Transmission Distribution Analysis of Regional Transfers

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SPP Southwest Power Pool

Abstract

SPP designed an analysis that assessed the responsiveness of various classes of transmission facilities to move power transfers among SPP's Pricing Zones. This paper describes the theory, assumptions and frequently asked questions regarding the analysis.

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Theory

The Transfer Distribution Factor (TDF) is a standard powerflow calculation that describes the percentage of a power transfer carried by a transmission element. The TDF value is a percentage calculated using the change in flow upon the transmission element due to a power transfer and the magnitude of the power transfer. The change in flow on the element is always a percentage of the total transfer, showing how the transfer has been distributed amongst the transmission elements. Since the transfer will be carried by multiple elements in the power system there will be multiple TDF values. Thus, the TDF percentage shows the support provided by the element to the transfer (i.e. This transmission line supports 5% of the transfer from area A to area B. A 5% TDF.) Conversely, it can be said that the transfer has an impact upon the element (i.e. This transfer from area A to area B has a 5% impact upon this transmission line.) Figure 1 shows a simple power system with a single transfer. The flows upon the lines (transmission elements) are the change in flow due to the 10-MW transfer from area A to area B.

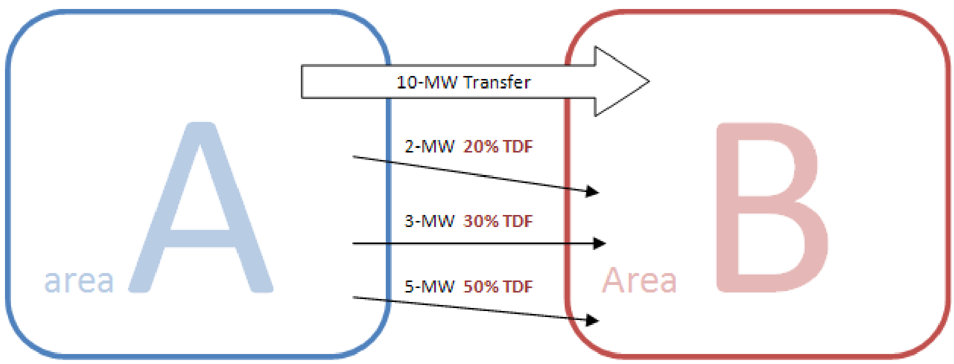

Figure 1: Simplified TDF Example

Assumptions

The SPP analysis defines areas and transmission elements to complete the TDF calculations. Commonly, the Balancing Authorities defined within SPP's powerflow models are used for the area transfers. Specifically defined geographic areas or voltage levels can also be used to create these transfers. This method ensures that all possible transactions between primary SPP areas are evaluated. For instance, in studies conducted for the Highway-Byway discussions, the pricing zones defined in attachment H where used. These areas are listed in Table 1. The transfers were simulated from each and every area to each and every other area, resulting in 182 individual transfers. Additionally, the analysis can utilize transfers between SPP and other Transmission Providers by including transfers between SPP areas and neighboring Transmission Providers' transmission systems. This too was done for the Highway-Byway discussions; and resulted in 56 additional transfers. See Appendix 2 for complete list of the transfers.

AEPW	LES	OPPD	WERE
EMDE	MIPU	SPS	WFEC
GRDA	NPPD	SUNC	
KACP	OKGE	SWPA	

Table 1: Control Areas for Attachment H Pricing Zones

The amount of power transferred is unimportant in this analysis. Because the TDFs show the percentage of the flow carried by an element rather than the actual magnitudes. The percentage of a 100-MW and a 1000-MW power transfer supported by a transmission element will always be the same.

The analysis will always include all of the transmission elements defined in the powerflow model used by SPP. Thus, the TDFs for each of the transmission lines and transformers within the SPP Reliability Footprint (The different SPP Footprints are described at www.spp.org) or all of the elements within the Eastern Interconnect can be specifically studied. Excluded from the analysis are transformers commonly referred to as “Step-up” transformers. These transformers exist solely to connect particular generation plants to the system and do not facilitate inter-area transfers.

Model & Software

SPP utilizes SIEMENS PSS® MUST and standard models in this analysis. The MUST tool allows the creation of the desired transfers from one area to another. SPP chooses certain settings that increases the generation in one area, while simultaneously decreasing generation in another area. This allows the study to maintain the generation dispatch and create transfers from one area to another. The DC powerflow model can be selected from any of the powerflow models maintained by SPP or its members. Models used in the STEP studies, TSR process or daily SPP operations may be used.

Analysis

The purpose of the analysis is to establish whether certain elements support the transfer of power between the SPP areas. The TDF of each element for each transfer is determined using the MUST tool. This yields numerous TDF values. The number of TDF values is always equal to the number of transfers, times the number of elements. For instance, the studies conducted for the Highway-Byway discussions yielded 935,298 TDF values. This was the result of evaluating 182 transfers with respect to 12 Balanced Portfolio elements and 5,127 other elements in the 345, 138, 115 and 69-kV voltage strata. Projects are treated on a per-element basis. A project with 5 lines will have 5 TDFs per transfer. No averaging, grouping or summing of these TDFs occurs. All lines and transformers are evaluated and reported singly.

Reporting

For this analysis the TDF values are organized by voltage class and magnitude. Higher TDF values indicate greater support for a given transfer. Lower TDF values indicate less support. To compare the ability of elements in different voltage strata to support the transfers, it is necessary to view the number of supporting elements as a percentage of the total number of elements at that voltage level. This approach can be compared to the use of a histogram in statistical operations. Percentages are used due to account for the different number of elements in each transmission category being evaluated. There may be many more elements (and consequently TDFs) in one voltage strata than in another. To provide a meaningful comparison the results are normalized by dividing the number of supporting TDFs by the total number of TDFs. A hypothetical example of such a calculation is shown in Table 2.

