

NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Severity Risk Index Enhancements

NERC Performance Analysis
Subcommittee

RELIABILITY | RESILIENCE | SECURITY



3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

Table of Contents

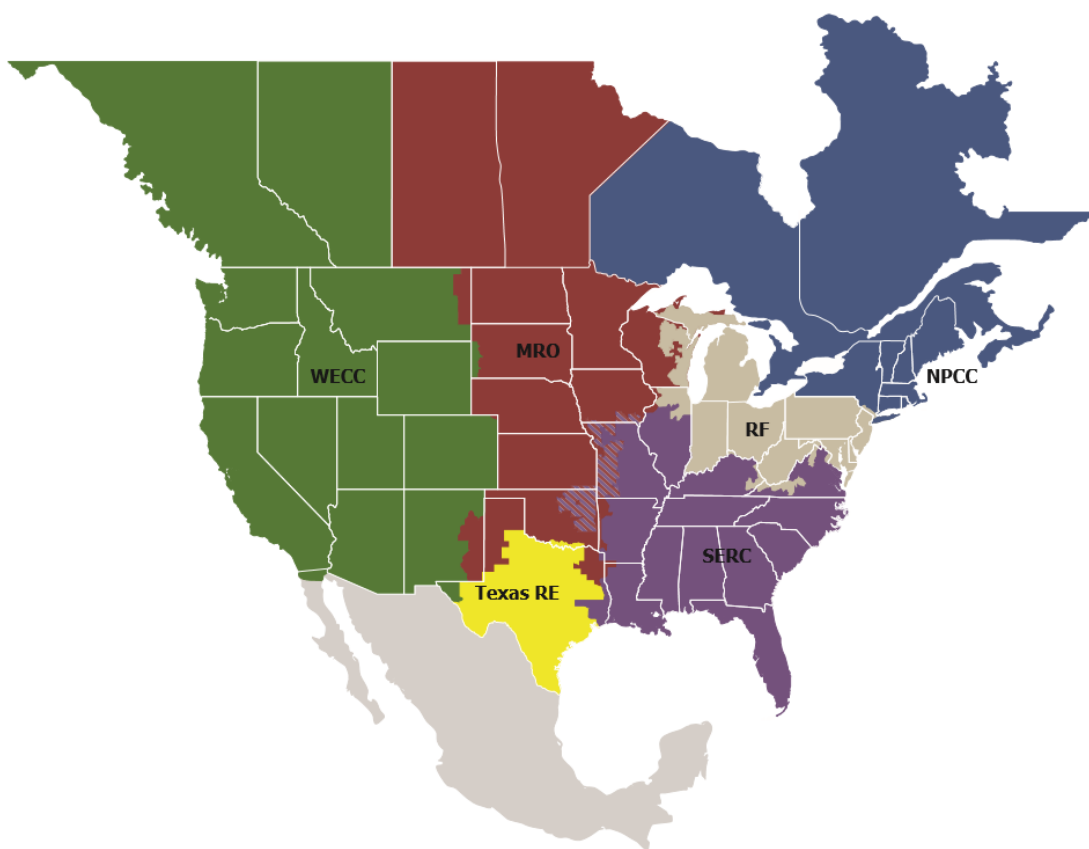
Preface.....	iii
Introduction.....	iv
Chapter 1: Generation, Transmission, and BES-related Load Loss Components.....	5
Bulk Power System SRI Calculation	5
Bulk Power System SRI Equation.....	5
Transmission Component Changes	6
Generation Component Changes.....	7
Appendix A: Interconnection-specific MVA values for TADS Elements.....	8
Expanded Eastern Interconnection.....	8
Western Interconnection.....	8
ERCOT Interconnection.....	8
Appendix B: Exporting Models from the PSS®E and PSLF Engines.....	9
PSLF Specific Information Gathering	9
PSS®E Specific Information Gathering.....	12
General filtering in Excel	13
Transformers.....	14
List of Acronyms	16

Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the six Regional Entities (REs), is a highly reliable and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six RE boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one RE while associated Transmission Owners (TOs)/Operators (TOPs) participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Introduction

In August 2010, the Reliability Metrics Working Group (RMWG) released its Integrated Bulk Power System Risk Assessment Concepts paper¹ introducing new concepts, such as the “universe of risk” of the bulk power system. Introduced in that concepts paper was a method to assess “event-driven” risks; the Severity Risk Index (SRI) established quantification of the impact of various events of the bulk power system. During the analysis of methods, the SRI became a foundational attempt to quantify the performance of the BPS on a daily basis. The SRI provided comparative context for evaluating current and historical performance of the system. The concept of quantifying “events” was not viable since there is no mechanism to aggregate operational data in a manner consistent with the concept of an event. However, it was determined that the daily measure of performance of the system was a good surrogate, still allowing for investigation, identification of ranges of performance and other measures important to gauge the current and historic bulk power system reliability. NERC’s Operating Committee (OC) and Planning Committee (PC) endorsed the concepts paper and SRI refinement calculation in September 2010. Subsequently, a companion whitepaper² Integrated Risk Assessment Approach – Refinement to Severity Risk Index was developed and approved by OC and PC in March 2011.

