CALCULATING ACE DISTRIBUTION FACTORS

Prepared for

Reliability Based Control Standard Drafting Team

by

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Introduction

The current Transmission Loading Relief (TLR) procedure only considers the effect of scheduled transactions and only adjusts scheduled energy transactions to provide the necessary relief to maintain reliability. The current TLR process fails to consider or manage the effects of unscheduled energy on transmission system reliability. The Reliability Based Control Standard Drafting Team (RBC SDT) is attempting to determine an equitable method to limit ACE contributions to SOL/IROL issues that are currently managed with the Transmission Loading Relief process. To achieve this, the RBC SDT must calculate the effect on the transmission system of unscheduled flows on an equivalent basis to scheduled flows. This paper provides a method to perform a calculation that will provide a link between ACE and flow contribution to a specific flow-gate.

1. THE IDC PROVIDES THE INITIAL INFORMATION

Assume a five BA interconnection with BAs numbered 1 through 5. Assume that there are six flow-gates on the interconnection that can become constrained labeled A through F. The IDC would calculate a Distribution Factor (DF) for each flow gate for each pair of BAs. For example, the Distribution Factor for flow-gate A for a schedule from BA_1 to BA_2 would be designated as DF_{A12}. One set of DFs for a specified flow-gate could be presented in a table as shown in the Example I.

Example I – Distribution Factors for Flow-gate A

From \ To	BA_1	BA_2	BA_3	BA_4	BA_5
BA_1	X	DF_{A12}	DF_{A13}	DF_{A14}	DF_{A15}
BA_2	DF_{A21}	X	DF_{A23}	DF_{A24}	DF_{A25}
BA_3	DF_{A31}	DF_{A32}	X	DF_{A34}	DF_{A35}
BA_4	DF_{A41}	DF_{A42}	DF_{A43}	X	DF_{A45}
BA_5	DF_{A51}	DF_{A52}	DF_{A53}	DF_{A54}	X

Of course the following equalities are maintained.

$DF_{A12} = -DF_{A21}$ (1) $DF_{A13} = -DF_{A31}$ (2) $DF_{A14} = -DF_{A41}$ (3)
$DF_{A15} = -DF_{A51}$ (4) $DF_{A23} = -DF_{A32}$ (5) $DF_{A24} = -DF_{A42}$ (6)
$DF_{A25} = -DF_{A52}$ (7) $DF_{A34} = -DF_{A43}$ (8) $DF_{A35} = -DF_{A53}$ (9)
$DF_{A45} = -DF_{A54}$ (10)

Each flow-gate would have a similar set of distribution factors and similar equalities would hold for each of these flow-gates. These could be represented by a general set of DFs for a Flow-gate. The distribution factors for flow-gate X for scheduled flows from BA_Y to BA_Z would be represented by the $\mathbf{DF_{XYZ}}$.

The basic problem is to convert these DF that were developed based on the assumption of balanced flow between two selected BAs into a set of ACE Distribution Factors (ADF). The resulting ADFs would be based on the assumption of singular injection by a single BA as indicated by that BAs ACE.

2. USING THE IDC TO DETERMINE ACE CONTRIBUTION TO FLOW-GATES

The Distribution Factors, provided for each flow-gate, can be used to calculate the contribution of an ACE error to the energy flow on that flow-gate. In this document those contributions will be called ACE Distribution Factors (ADF). The Frequency Response for every BA provides sufficient additional information when considered with the DF from the IDC to make the desired calculation. The following method shows how the ADF for a BA can be calculated for a specific flow-gate.

ACE Distribution Factor (ADF) Equation:

The DF for a given BA and a specific flow-gate provides the proportion of the scheduled flow that will impact the specific flow-gate for a scheduled transaction that is balanced. Assume that the only non-zero ACE on the interconnection is the ACE for BA_Y. Under these circumstances, we know that the ACE will represent the net control error within BA_Y. The ACE of BA_Y automatically adjusts the value to compensate for the Frequency Response provided by BA_Y. Thus the ACE of BA_Y will be different from the power flowing across BA_Y's borders. The flow across BA_Y's borders can be calculated from BA_Y's ACE and Frequency Response, $\boldsymbol{\beta_Y}$, and the Frequency Response(s), $\boldsymbol{\beta_Z}$, of all the other BAs on the interconnection. This total flow can be calculated as the sum of all of the flows that occur between the BA with the non-zero ACE and each other BA on the interconnection. The general equation for the ACE Distribution Factor (ADF) is derived in Appendix 1, Equation 24, and repeated as Equation 11 below.

$$\mathbf{ADF_{XY} = (1/\beta_T) \times \sum_{Z=1, Z \neq Y}^{Z=N} (\beta_Z \times DF_{XYZ})} \qquad \textbf{(11)}$$

Where:
- $\boldsymbol{\beta_Y}$ = The Frequency Response of the BA with the non-zero ACE
- $\boldsymbol{\beta_T}$ = The total Frequency Response of the interconnection
- $\boldsymbol{\beta_Z}$ = The Frequency Response of each other BA when paired with BA_Y
- $\mathbf{DF_{XYZ}}$ = The Distribution Factor from the IDC described above

The IDC can provide this relatively simple and easy calculation with the results of each IDC solution.