	Category A	Category B
Number of Elements	100	2000
Number of Transfers	182	182
Number of TDFs	18,200	364,000
Number of TDFs greater than zero (from MUST tool)	16,000	300,000
Number of TDFs greater than 0.1% (reference TDF)	8,000	200,000
Percentage of TDFs greater than zero (normalized)	88%	82%
Percentage of TDFs greater than 0.1% (normalized)	44%	67%

Table 2: Normalization of Supporting TDFs

With the results normalized the percentage of TDFs that exceed a certain cut-off threshold can be determined and compared to other classes or projects. Appendix 3 contains exhaustive tables specific to the Highway-Byway analysis.

Two visual layouts illustrating the results obtained in these studies are provided in Figure 2 and Figure 3. Figure 2 is a bar chart showing the percentage of the TDFs in each category with a magnitude of at least the cut-off value, 0.1%. The data shown corresponds to that of Table 2. This illustrates that the "Category B" elements provide more support than the "Category A" elements. The chart can be read as follows, "44% of the time, the transmission elements in Category A supported the power transfer under study by at least 0.1%." Figure 3 is an area chart showing the percentage of TDFs in each category for a whole spectrum of reference TDFs. Once again, the data corresponds to that of Table 2. The reference TDF of 0.1%, shown at the left side of the chart, corresponds to the cut-off value used in Figure 2. This chart shows the overall trend that could be missed if only a single reference (aka cut-off) TDF was used in the analysis and illustrates that "Category B" elements provide much greater support than "Category A" elements. Appendix 4 contains charts specific to the Highway-Byway analysis.

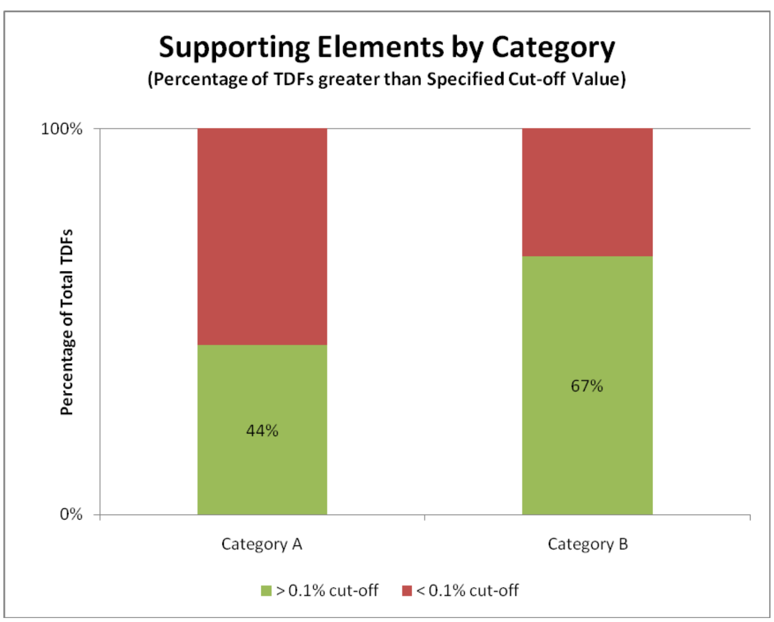

Figure 2: Supporting Elements by Category (Bar Chart)

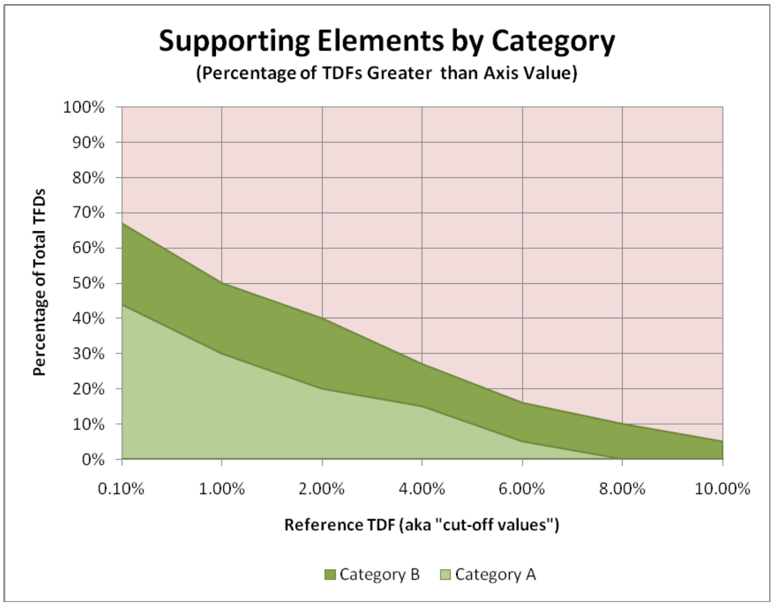

Figure 3: Supporting Elements by Category (Area Chart)

Conclusion

This analysis allows SPP to measure the effectiveness of certain transmission elements in the support of regional transfers in a straightforward manner. The results of any TDF analysis will vary depending upon the particular facility assumptions and elements studied. These variables allow for a wide range of applications and provide opportunities for further study in many directions.

Frequently Asked Questions

Q: In , the percentage of supporting elements was calculated using the number of TDFs greater than zero. Why is this and what significance do negative TDFs have in this analysis?

A: The TDFs below zero provide relevant, but redundant information. Because transfers are evaluated between all selected areas, each path has both a negative and positive component depending upon the directionality of the line being monitored. For instance, a line flowing from area A to area B will have a positive TDF when the transfer is evaluated from area A to area B and a negative TDF when the transfer is evaluated from area B to area A. In both cases, the magnitude of the TDF will be similar and indicates the impact of the transfer upon the line. This phenomenon is shown for all 345-kV elements and transfers evaluated for the Highway-Byway discussions in Figure 4.

