight Regions. Identification of this lowest voltage level served as a starting point to begin a closer examination into the voltage level where the presence of a contiguous loop should not affect the evaluation of radial systems under Exclusion E1 of the BES definition.

Step 1 Results

An examination of the line listings of the North American operating entities revealed that the majority of operating entities do not monitor elements below 69 kV as shown in Table 1. However, in some instances elements with line voltages of 34.5 kV were included in monitored element groupings. In no instance was a transmission line element below 34.5 kV included in the monitored element groupings.

Region	Key Monitored Element Grouping	Lowest Line Element Voltage
FRCC	Southern Interface	115
MRO	NDEX	69
NPCC	Total East PJM (Rockland Electric) – Hudson Valley (Zone G)[1]	34.5
RFC	MWEX	69
SERC	VACAR IDC[2]	100
SPP RE	SPSNORTH_STH	115
TRE	Valley Import GTL	138
WECC	Path 52 Silver Peak – Control 55 kV	55

Notes:

1. Two interfaces in NPCC/NYISO have lines with 34.5 kV elements.
2. The TVA area in SERC was not included in the tables attached to this report; however, a review of the Flowgates in TVA revealed monitored elements no lower than 115 kV. There were a number of Flowgates with 115 kV monitored elements in SERC, the monitored grouping listed is representative.

Table 1: Lowest Line Element Voltage Monitored by Region

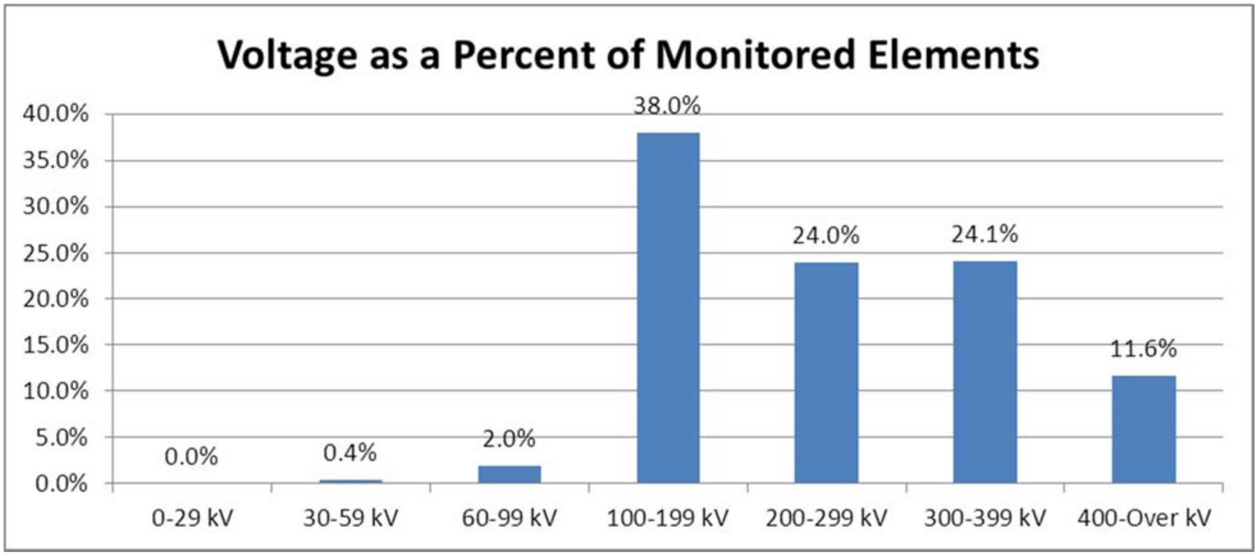
In a few rare occasions there were transformer elements with low-side windings lower than 30 kV included in the key monitored element groupings as shown in Table 2.

Region	Interface	Element	Voltage (kV)
NPCC/NYISO	WEST CENTRAL: Genesee (Zone B) – Central (Zone C)	(Farmtn 34.5/115kV&12/115 kV) #4 34.5/115 & 12/115	12/115
NPCC/ISO-NE	New England - Southwest Connecticut	SOTHNGTN 5X - Southington 115 kV /13.8 kV Transformer (4C-5X)	115/13.8
		SOTHNGTN 6X - Southington 115 kV /13.8 kV Transformer (4C-6X)	115/13.8
		SOTHNGTN 11X - Southington 115 kV /27.6 kV Transformer (4C-11X)	115/27.6

Table 2: Lowest Line Transformer Element Voltages Monitored by Region

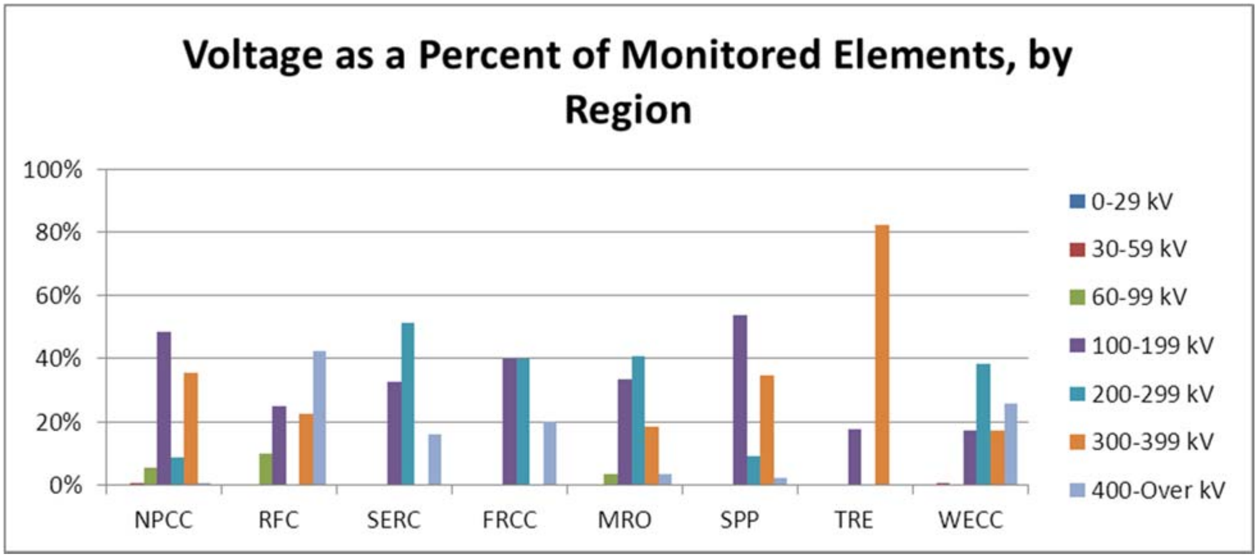
Upon closer investigation, for New England's Southwest Connecticut interface, it was determined that the inclusion of these elements was the result of longstanding, historical interface definitions and not for the purpose of addressing BES reliability concerns. Transformers serving lower voltage networks continue to be included based on familiarity with the existing interface rather than a specific technical concern. These transformers could be removed from the interface definition with no impact on monitoring the reliability of the interconnected transmission system. For the New York West Central interface, the low voltage element was included because the interface definition included boundary transmission lines between Transmission Owner control areas; hence, it was included for completeness to measure the power flow from one Transmission Owner control area to the other Transmission Owner control area.

Further examination of the information provided by the eight NERC regions revealed that half of the Regions only monitor transmission line elements with voltages above the 100 kV level. The other four Regions, NPCC, RFC, MRO, and WECC, monitor transmission line elements below 100 kV as part of key element groupings. However, in each of these cases, the number of below 100 kV transmission line elements comprised less than 2.5% of the total monitored key element groupings. Figures 1 and 2 below depict the results of Step 1 of this study.



Notes:
1. Data/Chart includes Transmission Lines only.
2. Data/Chart is a summary of individual elements (interfaces not included)

Figure 1: Voltage as Percent of Monitored Elements



Notes:
1. Data/Chart includes Transmission Lines only.
2. Data/Chart is a summary of individual elements (interfaces not included)

Figure 2: Voltage as Percent of Monitored Elements per Region

Step 1 Conclusion

The results of Step 1 of this study regarding regional monitoring levels resulted in a determination that 30 kV was a reasonable voltage level to initiate the sensitivity analysis conducted in Step 2 of this study. This value is below any of the regional monitoring levels. As noted herein, an examination of the line listings of the North American operating entities revealed that the majority of operating entities do not monitor elements below 69 kV as shown in Table 1. However, in some instances elements with line voltages of 34.5 kV were included in monitored element groupings. In no instance was a transmission line element below 34.5 kV included in the monitored element groupings.

STEP 2 - Load Flows and Technical Considerations

The threshold of 30 kV was established in Step 1 as a reasonable starting point to initiate the technical sensitivity analysis performed in Step 2 of this study. The purpose of this step was to determine if there is a technical justification to support a voltage threshold for the purpose of determining whether facilities greater than 100 kV can be considered to be radial under the BES Definition Exclusion E1. If the resulting voltage threshold was deemed appropriate through technical study efforts, then contiguous loop connections operated at voltages below this value would not preclude the application of Exclusion E1. Conversely, contiguous loops connecting radial lines at voltages above this kV value would negate the ability for an entity to use Exclusion E1 for the subject facilities.

This study focused on two typical configurations: a distribution loop and a sub-transmission loop. The study evaluated a range of voltages for the loop and the parallel transmission system with the goal of determining the voltage level below which single contingencies on the transmission system would not result in power flow from a low voltage distribution or sub-transmission loop to the BES. The study included sensitivity analysis varying the loads and impedances. Variations in loop and transmission system impedances account for a range of physical parameters such as conductor length, conductor type, system configuration, and proximity of the loop to the transmission system. This study provided the low voltage floor that can be used as a consideration for BES exclusion E1.

Analytical Approach – Distribution Circuit Loop Example

The Project 2010-17 Standard Drafting Team sought to examine the interaction and relative magnitude of flows on the 100 kV and above Facilities of the electric system and those of any underlying low voltage distribution loops. While not the determining factor leading to this study's recommendation, line outage distribution factors (LODF) were a useful tool in understanding the relationship between underlying systems and the BES elements. It illustrated the relative scale of interaction between the BES and the lower voltage systems and its review was a consideration when this study was performed. As an example, the Standard Drafting Team considered a system similar to the one depicted in Figure 3 below. In this simplified depiction of a portion of an electric system, two radial 115 kV lines emanate from 115 kV substations A and B to serve distribution loads via 115 kV distribution transformers at stations C and D. Stations C and D are "looped" together via either a distribution bus tie (zero impedance) or a feeder tie (modeled with typical distribution feeder impedances).

