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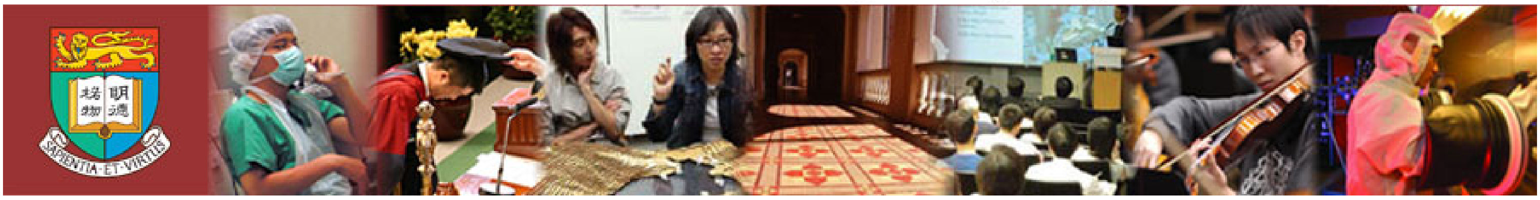

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Identification of Parallel Flows in Congestion Management with Multiple Electricity Markets

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***Abstract*—Parallel flow is a direct result of interconnected system operation. In this paper, the methodologies to calculate parallel flows for both market and non-market entities including market flows are investigated in order to identify the cause of potential loop flow issue in the congestion management process. In an interconnected system, the parallel flow identification is a complex issue because transmission congestion can be affected by all the entities of the system. To deal with it, the impact of market operation on loop flow is analyzed through market flow. In addition, for a system consisting of both market and non-market entities, the parallel flow due to the market flow methodology is investigated in details. To mitigate the loop flow, we propose to change the method to calculate the transaction impacts using generation-to-load instead of generation-to-generation. The numerical results on a simplified Eastern Interconnection system are described to demonstrate.**

***Index Terms*—Flowgate, congestion management, market flow, parallel flow, loop flow, regional transmission organization (RTO).**

I. Introduction

Loop flow is defined as the difference between scheduled and actual flow on a path. The Lake Erie loop flow problem is mainly caused by the congestion on the New York Independent System Operator, Inc. (NYISO) transmission system due to circuitous transactions involving multiple RTOs around Lake Erie [1]. A transaction means the transporting of scheduled power from a seller to a buyer along a prescribed contract path. It is well known that the energy transactions of RTOs can cause flows among parallel transmission paths in other connected systems that are not directly involved in the transaction, which are usually called parallel flows. It highlighted the importance of identifying the impact of parallel flows in an interconnected system as a result of scheduled bilateral transactions within RTO's market operations. Since all the bilateral transactions are tagged in the North American Electric Reliability Corporation (NERC) congestion management process, the parallel flow impact of a tagged transaction on any constraint or flowgate can be quantified and is called tag impact.

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For RTOs or Independent System Operators (ISOs), the market flow is used to quantify the parallel flow of an RTO's market operation on transmission constraints. Market flow means the amount of energy flows on a specified flowgate or facility as a result of dispatch of generating resources serving market load within a market-based operating entity's market (excluding tagged transactions) [2-4]. The reason that the tagged transactions are excluded from market flow calculation is because the transaction impacts have already been captured through tag impacts in the NERC process. For non-market entities, the parallel flow caused by non-market entity's generation serving the respective load on a flowgate is called generation-to-load (GTL) impact in NERC congestion management process.

Ideally, if all the calculations are based on the real-time data and system information, the sum of market flows of all market entities, the GTL impacts of all non-market entities, and the tag impacts of all the transactions among entities should be equal to the actual physical flow of the flowgate. The discrepancy between them is called unaccounted flow or loop flow. In addition to the Lake Erie loop flow problem, it is noticed that there exist a certain amount of loop flows in the real-time operations and sometimes they are very high on certain constraints. For example, Southwest Power Pool, Inc. (SPP) claimed that it has experienced a significant amount of loop flows on the Cooper South flowgate which consists of two 345 kV high voltage transmission lines [5]. Therefore, it is critical to accurately identify all the parallel flow impacts and mitigate the loop flows in order to ensure the reliability of bulk electric system as well as the equitable share of the congestion cost to manage flowgates.

