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CIGRE US National Committee
2012 Grid of the Future Symposium

METHODOLOGY OF COMPUTING SIMULTANEOUS VARIABLE TRANSFER LIMITS ON MULTIPLE PATHS

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SUMMARY

Integration of large amounts of Variable Energy Resources ("VERs") across a geographical region controlled by many Balancing Authorities requires the supply of ancillary services, such as frequency regulation and imbalance energy, from generating resources which may be located remotely from the intermittent energy source. This operating arrangement may be preferred in some instances due to economic, regulatory, and policy goals. The purpose of this paper is to present a) a systematic methodology to calculate the Variable Transfer Limits ("VTLs") for different flow gates and b) identify the maximum total Variable Transfer that can be accommodated through the system without violating operational voltage constraints, when a large quantity of variable energy sources, with the corresponding balancing resources, are operating concurrently.

Three conditions restricting the VTLs are discussed in this paper. A novel approach is presented to compute customer impact. Interactions due to different variable/balancing resources are discussed for customer impact calculations. A technique is presented to calculate the feasible region. The feasible region will be maximized when the change in critical bus voltages is not impacted by other variable/balancing resources. Choice of variable/balancing resource scenarios and location of transfer pairs impact the VTLs. In addition to the reliability constraints, the need for a generalized approach to compute customer impact when considering the impact of multiple variable/balancing resources in the system is discussed.

KEYWORDS

Variable Transfer – Static Transfer – Dynamic – System Operating Limit – Flowgate – Variable Resource – Wind – Balancing – Transmission - Non-linear Optimization

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INTRODUCTION

The installation of large amounts of Variable Energy Resources ("VERs") is resulting in a transition of the Electric Power industry from an operating model in which power transfers between Balancing Authority Areas ("BAAs") were generally fixed for the hour to one where schedules can change many times within an hour. The impact of these variations differs by location, depending partly on proximity to reactive reinforcement. [1] The presence of simultaneous interactions among multiple transmission paths adds to the need for a systematic impact analysis of Dynamic Transfers. [2] The variations of VERS require additional balancing resources, which can be located within the same BAA or in a remote BAA. This balancing action achieved across the transmission grid is accomplished via Dynamic Transfers.[1] A comprehensive approach to Dynamic Transfers associated with VERs considers the potential for transmission impacts along with several others factors. [3]

In October 2010, power system planners and operators from across the Western Interconnection, known as the WECC region, were invited to participate in a Dynamic Transfer Capability ("DTC") Task Force with the goal of investigating the impact of increased transfer variability across the grid. Their work focused on identifying the limiting factors, assessing how much variability a transmission system can handle, how often, and at what cost. [4]

Dynamic Transfers are only one component that make up what this paper defines as Variable Transfers across the grid. Paper [5] introduces the concept of Transfer Variability and the need for Variable Transfer Limits ("VTLs"). This paper presents a methodology of computing simultaneous VTLs on multiple paths.

BACKGROUND

An inherent characteristic of synchronous AC power systems is that power flow and voltage vary over time. Historically, these changes have been responses to load or generation re-dispatch and with the exception of contingency events, have been relatively slow and reasonably predictable. Variable resources and the development of regional markets that will provide a significant proportion of the balancing services required to support the variable generation, will result in increased variability and unpredictability across the transmission system. Variation in power flow can affect customer voltage quality, system reliability, equipment maintenance, and operator state awareness. The fundamental questions to explore are: "How much and how frequently can transfer across a flowgate and bus voltage vary without causing any adverse impacts?" Variability on Paths is expected to increase due to

- Increasing penetration levels of intermittent generation;
- Increased reliance on remote balancing of intermittent resources;
- Increased dynamic transfers;
- Increased adoption of smart grid measures, particularly demand responsive loads;
- Application of FACTS (Flexible AC Transmission Solutions) devices that change the topology of the transmission system;
- Increased reliance on generation RAS to manage events on the transmission system.