The NERC Performance Analysis Subcommittee (PAS), as successor to the RMWG, continued this analysis following the release of the *State of Reliability Report 2013*.³ At the April 2013 meetings, the OC and PC approved the 2013 State of Reliability report and provided recommendations to enhance the SRI. Implementation of these recommendations occurred in the SRI Enhancement Whitepaper.⁴

This whitepaper builds on the previous work of the RMWG and the PAS. It presents further enhancements in transmission and generation components as well as introduces an improved methodology for SRI analysis by Interconnection.

¹ http://www.nerc.com/docs/pc/rmwg/Integrated_Bulk_Power_System_Risk_Assessment_Concepts_Final.pdf

² http://www.nerc.com/docs/pc/rmwg/SRI_Equation_Refinement_May6_2011.pdf

³ State of Reliability Report 2013, http://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/2013_SOR_May%2015.pdf

⁴ <https://www.nerc.com/comm/PC/Performance%20Analysis%20Subcommittee%20PAS%202013/SRI%20Enhancement%20Whitepaper.pdf#search=SRI%20enhancement>

Chapter 1: Generation, Transmission, and BES-related Load Loss Components

As defined in the 2014 SRI Enhancement whitepaper, SRI is a daily metric where transmission loss, generation loss, and load loss events aggregate into a single value that indicates performance of the Bulk Electric System (BES). The SRI values range from zero to 1000. Zero is a theoretical condition where no transmission, generation or load loss occurred during the entire day. To the corollary, a value of 1000 would represent a situation where every transmission, generation and load⁵ was lost during the entire day. The SRI was designed to be usable for the entirety of NERC as well as applied more granularly, such as at an interconnection level. Thus, in the NERC State of Reliability reports for the years 2019 and 2020,⁶ NERC-level SRI analysis of extreme days was complemented with the extreme day analysis by Interconnection.

Bulk Power System SRI Calculation

Formula 1 shows the aggregation of the three components representing a daily transmission loss, a daily generation loss and a daily load loss into a single daily Severity Risk Index. The load loss component of SRI is based on data collected from the IEEE Power and Energy Society (PES) Distribution Reliability Working Group (DRWG) Benchmark Study⁷ as described in the 2014 SRI Enhancement whitepaper. The **Transmission Component Changes** and **Generation Component Changes** sections are discussed below. NERC's State of Reliability report in 2020 incorporates these changes. Provided in Appendix A is the analysis of the SRI from the 2020 State of Reliability.

Bulk Power System SRI Equation

Formula (1): Calculation of a daily SRI value

$$SRI = [(RPL) * w_L * (MW_L) + w_T * (Loss_T) + w_G * (Loss_G)] * 1000 \quad (1)$$

Where:

- SRI = Severity Risk Index for a given day,
- w_L = 60% - weighting of the load loss component,
- MW_L = normalized MW_L load loss due to transmission or generation sources (MW) for the day;

$$MW_L = \left(\frac{MW_{Peak}}{Total_{C/D}} \right) * (CI)$$

Where:

- MW_{Peak} = daily peak load (MW) is aggregated at NERC level obtained from FERC
- $Total_{C/D}$ = Total Customer served for the day obtained from IEEE benchmark data
- CI = Customers Interrupted due to transmission or generation sources for the day obtained from the IEEE PES Distribution Reliability Working Group (DRWG) benchmark data.

RPL = load Restoration Promptness Level:

- RPL = 1/4, if $T_{CAIDI} < 50$,
- RPL = 2/4, if $50 \leq T_{CAIDI} < 100$,
- RPL = 3/4, if $100 \leq T_{CAIDI} < 200$,
- RPL = 4/4, if $T_{CAIDI} \geq 200$,

⁵ Load loss is reduced in its impact if it is restored relatively rapidly after an outage event, for the day, such that load restored within 50 minutes is factored by 0.25, as outlined by the RPL noted above. If the restoration doesn't occur within 200 minutes no reduction is considered.

⁶ 2019: https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2019.pdf

2020: https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2020.pdf

⁷ The IEEE DRWG Annual Benchmark Study does not explicitly distinguish between customer interruptions that are the result of generation or transmission; rather it identifies source outages that cause distribution customer interruptions. Appendix B. IEEE Reliability Benchmark

Data: <https://cmte.ieee.org/pes-drwg/benchmarking/>

<http://www.smartgrid.gov/sites/default/files/doc/files/Distribution%20Reliability%20Report%20-%20Final.pdf>

T_{CAIDI}	=	Transmission (or Generation Source) Customer Average Interruption Duration (in minutes) obtained from IEEE PES DRWG benchmark data ⁸
w_T	=	30% - weighting of the transmission component,
$LOSS_T$	=	daily transmission loss calculated as normalized equivalent MVA of transmission elements lost on a given day, obtained from TADS inventory and outage data ⁹ ,
w_G	=	10% - weighting of the generation component,
$LOSS_G$	=	daily generation loss calculated as normalized MW lost, obtained from GADS inventory and outage data ¹⁰

Additional information on formula and weighting factors above is available in the Refinement to Severity Risk Index¹¹ and 2014 SRI Enhancement whitepapers.