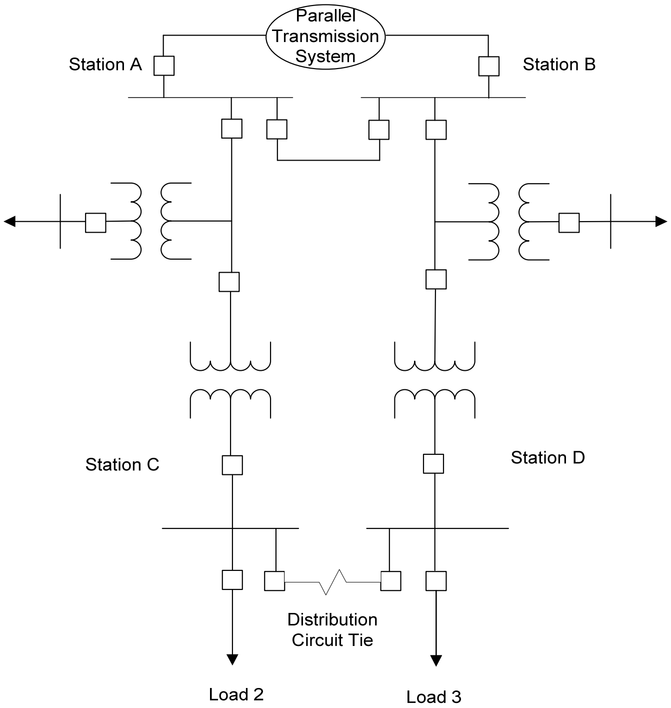


Figure 3: Example Radial Systems with Low Voltage Distribution Loop

With the example system, the Standard Drafting Team conducted power flow simulations to assess the performance of the power system under single contingency outages of the line between stations A and B. The analyses determined the LODF which represent the portion of the high voltage transmission flow that would flow across the low voltage distribution circuit or bus ties under a single contingency outage of the line between stations A and B. To the extent that the LODF values were negligible, this indicated a minor or insignificant contribution of the distribution loops to the operation of the high voltage system. But, more importantly, the analyses determined whether any instances of power flow reversal, i.e., resultant flow delivered into the BES, would occur during contingent operating scenarios. Instances of flow reversal into the BES would indicate that the underlying distribution looped system is exhibiting behavior similar to a sub-transmission or transmission system, which would call into question the applicability of radial exclusion E1.

The study work in this approach examined the sensitivity of parallel circuit flow on the distribution elements to the size of the distribution transformers, the operating voltage of distribution delivery buses at stations C and D and the strength of the transmission network serving stations A and B as manifested in the variation of the transmission network transfer impedances used in the model.
In order to simply, yet accurately, represent this low voltage loop scenario between two radial circuits, a Power System Simulator for Engineering (PSSE) model was created. Elements represented in this model included the following:

- Radial 115 kV lines from station A to station C and station B to station D;
- Interconnecting transmission line from station A to station B;
- Distribution transformers tapped off the 115 kV lines between stations A and C and between stations B and D and at stations C and D;
- Feeder tie impedance to represent a feeder tie (or zero impedance bus tie) between distribution buses at stations C and D;
- Transfer impedance equivalent between stations A and B, representing the strength of the interconnected transmission network[3].

Within this model, parameters were modified to simulate differences in the length and impedance of the transmission lines, the amount of distribution load, the strength of the transmission network supplying stations A and B, the size of the distribution transformers and the character of the bus or feeder ties at distribution Stations C and D.

Distribution Model Simulation

Table 3 below illustrates the domain of the various parameters that were simulated in this distribution circuit loop scenario. A parametric analysis was performed using all combinations of variables shown in each column of the upper portion of Table 3. Sensitivity analysis was performed as indicated in the lower portion of the table.

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[3] The relative strength of the surrounding transmission system network is a function of the quantity of parallel transmission paths and the impedance of those paths between the two source substations. A high number of parallel paths with low impedance translates to a low transfer impedance, which allows power to more readily flow between the stations. Conversely, a low number of parallel paths having higher impedance is represented by a relatively large transfer impedance.

Trans KV	Trans Length	Dist KV	Dist Length	XFMR MVA	Dist Load % rating	Z Transfer
115	10 miles	12.5	0 (bus tie)	10	40	Weak
		23	2 miles	20	80	
		34.5	5 miles	40		
Sensitivity Analysis:		46				Strong Medium

Notes:

1. The “medium” value for transfer impedances was derived from an actual example system in the northeastern US. This was deemed to be representative of a network with typical, or medium, transmission strength. Variations of a stronger (more tightly coupled) and a weaker transmission network were selected for the “strong” and “weak” cases, respectively. Impedance values of X=0.54%, X=1.95%, and X=4.07% were applied for the strong, medium and weak cases, respectively.

Table 3: Model Parameters Varied

The model was used to examine a series of cases simulating a power transfer on the 115 kV line[4] from station A to station B of slightly more than 100 MW. Loads and impedances were simulated at the location shown in Figure 5 of Appendix 2. Two load levels were used in each scenario: 40% of the rating of the distribution transformer and 80% of the rating. Distribution transformer ratings were varied in three steps: 10 MVA, 20 MVA, and 40 MVA. Finally, the strength of the interconnected transmission network was varied in three steps representing a strong, medium, and weak transmission network. The choices of transfer impedance were based on typical networks in use across North America. A specific model from the New England area of the United States yielded an actual transfer impedance of 0.319 + j1.954%. This represents the ’medium’ strength transmission system used in the analyses. The other values used in the study are minimum (’strong’) and maximum (’weak’) ends of the typical range of transfer impedances for 115 kV systems interconnected to the Bulk Electric System of North America. Distribution feeder connections were simulated in three different ways, first with zero impedance between the distribution buses at stations C and D, second with a 2-mile feeder connection with typical overhead conductor, and third with a 5-mile connection.

Distribution Model Results

23 kV Distribution System

The results show LODFs ranging from a low of 0.2% to a high of 6.7%. In all of the cases, the direction of power flow to the radial lines at stations A and B was *toward* stations C and D. In other words, there were no instances of flow reversal from the distribution system back to the 115 kV transmission system. The lowest LODF was found in the case with the smallest distribution transformers (10 MVA), the 5-mile distribution circuit tie, and the strong transmission transfer impedance. The case with the highest LODF

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[4] The threshold voltage of 115 kV provides conservative results. At a higher voltage, such as 230 kV, the reflection of distribution impedance to the transmission system is significantly larger, and hence, the amount of distribution power flow will be much smaller.

was that which used the largest distribution transformers (40 MVA) with the lightest load and the use of a zero-impedance bus tie between the two distribution stations.

12.5 kV Distribution System

As compared to the simulations using the 23 kV distribution system, the 12.5 kV system model yielded far lower LODF values. This result is reasonable, as the reflection of impedances on a 12.5 kV distribution system will be nearly four times as large as those for a 23 kV distribution system, and the transformer sizes in use at the 12.5 kV class are generally smaller, i.e., higher impedance. As with the cases simulated for the 23 kV system, the 12.5 kV system exhibited a power flow direction in the radial line terminals at stations A and B in the direction of the distribution stations C and D; no flow reversal was seen in any of the contingency cases.

Given the lower voltage of the distribution system, the cases studied at this low voltage level were limited to the scenario with the high transfer impedance value (’weak’ transmission case). This is a conservative assumption as all cases with lower transfer impedance will yield far lower LODF values. With that, the range of LODF values was found to be 1.0% to 6.7%. When compared with the 23 kV system results in the weak transmission case, the range of LODF values was 1.8% to 6.7%. Higher LODF values were found in the cases with the largest transformer size, which is to be expected.

Table 4 below provides a sample of the results of the various simulations that were conducted. The full collection of results is provided in Appendix 3.

Case	**D, KV**	Z_{xfer}	Z_{Dist}	**XFMR MVA**	**Load, MW**	**LODF**
623a5	23	strong	5 mi	10	4	0.2%
623a5pk	23	strong	5 mi	10	8	0.3%
633b0pk	23	strong	0	20	16	0.4%
723c0	23	medium	0	40	16	3.4%
723c5pk	23	medium	5 mi	40	32	1.6%
823b0	23	weak	0	20	8	3.8%
823c0	23	weak	0	40	16	6.7%
812a5	12.5	weak	5 mi	10	4	1.0%
812b0	12.5	weak	0	20	8	3.8%
812b5pk	12.5	weak	5 mi	20	16	1.3%
812c0	12.5	weak	0	40	16	6.7%
834a5pk	34.5	weak	5 mi	10	8	1.7%
834b5pk	34.5	weak	5 mi	20	16	3.0%
834d0	34.5	weak	0	40	16	8.9%
834d0pk	34.5	weak	0	40	32	8.7%
846e0	46	weak	0	50	16	10.3%
846e2	46	weak	2 mi	50	20	9.0%
846e5	46	weak	5 mi	50	20	7.4%

Table 4: Select Sample of Study Results for Distribution Scenario

34.5 kV and 46 kV Distribution Systems

As with the analysis done for the 12.5 kV system, a conservative transfer impedance value, that of the 'weak' transmission network, was used in selecting the transfer impedance to be used in the simulations at 34.5 kV and 46 kV. With this conservative parameter, the simulation results show distribution factors (LODF) ranging from a low of 1.7% to a high of 10.3%. In all of the cases, the direction of power flow to the radial lines remained *from* stations A and B *toward* stations C and D. In other words, there were no instances of flow reversal from the distribution system back to the 115 kV transmission system.

Analytical Approach – Sub-transmission Example

In addition to the distribution circuit loop example described above, the study examined the performance of systems typically described as 'sub-transmission.' The study sought to examine the interaction and relative magnitude of flows on the 100 kV and above Facilities of the interconnected transmission system and those of the underlying parallel sub-transmission facilities. The study considered a system similar to the one depicted in Figure 4 below. In this simplified depiction of a portion of a transmission and sub-transmission system, a 40-mile transmission line connecting two sources with transfer impedance between the two sources representing the parallel transmission network. Each source also supplies a 10-mile transmission line with a load tap at the mid-point of the line, each serving a load of 16 MW. At the end of each of these lines is a step-down transformer to the sub-transmission voltage, where an additional load is served. The two sub-transmission stations are connected by a 25-mile sub-transmission tie line. Loads and impedances were simulated at the location shown in Figure 6 of Appendix 2.

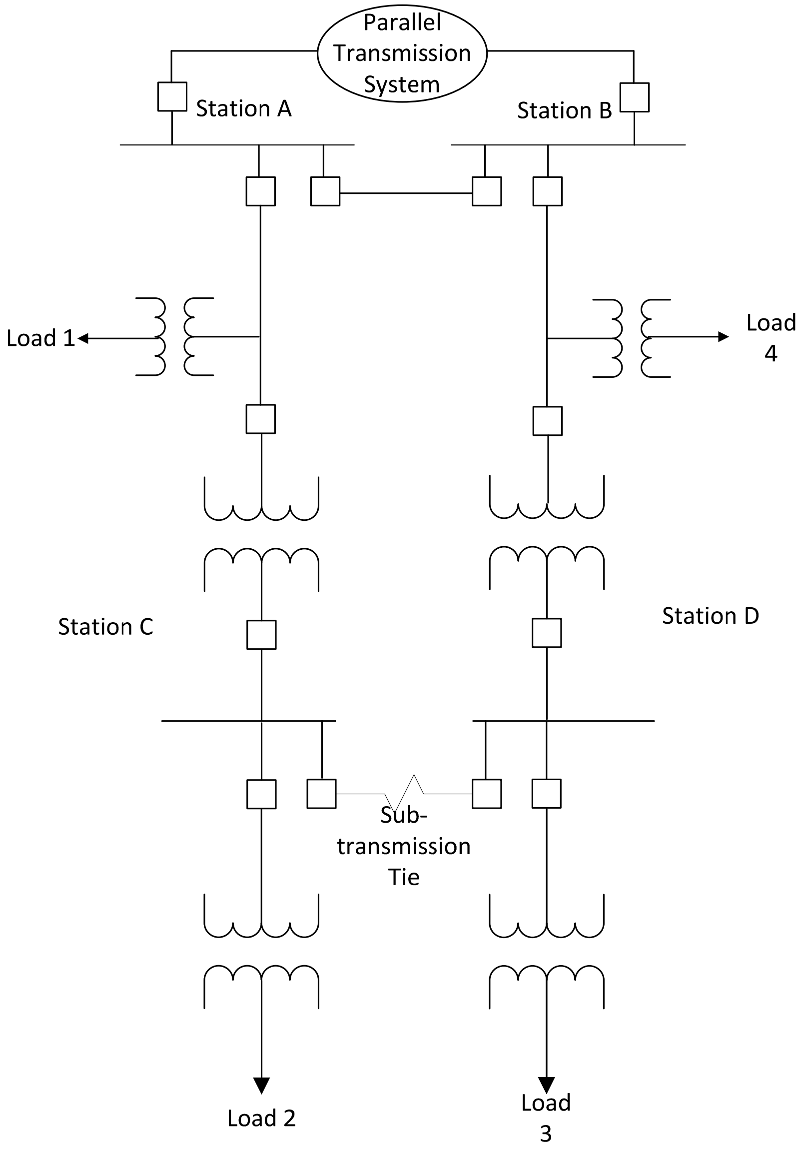


Figure 4: Example Radial Systems with Sub-transmission Loop

Given this example sub-transmission system, a PSSE model was created to simulate the power flow characteristics of the system during a contingency outage of the transmission line between stations A and B. Within this model, parameters were modified to simulate differences in the amount of load being served, transformer size and the amount of pre-contingent power flow on the transmission line. All simulations were performed with a transfer impedance representative of a ‘weak’ transmission network, which was confirmed as conservative in the distribution system analysis.