By identifying what reliability impacts increasing variability can have on the transmission system, we can predict the need to manage transmission variability either through application of limits (e.g. VTLs) or planning for increased flexibility.

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[1] Dynamic transfer is a means by which a balancing resource is controlled in real-time by an entity other than the BA in whose area the variable resource resides.

VARIABLE TRANSFER LIMIT

VTL is defined as the amount of frequently anticipated variability in the power transfer across a flowgate that can be accommodated over a specified intra-hourly timeframe while ensuring the reliable operation of the system and the avoidance of unacceptable adverse impacts on equipment and customers. The maximum VTL is referred to as the Transfer Variability Limit ("TVL") and cannot be greater than the System Operating Limit ("SOL"). The SOL has traditionally been calculated using constant, non-varying flows.

System Operating Limits are normally determined with a well-adjusted voltage profile across the system which is based on the condition of adequate reactive and dynamic support and sufficient time is available for the dispatchers to effect the necessary switching operations to accommodate the changing operating conditions. However with increased variable power injections, certain parts of the system could more frequently experience low voltage conditions and/or significant voltage deviations due to sudden large flow increases.

As a result the actual operating point and corresponding system conditions would be different than what was assumed when calculating the SOL. Until a dispatcher is able to readjust the system back to a normal operation range – in particular restoring the voltage profile and an adequate reactive margin - the system could be at a risk of unacceptable dynamic and/or post-transient response if a credible contingency occurred.

THREE CONDITIONS RESTRICTING DYNAMIC TRANSFERS

For Dynamic Transfers across a given Flow gate, the VTL could be calculated by quantifying adverse impacts from three perspectives: 1) Impact on Customers, 2) Impact on System Equipment and 3) Reliability. These three perspectives can be translated into conditions that the VTL must meet. Figure 1 below illustrates the proposed three-part VTL methodology.

Figure 1: Three-part VTL methodology

The customer impacts due to voltage fluctuations resulting from transfer variations could be significant depending on the nature of the load and customer equipment. An acceptable increase in equipment impacts would be closely related to the equipment maintenance program and practices of the respective transmission provider. Reliability impacts due to variability would still need to be within current operating criteria.

Determining customer impact however, cannot be done efficiently using standard study methods. A method to compute the customer impact is presented using a simple five bus example. The method is presented first with single pair of variable/balancing resources. The same five bus example is extended to two single pairs of variable/balancing resources to show the impact of multiple transfers. There is a need to develop a generalized approach to determine VTLs for multiple variable/balancing resources.

CUSTOMER IMPACT METHODOLOGIES:

SINGLE PAIR OF VARIABLE/BALANCING RESOURCES

The following section describes a methodology to compute the customer impact due to single injection pair combination. The methodology is presented using a simple five bus model as shown in Figure 2. The bus voltage change, at any bus “i", can be computed using the voltage to transfer sensitivity. In general terms it can be stated as:

$[\delta Vi/\delta T] * [\Delta T] <=$ [Allowable bus voltage change due to customer impact at bus i]