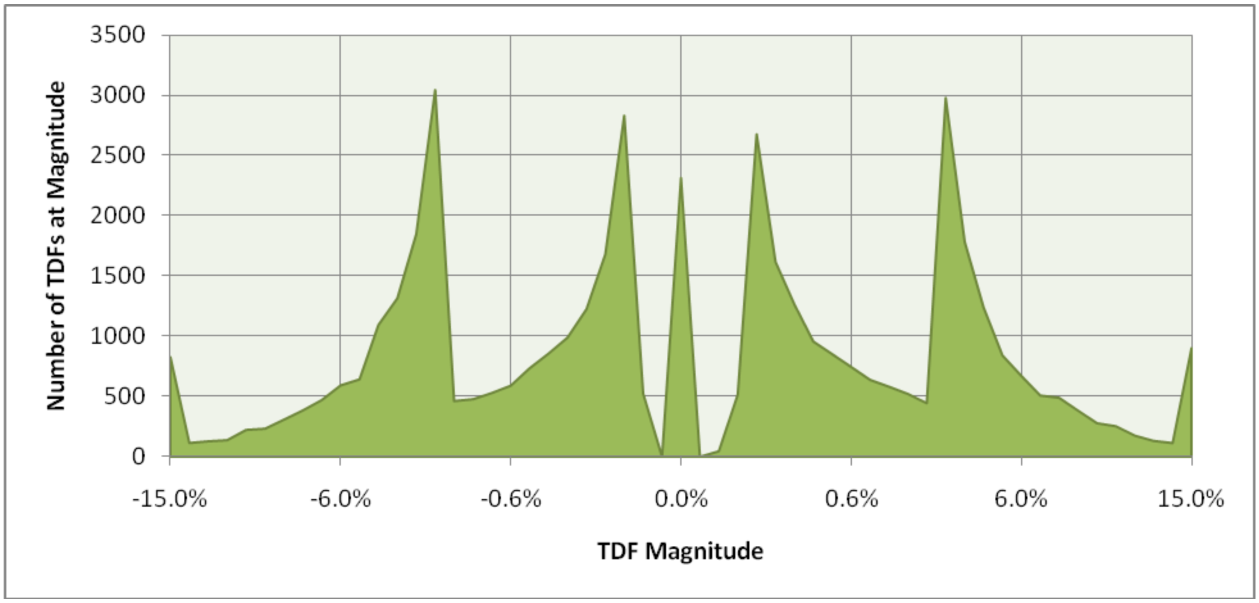

Figure 4: TDF Directionality & Magnitude

Q: In , the percentage of supporting elements was calculated using the number of TDFs greater than 0.1%. What is this percentage and why is it used?
A: This percentage reflects the a precision of the analysis tools and models used in this study and was chosen as the cut-off between those TDFs that show significant impact upon the transmission element and those that do not.

Q: Do the TDF values represented in this analysis simply result from the location of the lines and transformers being reported?
A: The location of the lines and transformers do affect how well they support transfers in the region. This analysis, since it evaluates the regional paths between all of the SPP membership catches the placement of each element with SPP as a whole, rather than being biased by a singularly beneficial placement. The selection of the areas

Q: In Figure 5 and the Highway-Byway presentations the 230-kV and 161-kV existing system support is not shown. Is there a reason that these voltages were not shown? Was any analysis of these voltages performed?
A: The review of the 115-kV and 138-kV facilities was an arbitrary choice between 69-kV and 345-kV. The 230-kV and 161-kV systems were not reported or studied in the Highway-Byway analysis due to time constraints. Engineering tests indicated little value added by increasing the study details. Staff feels increased detail would only continue to yield similar patterns of increasing transfer support for each incremental voltage level.

Q: Are the TDFs summed or averaged in any way?
A: No, the TDFs are not summed, averaged or otherwise changed. The number of TDFs at a particular magnitude are totaled. (The reader may be familiar with the histogram which presents the data in the same manner.) For instance, 30% of the TDF values had a magnitude of at least 2%. The data and charts presented in Appendices 3 and 4 should be read in this manner.

Appendix 1: Highway – Byway Analysis Statistics

All Systems and Projects

The statistics that follow represent all of the transfer paths, system elements and TDF values obtained in the Highway-Byway analysis, presented to the SPP MOPC Markets and Operations Policy Committee (MOPC) on Tuesday, March 2nd 2010.

- Number of Evaluated Paths: 238 total, 56 external and 182 internal area pairs.
- In the statistics below, "least" refers to the path with lowest average TDF.
- In the statistics below, "most" refers to the path with highest average TDF.
- Maximum TDFs are the highest value for the given transfer, for all elements.
- Minimum TDFs are the lowest value for the given transfer, for all elements.

Balanced Portfolio

The analysis of the transmission elements in the SPP Balanced Portfolio yielded the following.

- Least supported path & min/max TDFs: OPPD - LES 0.04% / 1.64%.
    - No path created less than a 0.04% response factor on any element in the Balanced Portfolio.
- Most supported path & min/max TDFs: KACP - SPS 3.91% / 19.94%.
- Least helpful project & min/max TDFs: Iatan – Nashua 0.03% / 11.1%.
    - TDFs refer to all paths
- Most helpful project & min/max TDFs: Spearville – Knoll – Axtell 0.05% / 27.43%
    - TDFs refer to all paths

345 kV System Elements

- Least supported path & min/max TDFs: AMIL - AECI 0.00% / 3.19%.
- Most supported path & min/max TDFs: SPS - LES 0.00% / 38.74%.

115-138 kV System Elements

- Least supported path & min/max TDFs: AMIL - AECI 0.00% / 0.61%.
- Most supported path & min/max TDFs: WFEC - LES 0.00% / 32.6%.