Sub-transmission Model Simulation

Simulations were performed for each sub-transmission voltage (34.5 kV, 46 kV, 55 kV, and 69 kV) using a transmission voltage of 115 kV. This analysis identified the potential for power flowing back to the transmission system only for sub-transmission voltages of 55 kV and 69 kV. Sensitivity analysis was performed using higher transmission voltages to confirm that cases modeling a 115 kV transmission system yield the most conservative results. Therefore, it was not necessary to perform sensitivity analysis for sub-transmission voltages of 34.5 kV and 46 kV for transmission voltages higher than 115 kV. Table 5 below illustrates the domain of the various parameters that were simulated in this sub-transmission circuit loop scenario. A parametric analysis was performed using combinations of variables shown in each column of Table 5.

Trans KV	Trans Length	Sub-T KV	Sub-T Length	XFMR MVA	Dist Load % rating	Trans MW Preload
115	40 miles	34.5	25 miles	40	40	115
		46		50		
		55		60		
		69				
Sensitivity Analyses:						
138	40 miles	55	25 miles	50	40	115
161		69		60		135
230						150
						220

Table 5: Model Parameters and Sensitivities

Sub-transmission Model Results

115 kV Transmission System with 34.5-69 kV Sub-transmission

The results for cases depicting a 115 kV transmission system voltage and ranges of 34.5 kV to 69 kV sub-transmission voltages show line outage distribution factors (LODF) in the range of 9% to slightly higher than 20%. Several cases show a reversal of power flow in the post-contingent system such that power flow is delivered from the sub-transmission system *into the 115 kV BES*. The worst case is found in the 69 kV sub-transmission voltage class. This result is as expected, given that the impedance of the 69 kV sub-transmission system is less than the impedances of lower voltage systems. In no instance was a reversal of power flow observed in sub-transmission systems rated below 50 kV.

138 kV and 161 kV Transmission Systems with 55-69 kV Sub-transmission

The results for cases of 138 kV and 161 kV transmission system voltages supplying sub-transmission voltages of 55 kV and 69 kV show LODFs ranging from 9% to 16%. These cases also result in reversal of power flows in the post-contingent system such that power flow is delivered from the sub-transmission system into the 115 kV BES.

230 kV Transmission System with 55-69 kV Sub-transmission

By simulating a higher BES source voltage of 230 kV paired with sub-transmission voltages of 55 kV and 69 kV, the transformation ratio is sufficiently large to result in a significant increase to the reflected sub-transmission system impedance. Therefore, in these cases, LODFs range from 5% to 7%, and these cases also show no reversal of power flow toward the BES in the post-contingent system. Table 6 below provides a sample of the results of the various simulations that were conducted. All results are provided in Appendix 3.

Case	T, KV	S-T, KV	Trans Pre-load, MW	XFMR MVA	Load, MW	LODF	Flow Rev to BES?
834d25	115	34.5	115	40	20	9.4%	
846e25	115	46	114	50	20	13.3%	
855e25	115	55	112	50	20	15.7%	Yes
869f25	115	69	110	60	24	20.3%	Yes
855e25-138	138	55	114	50	20	11.7%	
855e25-138’	138	55	134	60	20	11.9%	Yes
869f25-138	138	69	112	60	24	15.6%	Yes
869f25-138’	138	69	132	60	24	15.8%	Yes
855e25-161	161	55	114	50	20	9.1%	
855e25-161’	161	55	155	60	20	9.2%	
869f25-161	161	69	113	60	24	12.5%	
869f25-161’	161	69	153	60	24	12.6%	Yes
855e25-230	230	55	116	50	20	4.9%	
855e25-230’	230	55	219	60	20	5.0%	
869f25-230	230	69	116	60	24	7.0%	
869f25-230’	230	69	218	60	24	7.0%	

Table 6: Select Sample of Study Results for Sub-transmission Scenario

Step 2 Conclusion

After conducting extensive simulations (included in Appendix 3), the results of Step 2 of this analysis indicates that 50 kV is the appropriate low voltage loop threshold below which sub-100 kV loops should not affect the application of Exclusion E1 of the BES Definition. Simulations of power flows for the cases modeled in this study show there is no power flow reversal into the BES when circuit loop operating voltages are below 50 kV. This study also finds, for loop voltages above 50 kV, certain cases result in power flow toward the BES. Therefore, the study concludes that low voltage circuit loops operated below 50 kV should not affect the application of Exclusion E1.

As described throughout the preceding section, the scenarios and configurations utilized in this analysis represent the majority of cases that will be encountered in the industry. The models used in this analysis establish reasonable bounds and use conservative parameters in the scenarios. However, there may be actual cases that deviate from these modeled scenarios, and therefore, results could be somewhat different than the ranges of results from this analysis. Such deviations are expected to be rare and can be processed through the companion BES Exception Process.

Study Conclusion

The Project 2010-17 Standard Drafting Team conducted a two-step study process to yield a technical justification for the establishment of a voltage threshold below which sub-100 kV loops should not affect the application of Exclusion E1.

All operating entities have guidelines to identify the elements they believe need to be monitored to facilitate the reliable operation of the interconnected transmission system. Pursuant to these guidelines, operating entities in each of the eight Regions in North America have identified and monitor key groupings of the transmission elements that limit the amount of power that can be reliably transferred across their systems. The objective of Step 1 was to identify the lowest monitored voltage level on these key element groupings. The lowest monitored line voltage on the major element groupings provides an indication of the lower limit which operating entities have historically believed necessary to ensure the reliable operation of the interconnected transmission system.

As a result of studying such regional monitoring levels, Step 1 concluded that 30 kV was a reasonable voltage level to initiate the sensitivity analysis conducted in Step 2. This is a conservative value as it is below any of the regional monitoring levels.

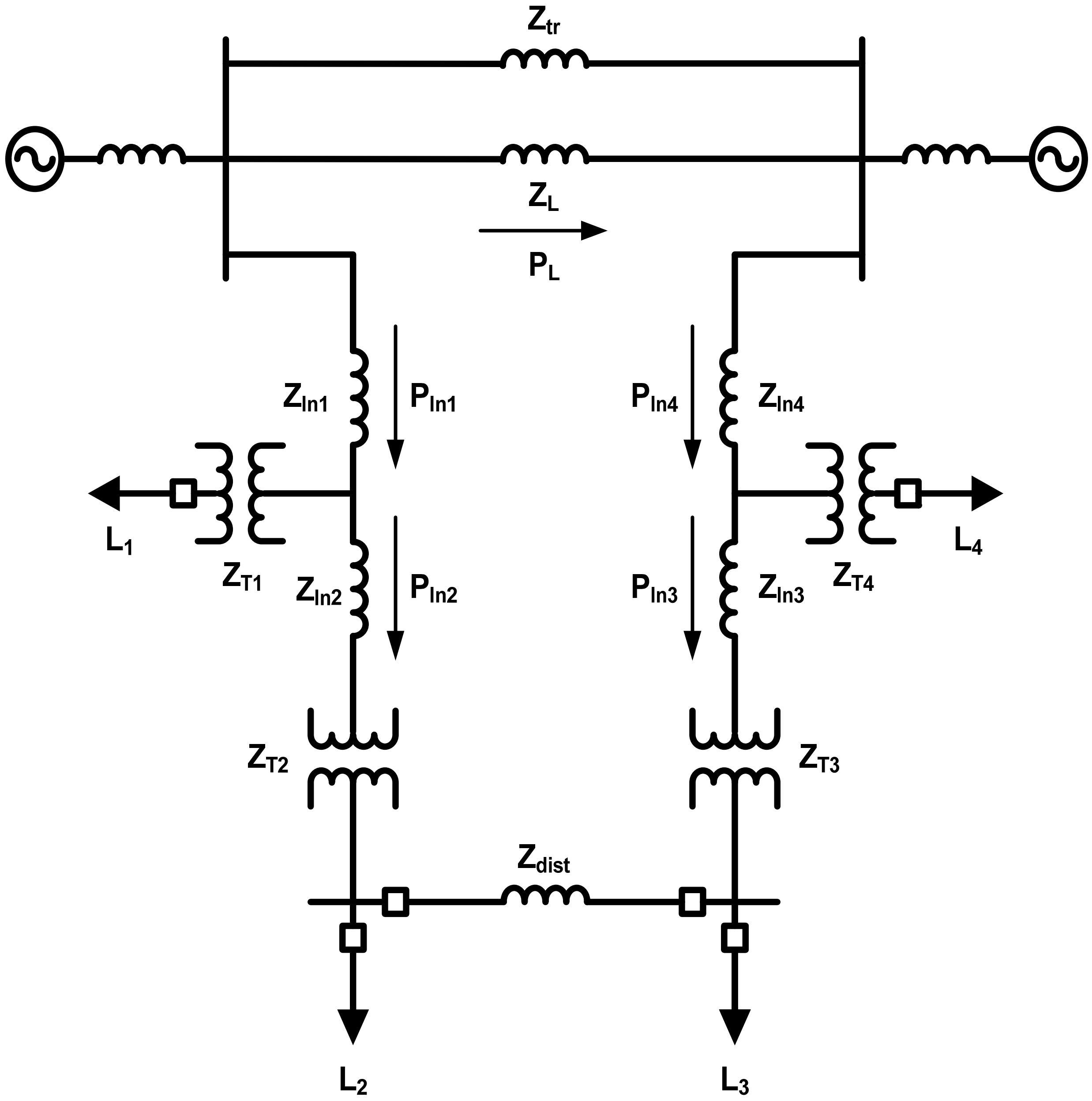
Using the conservative value established by Step 1, the Standard Drafting Team conducted extensive simulations of power flows which demonstrated that there is no power flow reversal into the BES when circuit loop operating voltages are below 50 kV. Therefore, the study concludes that low voltage circuit loops operated below 50 kV should not affect the application of Exclusion E1. This analysis provides an equally effective and efficient alternative to address the Commission’s directives expressed in Order No. 773 and 773-A.

The scenarios and configurations utilized in this analysis represent the majority of cases that will be encountered in the industry. The models used in this analysis establish reasonable bounds and use conservative parameters in the scenarios. However, there may be actual cases that deviate from these modeled scenarios, and therefore, results could be somewhat different than the ranges of results from this analysis. Such deviations are expected to be rare and can be processed through the companion BES Exception Process.