ACE Distribution Factor (ADF) Use:

For any selected flow-gate the ADF for a BA for that specific flow-gate provides the ACE Flow Contribution (FC) by simply multiplying the ACE for the BA by the ADF for the BA for the flow-gate in question. The result would be the MW contribution to the flow on that flow-gate.

$$\mathbf{FC_{XY} = ACE_Y \times ADF_{XY}} \qquad \textbf{(12)}$$

In the equation, the ACE Distribution Factor, ADF, is dimensionless while the ACE is scaled in MWs. Therefore, the flow contribution to the flow-gate would be in MWs.

It is useful to note that the Flow Contribution for the flow-gate is the sum of the individual Flow Contributions from each of the balanced flows from each of the other BAs on the interconnection. These individual Flow Contributions are calculated from the balanced flows between the BA with non-zero ACE and each of the other BAs. The sign must be changed because they represent the flow at the other BA. Equation 13 provides these contributions:

$$\mathbf{FC_{XY} = ACE_Y \times (\beta_Z / \beta_T) \times DF_{XYZ}} \qquad \textbf{(13)}$$

Relative Contribution of DF as Compared to ADF:

It may be necessary to determine the relative contribution of a DF to an ADF on a specific flow-gate. The Reliability Coordinators (RC) can determine the relative contribution by simply comparing the contribution to that specific flow-gate by determining the change in flow of an ACE contribution relative to a schedule contribution. For example, an ACE of 100 MW for BA_1 will indicate the contribution to the flow on a specific flow-gate while the contribution to that same flow-gate from a schedule will be equivalent to an ACE of 100 MW for BA_1 and an ACE of -100 MW for a different BA. Thus, the contribution of ACE to a flow-gate should be approximately one-half the contribution of a 100 MW schedule on that same flow-gate. The relative sensitivity can be determined from the specific circumstances as they occur. This should be investigated in greater depth as implementation moves forward.

3. OTHER CONSIDERATIONS

One of the basic problems that will occur as implementation move forward will be inputting good estimates of the Frequency Response for each BA. The best estimates of Frequency Response available at this time are the Frequency Bias values reported each year by the BAs included on the CPS2 Report. However, these estimates are significantly influenced by the current rules on minimum Frequency Bias in BAL-003. The estimates for Frequency Response could be significantly improved with the elimination of this minimum Frequency Bias requirement.

4. SUMMARY AND CONCLUSIONS

This paper provides a simple and effective way to convert the Distribution Factors provided by the IDC for each flow-gate into a set of additional ACE Distribution Factors. These ADF could be used to evaluate ACE on an equivalent basis to that currently provided to the RCs by the IDC. One of the significant advantages of determining the ADFs in this manner is that they are calculated and available at the same periodicity as the DFs from the IDC. This allows the RCs to set limits for ACE only when necessary to beneficially impact interconnection reliability. All BAs would continue to be able to operate with the minimum constraints on ACE resulting from transmission system limitations.

Appendix 1 – Derivation of ACE Contribution to Total Flow

Assume that BA_1 is the only BA with an **ACE** not equal to zero on a five BA interconnection. Additionally, if each BA has their Frequency Bias in their ACE Equation properly set to their Frequency Response, only BA_1 will have a non-zero ACE.

$$\mathbf{ACE_1 = T_1 - 10 \times \beta_1 \times \Delta F} \tag{1}$$

$$\mathbf{ACE_2 = 0 = T_2 - 10 \times \beta_2 \times \Delta F} \tag{2}$$

$$\mathbf{ACE_3 = 0 = T_3 - 10 \times \beta_3 \times \Delta F} \tag{3}$$

$$\mathbf{ACE_4 = 0 = T_4 - 10 \times \beta_4 \times \Delta F} \tag{4}$$

$$\mathbf{ACE_5 = 0 = T_5 - 10 \times \beta_5 \times \Delta F} \tag{5}$$

In addition, the tie flows on an interconnection must sum to zero.

$$\mathbf{0 = T_1 + T_2 + T_3 + T_4 + T_5} \tag{6}$$

The interconnection Frequency Response, $\boldsymbol{\beta_T}$, must be the sum of the BA Frequency Responses.

$$\boldsymbol{\beta_T = \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5} \tag{7}$$

The only value known is $\mathbf{ACE_1}$; therefore, all values are converted to quantities represented relative to $\mathbf{ACE_1}$.