69 kV System Elements

- Least supported path & min/max TDFs: AMIL - AECI 0.00% / 0.23%.
- Most supported path & min/max TDFs: WFEC - EMDE 0.00% / 3.38%.

Appendix 2: Highway – Byway Path Definitions

The transfer paths used in the Highway-Byway analysis are shown in the following tables. The "_I" suffix on the sink areas indicate that the area received the transfer (power was imported to that area).

External Transfer Paths

Source	Sink	Source	Sink	Source	Sink	Source	Sink
AECI	AMIL_I	EES	AECI_I	MEC	AECI_I	WAUE	AECI_I
AECI	EES_I	EES	AMIL_I	MEC	AMIL_I	WAUE	AMIL_I
AECI	ERCOT_I	EES	ERCOT_I	MEC	EES_I	WAUE	EES_I
AECI	MEC_I	EES	MEC_I	MEC	ERCOT_I	WAUE	ERCOT_I
AECI	WAPA_I	EES	WAPA_I	MEC	WAPA_I	WAUE	MEC_I
AECI	WAUE_I	EES	WAUE_I	MEC	WAUE_I	WAUE	WAPA_I
AECI	WECC_I	EES	WECC_I	MEC	WECC_I	WAUE	WECC_I
AMIL	AECI_I	ERCOT	AECI_I	WAPA	AECI_I	WECC	AECI_I
AMIL	EES_I	ERCOT	AMIL_I	WAPA	AMIL_I	WECC	AMIL_I
AMIL	ERCOT_I	ERCOT	EES_I	WAPA	EES_I	WECC	EES_I
AMIL	MEC_I	ERCOT	MEC_I	WAPA	ERCOT_I	WECC	ERCOT_I
AMIL	WAPA_I	ERCOT	WAPA_I	WAPA	MEC_I	WECC	MEC_I
AMIL	WAUE_I	ERCOT	WAUE_I	WAPA	WAUE_I	WECC	WAPA_I
AMIL	WECC_I	ERCOT	WECC_I	WAPA	WECC_I	WECC	WAUE_I

Table 3: External Transfer Paths

Internal Transfer Paths

Source	Sink	Source	Sink	Source	Sink	Source	Sink	Source	Sink
AEPW	EMDE_I	EMDE	AEPW_I	GRDA	AEPW_I	KACP	AEPW_I	LES	AEPW_I
AEPW	GRDA_I	EMDE	GRDA_I	GRDA	EMDE_I	KACP	EMDE_I	LES	EMDE_I
AEPW	KACP_I	EMDE	KACP_I	GRDA	KACP_I	KACP	GRDA_I	LES	GRDA_I
AEPW	LES_I	EMDE	LES_I	GRDA	LES_I	KACP	LES_I	LES	KACP_I
AEPW	MIPU_I	EMDE	MIPU_I	GRDA	MIPU_I	KACP	MIPU_I	LES	MIPU_I
AEPW	NPPD_I	EMDE	NPPD_I	GRDA	NPPD_I	KACP	NPPD_I	LES	NPPD_I
AEPW	OKGE_I	EMDE	OKGE_I	GRDA	OKGE_I	KACP	OKGE_I	LES	OKGE_I
AEPW	OPPD_I	EMDE	OPPD_I	GRDA	OPPD_I	KACP	OPPD_I	LES	OPPD_I
AEPW	SPS_I	EMDE	SPS_I	GRDA	SPS_I	KACP	SPS_I	LES	SPS_I
AEPW	SUNC_I	EMDE	SUNC_I	GRDA	SUNC_I	KACP	SUNC_I	LES	SUNC_I
AEPW	SWPA_I	EMDE	SWPA_I	GRDA	SWPA_I	KACP	SWPA_I	LES	SWPA_I
AEPW	WERE_I	EMDE	WERE_I	GRDA	WERE_I	KACP	WERE_I	LES	WERE_I
AEPW	WFEC_I	EMDE	WFEC_I	GRDA	WFEC_I	KACP	WFEC_I	LES	WFEC_I
MIPU	AEPW_I	NPPD	AEPW_I	OKGE	AEPW_I	OPPD	AEPW_I	SPS	AEPW_I
MIPU	EMDE_I	NPPD	EMDE_I	OKGE	EMDE_I	OPPD	EMDE_I	SPS	EMDE_I
MIPU	GRDA_I	NPPD	GRDA_I	OKGE	GRDA_I	OPPD	GRDA_I	SPS	GRDA_I
MIPU	KACP_I	NPPD	KACP_I	OKGE	KACP_I	OPPD	KACP_I	SPS	KACP_I