Appendix 1: Regional Elements

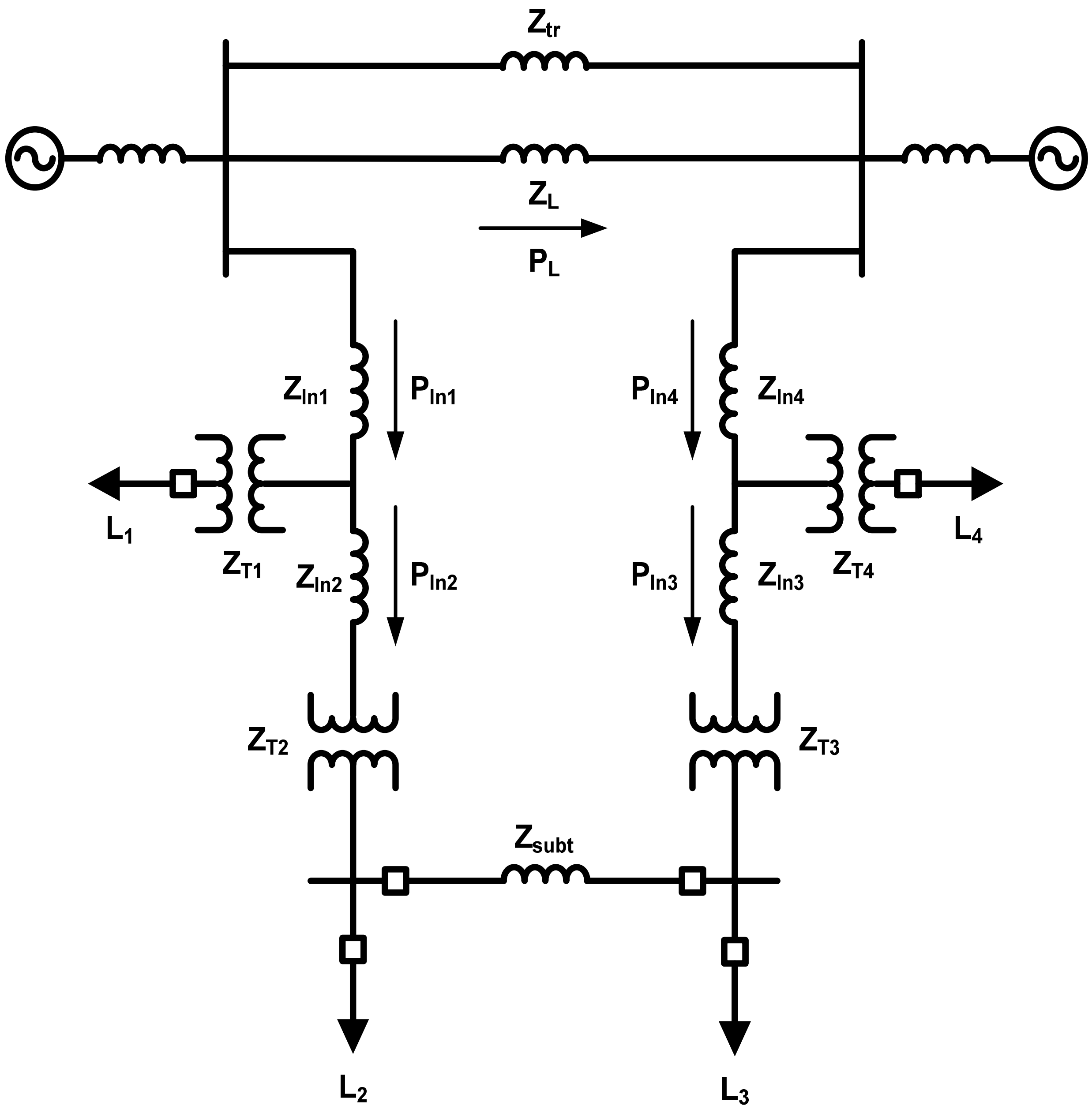
PRIVILEGED AND CONFIDENTIAL INFORMATION HAS BEEN REDACTED FROM THIS PUBLIC VERSION

Appendix 2: One-Line Diagrams



Note: Refer to the notes in Appendix 3 for a description of the symbols in this diagram.

Figure 5: Example Radial Systems with Low Voltage Distribution Tie



Notes: Refer to the notes in Appendix 3 for a description of the symbols in this diagram.
Step-down transformers from sub-transmission voltage to distribution voltage were not explicitly modeled in the simulations.

Figure 6: Example Radial Systems with Sub-transmission Tie

Appendix 3: Simulation Results

Case	Z_L (mi.)	Z_{tr} (mi.)	$Z_{ln1\text{-}4}$ (total mi.)	Z_{dist} (mi.)	Z_{T1}, $Z_{T\text{-}4}$ (Z/MVA)	Z_{T2}, Z_{T3} (Z/MVA)	L_1, L_4 (MW)	L_2, L_3 (MW)	P_L (MVA)	------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				LODF
										P_{ln1} (MVA)	P_{ln2} (MVA)	P_{ln3} (MVA)	P_{ln4} (MVA)	$P_{ln1'}$ (MVA)	$P_{ln2'}$ (MVA)	$P_{ln3'}$ (MVA)	$P_{ln4'}$ (MVA)	
23 kV Base Cases																		
623a0	10	Strong	15	0	10%/10	10%/10	4.0	4.0	110.7	10.9	6.9	1.1	5.1	11.2	7.2	0.8	4.8	0.003
623a2	10	Strong	15	2	10%/10	10%/10	4.0	4.0	110.7	10.7	6.7	1.4	5.4	10.9	6.9	1.1	5.1	0.002
623a5	10	Strong	15	5	10%/10	10%/10	4.0	4.0	110.7	10.3	6.3	1.7	5.7	10.5	6.5	1.5	5.5	0.002
623a0pk	10	Strong	15	0	10%/10	10%/10	8.0	8.0	111.4	19.0	10.9	5.1	13.1	19.3	11.2	4.8	12.8	0.003
623a2pk	10	Strong	15	2	10%/10	10%/10	8.0	8.0	111.4	18.7	10.7	5.4	13.4	18.9	10.9	5.1	13.1	0.002
623a5pk	10	Strong	15	5	10%/10	10%/10	8.0	8.0	111.5	18.3	10.3	5.7	13.7	18.6	10.5	5.5	13.5	0.003
623b0	10	Strong	15	0	10%/20	10%/20	8.0	8.0	111.1	21.7	13.7	2.3	10.3	22.3	14.2	1.8	9.8	0.005
623b2	10	Strong	15	2	10%/20	10%/20	8.0	8.0	111.2	20.7	12.7	3.3	11.3	21.2	13.2	2.9	10.9	0.004
623b5	10	Strong	15	5	10%/20	10%/20	8.0	8.0	111.3	19.7	11.7	4.3	12.3	20.1	12.1	4.0	12.0	0.004
623b0pk	10	Strong	15	0	10%/20	10%/20	16.0	16.0	112.6	37.8	21.7	10.3	26.3	38.3	22.3	9.7	25.8	0.004
623b2pk	10	Strong	15	2	10%/20	10%/20	16.0	16.0	112.7	36.7	20.7	11.3	27.3	37.2	21.2	10.9	26.9	0.004
623b5pk	10	Strong	15	5	10%/20	10%/20	16.0	16.0	112.8	35.7	19.7	12.3	28.4	36.1	20.1	12.0	28.0	0.004

										------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
623c0	10	Strong	15	0	10%/40	10%/40	16.0	16.0	112.2	42.7	26.6	5.4	21.4	43.7	27.7	4.3	20.3	0.009
623c2	10	Strong	15	2	10%/40	10%/40	16.0	16.0	112.5	39.6	23.6	8.4	24.4	40.4	24.4	7.7	23.7	0.007
623c5	10	Strong	15	5	10%/40	10%/40	16.0	16.0	112.7	37.3	21.3	10.8	26.8	37.8	21.8	10.3	26.3	0.004
623c0pk	10	Strong	15	0	10%/40	10%/40	32.0	32.0	115.1	74.9	42.8	21.2	53.3	76.0	43.9	20.2	52.2	0.010
623c2pk	10	Strong	15	2	10%/40	10%/40	32.0	32.0	115.4	71.8	39.7	24.3	56.4	72.6	40.5	23.6	55.6	0.007
623c5pk	10	Strong	15	5	10%/40	10%/40	32.0	32.0	115.6	69.4	37.4	26.7	58.8	70.0	37.9	26.2	58.3	0.005
723a0	10	Medium	15	0	10%/10	10%/10	4.0	4.0	108.3	10.9	6.9	1.1	5.1	11.9	7.9	0.1	4.1	0.009
723a2	10	Medium	15	2	10%/10	10%/10	4.0	4.0	108.3	10.6	6.6	1.4	5.4	11.5	7.5	0.5	4.5	0.008
723a5	10	Medium	15	5	10%/10	10%/10	4.0	4.0	108.4	10.3	6.3	1.8	5.8	11.1	7.1	1.0	5.0	0.007
723a0pk	10	Medium	15	0	10%/10	10%/10	8.0	8.0	110.4	18.9	10.9	5.1	13.1	20.0	12.0	4.0	12.1	0.010
723a2pk	10	Medium	15	2	10%/10	10%/10	8.0	8.0	110.5	18.6	10.6	5.4	13.4	19.6	11.6	4.4	12.5	0.009
723a5pk	10	Medium	15	5	10%/10	10%/10	8.0	8.0	110.6	18.3	10.3	5.7	13.7	19.1	11.1	4.9	12.9	0.007
723b0	10	Medium	15	0	10%/20	10%/20	8.0	8.0	109.7	21.6	13.6	2.4	10.4	23.6	15.6	0.4	8.4	0.018
723b2	10	Medium	15	2	10%/20	10%/20	8.0	8.0	110.0	20.6	12.6	3.4	11.4	22.3	14.3	1.7	9.8	0.015
723b5	10	Medium	15	5	10%/20	10%/20	8.0	8.0	110.2	19.7	11.7	4.4	12.4	21.0	13.0	3.1	11.1	0.012
723b0pk	10	Medium	15	0	10%/20	10%/20	16.0	16.0	114.0	37.8	21.8	10.2	26.3	39.9	23.8	8.2	24.2	0.018
723b2pk	10	Medium	15	2	10%/20	10%/20	16.0	16.0	114.3	36.8	20.8	11.3	27.3	38.5	22.5	9.6	25.6	0.015
723b5pk	10	Medium	15	5	10%/20	10%/20	16.0	16.0	114.5	35.8	19.8	12.3	28.3	37.2	21.1	10.9	27.0	0.012