Transmission Component Changes

In Formula (1) for SRI calculation, the daily transmission component, Daily $LOSS_T$, is defined by Formula (2)

$$Daily\ Loss_T = \frac{\sum_{outages\ started\ on\ this\ day} MVA(outaged\ elements)}{\sum_{elements\ in\ TADS\ inventory} MVA}, \quad (2)$$

with TADS inventory as reported for a given year.

$LOSS_T$ is a share of the total MVA of the annual TADS inventory lost on a given day due to sustained automatic outages.

Prior to the 2019 State of Reliability Report, the sum in the numerator consisted of all automatic outages of the 200kV+ ac circuits, and the sum in the denominator reflected the TADS inventory of the 200 kV+ ac circuits. Each ac circuit across the NERC footprint had the same equivalent MVA value for the voltage class reported in TADS.

Beginning with the 2019 State of Reliability report, the following changes occurred and continued for the 2020 State of Reliability report:

1. The Daily Loss calculation for transmission includes two additional TADS element types: transformers and dc circuits.
2. Inclusion of lower voltages which reflect changes in TADS data collection that became effective in 2015 in accordance with a FERC-approved BES definition; 100 kV+ ac circuits, transformers, and dc circuits data are used to calculate the daily transmission loss component.
3. Only sustained outages are included in the calculation. TADS does not collect momentary outages for elements below 200 kV.
4. In the denominator, the TADS inventory for a given year includes 100 kV+ ac circuits, transformers, and dc circuits.
5. Interconnection-specific equivalent MVA values were introduced based on element type and voltage class as described in : Interconnection-specific MVA values for TADS Elements [Appendix A](#).

⁸ Appendix A. Reliability Indices, <http://www.smartgrid.gov/sites/default/files/doc/files/Distribution%20Reliability%20Report%20-%20Final.pdf>

⁹ <http://www.nerc.com/pa/RAPA/tads/Pages/default.aspx>

¹⁰ <http://www.nerc.com/pa/RAPA/gads/Pages/default.aspx>

¹¹ https://www.nerc.com/docs/pc/rmwg/SRI_Equation_Refinement_May6_2011.pdf

Generation Component Changes

The Daily Loss_G component is in Formula (3):

$$\text{Daily Loss}_G = \frac{\sum(\text{MW rating of generators with unplanned outages that started on a given day})}{\sum(\text{MW rating of all available generators in the month})}$$

In Formula (3):

- Only conventional generation reported in the GADS is included;
- The denominator uses a monthly normalization capacity value.

Loss_G is a share of the total MW rating of conventional generation reported in GADS on a given day due to immediate forced outages and derates.¹²

Prior to the State of Reliability 2019 report, the sum in the numerator only included immediate unforced outages, and the sum in the denominator was calculated using the average annual capacity of the GADS inventory.

The State of Reliability 2019 report included the following changes:

1. Analysis is limited to units with a mandatory reporting requirement.
2. Immediate forced outages (U1) and immediate derates (D1) are included.
3. Denominator for each day is the monthly reporting capacity, not average annual capacity. Excluded from that month's capacity calculation are units with a commercial operation date after the 15th of the month, or units that retire before the 15th of the month.

¹² The sum is multiplied by 1000 for convenience to avoid working with and presenting very small numbers.

Appendix A: Interconnection-specific MVA values for TADS Elements

The equivalent MVA values for Formula (2) were estimated by NERC staff from the Power Systems Load Flow models for the Expanded Eastern Interconnection (EI), the Western Interconnection (WI), and the ERCOT Interconnection. The methodology and process are in [Appendix B](#). Annual reviews of the Equivalent MVA values are and updates will be performed on an add needed basis. Updates to the equivalent MVA values shown below occurred in February 2020. The SRI calculations for the 2020 State of Reliability report used these values.

Expanded Eastern Interconnection

AC Circuit	Equivalent MVA
0-99 KV	64
100-199 KV	213
200-299 KV	565
300-399 KV	1156
400-599 KV	2452
600-799 KV	3854
Transformer	Equivalent MVA
0-99 KV	36
100-199 KV	76
200-299 KV	194
300-399 KV	344
400-599 KV	738
600-799 KV	1408
DC	Equivalent MVA
100-199 kV	549
200-299 kV	140
400-499 kV	1033
500-599 kV	818

Western Interconnection

AC Circuit	Equivalent MVA
0-99 KV	90
100-199 KV	160
200-299 KV	543
300-399 KV	985
400-599 KV	2472
AC/DC BTB Converter	Equivalent MVA
100-199 KV	150
200-299 KV	184
300-399 KV	200
Transformer	Equivalent MVA
0-99 KV	26
100-199 KV	53
200-299 KV	195
300-399 KV	366
400-599 KV	836
DC	Equivalent MVA
100-199 kV	549
200-299 kV	140
400-499 kV	1033
500-599 kV	818

ERCOT Interconnection

AC Circuit	Equivalent MVA
0-99 KV	62
100-199 KV	328
200-299 KV	160
300-399 KV	1570
AC/DC BTB Converter	Equivalent MVA
300-399 KV	216
Transformer	Equivalent MVA
0-99 KV	44
100-199 KV	117
200-299 KV	312
300-399 KV	387

Appendix B: Exporting Models from the PSS®E and PSLF Engines

This appendix describes the steps taken to isolate the AC lines and transformers from the WI, TI, and EI wide base cases. Use GE's Positive Sequence Load Flow software (PSLF®) v21 and Siemen's Power System Simulation for Engineering (PSS®E) v33 or E v34 for gathering the data.