Where: $[\delta Vi/\delta T]$ = voltage to transfer sensitivity at bus i

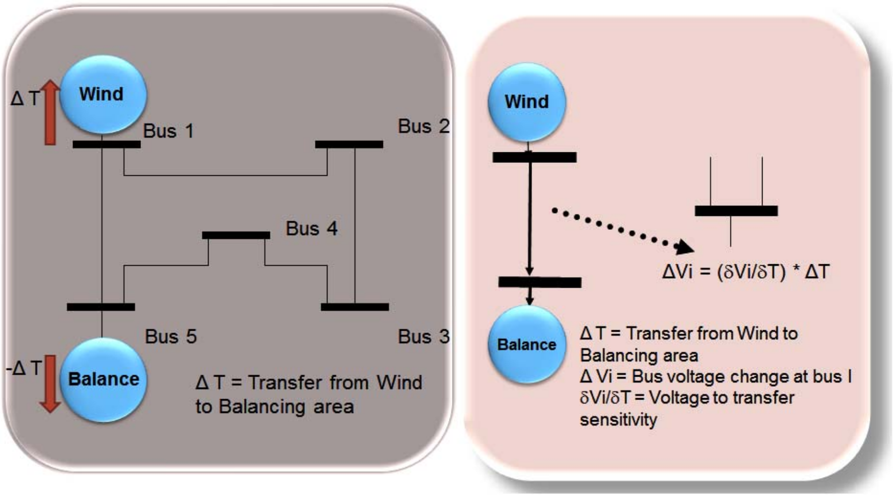

Figure 2: Sample five bus system for a single pair of variable/balancing resources

All five buses in this example should meet the voltage change constraint: the maximum $[\Delta T]$ can be calculated by solving the above equation. The sensitivities are not constant and change based on the operating conditions, consequently it is necessary to recalculate sensitivities when conditions change. The methodology was tested on 2011 WECC summer base case for four paths BC to Northwest, Montana to Northwest, Idaho to Northwest and California Oregon Intertie [4,5].

MULTIPLE PAIRS VARIABLE/BALANCING RESOURCES

The five bus model presented for single injection pair is expanded to include an additional set of injection pair as shown below in Figure 3.

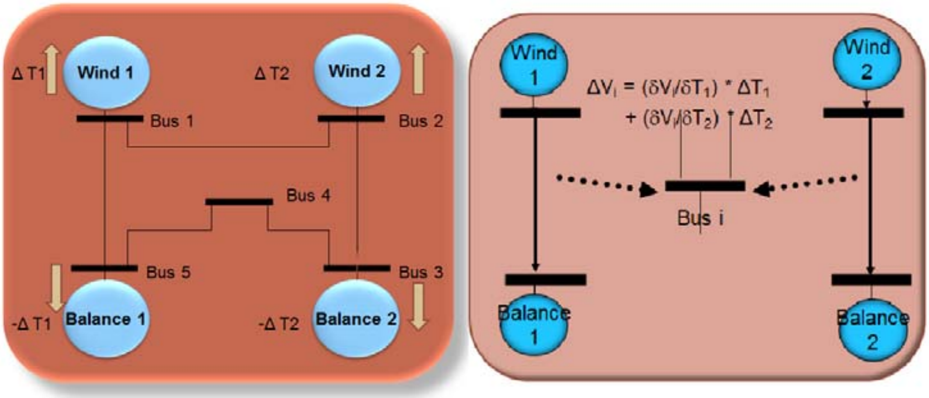

Figure 3: Sample five bus system for multiple variable/balancing resources

In this illustration, wind 1 is balanced by units in balancing area 1 and wind 2 is balanced by units in balancing area 2. Then the bus voltage change at any bus “i" can be computed using the voltage to transfer sensitivities. When additional transfers are added the bus voltage is impacted by the amount of transfers as well as location of the injection groups. The impact can be calculated using a superposition based approach as shown in Figure 3.

In this example there are two pairs of variable source/balancing resource. So the bus voltage change (ΔVi) at any bus i will be impacted by the transfer levels, (ΔT1) and (ΔT2), associated with the first (Wind 1/Balance 1) and second (Wind 2/Balance 2) pairs of variable source/balancing resources. So the bus voltage change at any bus “i" will be the sum of ΔVi associated with each ΔT. Based on the flow direction the voltage change can be positive or negative. The balancing flow direction is going to change based on the variable source operating conditions. The maximum bus voltage change for the worst case condition[2] can be obtained as follows:

> Abs {[δVi/δT1] * [ΔT1]} + Abs {[δVi/δT2] * [ΔT2]} <= [Allowable Bus Voltage Change due to customer impact at bus i]
>
> Where [δVi/δT1] and [δVi/δT2] are voltage change transfer sensitivity at bus “i” due to transfer 1 and 2 respectively.