										------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				
Case	Z_L (mi.)	Z_{tr} (mi.)	Z_{ln1-4} (total mi.)	Z_{dist} (mi.)	Z_{T1}, Z_{T-4} (Z/MVA)	Z_{T2}, Z_{T3} (Z/MVA)	L_1, L_4 (MW)	L_2, L_3 (MW)	P_L (MVA)	P_{ln1} (MVA)	P_{ln2} (MVA)	P_{ln3} (MVA)	P_{ln4} (MVA)	$P_{ln1'}$ (MVA)	$P_{ln2'}$ (MVA)	$P_{ln3'}$ (MVA)	$P_{ln4'}$ (MVA)	LODF
723c0	10	Medium	15	0	10%/40	10%/40	16.0	16.0	112.6	42.7	26.7	5.3	21.3	46.5	31.4	1.6	17.6	0.034
723c2	10	Medium	15	2	10%/40	10%/40	16.0	16.0	113.5	39.7	23.7	8.4	24.4	42.4	26.4	5.7	21.7	0.024
723c5	10	Medium	15	5	10%/40	10%/40	16.0	16.0	114.1	37.4	21.4	10.7	26.7	39.3	23.3	8.8	24.8	0.017
723c0pk	10	Medium	15	0	10%/40	10%/40	32.0	32.0	121.2	75.5	43.4	20.7	52.7	79.5	47.4	16.7	48.7	0.033
723c2pk	10	Medium	15	2	10%/40	10%/40	32.0	32.0	122.0	72.2	40.1	23.9	55.9	75.2	43.1	21.1	53.1	0.025
723c5pk	10	Medium	15	5	10%/40	10%/40	32.0	32.0	122.7	69.8	37.7	26.4	58.5	71.8	39.7	24.4	56.5	0.016
823a0	10	Weak	15	0	10%/10	10%/10	4.0	4.0	106.1	10.8	6.8	1.2	5.2	12.9	8.9	-0.9	3.1	0.020
823a2	10	Weak	15	2	10%/10	10%/10	4.0	4.0	106.2	10.5	6.5	1.5	5.5	12.4	8.4	-0.4	3.6	0.018
823a5	10	Weak	15	5	10%/10	10%/10	4.0	4.0	106.4	10.2	62.0	1.8	5.8	11.9	7.9	0.2	4.2	0.016
823a0pk	10	Weak	15	0	10%/10	10%/10	8.0	8.0	109.6	18.9	10.9	5.1	13.1	21.1	13.0	3.0	11.0	0.020
823a2pk	10	Weak	15	2	10%/10	10%/10	8.0	8.0	109.7	18.6	10.6	5.4	13.4	20.6	12.6	3.5	11.5	0.018
823a5pk	10	Weak	15	5	10%/10	10%/10	8.0	8.0	109.8	18.3	10.3	5.7	13.8	20.0	12.0	4.0	12.1	0.015
823b0	10	Weak	15	0	10%/20	10%/20	8.0	8.0	108.4	21.5	13.5	2.5	10.5	25.6	17.6	-1.6	6.4	0.038
823b2	10	Weak	15	2	10%/20	10%/20	8.0	8.0	108.8	20.6	12.6	3.4	11.4	24.0	16.0	0.1	8.1	0.031
823b5	10	Weak	15	5	10%/20	10%/20	8.0	8.0	109.2	19.6	11.6	4.4	12.4	22.3	14.3	1.8	9.8	0.025
823b0pk	10	Weak	15	0	10%/20	10%/20	16.0	16.0	115.3	37.9	21.9	10.2	26.2	42.2	26.1	5.9	21.9	0.037
823b2pk	10	Weak	15	2	10%/20	10%/20	16.0	16.0	115.7	36.9	20.8	11.2	27.2	40.4	24.4	7.7	23.7	0.030
823b5pk	10	Weak	15	5	10%/20	10%/20	16.0	16.0	116.2	35.9	19.8	12.2	28.2	38.7	22.7	9.4	25.5	0.024

										------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
823c0	10	Weak	15	0	10%/40	10%/40	16.0	16.0	113.1	42.7	26.7	5.3	21.3	50.3	34.3	-2.3	13.7	0.067
823c2	10	Weak	15	2	10%/40	10%/40	16.0	16.0	114.4	39.7	23.7	8.3	24.3	45.4	29.3	2.8	18.8	0.050
823c5	10	Weak	15	5	10%/40	10%/40	16.0	16.0	115.5	37.4	21.4	10.6	26.7	41.4	25.4	6.8	22.8	0.035
823c0pk	10	Weak	15	0	10%/40	10%/40	32.0	32.0	126.7	76.0	43.9	20.2	52.2	84.4	52.3	11.8	43.8	0.066
823c2pk	10	Weak	15	2	10%/40	10%/40	32.0	32.0	128.2	72.7	40.6	23.5	55.6	78.9	48.6	17.4	49.5	0.048
823c5pk	10	Weak	15	5	10%/40	10%/40	32.0	32.0	129.3	70.1	38.0	26.1	58.2	74.5	42.4	21.8	53.9	0.034
Sensitivity to Length of Lines 1-4																		
723a0_30	10	Medium	30	0	10%/10	10%/10	4.0	4.0	108.3	10.8	6.8	1.2	5.2	11.8	7.8	0.2	4.2	0.009
723a2_30	10	Medium	30	2	10%/10	10%/10	4.0	4.0	108.4	10.5	6.5	1.5	5.5	11.4	7.4	0.6	4.6	0.008
723a5_30	10	Medium	30	5	10%/10	10%/10	4.0	4.0	108.5	10.2	6.2	1.8	5.8	11.0	7.0	1.0	5.0	0.007
Selected 34.5 kV cases																		
834a0	10	Weak	15	0	10%/10	10%/10	4.0	4.0	106.1	10.8	6.8	1.2	5.2	12.9	8.9	-0.9	3.1	0.020
834a2	10	Weak	15	2	10%/10	10%/10	4.0	4.0	106.1	10.7	6.7	1.3	5.3	12.7	8.7	-0.7	3.3	0.019
834a5	10	Weak	15	5	10%/10	10%/10	4.0	4.0	106.2	10.5	6.5	1.5	5.5	12.4	8.4	-0.4	3.6	0.018
834a0pk	10	Weak	15	0	10%/10	10%/10	8.0	8.0	109.6	18.9	10.9	5.1	13.1	21.1	13.0	3.0	11.0	0.020
834a2pk	10	Weak	15	2	10%/10	10%/10	8.0	8.0	109.6	18.8	10.8	5.2	13.3	20.8	12.8	3.2	11.2	0.018
834a5pk	10	Weak	15	5	10%/10	10%/10	8.0	8.0	109.7	18.6	10.6	5.4	13.4	20.5	12.5	3.5	11.5	0.017
834b0	10	Weak	15	0	10%/20	10%/20	8.0	8.0	108.4	21.5	13.5	2.5	10.5	25.6	17.6	-1.6	6.4	0.038

										------------ HV Line "L" in-service		------------		-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
834b2	10	Weak	15	2	10%/20	10%/20	8.0	8.0	108.6	21.1	13.1	2.9	10.9	24.8	16.8	-0.7	7.3	0.034
834b5	10	Weak	15	5	10%/20	10%/20	8.0	8.0	108.9	20.5	12.5	3.5	11.5	23.8	15.8	0.3	8.3	0.030
834b0pk	10	Weak	15	0	10%/20	10%/20	16.0	16.0	115.3	37.9	21.9	10.2	26.2	42.2	26.1	5.9	21.9	0.037
834b2pk	10	Weak	15	2	10%/20	10%/20	16.0	16.0	115.5	37.4	21.4	10.7	26.7	41.3	25.3	6.8	22.8	0.034
834b5pk	10	Weak	15	5	10%/20	10%/20	16.0	16.0	115.8	36.8	20.7	11.3	27.3	40.3	24.2	7.8	23.9	0.030
834c0	10	Weak	15	0	10%/40	10%/40	16.0	16.0	113.1	42.7	26.7	5.3	21.3	50.3	34.3	-2.3	13.7	0.067
834c2	10	Weak	15	2	10%/40	10%/40	16.0	16.0	113.8	41.2	25.2	6.9	22.9	47.8	31.7	0.4	16.4	0.058
834c5	10	Weak	15	5	10%/40	10%/40	16.0	16.0	114.6	39.5	23.5	8.5	24.6	45.0	29.0	3.2	19.2	0.048
834c0pk	10	Weak	15	0	10%/40	10%/40	32.0	32.0	126.7	76.0	43.9	20.2	52.2	84.4	52.3	11.8	43.8	0.066
834c2pk	10	Weak	15	2	10%/40	10%/40	32.0	32.0	127.5	74.2	42.1	21.9	54.0	81.5	49.4	14.7	46.8	0.057
834c5pk	10	Weak	15	5	10%/40	10%/40	32.0	32.0	128.3	72.4	40.3	23.8	55.8	78.5	46.4	17.9	49.9	0.048
834d0	10	Weak	15	0	7%/40	7%/40	16.0	16.0	111.6	46.3	30.3	1.7	17.7	56.2	40.1	-8.1	7.9	0.089
834d2	10	Weak	15	2	7%/40	7%/40	16.0	16.0	112.8	43.6	27.6	4.4	20.4	51.8	35.8	-3.6	12.4	0.073
834d5	10	Weak	15	5	7%/40	7%/40	16.0	16.0	113.9	41.1	25.1	7.0	23.0	47.6	31.6	0.6	16.6	0.057
834d0pk	10	Weak	15	0	7%/40	7%/40	32.0	32.0	124.9	80.0	47.9	16.2	48.2	90.9	58.8	5.3	37.3	0.087
834d2pk	10	Weak	15	2	7%/40	7%/40	32.0	32.0	126.3	77.0	44.9	19.2	51.2	86.1	54.0	10.2	42.2	0.072
834d5pk	10	Weak	15	5	7%/40	7%/40	32.0	32.0	127.5	74.2	42.1	22.0	54.1	81.4	49.3	15.0	47.0	0.056

										------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
Selected 12.47 kV cases																		
812a0	10	Weak	15	0	10%/10	10%/10	4.0	4.0	106.1	10.8	6.8	1.2	5.2	12.9	8.9	-0.9	3.1	0.020
812a2	10	Weak	15	2	10%/10	10%/10	4.0	4.0	106.4	10.1	6.1	1.9	5.9	11.6	7.6	0.4	4.4	0.014
812a5	10	Weak	15	5	10%/10	10%/10	4.0	4.0	106.7	9.4	5.4	2.6	6.6	10.5	6.5	1.5	5.5	0.010
812a0pk	10	Weak	15	0	10%/10	10%/10	8.0	8.0	109.6	18.9	10.9	5.1	13.1	21.1	13.0	3.0	11.0	0.020
812a2pk	10	Weak	15	2	10%/10	10%/10	8.0	8.0	109.9	18.1	10.1	5.9	13.9	19.7	11.7	4.3	12.4	0.015
812a5pk	10	Weak	15	5	10%/10	10%/10	8.0	8.0	110.2	17.5	9.5	6.5	14.5	18.6	10.6	5.5	13.5	0.010
812b0	10	Weak	15	0	10%/20	10%/20	8.0	8.0	108.4	21.5	13.5	2.5	10.5	25.6	17.6	-1.6	6.4	0.038
812b2	10	Weak	15	2	10%/20	10%/20	8.0	8.0	109.4	19.2	11.2	4.8	12.8	21.7	13.6	2.5	10.5	0.023
812b5	10	Weak	15	5	10%/20	10%/20	8.0	8.0	110.0	17.9	9.9	6.1	14.1	19.4	11.4	4.7	12.7	0.014
812b0pk	10	Weak	15	0	10%/20	10%/20	16.0	16.0	115.3	37.9	21.9	10.2	26.2	42.2	26.1	5.9	21.9	0.037
812b2pk	10	Weak	15	2	10%/20	10%/20	16.0	16.0	116.4	35.4	19.4	12.6	28.6	38.0	22.0	10.2	26.2	0.022
812b5pk	10	Weak	15	5	10%/20	10%/20	16.0	16.0	117.0	34.1	18.0	14.0	30.0	35.6	19.6	12.6	28.6	0.013
812c0	10	Weak	15	0	10%/40	10%/40	16.0	16.0	113.1	42.7	26.7	5.3	21.3	50.3	34.3	-2.3	13.7	0.067
812c2	10	Weak	15	2	10%/40	10%/40	16.0	16.0	115.9	36.6	20.6	11.5	27.5	40.0	24.0	8.3	24.3	0.029
812c5	10	Weak	15	5	10%/40	10%/40	16.0	16.0	116.8	34.4	18.4	13.7	29.7	36.2	20.2	12.0	28.0	0.015
812c0pk	10	Weak	15	0	10%/40	10%/40	32.0	32.0	126.7	76.0	43.9	20.2	52.2	84.4	52.3	11.8	43.8	0.066
812c2pk	10	Weak	15	2	10%/40	10%/40	32.0	32.0	129.7	69.2	37.1	27.1	59.1	73.0	40.9	23.5	55.5	0.029