MIPU	LES_I	NPPD	LES_I	OKGE	LES_I	OPPD	LES_I	SPS	LES_I
MIPU	NPPD_I	NPPD	MIPU_I	OKGE	MIPU_I	OPPD	MIPU_I	SPS	MIPU_I
MIPU	OKGE_I	NPPD	OKGE_I	OKGE	NPPD_I	OPPD	NPPD_I	SPS	NPPD_I
MIPU	OPPD_I	NPPD	OPPD_I	OKGE	OPPD_I	OPPD	OKGE_I	SPS	OKGE_I
MIPU	SPS_I	NPPD	SPS_I	OKGE	SPS_I	OPPD	SPS_I	SPS	OPPD_I
MIPU	SUNC_I	NPPD	SUNC_I	OKGE	SUNC_I	OPPD	SUNC_I	SPS	SUNC_I
MIPU	SWPA_I	NPPD	SWPA_I	OKGE	SWPA_I	OPPD	SWPA_I	SPS	SWPA_I
MIPU	WERE_I	NPPD	WERE_I	OKGE	WERE_I	OPPD	WERE_I	SPS	WERE_I
MIPU	WFEC_I	NPPD	WFEC_I	OKGE	WFEC_I	OPPD	WFEC_I	SPS	WFEC_I
SUNC	AEPW_I	SWPA	AEPW_I	WERE	AEPW_I	WFEC	AEPW_I		
SUNC	EMDE_I	SWPA	EMDE_I	WERE	EMDE_I	WFEC	EMDE_I		
SUNC	GRDA_I	SWPA	GRDA_I	WERE	GRDA_I	WFEC	GRDA_I		
SUNC	KACP_I	SWPA	KACP_I	WERE	KACP_I	WFEC	KACP_I		
SUNC	LES_I	SWPA	LES_I	WERE	LES_I	WFEC	LES_I		
SUNC	MIPU_I	SWPA	MIPU_I	WERE	MIPU_I	WFEC	MIPU_I		
SUNC	NPPD_I	SWPA	NPPD_I	WERE	NPPD_I	WFEC	NPPD_I		
SUNC	OKGE_I	SWPA	OKGE_I	WERE	OKGE_I	WFEC	OKGE_I		
SUNC	OPPD_I	SWPA	OPPD_I	WERE	OPPD_I	WFEC	OPPD_I		
SUNC	SPS_I	SWPA	SPS_I	WERE	SPS_I	WFEC	SPS_I		
SUNC	SWPA_I	SWPA	SUNC_I	WERE	SUNC_I	WFEC	SUNC_I		
SUNC	WERE_I	SWPA	WERE_I	WERE	SWPA_I	WFEC	SWPA_I		
SUNC	WFEC_I	SWPA	WFEC_I	WERE	WFEC_I	WFEC	WERE_I		

Table 4: Internal Transfer Paths

Appendix 3: Highway – Byway TDF Percentages

TDF Table for All Transactions

The table shown below summarizes the impacts for all internal and external paths. The 0.1% TDF was used for reference in the testimony and as our cutoff value. Values below that were considered as non-supporting responses. The 1.0% and 5.0% TDFs are highlighted as the last points at which 69 kV and 138-115 kV systems provide any support.

Reference TDF	*Balanced Portfolio*	*Existing 345 kV Systems*	*Existing 138 & 115 kV Systems*	*Existing 69 kV Systems*
0.00000%	100%	90%	67%	42%
0.00010%	100%	90%	67%	42%
0.00100%	100%	90%	66%	41%
0.01000%	100%	88%	59%	33%
0.10000%	98%	77%	37%	13%
0.20000%	95%	70%	28%	7%
0.30000%	93%	65%	22%	4%
0.40000%	91%	61%	18%	3%
0.50000%	89%	57%	15%	2%
0.60000%	86%	54%	13%	2%
0.70000%	84%	51%	11%	1%
0.80000%	81%	49%	9%	1%
0.90000%	79%	47%	8%	1%
1.00000%	76%	45%	7%	1%
2.00000%	59%	33%	3%	0%
3.00000%	48%	26%	1%	0%
4.00000%	39%	21%	1%	0%
5.00000%	34%	18%	1%	0%
6.00000%	29%	15%	0%	0%
7.00000%	26%	13%	0%	0%
8.00000%	23%	11%	0%	0%
9.00000%	20%	10%	0%	0%
10.00000%	17%	9%	0%	0%
11.00000%	14%	8%	0%	0%
12.00000%	13%	7%	0%	0%
13.00000%	11%	6%	0%	0%
14.00000%	9%	6%	0%	0%
15.00000%	7%	3%	0%	0%

Table 5: Percentage of TDFs greater than reference TDF for all transfers

TDF Table for External Transfers

The table shown below summarizes the impacts for all external paths. The 0.1% TDF was used for reference in the testimony and as our cutoff value. Values below that were considered as non-supporting responses. The 0.4% and 3.0% TDFs are highlighted as the last points at which 69 kV and 138-115 kV systems provide any support.

Reference TDF	*Balanced Portfolio*	*Existing 345 kV Systems*	*Existing 138 & 115 kV Systems*	*Existing 69 kV Systems*
0.00000%	100%	90%	67%	43%
0.00010%	100%	90%	67%	43%
0.00100%	100%	89%	66%	41%
0.01000%	100%	88%	59%	32%
0.10000%	97%	76%	36%	9%
0.20000%	95%	68%	25%	3%
0.30000%	93%	62%	19%	2%
0.40000%	89%	57%	15%	1%
0.50000%	88%	53%	12%	0%
0.60000%	85%	49%	9%	0%
0.70000%	84%	47%	8%	0%
0.80000%	79%	44%	6%	0%
0.90000%	77%	42%	5%	0%
1.00000%	75%	40%	4%	0%
2.00000%	58%	29%	1%	0%
3.00000%	44%	22%	1%	0%
4.00000%	34%	18%	0%	0%
5.00000%	30%	14%	0%	0%
6.00000%	23%	11%	0%	0%
7.00000%	20%	9%	0%	0%
8.00000%	18%	8%	0%	0%
9.00000%	16%	7%	0%	0%
10.00000%	12%	6%	0%	0%
11.00000%	8%	5%	0%	0%
12.00000%	6%	4%	0%	0%
13.00000%	5%	4%	0%	0%
14.00000%	4%	3%	0%	0%
15.00000%	4%	3%	0%	0%

Table 6: Percentage of TDFs greater than reference TDF for external transfers

TDF Table for Internal Transactions

The table shown below summarizes the impacts for all internal paths. The 0.1% TDF was used for reference in the testimony and as our cutoff value. Values below that were considered as non-supporting responses. The 1.0% and 5.0% TDFs are highlighted as the last points at which 69 kV and 138-115 kV systems provide any support.