The above equations are represented in Figure 5. Each line represents the bus voltage constraint based on the |ΔT1| and |ΔT2| transfer levels. Below the line the bus voltage change constraints will be satisfied.

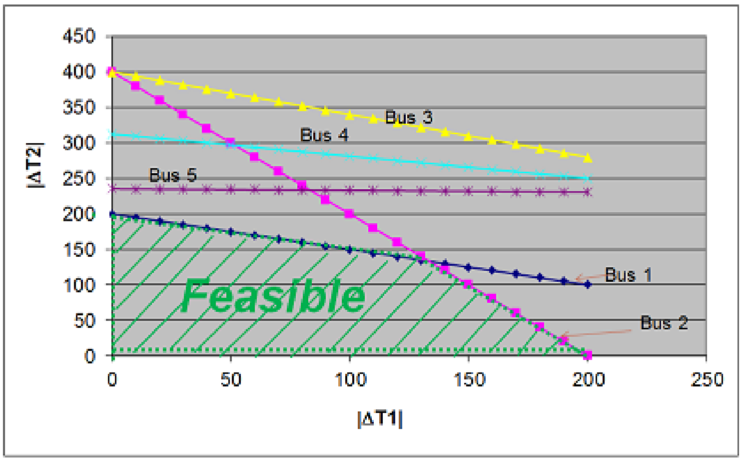

Figure 4: Change in bus voltage constraints

From the Figure 4, it can be observed for this case, buses 1 and 2 limit the change in bus voltage criteria which impacts Variable Transfer Limit (“VTL”). The bus 1 and bus 2 voltage change equations are binding constraints. The buses 3, 4 and 5 are not binding constraints and therefore do not impacts the “Feasible” area where the system can be operated without exceeding the maximum acceptable bus voltage change constraints. This approach is valid where the sensitivity approximates actual performance and the solution needs to be confirmed with powerflow; if there is a violation the sensitivities need to be recalculated and the process repeated.

Assuming the conditions of Figure 4, to maintain the bus voltage constraints the maximum values based on the worst conditions for |ΔT1| and |ΔT2| cannot exceed 200 MW as the maximum value for

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[2] There are four possible combinations of transfers for this simple case. To identify a specific limit for a given operating condition, the actual transfer direction and associated sensitivities need to be taken into account.

|ΔT1| happens when |ΔT2| is zero and vice versa. Also from Figure 4 it is clear both |ΔT1| and |ΔT2| cannot be 200 MW at the same time. Hence it is critical to consider the interactions when multiple variable/balancing resources impact the same bus voltage and those buses are critical buses. Also it is important to note that the location of balancing resources can have significant impacts on transmission system operation.

As the number of transactions increases and they interact with each other, then the problem becomes very complex and a generalized optimization formulation [6] is needed and which will be presented in a future paper. Once the variable/balancing resource MWs limits are known the Variable Transfer Limits and Transfer Variability Limits can be computed using power transfer distribution factors or by power flow.

OBSERVATIONS

Following are the observations:

- It is important to consider the impact of multiple variable/balancing resources in the system when they impact the same critical busses.
- Within the feasible region, the customer impact criteria will be satisfied.
- Feasible area will be maximized when the change in critical bus voltages is not impacted by other variable/balancing resources.
- Feasible area will be reduced when there are interactions.
- When variable/balancing resource pairs have interactions and at the worst condition:
    - Maximum value for pair 1 variable/balancing resource happens when pair 2 variable/balancing resource is zero.
    - Maximum value for pair 2 variable/balancing resources happens when pair 1 variable/balancing resource is zero.
- Results are impacted by choice of variable/balancing resources and location of transfer pairs.

ACKNOWLEDGEMENT

The authors thank Columbia Grid, Northern Tier and the BC Coordinated Planning Group for their assistance in encouraging and facilitating the work of the Dynamic Transfer Capability Task Force. In particular, the authors recognize the valuable contributions of the other Task Force members who actively participated in the development of the ideas discussed in this paper.

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