For both software platforms, the goal is not to get the direct information in the software and utilize the tool to provide the information. The goal is to get the information into an Excel spreadsheet for filtering. The filtering tools in the powerflow software may change rapidly and even during major releases of the software. However, since the major powerflow software platforms have a .RAW file export, exports of the data into Excel or other character-delimited software can be made.

PSLF Specific Information Gathering

PSLF already takes the capability inside each of the EDIT tables that tabulate each of the buses, lines, transformers, and other components of ac equipment as well as the representation of dc lines and converters. Below is an overview of the EDIT table. Clicking the EDIT button on the first bar allows for the selection of each of these sub-tables; however, shortcuts exist to load this information quickly into RAM. Figures below highlight each of the steps to get to the sub-tables. Inherent in this process is the loading of a binary .sav or an ASCII .raw file into the program. Please consult the PSLF® user manual for that process.

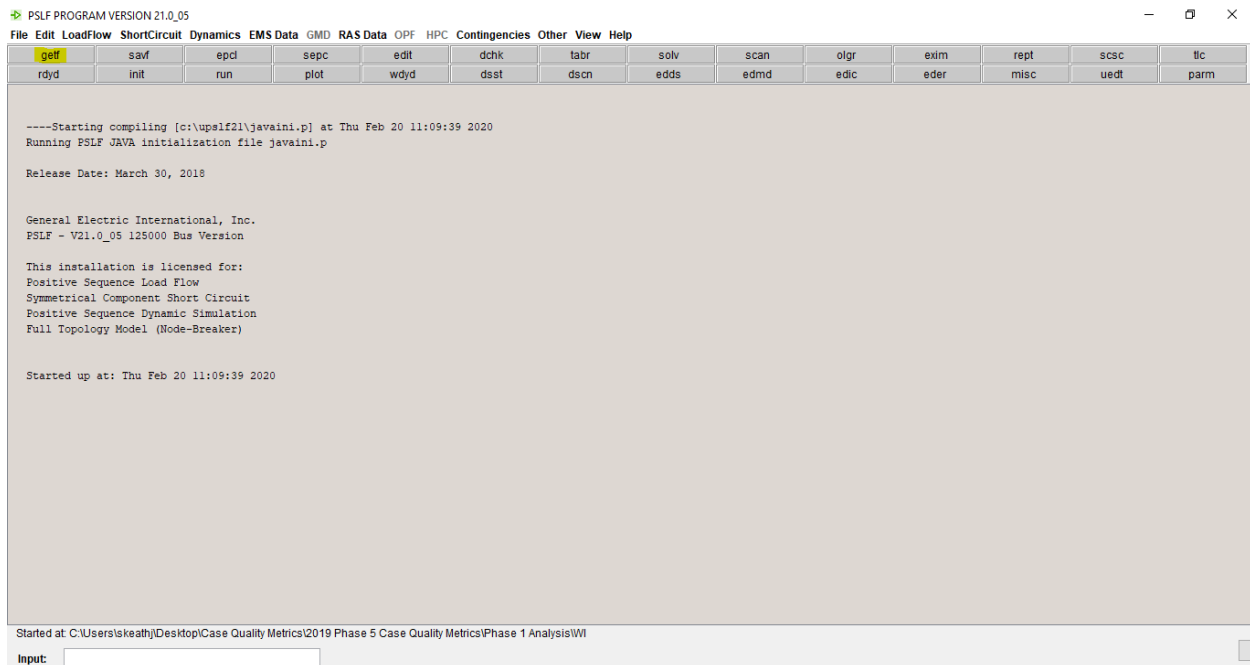


Figure B.1: PSLF start screen with open function highlighted

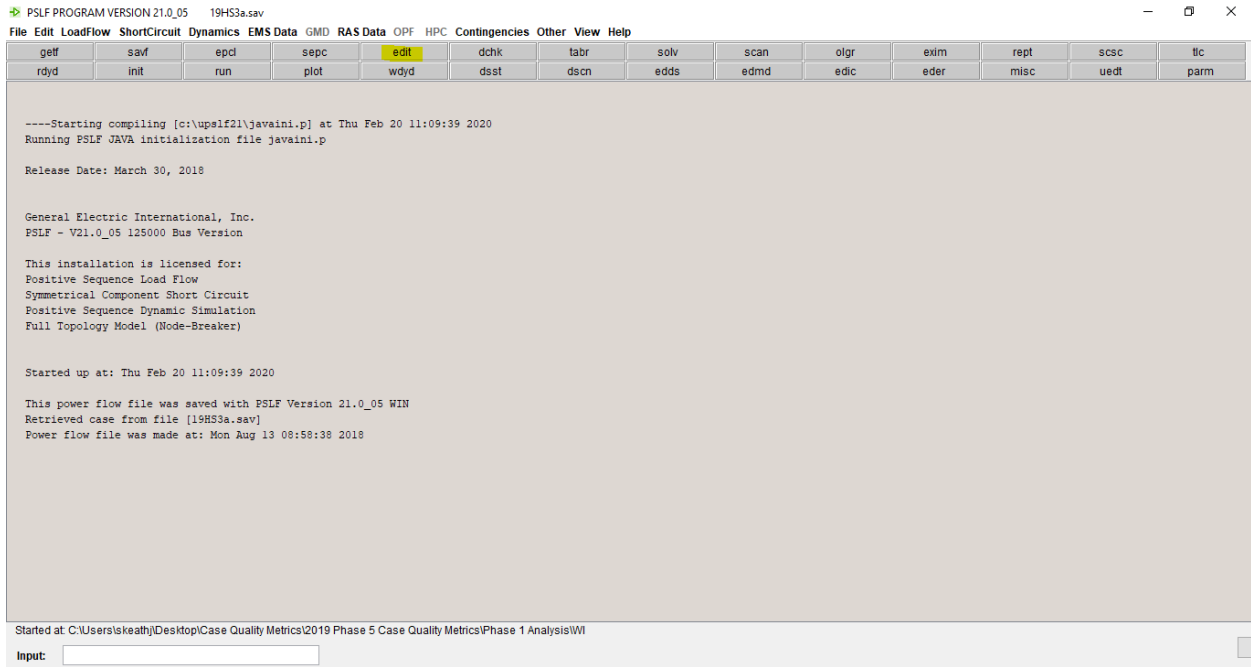


Figure B.2: PSLF start screen with EDIT button highlighted