										----------- HV Line "L" in-service -----------				-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
812c5pk	10	Weak	15	5	10%/40	10%/40	32.0	32.0	130.8	66.7	34.7	29.4	61.5	68.8	36.7	27.6	59.6	0.016
Selected 46 kV cases																		
846e0	10	Weak	15	0	10%/40	7%/50	16.0	20.0	112.1	53.1	37.1	2.9	18.9	64.7	48.7	-8.6	7.4	0.103
846e2	10	Weak	15	2	10%/40	7%/50	16.0	20.0	113.2	50.7	34.7	5.3	21.3	60.9	44.8	-4.7	11.3	0.090
846e5	10	Weak	15	5	10%/40	7%/50	16.0	20.0	114.3	48.2	32.1	7.9	24.0	56.7	40.7	-0.4	15.6	0.074
Sub-transmission cases																		
115-69 kV																		
669f25	40	Strong	20	25	10%/40	7%/60	16.0	24.0	114.0	76.0	59.8	-10.8	5.2	79.6	63.4	-14.2	1.8	0.032
769f25	40	Medium	20	25	10%/40	7%/60	16.0	24.0	111.7	75.3	59.1	-10.1	5.9	87.3	71.0	-21.2	-5.2	0.107
869f25	40	Weak	20	25	10%/40	7%/60	16.0	24.0	109.8	74.7	58.5	-9.6	6.4	97.0	80.6	-30.0	-14.0	0.203
115-55 kV																		
655e25	40	Strong	20	25	10%/40	7%/50	16.0	20.0	114.5	62.1	46.0	-5.0	11.0	64.8	48.7	-7.5	8.5	0.024
755e25	40	Medium	20	25	10%/40	7%/50	16.0	20.0	113.3	61.8	45.7	-4.8	11.2	70.9	54.8	-13.0	3.0	0.080
855e25	40	Weak	20	25	10%/40	7%/50	16.0	20.0	112.1	61.5	45.4	-4.5	11.5	79.1	62.9	-20.2	-4.2	0.157
855f25																		
115-46 kV																		
646e25	40	Strong	20	25	10%/40	7%/50	16.0	20.0	115.0	57.3	41.2	-0.2	15.8	59.5	43.4	-2.1	13.9	0.019
746e25	40	Medium	20	25	10%/40	7%/50	16.0	20.0	114.6	57.2	41.2	-0.1	15.9	64.9	48.8	-6.8	9.2	0.067
846e25	40	Weak	20	25	10%/40	7%/50	16.0	20.0	114.2	57.2	41.1	0.0	16.0	72.4	56.2	-13.1	2.9	0.133
115-34.5 kV																		
634d25	40	Strong	20	25	10%/40	7%/40	16.0	16.0	115.3	46.2	30.2	2.6	18.7	47.7	31.7	1.4	17.4	0.013

										------------ HV Line "L" in-service ------------				-- HV Line "L" out-of-service --				
Case	**Z_L (mi.)**	**Z_{tr} (mi.)**	**Z_{ln1-4} (total mi.)**	**Z_{dist} (mi.)**	**Z_{T1}, Z_{T-4} (Z/MVA)**	**Z_{T2}, Z_{T3} (Z/MVA)**	**L_1, L_4 (MW)**	**L_2, L_3 (MW)**	**P_L (MVA)**	**P_{ln1} (MVA)**	**P_{ln2} (MVA)**	**P_{ln3} (MVA)**	**P_{ln4} (MVA)**	**$P_{ln1'}$ (MVA)**	**$P_{ln2'}$ (MVA)**	**$P_{ln3'}$ (MVA)**	**$P_{ln4'}$ (MVA)**	**LODF**
734d25	40	Medium	20	25	10%/40	7%/40	16.0	16.0	115.4	46.3	30.2	2.6	18.6	51.5	35.5	-1.9	14.1	0.045
834d25	40	Weak	20	25	10%/40	7%/40	16.0	16.0	115.5	46.3	30.2	2.6	18.6	57.1	41.0	-6.4	9.6	0.094
138-69 kV																		
869f25-138	40	Weak	20	25	10%/40	7%/60	16.0	24.0	112.0	66.5	50.4	-1.8	14.2	84.0	67.9	-18.3	-2.3	0.156
869f25-138'	40	Weak	20	25	10%/40	7%/60	16.0	24.0	131.9	71.1	55.0	-6.3	9.8	92.0	75.8	-25.6	-9.6	0.158
138-55 kV																		
855e25-138	40	Weak	20	25	10%/40	7%/50	16.0	20.0	113.5	55.1	39.0	1.5	17.5	68.4	52.3	-10.8	5.2	0.117
855e25-138'	40	Weak	20	25	10%/40	7%/60	16.0	20.0	134.0	58.5	42.4	-1.7	14.3	74.4	58.3	-16.2	-0.2	0.119
161-69 kV																		
869f25-161	40	Weak	20	25	10%/40	7%/60	16.0	24.0	113.2	60.7	44.7	3.7	19.7	74.8	58.8	-9.8	6.2	0.125
869f25-161'	40	Weak	20	25	10%/40	7%/60	16.0	24.0	153.0	68.0	52.0	-3.3	12.7	87.3	71.2	-21.4	-5.4	0.126
161-55 kV																		
855e25-161	40	Weak	20	25	10%/40	7%/50	16.0	20.0	114.1	50.7	34.7	5.6	21.6	61.1	45.1	-4.2	11.8	0.091
855e25-161'	40	Weak	20	25	10%/40	7%/60	16.0	20.0	154.8	56.0	40.0	0.6	16.6	70.3	54.3	-12.6	3.4	0.092
230-69 kV																		
869f25-230	40	Weak	20	25	10%/40	7%/60	16.0	24.0	116.3	51.3	35.3	12.8	28.8	59.4	43.3	5.0	21.0	0.070
869f25-230'	40	Weak	20	25	10%/40	7%/60	16.0	24.0	217.7	61.2	45.2	3.2	19.2	76.5	60.4	-11.4	4.7	0.070
230-55 kV																		
855e25-230	40	Weak	20	25	10%/40	7%/50	16.0	20.0	116.1	43.8	27.8	12.3	28.3	49.5	33.5	6.7	22.8	0.049
855e25-230'	40	Weak	20	25	10%/40	7%/50	16.0	20.0	218.7	50.8	34.8	5.6	21.6	61.7	45.7	-4.7	11.3	0.050

Notes:

The following notes provide information to understand the meaning of each column heading and underlying assumptions used in the analysis. See also the one-line diagrams in Figures 5 and 6 of Appendix 2 for additional information.

Z_L

The table provides the length of line "L" in miles to provide a high-level, qualitative understanding of the line impedance. The line impedance (Z_L) is the length of the line in miles times the per mile impedance. Assumptions used in determining the per mile impedance are as follows:

Voltage (kV)	Conductor	Phase Spacing	GMD	Impedance (Ω/mile)	Impedance (p.u./mile)
230	954 ACSR	20' H-frame	25.20'	0.100 + j0.786	0.000189 + J 0.00149
161	954 ACSR	16' H-frame	20.16'	0.100 + j0.759	0.000384 + j 0.00293
138	795 ACSR	13' H-frame	16.38'	0.117 + j0.738	0.000615 + j 0.00388
115	795 ACSR	11' H-frame	13.86'	0.117 + j0.718	0.000886 + j 0.00543

Z_{tr}

The transfer impedance (Z_{tr}) represents the impedance of the system in parallel with the subsystem under study. Analysis was performed for three levels of parallel transfer impedance which have been characterized as strong, medium, and weak. The strong system has relatively low impedance and thus will pick up more power flow when line "L" is tripped. The weak system has relatively high impedance and thus will pick up less power flow when line "L" is tripped. The medium system has a mid-range impedance value. The actual values of the transfer impedance vary between the distribution cases and the sub-transmission cases.

	Z_{tr} in distribution cases (p.u.)	Z_{tr} in sub-transmission cases (p.u.)
Strong	0.00089 + j 0.00543	0.00354 + j 0.0217
Medium	0.00319 + j 0.0195	0.0128 + j 0.0782
Weak	0.00664 + j 0.0407	0.0266 + j 0.163

Z_{ln1-4}

The table provides the total length of lines "ln1" through "ln4." In all simulations these four lines have equal length. The total length in miles provides a high-level, qualitative understanding of the line impedance. The line impedances are the length of each line in miles times the per mile impedance. Assumptions used in determining the per mile impedance are the same as provided above for line "L."

Z_{dist}

The table provides the length of the line in miles to provide a high-level, qualitative understanding of the line impedance. The impedance of the distribution system or sub-transmission system (Z_{dist}) is the length of the distribution tie or sub-transmission line in miles times the per mile impedance. A value of zero miles is used when the distribution tie is a solid bus tie. Assumptions used in determining the per mile impedance are as follows:

Voltage (kV)	Conductor	Phase Spacing	GMD	Impedance (Ω/mile)	Impedance (p.u./mile)
69	636 ACSR	6’ Horizontal	7.56’	0.145 + j0.657	0.00305 + j 0.0138
55	556 ACSR	6’ Horizontal	7.56’	0.168 + j0.677	0.00555 + j 0.0224
46	477 ACSR	6’ Triangular	6.00’	0.193 + j0.647	0.00913 + j 0.0306
34.5	477 ACSR	4’ Triangular	4.00’	0.193 + j0.598	0.0162 + j 0.0503
23	477 ACSR	4’ Triangular	4.00’	0.193 + j0.598	0.0365 + j 0.113
12.47	336 ACSR	2’ Horizontal	2.52’	0.274 + j0.563	0.176 + j 0.362

$Z_{T1\text{-}4}$

The transformer impedance is reported as percent impedance on the transformer MVA base. Each transformer has three ratings: OA (oil and air), FA (forced air – i.e., fans), and FOA (forced oil and air – i.e., pumps and fans). The transformer MVA base rating is the OA rating. The FA rating is 133% of the OA rating and the FOA rating is 167% of the OA rating (e.g., a 20 MVA transformer has a 20 MVA OA rating, 26.7 MVA FA rating, and 33.3 MVA FOA rating, typically identified as a nameplate of 20/26.7/33.3 MVA).

The transformer impedance and rating for each voltage level are based on typical values. Distribution transformer impedance is generally higher to limit current on the distribution equipment. Secondary current typically is not a concern on sub-transmission transformers, so impedance is typically lower to limit reactive power losses and voltage drop.

L_1, L_2, L_3, L_4

The transformer load is based on the transformer OA rating. Transformers are loaded at 80 percent of the transformer base MVA in the simulations modeling a peak system load condition. The substations modeled have two transformers, with each transformer able to supply the total station load. Thus, if one transformer is forced out-of-service, the load on the remaining transformer will be 160 percent of its base rating, which is approximately equal to its FOA rating.

Transformers are loaded at 40 percent of the transformer base MVA in the simulations modeling a light system load condition.

HV Line "L" in-service: P_L, P_{ln1}, , P_{ln2}, P_{ln3}, P_{ln4}

The loading on each line, with all lines in service, is listed in MVA. The loading on line “L” is the power that is redistributed between the parallel transmission system and the distribution or sub-transmission system when line “L” is taken out of service.

HV Line "L" out-of-service: P_{ln1}, , P_{ln2}, P_{ln3}, P_{ln4}

The loading on each line, with line “L” out-of-service, is listed in MVA.