$$\mathbf{T_1 = ACE_1 + 10 \times \beta_1 \times \Delta F} \tag{8}$$

$$\mathbf{T_2 = 10 \times \beta_2 \times \Delta F} \tag{9}$$

$$\mathbf{T_3 = 10 \times \beta_3 \times \Delta F} \tag{10}$$

$$\mathbf{T_4 = 10 \times \beta_4 \times \Delta F} \tag{11}$$

$$\mathbf{T_5 = 10 \times \beta_5 \times \Delta F} \tag{12}$$

$$\mathbf{0 = ACE_1 + 10 \times \beta_1 \times \Delta F + 10 \times \beta_2 \times \Delta F + 10 \times \beta_3 \times \Delta F + 10 \times \beta_4 \times \Delta F + 10 \times \beta_5 \times \Delta F} \tag{13}$$

$$\mathbf{ACE_1 = -10 \times \beta_1 \times \Delta F - 10 \times \beta_2 \times \Delta F - 10 \times \beta_3 \times \Delta F - 10 \times \beta_4 \times \Delta F - 10 \times \beta_5 \times \Delta F} \tag{14}$$

$$\mathbf{ACE_1 = -10 \times (\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5) \times \Delta F} \tag{15}$$

$$\mathbf{ACE_1 = -10 \times \beta_T \times \Delta F} \tag{16}$$

$$\mathbf{\Delta F = \frac{ACE_1}{-10 \times \beta_T}} \tag{17}$$

$$\mathbf{T_1 = ACE_1 \left(1 - \frac{\beta_1}{\beta_T}\right)} \tag{18}$$

$$\mathbf{T_2 = -(\beta_2 / \beta_T) \times ACE_1} \tag{19}$$

$$\mathbf{T_3 = -(\beta_3 / \beta_T) \times ACE_1} \tag{20}$$

$$\mathbf{T_4 = -(\beta_4 / \beta_T) \times ACE_1} \tag{21}$$

$$\mathbf{T_5 = -(\beta_5 / \beta_T) \times ACE_1} \tag{22}$$

Equation 18 indicates the total flow that crosses the boundaries of BA_1. Equations 19, 20, 21, and 22 indicate that the flow represented by Equation 18 is apportioned between the other BAs in proportion to their relative Frequency Responses. Since each flow represented by Equations 19, 20, 21 and 22 has a balanced flow associated with it represented as a portion of the flow from Equation 18, the total set of equations represents a set of balanced flows to which the Distribution Factors developed for balanced scheduled flows can be applied. As a consequence, the ADF for a flow-gate related to the ACE of any BA is given by the sum of all of the balanced flows contributing to that flow-gate caused by the offending ACE. Equation 22 provides the ADF for flow-gate A for the BA_1 ACE. This equation normalizes the value of ACE for BA_1 to 1 MW and provides a true distribution factor for the ACE of BA_1. It also indicates the direction of the flow and since the sign of the flow changes from the flow out of BA_1 to the flow into the other BAs in question, the sign must be changed to be consistent with the sign of the ACE of BA_1.

$$\mathbf{ADF_{A1} = (\beta_2/\beta_T) \times DF_{A12} + (\beta_3/\beta_T) \times DF_{A13} + (\beta_4/\beta_T) \times DF_{A14} + (\beta_5/\beta_T) \times DF_{A15}} \qquad \mathbf{(23)}$$

The ADF for a BA for a flow-gate is simply the DF for the flow-gate for a scheduled flow to each of the other BAs on the interconnection times the ratio of each BA's Frequency Response over the total interconnection Frequency Response.

If the above is written in general terms, Equation 23 becomes:

$$\mathbf{ADF_{XY} = (1/\beta_T) \times \sum_{Z=1, Z \neq Y}^{Z=N} (\beta_Z \times DF_{XYZ})} \qquad \mathbf{(24)}$$

This general equation can be used to calculate the $\mathbf{ADF_{XY}}$ for any BA, Y, for any flow-gate, X.

The final step in the derivation is to understand that the value of ACE is always equal to the Tie-flow error for a BA that has the correct Frequency Response in its ACE equation. This is always due to an imbalance within the BA. In other words, a BA's ACE can never be caused to change to a value different from zero as the result of imbalances that are external to the BA. Thus the Superposition Theorem tells us that we can add the effects of all of the individual ADFs together and the sum will be a valid representation for the interconnection.

The reader must be warned of one additional caveat. Since the direction of the flow on a flow-gate as represented by the ADF is always relative to the sign of the ACE for the contributing BA, it is necessary to correctly represent the sign of the flow-gate flow relative to the contributing BA. The flow on flow-gate X contributed by the ACE of BA1 could have a sign opposite to the flow on flow-gate X contributed by the ACE of BA5.