Reference TDF	*Balanced Portfolio*	*Existing 345 kV Systems*	*Existing 138 & 115 kV Systems*	*Existing 69 kV Systems*
0.00000%	100%	91%	67%	42%
0.00010%	100%	91%	67%	42%
0.00100%	100%	90%	66%	41%
0.01000%	100%	88%	59%	33%
0.10000%	98%	78%	38%	14%
0.20000%	95%	71%	29%	8%
0.30000%	93%	66%	23%	5%
0.40000%	91%	62%	19%	4%
0.50000%	89%	59%	16%	3%
0.60000%	87%	56%	14%	2%
0.70000%	84%	53%	12%	2%
0.80000%	81%	51%	10%	1%
0.90000%	79%	49%	9%	1%
1.00000%	77%	47%	8%	1%
2.00000%	60%	35%	3%	0%
3.00000%	49%	27%	2%	0%
4.00000%	41%	22%	1%	0%
5.00000%	35%	19%	1%	0%
6.00000%	31%	16%	0%	0%
7.00000%	28%	14%	0%	0%
8.00000%	24%	12%	0%	0%
9.00000%	21%	11%	0%	0%
10.00000%	18%	10%	0%	0%
11.00000%	16%	9%	0%	0%
12.00000%	15%	8%	0%	0%
13.00000%	12%	7%	0%	0%
14.00000%	10%	7%	0%	0%
15.00000%	8%	3%	0%	0%

Table 7: Percentage of TDFs greater than reference TDF for internal transfers

Appendix 4: Highway – Byway Charts

These charts were used in the analysis to visualize the TDFs obtained in the Highway – Byway analysis (the data in Table 5, Table 6 and Table 7). Each transmission category provides some measure of support to transfers. The graphs show the percentage of the supported transfers (i.e. the 14% in Figure 5 indicates that 14% of the calculated TDFs for the 69-kV system supported the internal transfers).

These results indicate that EHV projects designed for regional expansion (i.e. the SPP Balanced Portfolio) benefit the whole SPP region, while lower voltage systems provide localized support.

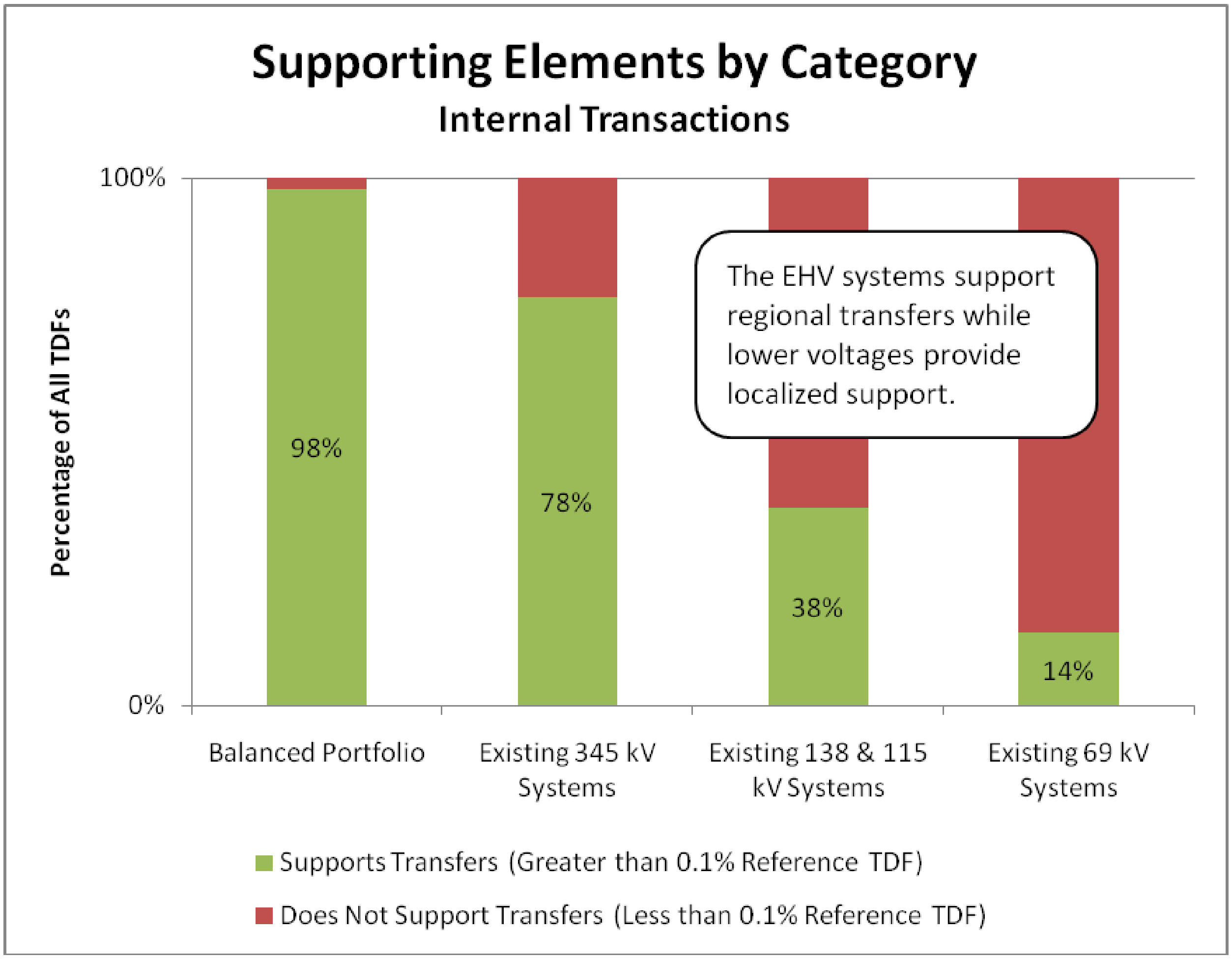

Figure 5: Percentages greater than 0.1% reference TDF by element category for internal transfers