To improve the wide-area view of the Eastern Interconnection, NERC and North American Energy Standards Board (NAESB) initiated Parallel Flow Visualization project to better calculate the parallel flows using real-time data for more accurate assignment of relief obligations to entities actually contributing to the congestion [6]. In this paper, we are trying to revisit the parallel flow calculation for both market and non-market entities based on the methodology to identify the possible drivers of loop flow issue due to methodology and provide recommendations to eliminate loop flow.

The work is organized as follows. In Section II, the market flows of RTOs are investigated to demonstrate the impact on parallel flows. In addition, the market flows, the GTL impacts and tag impacts are compared against the actual flow to identify the loop flow issue. To resolve the loop flow issue, we propose to calculate tag impacts based on generation-to-load

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instead of generation-to-generation in the current practice. Section III illustrates and compares the results using a simplified Eastern Interconnection case. Section IV draws the conclusion.

II. Parallel Flow Identification

In an interconnected system, such as the Eastern Interconnection, there are both RTOs and non-market entities with tagged interchange transactions among them. Each RTO's market operation has an impact on any constraint in the system quantified by its market flow. In this section, the market flows of multiple RTOs are investigated first to demonstrate that their impacts on the flowgates can be treated by market flows in the same manner without causing loop flow issue.

Suppose an RTO has n number of control areas (CAs) under its control within the balancing authority (BA) area, namely, $\mathrm{CA_1}, \mathrm{CA_2}, \dots, \mathrm{CA_n}$. For each CA, the total generation output is $P_1, P_2, \dots, P_n$, and the total load amount is $L_1, L_2, \dots, L_n$, respectively. When the RTO is power balanced and the transmission loss is included in the load, there is

$$\sum_{i=1}^{n} P_i = \sum_{i=1}^{n} L_i. \tag{1}$$

In real-time operations, there are interchange transactions between the RTO and external BAs. The RTO dispatches the generation resources to maintain load-interchange-generation balance. It utilizes automatic generation control (AGC) to control the net actual interchange (NAI) to match the net scheduled interchange (NSI) calculated based on scheduled import and export transactions. Assume there is no inadvertent interchange, the adjustments can be made to proportionally scale the generation down for export, and scale the load down for import. As a result, the power balance can still be maintained after the export and import adjustments. The procedure of market flow calculation as well as different calculation logics have already been described in detail in [3] and will not be repeated here due to length limitation. More description on how the adjustments are performed and the impact of different adjustment logics on market flows is discussed in [4].

For CA_i, suppose it has g_i number of generators with the output of $p_i^1, p_i^2, \dots, p_i^{g_i}$ and generation shift factors (GSFs) of $gsf_i^1, gsf_i^2, \dots, gsf_i^{g_i}$ on a given flowgate. It also contains h_i number of loads with the amount of $l_i^1, l_i^2, \dots, l_i^{h_i}$ and load shift factors (LSFs) of $lsf_i^1, lsf_i^2, \dots, lsf_i^{h_i}$, respectively. The CA aggregated GSFs are $GSF_1, GSF_2, \dots, GSF_n$ and the CA aggregated LSFs are $LSF_1, LSF_2, \dots, LSF_n$. We have

$$\sum_{j=1}^{g_i} p_i^j = P_i, \qquad \sum_{j=1}^{h_i} l_i^j = L_i \tag{2}$$

$$GSF_i = \sum_{j=1}^{g_i} gsf_i^j p_i^j \Big/ P_i, LSF_i = \sum_{j=1}^{h_i} lsf_i^j l_i^j \Big/ L_i. \tag{3}$$

Let's first examine the impact of proportional adjustment on the distribution factors. For CA_i, the export and import are EXP_i and IMP_i, respectively. After the generation adjustment for export and the load adjustment for import, the aggregated CA GSF and LSF become

$$GSF_i' = \frac{\sum_{j=1}^{g_i} gsf_i^j q_i^j}{\sum_{j=1}^{g_i} q_i^j}, LSF_i' = \frac{\sum_{j=1}^{h_i} lsf_i^j s_i^j}{\sum_{j=1}^{h_i} s_i^j} \tag{4}$$

where $q_i^j = p_i^j (1 - EXP_i / \sum_{k=1}^{g_i} p_i^k)$, and $s_i^j = l_i^j (1 - IMP_i / \sum_{k=1}^{h_i} l_i^k)$.