After clicking on the EDIT button, a separate list of header buttons are selectable. In order to get the ac lines, “secdd” is required to be selected; for transformers, trans, and so on. [Table B.1](#) demonstrates the list of tables for all of AC lines, Transformers, and DC lines. For back to back dc converter information, there is a need to contact the MOD-032 Designee for the WI to obtain a separate list of B2B DC Converter equipment as those are not fully represented as a dc converter in the powerflow models, but rather as an equivalent equipment representation.

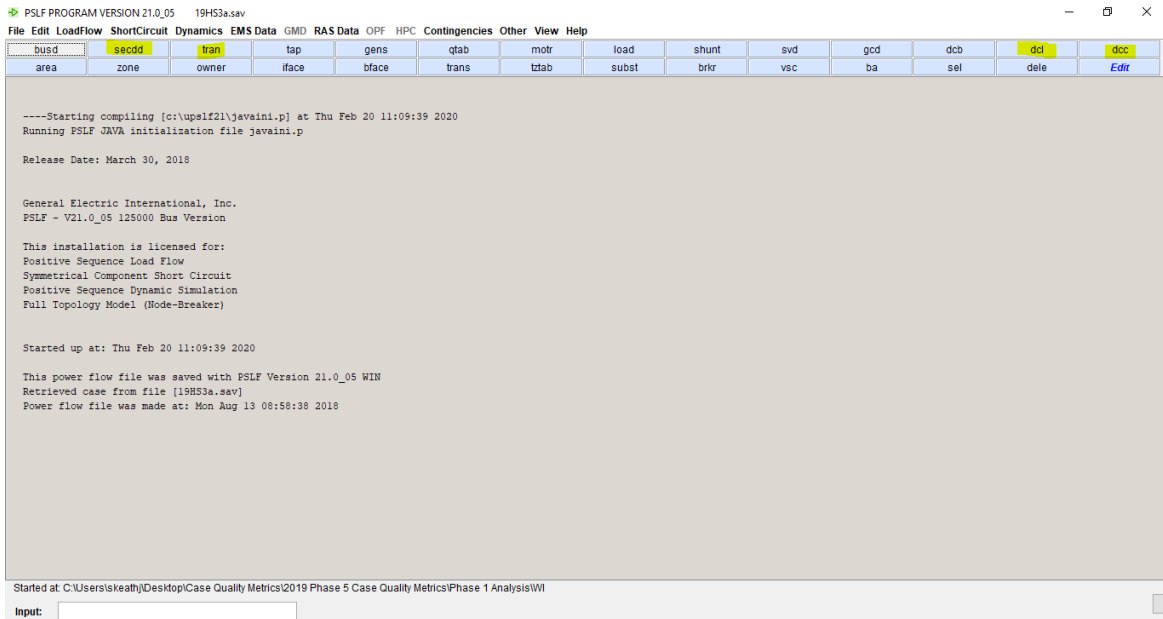


Figure B.3: PSLF Start screen with new EDIT functions

Additional sub-tables can be useful for use in attributing the records in the powerflow data into other sections. Those additional tables are the areas, zones, and owners tables and are represented in [Table B.1](#) below.

Table B.1: PSLF Map for Equipment to EDIT/Shortcut		
Equipment / Information	EDIT Table	Shortcut
AC Lines	secdd	Ctrl+Shift+s
Transformers	trans	Ctrl+Shift+t
DC Lines	dcl	N/A
B2B Converters ¹³	N/A	N/A
Area	area	Ctrl+Shift+a
Zone	zone	Ctrl+Shift+z
Owner	owner	N/A

After getting into each of these sub-tables, there is an option on each to export the information into an “.xls” (older Excel file) that contains the total data listing based on the records entered by the Planning Coordinator or Transmission Planner (TP).