LODF

The Line Outage Distribution Factor (LODF) is the fraction of the load on line “L” that is picked up on the distribution or sub-transmission system. This information is included for illustrative purposes to understand the analysis, but was not used in identifying the voltage threshold for Exclusion E1.

Appendix 4: Summary of Loop Flow Issue Through Systems <50 kV

In the course of developing 'real-world' scenarios for the analysis of potential sub-100 kV loop flows, the Standard Drafting Team found that the industry has employed various measures to minimize the subject loop flows. Some of these methods that were found to be applied by entities on sub-100 kV loop systems are described below. However, it is important to note that the presence of the equipment in the following examples does not remove or lessen an entity's obligations associated with the bright-line application of the Bulk Electric System (BES) definition.

Sustained power flow through substation power transformers and low voltage loops is generally undesirable and, in some instances injurious. For this reason, power system engineers typically address this issue in their design, operating, and planning criteria and apply methods to prevent this condition from occurring. The high impedance of transformers and low voltage elements inherently prevent excessive flow, but in many instances this flow can exceed ratings of equipment. For these reasons entities develop control schemes, add relaying, and provide operational and planning guidelines to prevent this loop flow. Figure 7 depicts two systems that could provide a possible loop flow across the low voltage system and back up to the high voltage system. The loop flow in these diagrams is increased when the breaker on the high voltage side (breaker B) is opened.

The diagrams presented below depict a generic power system. The higher voltage and lower voltage circuit breakers and bus arrangements will, in practice, vary (i.e., straight bus, half-breaker, ring bus, breaker-and-a-half, etc.), but the concepts remain the same.

Specifically, Figure 7, shown below, depicts segments of an electrical power system. They consist of a greater than 100 kV system and a sub-100 kV system. Figure 7 depicts the power flow through the electrical system under the condition that all circuit breakers are closed (normal condition). In the event that circuit breaker B opens (i.e., manually, supervisory control, or protective device operation) and (1) and either of the sub-100 kV line circuit breakers (A or C) or (2) either of the low-side transformer circuit breakers (D or F) or (3) the low-side bus tie circuit breaker (E) does not open, a condition could occur where some amount of flow will occur through the sub-100 kV system to the greater than 100 kV system. This flow is severely limited by the high impedance of the two transformers in series and the sub-100 kV system impedance. This condition, however, may be deemed undesirable from an equipment standpoint and precautions may be taken to prevent it. Subsequent sections of this appendix show some of the physical schemes that entities can employ in this regard.

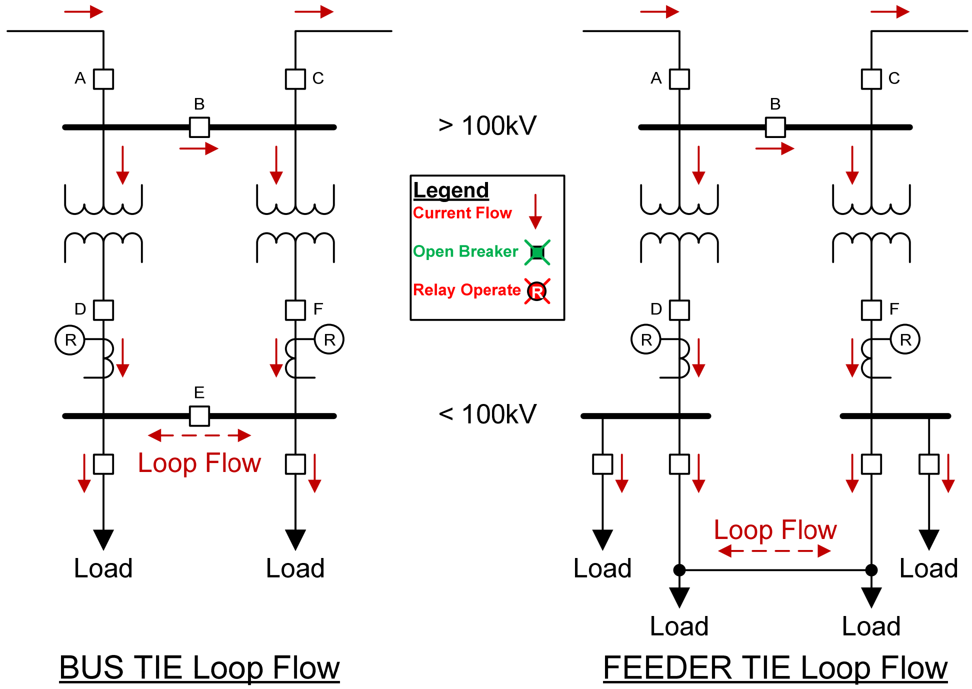


Figure 7. Summary of Loop Flow

Interlocked Control Schemes

Interlocking control schemes can be used to prevent low voltage loop flow. One method to preclude sustained power flow from the lower voltage to the higher voltage portion of the system is to include control system interlocks which will cross-trip certain circuit breaker(s) when other specified circuit breakers are opened. This condition is generally rare since bus designs and protective relay system operations generally do not result in this condition occurring. Operational guidelines usually instruct personnel to avoid the use of the interlocking schemes during normal or planned switching. However, unplanned actions can cause breakers to open and result in the desirable operation of the interlocking schemes. This method, therefore, is considered to be conservative but, never-the-less, it is applied in some instances.

Figure 8 below shows how an interlock scheme would function to prevent low voltage loop flow. When the high side breaker (breaker B) is opened, the low side breaker (breaker E) is also opened. This action prevents low side loop flow. The interlocking scheme could be applied in various combinations and the figure below is a simplified illustration of such a scheme.

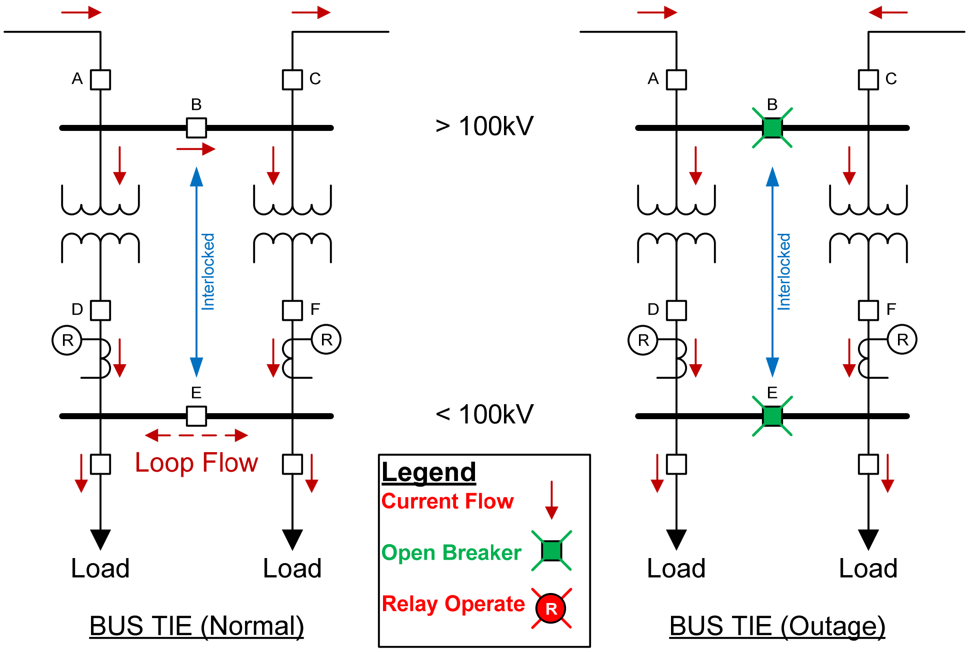


Figure 8. Interlocking Schemes

Reverse Power Schemes

Protection schemes can also be deployed to prevent sustained loop flows through the sub-100 kV system. Reverse power applications are one example of a protection scheme that prevents sustained undesirable low voltage loop flow. In some instances, protective devices will preclude sustained loop flows due to their settings and in other instances protective schemes are specifically applied to preclude this undesirable operating condition.

Figure 9 below shows how a reverse power scheme would function to prevent sub-100 kV loop flow. When the high side breaker (breaker B) is opened, current may flow from the high voltage side (breaker A) through the low voltage bus and back to the high voltage side (breaker C). A relay on breaker F is applied to sense the reverse flow (relay shown in yellow in the diagram) and will operate if this flow continues (relay shown in red in the diagram). When the reverse power relay operates it will trip breaker F. This action prevents reverse power flow through the transformer and low voltage loop flow. The reverse power scheme is set to sense a minimum amount of power flowing in a reverse direction and is usually set much less than the transformer rating. The figure below is a simplified illustration of a reverse power scheme.

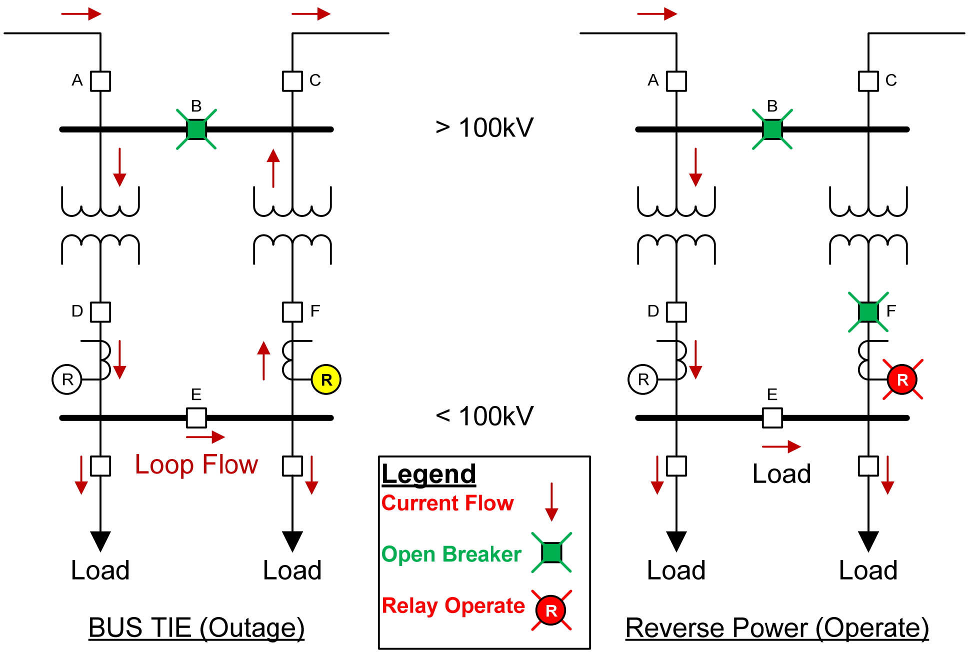


Figure 9. Reverse Power Schemes

Transformer Overcurrent Limitations

Transformer overcurrent protection schemes can also be deployed to prevent sustained loop flows through the sub-100 kV system. Figure 10 below shows how a transformer overcurrent scheme would function to prevent sub-100 kV loop flow. When the high side breaker (breaker B) is opened, current may flow from the high voltage side (breaker A) through the low voltage bus and back to the high voltage side (breaker C). The relay on the transformer and breaker D is applied to protect the transformer from excessive overloads and faults on the low voltage system. If a fault occurs or the transformer is over-loaded then the relay on breaker D will sense this excessive flow (relay shown in yellow in the diagram) and will operate if this flow continues (relay shown in red in the diagram). When the transformer overcurrent relay operates it will trip breaker D. This action unloads the transformer in question and prevents low voltage loop flow. The transformer overcurrent relay is typically set to allow the transformer to be loaded to the emergency rating of the transformer plus a small safety margin. The figure below is a simplified illustration of a transformer overcurrent scheme.