***Proposition 1*:** For any CA, the CA GSF and LSF remain unchanged after the proportional scaling down the CA generation for export and the CA load for import, i.e., for any $i \in [1, n]$, $GSF_i' = GSF_i, LSF_i' = LSF_i$.

Proof:

$$GSF_i - GSF_i' = \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j}{\sum_{j=1}^{g_i} p_i^j} - \frac{\sum_{j=1}^{g_i} gsf_i^j q_i^j}{\sum_{j=1}^{g_i} q_i^j}$$
$$= \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i} q_i^j - \sum_{j=1}^{g_i} gsf_i^j q_i^j \sum_{j=1}^{g_i} p_i^j}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j}$$
$$= \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i} [p_i^j (1 - Exp_i / \sum_{k=1}^{g_i} p_i^k)]}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j}$$
$$- \frac{\sum_{j=1}^{g_i} gsf_i^j [p_i^j (1 - Exp_i / \sum_{k=1}^{g_i} p_i^k)] \sum_{j=1}^{g_i} p_i^j}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j}$$
$$= \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \left(\sum_{j=1}^{g_i} p_i^j - Exp_i\right)}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j}$$
$$- \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \left(\sum_{j=1}^{g_i} p_i^j - Exp_i\right)}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j} = 0. \tag{5}$$

Similarly, we can obtain $LSF_i' = LSF_i$. □

***Proposition 2*:** For any RTO consisting of multiple CAs, the RTO GSF and LSF are unchanged after the proportional scaling down the RTO generation for export and the RTO load for import.

Proof:

For RTO GSF,

$$GSF_{RTO} = \frac{\sum_{i=1}^{n} GSF_i P_i}{\sum_{i=1}^{n} P_i}, GSF_{RTO}' = \frac{\sum_{i=1}^{n} GSF_i \hat{P}_i}{\sum_{i=1}^{n} \hat{P}_i}$$

where $\hat{P}_i = P_i (1 - EXP / \sum_{k=1}^{n} P_k)$.

Therefore,

$$GSF_{RTO} - GSF_{RTO}' = \frac{\sum_{i=1}^{n} GSF_i P_i}{\sum_{i=1}^{n} P_i} - \frac{\sum_{i=1}^{n} GSF_i \hat{P}_i}{\sum_{i=1}^{n} \hat{P}_i}$$
$$= \frac{\sum_{i=1}^{n} GSF_i P_i \sum_{i=1}^{n} \hat{P}_i - \sum_{i=1}^{n} GSF_i \hat{P}_i \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} P_i \sum_{i=1}^{n} \hat{P}_i}$$
$$= \frac{\sum_{i=1}^{n} GSF_i P_i \sum_{i=1}^{n} [P_i (1 - EXP / \sum_{k=1}^{n} P_k)]}{\sum_{i=1}^{n} P_i \sum_{i=1}^{n} \hat{P}_i}$$
$$- \frac{\sum_{i=1}^{n} GSF_i [P_i (1 - EXP / \sum_{k=1}^{n} P_k)] \sum_{i=1}^{n} P_i}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j}$$
$$= \frac{\sum_{i=1}^{n} GSF_i P_i \left(\sum_{i=1}^{n} P_i - EXP\right)}{\sum_{i=1}^{n} P_i \sum_{i=1}^{n} \hat{P}_i}$$
$$- \frac{\sum_{i=1}^{n} GSF_i P_i \left(\sum_{i=1}^{n} P_i - EXP\right)}{\sum_{j=1}^{g_i} p_i^j \sum_{j=1}^{g_i} q_i^j} = 0. \tag{6}$$

For RTO LSF,

$$LSF_{RTO} = \frac{\sum_{i=1}^{n} LSF_i L_i}{\sum_{i=1}^{n} L_i}, LSF'_{RTO} = \frac{\sum_{i=1}^{n} LSF_i \hat{L}_i}{\sum_{i=1}^{n} \hat{L}_i}$$

where $\hat{L}_i = L_i(1 - IMP/\sum_{k=1}^{n} L_k)$.
Similarly, we can get $LSF_{RTO} - LSF'_{RTO} = 0$. □

Proposition 3: For any CA or RTO, there is $\sum GSF_i(p_i^j - q_i^j) = \sum gsf_i^j(p_i^j - q_i^j)$ after the proportional scaling down the CA or RTO generation for export.