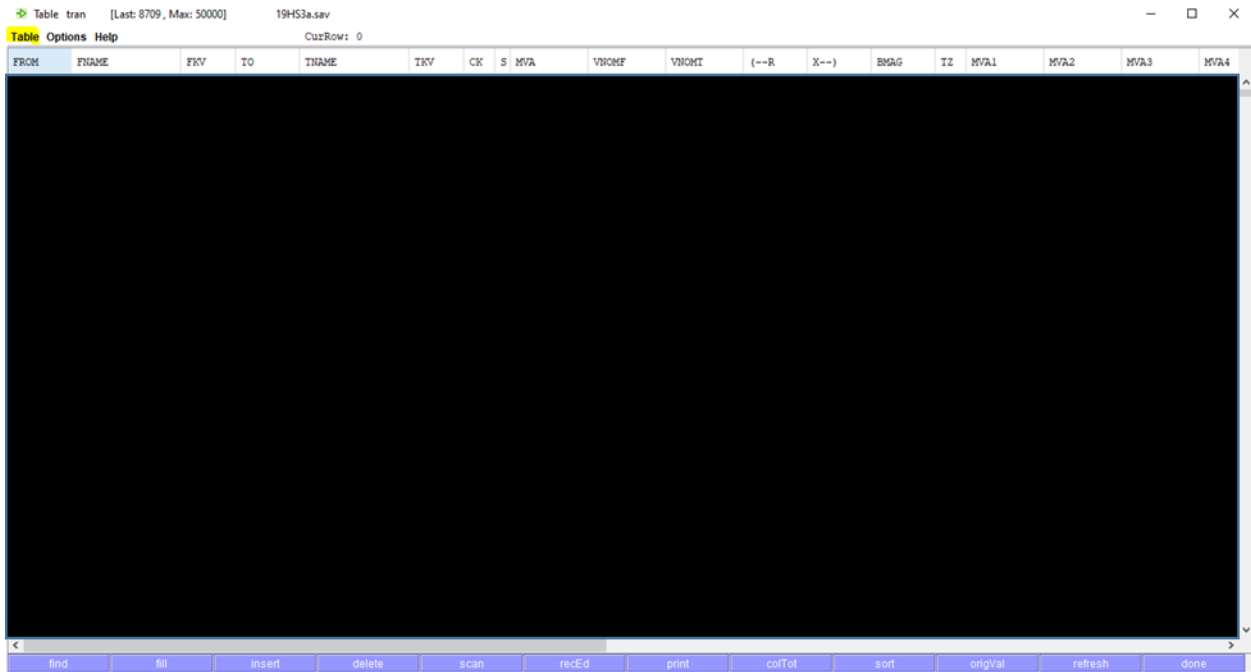


Figure B.4: PSLF sub-table with a highlight of dropdown options

Using the highlighted dropdown table in [Figure B.4](#) and selecting print, or by pressing F9, a series of two text boxes will pop up. Select row print, and then, select to export to the Excel sheet. Then select the choose file button and save this as a name of your choice. Filter and perform supplemental calculations afterwards. For the dc lines tab, those values are in amps, and most of the information in Generating Availability Data System (GADS) and Transmission Availability Data System (TADS) is in MW or MVA values. To get to MW values, utilize the dc bus voltage

¹³ Please see the MOD-032 Tracking sheet to find a contact to obtain the list of equipment and their MW capabilities. This document is posted to the SAMS webpage [here](#), but the direct link to the report is [here](#)

(the voltage in the dcl PSLF tables) and the amperage rating. Kilovolts multiplied by amperage rating will provide this information.

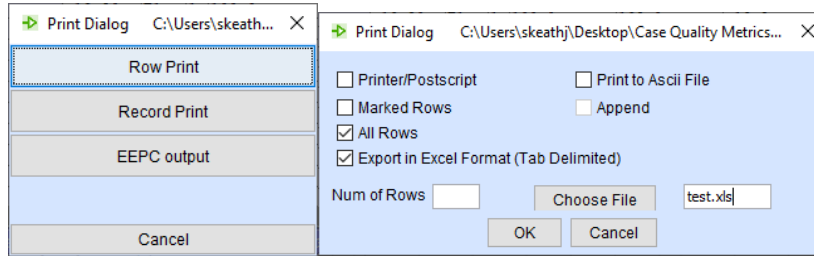


Figure B.5. Export to Excel from PSLF

PSS®E Specific Information Gathering

Due to the PSS®E data structure, after loading their binary save file, a direct copy and paste from the tables can be utilized to export the information into an Excel spreadsheet. Clicking on the select all button or via selecting all records will allow the user to copy and paste the information into an Excel workbook. Figure B.6 demonstrates the highlighted tabs that contain the ac lines, dc lines, Transformers, and dc converters. Some of those dc converters are associated with the dc lines. Verify with the NERC Standard MOD-032 designee for each Interconnection (EI is with Quebec. NPCC personnel know their DC converters.) that the records sufficiently represent the equipment.