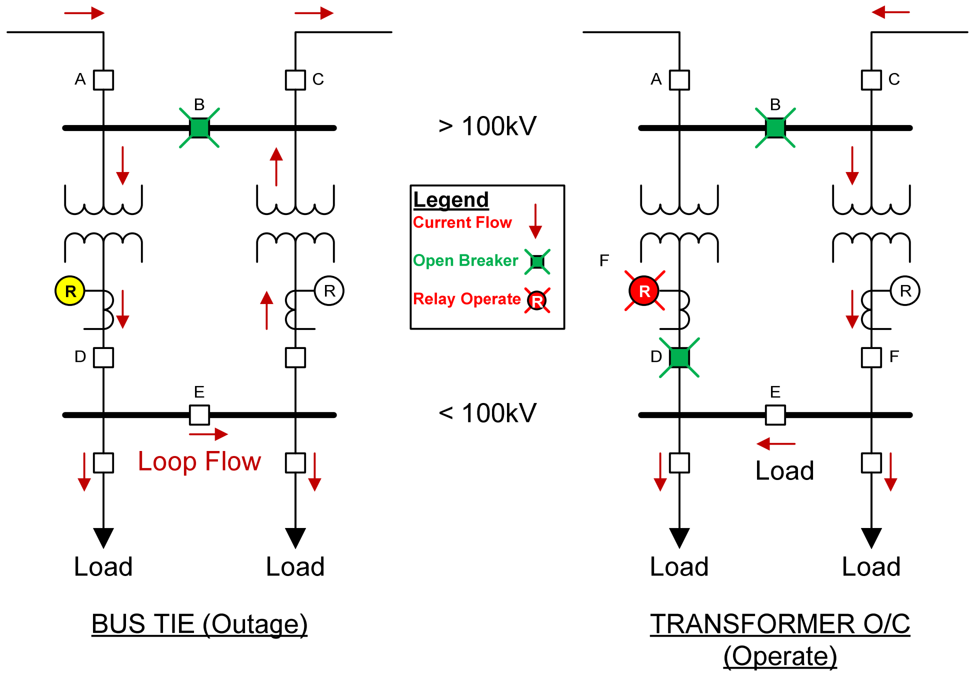


Figure 10. Transformer Overcurrent Limitations

Feeder Overcurrent Limitations

Feeder overcurrent protection schemes can also be deployed to prevent sustained loop flows through the sub-100 kV system. Figure 11 below shows how a feeder overcurrent scheme would function to prevent sub-100 kV loop flow. When the high side breaker (breaker B) is opened, current may flow from the high voltage side (breaker A) through the low voltage feeder, through a feeder tie, and back to the high voltage side (breaker C). The relay on the feeder and breaker G is applied to protect the feeder from excessive overloads and faults on the low voltage feeder. If a fault occurs or the feeder is over loaded, the relay on breaker G will sense this excessive flow (relay shown in yellow in the diagram) and will operate if this flow continues (relay shown in red in the diagram). When the feeder overcurrent relay operates it will trip breaker G. This action opens the feeder breaker and prevents low voltage loop flow. The feeder overcurrent relay is typically set to allow the feeder to be loaded to the emergency rating of the feeder rating plus a small safety margin. The figure below is a simplified illustration of a feeder overcurrent power scheme.

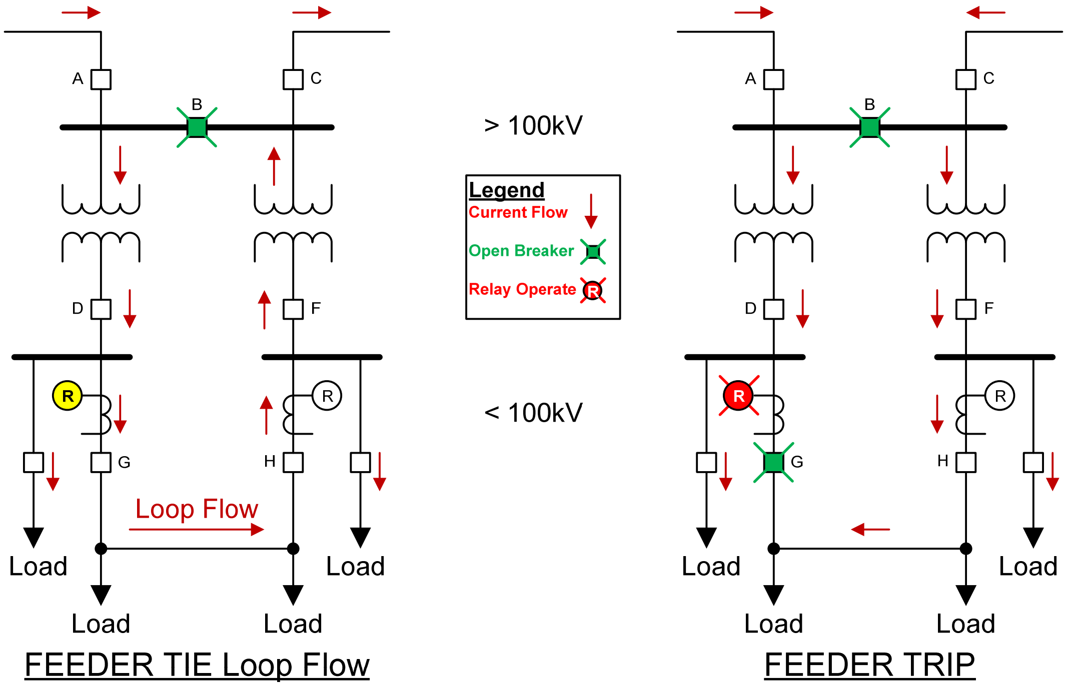


Figure 11. Feeder Overcurrent Limitations

Bus Tie Overcurrent Limitations

Bus tie overcurrent protection schemes can also be deployed to prevent sustained loop flows through the sub-100 kV system. Figure 12 below shows how a bus tie overcurrent scheme would function to prevent sub-100 kV loop flow. When the high side breaker (breaker B) is opened, current may flow from the high voltage side (breaker A) through the low voltage bus and back to the high voltage side (breaker C). The relay on the bus tie and breaker E is applied to protect the bus from excessive overloads and faults on the low voltage bus(ses). If a fault occurs or the bus is over loaded, then the overcurrent relay on breaker E will sense this excessive flow (relay shown in yellow in the diagram) and will operate if this flow continues (relay shown in red in the diagram). When the bus tie overcurrent relay operates, it will trip breaker E. This action opens the bus tie breaker and prevents sustained low voltage loop flow. The bus tie overcurrent relay is typically set to allow the bus to be loaded to the emergency rating plus a small safety margin. The figure below is a simplified illustration of a bus tie overcurrent power scheme.

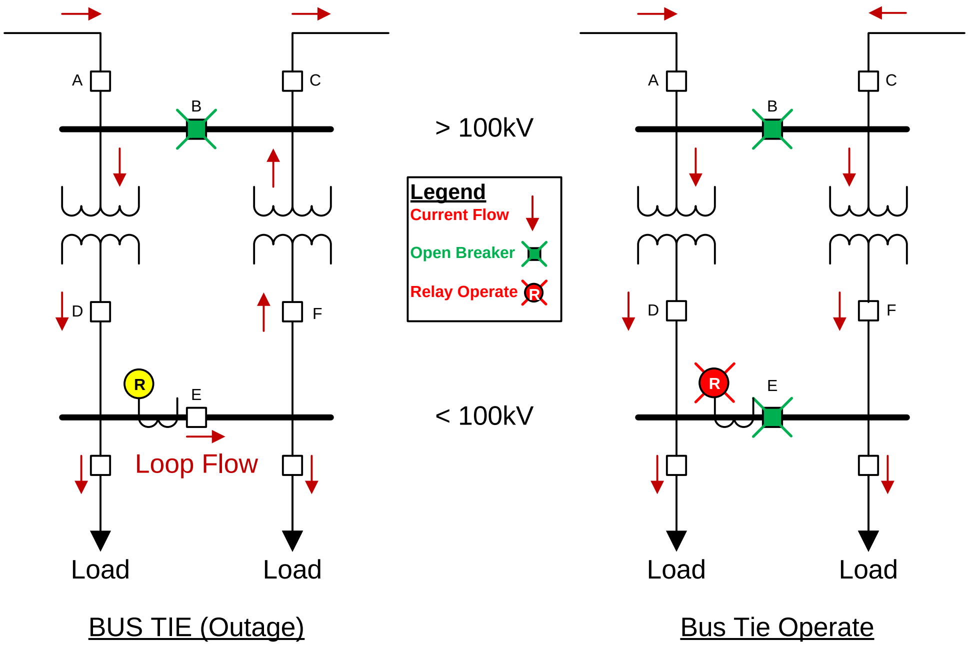


Figure 12. Bus Tie Overcurrent Limitations

Custom Protection and Control Schemes

Custom protection and control schemes may also be deployed to prevent loop flows through the sub-100 kV system. Figure 13 below shows how such schemes would function to prevent sub-100 kV loop flow. When the greater than 100 kV line 1 breakers (breakers D and G) open, current may flow from the high voltage side (breaker E) through the low voltage bus and back to the high voltage side (breaker H). The custom scheme implemented at the substation will trip or run back generation to prevent over loads and sustained loop flows on the low voltage system.

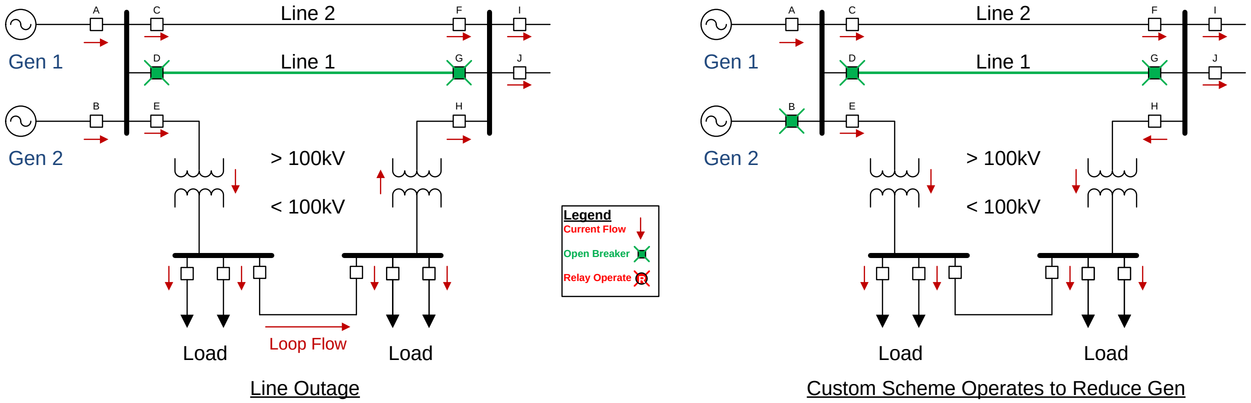


Figure 13. Custom Scheme Operations

Appendix 4 Summary

The issues and methods described in Appendix 4 are reflective of why, in most instances, conditions of sustained loop flows through sub-100 kV systems are alleviated. When the low voltage is much less than 100 kV, the design considerations shown above become even more pertinent and preventative methods are employed; BES reliability is not the main concern, protecting the equipment from physical damage is the primary concern. In the vast majority of cases, robust planning and operating criteria and procedures will alleviate any concerns regarding sustained loop flows.