Proof:

For CA_i, there is

$$\begin{aligned}
&\sum_{j=1}^{g_i} GSF_i(p_i^j - \hat{p}_i^j) - \sum_{j=1}^{g_i} gsf_i^j(p_i^j - \hat{p}_i^j) \\
&= \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i}(p_i^j - \hat{p}_i^j) - \sum_{j=1}^{g_i} gsf_i^j(p_i^j - \hat{p}_i^j)\sum_{j=1}^{g_i} p_i^j}{\sum_{j=1}^{g_i} p_i^j} \\
&= \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i} p_i^j - \sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i} \hat{p}_i^j}{\sum_{j=1}^{g_i} p_i^j} \\
&\quad - \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i} p_i^j + \sum_{j=1}^{g_i} gsf_i^j \hat{p}_i^j \sum_{j=1}^{g_i} p_i^j}{\sum_{j=1}^{g_i} p_i^j} \\
&= \frac{-\sum_{j=1}^{g_i} gsf_i^j p_i^j \sum_{j=1}^{g_i}\left[p_i^j\left(1 - EXP_i/\sum_{k=1}^{g_i} p_i^k\right)\right]}{\sum_{j=1}^{g_i} p_i^j} \\
&\quad + \frac{\sum_{j=1}^{g_i} gsf_i^j\left[p_i^j\left(1 - EXP_i/\sum_{k=1}^{g_i} p_i^k\right)\right]\sum_{j=1}^{g_i} p_i^j}{\sum_{j=1}^{g_i} p_i^j} \\
&= \frac{-\sum_{j=1}^{g_i} gsf_i^j p_i^j \left(\sum_{j=1}^{g_i} p_i^j - EXP_i\right)}{\sum_{j=1}^{g_i} p_i^j} \\
&\quad + \frac{\sum_{j=1}^{g_i} gsf_i^j p_i^j \left(\sum_{j=1}^{g_i} p_i^j - EXP_i\right)}{\sum_{j=1}^{g_i} p_i^j} = 0. \qquad (7)
\end{aligned}$$

Similarly, for RTO we can also obtain $\sum_{RTO} GSF_{RTO}(p_i^j - \hat{p}_i^j) = \sum_{RTO} gsf_i^j(p_i^j - \hat{p}_i^j)$. □

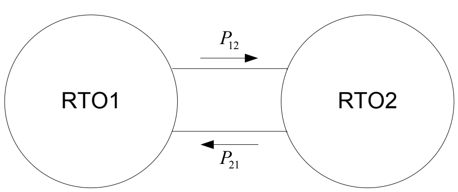

Fig. 1. Two RTOs with two-way interchange transactions

Proposition 4: For two RTOs namely RTO_1 and RTO_2, the total directional interchange transactions from RTO_1 to RTO_2 and from RTO_2 to RTO_1 are P_{12} and P_{21}, respectively, as shown in Fig. 1. For any flowgate, the sum of the market flows of RTO_1 and RTO_2 plus the total tag impact of all interchange transactions is equal to the actual physical flow (DC flow) of the flowgate. In other words,

$$\begin{aligned}
&MF_{RTO1} + MF_{RTO2} + Tag\ Impact \\
&\quad = \sum_{RTO1 \cup RTO2} p_i(gsf_i - LSF) \qquad (8)
\end{aligned}$$

where

$$MF_{RTO1} = \sum_{RTO1} q_i(gsf_i - LSF_{RTO1})$$

$$MF_{RTO2} = \sum_{RTO2} q_i(gsf_i - LSF_{RTO2})$$

$$\begin{aligned}
Tag\ Impact &= (GSF_{RTO1} - LSF_{RTO2})P_{12} \\
&+ (GSF_{RTO2} - LSF_{RTO1})P_{21}.
\end{aligned}$$

Proof:

Since

$$P_{12} = \sum_{RTO_1}(p_i^j - \hat{p}_i^j) = \sum_{RTO_2}(l_i^j - \hat{l}_i^j)$$

$$P_{21} = \sum_{RTO_2}(p_i^j - \hat{p}_i^j) = \sum_{RTO_1}(l_i^j - \hat{l}_i^j)$$

$$\sum_{RTO_1} l_i^j = \sum_{RTO_1} p_i^j - P_{12} + P_{21}$$

$$\sum_{RTO_2} l_i^j = \sum_{RTO_2} p_i^j - P_{21} + P_{12}$$

$$\begin{aligned}
GSF_{RTO_1}P_{12} &= \sum_{RTO_1} GSF_{RTO_1}(p_i^j - \hat{p}_i^j) \\
&= \sum_{RTO_1} gsf_i^j p_i^j - \sum_{RTO_1} gsf_i^j \hat{p}_i^j
\end{aligned}$$

$$\begin{aligned}
GSF_{RTO_2}P_{21} &= \sum_{RTO_2} GSF_{RTO_2}(p_i^j - \hat{p}_i^j) \\
&= \sum_{RTO_2} gsf_i^j p_i^j - \sum_{RTO_2} gsf_i^j \hat{p}_i^j
\end{aligned}$$

$$\begin{aligned}
&\sum_{RTO_1 \cup RTO_2} p_i^j LSF_{sys} = \sum_{RTO_1 \cup RTO_2} l_i^j LSF_{sys} \\
&= \sum_{RTO_1} l_i^j LSF_{RTO_1} + \sum_{RTO_2} l_i^j LSF_{RTO_2} \\
&= \sum_{RTO_1} LSF_{RTO_1} p_i^j - LSF_{RTO_1}P_{12} + LSF_{RTO_1}P_{21} \\
&\quad + \sum_{RTO_2} LSF_{RTO_2} p_i^j - LSF_{RTO_2}P_{21} + LSF_{RTO_2}P_{12}
\end{aligned}$$

$$\begin{aligned}
&\sum_{RTO_1 \cup RTO_2} p_i^j(gsf_i^j - LSF_{sys}) = \sum_{RTO_1} gsf_i^j p_i^j \\
&\quad + \sum_{RTO_2} gsf_i^j p_i^j - LSF_{RTO_1}\sum_{RTO_1} p_i^j + LSF_{RTO_1}P_{12} \\
&\quad - LSF_{RTO_1}P_{21} - LSF_{RTO_2}\sum_{RTO_2} p_i^j + LSF_{RTO_2}P_{21} \\
&\quad - LSF_{RTO_2}P_{12}
\end{aligned}$$

Then

$$\begin{aligned}
&\text{Tag Impact} + \text{MF}_{RTO_1} + \text{MF}_{RTO_2} \\
&\qquad - \sum_{RTO_1 \cup RTO_2} p_i^j(gsf_i^j - LSF_{sys}) \\
&= (GSF_{RTO_1} - LSF_{RTO_2})P_{12} + (GSF_{RTO_2} - LSF_{RTO_1})P_{21} \\
&\quad + \sum_{RTO_1} \hat{p}_i^j(gsf_i^j - LSF_{RTO_1}) + \sum_{RTO_2} \hat{p}_i^j(gsf_i^j - LSF_{RTO_2}) \\
&\quad - \sum_{RTO_1 \cup RTO_2} p_i^j(gsf_i^j - LSF_{sys})
\end{aligned}$$

$$= \sum_{RTO_1} gsf_i^j p_i^j - \sum_{RTO_1} gsf_i^j \hat{p}_i^j - LSF_{RTO_2} P_{12} + \sum_{RTO_2} gsf_i^j p_i^j$$
$$- \sum_{RTO_2} gsf_i^j \hat{p}_i^j - LSF_{RTO_1} P_{21} + \sum_{RTO_1} \hat{p}_i^j gsf_i^j$$
$$-LSF_{RTO_1} \sum_{RTO_1} \hat{p}_i^j + \sum_{RTO_2} \hat{p}_i^j gsf_i^j - LSF_{RTO_2} \sum_{RTO_2} \hat{p}_i^j$$
$$- \sum_{RTO_1} gsf_i^j p_i^j - \sum_{RTO_2} gsf_i^j p_i^j + LSF_{RTO_1} \sum_{RTO_1} p_i^j$$
$$-LSF_{RTO_1} P_{12} + LSF_{RTO_1} P_{21} + LSF_{RTO_2} \sum_{RTO_2} p_i^j$$
$$-LSF_{RTO_2} P_{21} + LSF_{RTO_2} P_{12}$$
$$= LSF_{RTO_1} \left(\sum_{RTO_1} p_i^j - \sum_{RTO_1} \hat{p}_i^j \right)$$
$$+LSF_{RTO_2} \left(\sum_{RTO_2} p_i^j - \sum_{RTO_2} \hat{p}_i^j \right) - LSF_{RTO_1} P_{12} - LSF_{RTO_2} P_{21}$$
$$= LSF_{RTO_1} P_{12} + LSF_{RTO_2} P_{21} - LSF_{RTO_1} P_{12} - LSF_{RTO_2} P_{21}$$
$$= 0 . \tag{9}$$