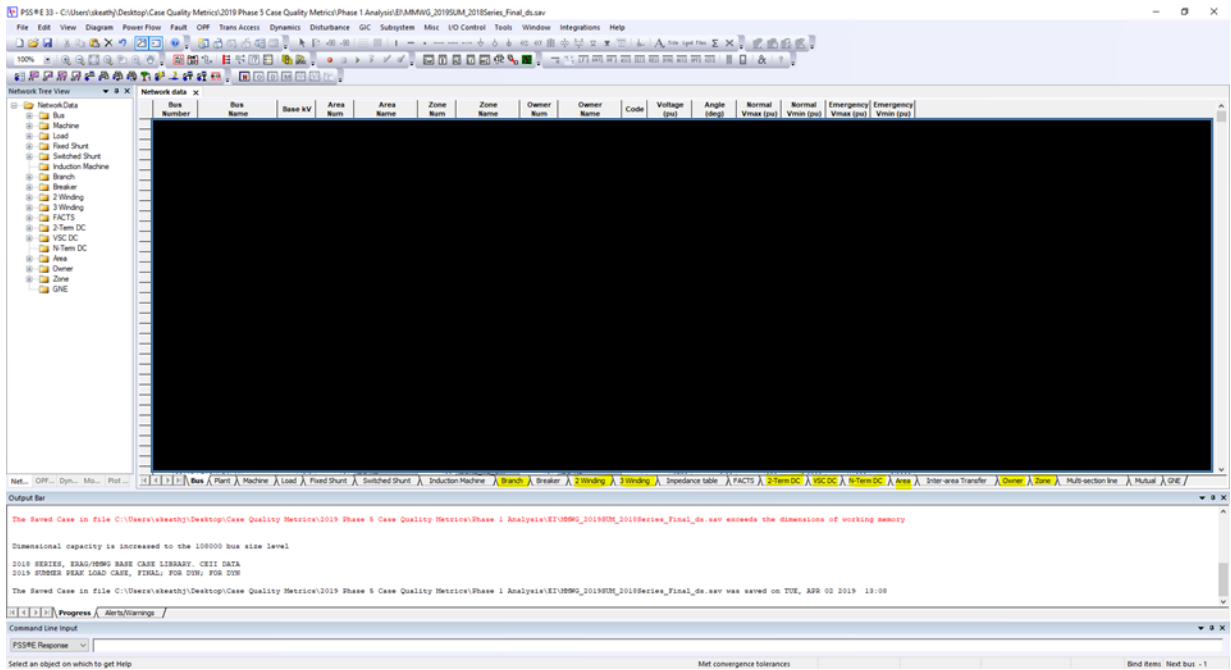


Figure B.6: PSS®E 33 Start menu with highlight of important tabs

With regard to version differences, PSS®E version 34 places the data in a slightly different place rather than all in one line. Select the Branch data and go to the highlighted tables to get the information. The multi-section line tab can be useful, but may not be a good representation of the MVA values for each line. Use those lines when readily available, but since the functionality (even in v33) is new to most TPs, much of the data can be entered in incorrectly. To get to Owner and Area tabs, select the other tab must first in v34.

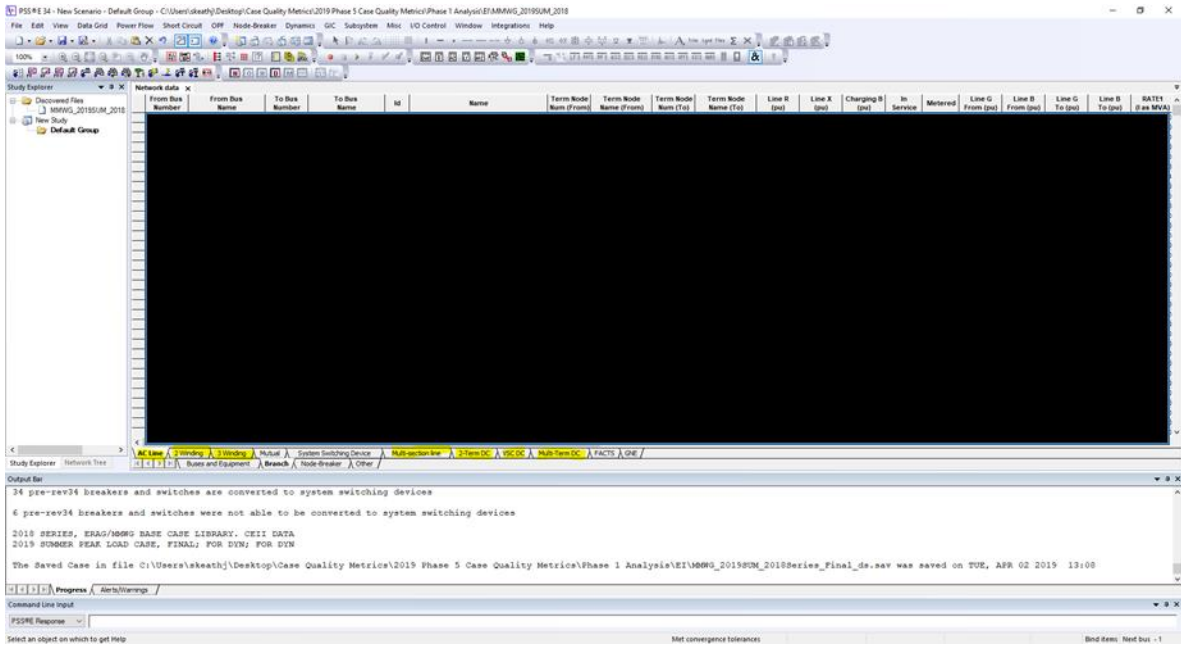


Figure B.7: PSS®E v34 Start menu with highlight of important tabs

To copy the data, simply click the top left corner of each of the tables, right click, and then select copy. It may take some time to load into RAM, but then you can paste directly into an open Excel sheet. Additionally, the normal shortcuts for copy and paste also work.