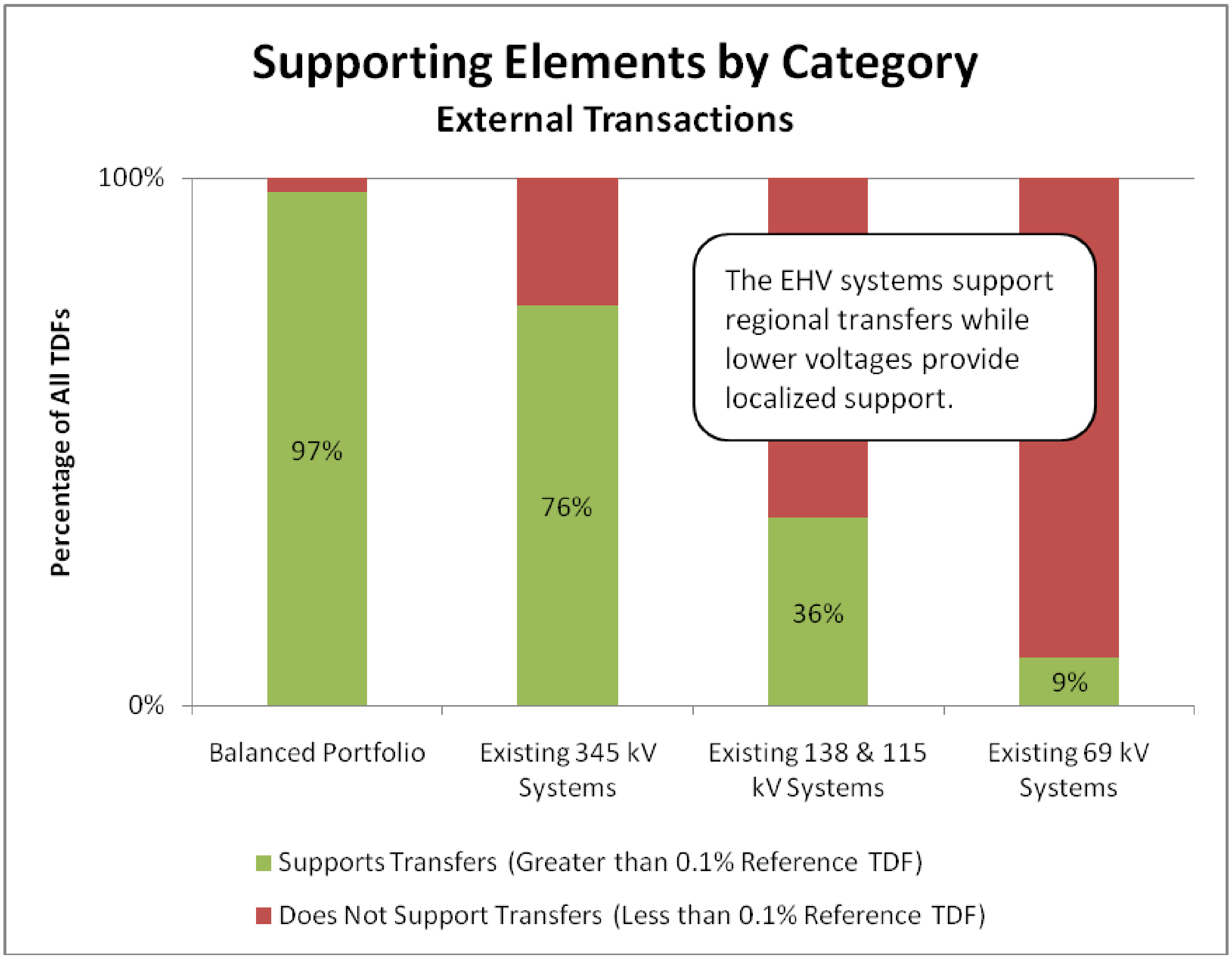

Figure 6: Percentages greater than 0.1% reference TDF by element category for external transfers