General filtering in Excel

Now that you have obtained the data from the powerflow software, a few assumptions are required before filtering the data. In the MVA values, the rating set (can be listed as Rate A, Rate B, etc. or MVA base), will be the key data point in updating the MVA values for use in the SOR. Each Interconnection has specific ways to provide rating sets for seasonal cases. In general, using a “heavy summer” or “light summer” base case will likely be the most available and a good choice for the MVA values. Each set of binary powerflow data is produced by a manual maintained by each MOD-032 designee. The manuals provide the full set of assumptions. However, major assumptions are:

1. MVA for lines and transformers reflect the ambient temperature modeled. Other temperatures throughout the year may alter these values. Summer cases generally have the lowest MVA as higher ambient temperatures lead to lower amounts of MVA on the lines or transformers due to lack of cooling.
2. Definitions for continual, emergency, and instantaneous ratings can vary between Interconnection. Look in the manual for the rating set to use for the values. In general, the first rating in each case is the continual operation (i.e. Rate A or Rate 1) and is well suited for SOR analysis. Emergency ratings and those sets are dictated partially by FAC standard requirements as well as Interconnection specific modeling practices.

Based on talks and discussions internally within NERC, filter the following by:

1. Removing jumpers in the system
2. Removing very high X/R ratio lines
3. Removing negative reactance values

To accomplish the filtering described above, the following calculations are performed:

1. $\text{Sqrt}(X^2+R^2) < 0.001$

2. If $R = 0$, automatic filter, otherwise if $X/R > 100$
3. $X < 0$

These filtering thresholds remove many modeling tricks TPs and PCs use to model short sections of bus work in order to monitor specific points. However, this either doubles or even triples count sections of transmission lines outside of the inventory of TADS and GADS. The filters are not error proof however, and can be revised as seen fit. Additionally, these only apply to the AC lines portion of the inventory.

Additionally, for many elements marked with an “EQ” for their ID, those likely Equivalent networks that are not representative of installed equipment. Additionally, MVA values outside the range for the following kV ranges are unreasonable according to the table. These use a 185 rating for the smallest overhead all aluminum conductor rating on the extremes of the kV bucket. Most common kVs for these areas are 34.5, 44.5, 69, 115, 138, 230, 345, 500, 765 kV. It is highly likely that at higher kV values, there are multiple conductors in each of the phases, indicating an increased maximum. It is safe to assume any MVA higher than 8000 MVA is incorrect, and any outside those boundaries are suspect. Since it is typical for multi conductors at higher kVs, a doubling of the high and low MVA at 300+ kV is more likely for certain equipment installations. In addition, this table assumes the transmission line is the limiting element between each substation, so this should only be used as a starting point/guide and not sacrosanct.

Table B.2: Guide for Single Conductor Lines

kV Bucket	Low MVA	High MVA
0-99	0	293
100-199	32	588
200-299	64	883
300-399	96	1179
400-499	128	1474
500-599	160	1769
600-699	192	2065
700-799	224	2361

Transformers

For transformers, much filtering cannot be done without direct knowledge on the type of transformer as well as if there are 3 two winding transformers representing 1 three winding transformer (TPs have done this as setting up a three winding transformer record can be time consuming and very sensitive when parameterized incorrectly). As transformers are tricky to figure out if they are a “real” transformer or that they are used to represent some complex system structure¹⁴, it is very difficult to fully capture only the transformers reported into TADS. However, a few filters and things can be done.

Simplistic filtering on anything higher than 2 MVA is recommended as many of the under 2 MVA are likely not a TADS transformer and are used to represent different bus voltages inside a generator plant that are not needed. The tricky part is determining the transformer attached to a Generator, and the number of transformations required before

¹⁴ such as the collector bus of an IBR plant and it’s connections up to the POI

reaching the transmission system. There are no good heuristics to filter these out, so use a breadth first search program constructed to look through the topology to find where the first bus in the transmission system is. In 2020, only one level of this program filtered out the commonly modeled GSUs. Construction of better methods which exist should be used to capture all non-BES transformations.

To summarize:

1. Filter out any MVA transformer that is less than 2 MVA.
2. Filter out any MVA transformer that is above 8888 MVA. Those are highly unrealistic
3. Filter out MVA transformers that are either a GSU, a MSU, or any of the transformations inside a modeled generator's footprint.

List of Acronyms

AC	Alternating Current
ASCII	American Standard Code for Information Interchange
BES	Bulk Electric System
DC	Direct Current
EI	Eastern Interconnection
GSU	Generator Step-Up transformer
kV	kiloVolts
MSU	Main Step-Up transformer
MVA	Mega Volt Amp
MVAR	MegaVAR
MW	Megawatt
PC	Planning Coordinator
POI	Point of Interconnections
PSLF	Power Systems Load Flow
PSS®E	Power Systems Simulator for Engineers
RAM	Random Access Memory
TI	Texas Interconnection
TP	Transmission Planner
VAR	Volt Amp Reactive
WI	Western Interconnection