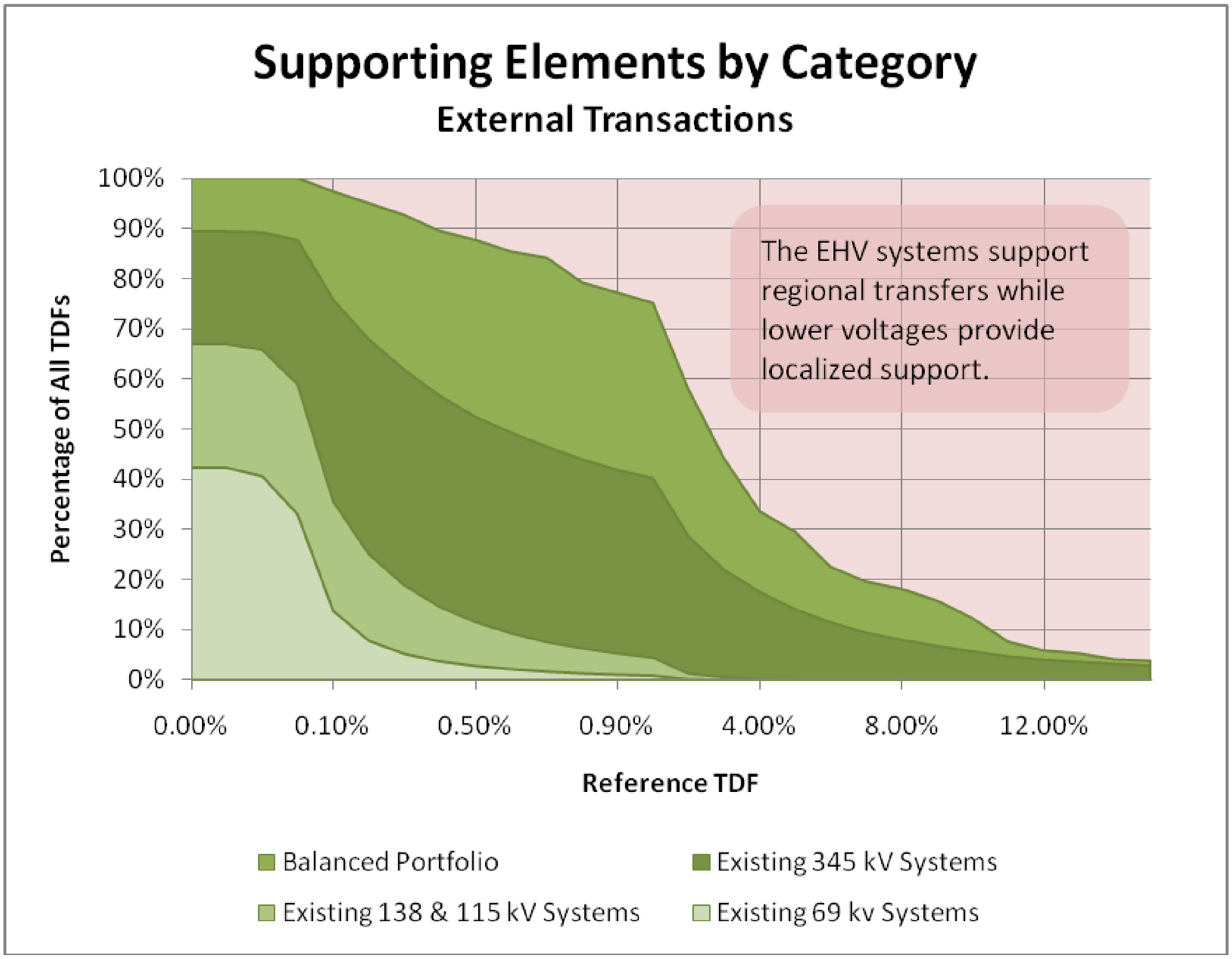

Figure 7: Supporting TDFs by element category for external transfers

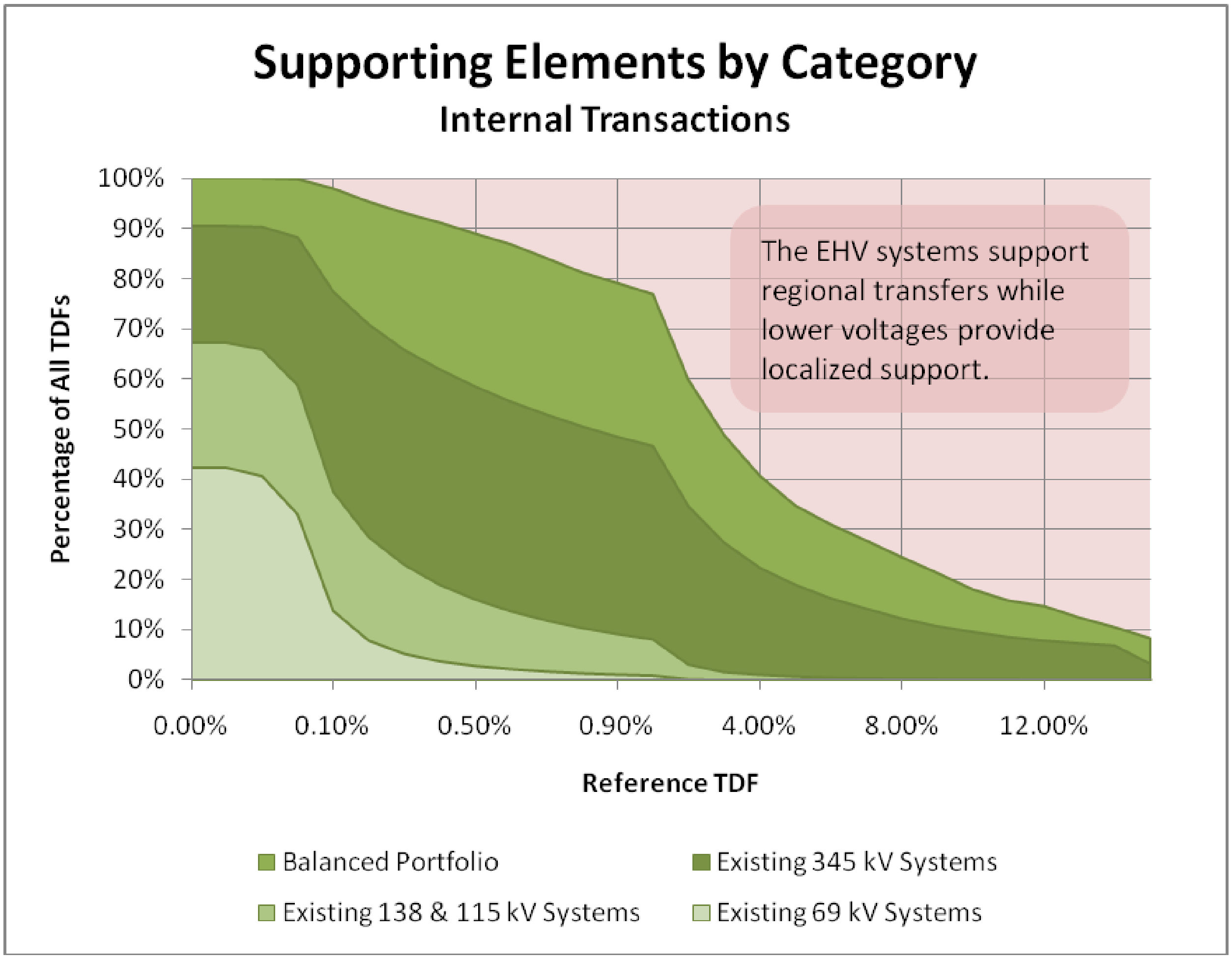

Figure 8: Supporting TDFs by element category for internal transfers