□

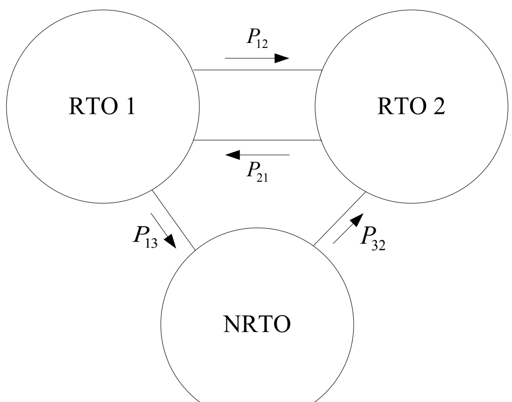

Fig. 2. Two RTOs and non-RTO with bilateral transactions

***Proposition 5*:** For an interconnection with multiple market and non-market entities, without loss of generality, let's assume there exist two RTOs namely RTO_1 and RTO_2, and one non-RTO namely NRTO. There are bilateral transactions among them as shown in Fig. 2. For any flowgate, the sum of the market flows of RTO_1 and RTO_2 and GTL impact of NRTO plus the total tag impact of all interchange transactions is equal to the actual physical flow (DC flow) of the flowgate. In other words,

$$MF_{RTO1} + MF_{RTO2} + GTL + Tag\ Impact = \sum_{RTO1 \cup RTO2 \cup NRTO} p_i (gsf_i - LSF) \tag{10}$$

where

$$MF_{RTO1} = \sum_{RTO1} q_i (gsf_i - LSF_{RTO1})$$
$$MF_{RTO2} = \sum_{RTO2} q_i (gsf_i - LSF_{RTO2})$$
$$GTL = \sum_{NRTO} q_i (gsf_i - LSF_{NRTO})$$
$$Tag\ Impact = (GSF_{RTO1} - LSF_{RTO2}) P_{12} + (GSF_{RTO2} - LSF_{RTO1}) P_{21} + (GSF_{RTO1} - LSF_{NRTO}) P_{13} + (GSF_{NRTO} - LSF_{RTO2}) P_{32}.$$

Proof: The proof process is similar to the proof of Proposition 4 and is omitted here due to space limitation. □

Based on Propositions 1-5, it can be seen the different calculation logics for the market flows of RTOs will not cause unaccounted flow issue, as long as the import and export transactions in the market flow calculation are treated consistently with the tag impacts associated with the respective transactions. It is recommended that the GTL impacts need to be evaluated similar to the market flows using the actual generation and load information. Meanwhile, it should be pointed out that the tag impacts should be calculated based on generation-to-load instead of generation-to-generation in the current NERC practice to better capture the parallel flows contributed by transactions and avoid the loop flow issue due to the evaluation of transaction impacts.

III. Numerical Example

The market flow methodology is tested on a simplified Eastern Interconnection 7917-bus system. It is divided into 64 CAs (CAs 1-64). The system contains 10796 transmission lines and 2219 transformers. It has 1325 generators with the total generation output of 367.2 GW, where 27 generators have negative output totally of 3402.5 MW and are treated as loads in the unit impact calculation. It also has 5590 loads with the total load amount of 360.7 GW, where 50 loads are negative totally of −2857.8 MW and are considered as generators in the market flow calculation. The total transmission losses are 6533.9 MW and are treated as loads on a CA basis. A 345 kV tie line between bus 1715 in CA 17 and bus 4458 in CA 47 is chosen in the parallel flow analysis.

Two scenarios are considered in the analysis which contains either one RTO or multiple RTOs in the system.

A. Single RTO

Assume the system has a single RTO A which consists of 13 CAs (5, 9, 20-28, 47 and 50). Table I shows the RTO's CA information. The CA loads include the transmission losses within the CA. The RTO A total generation and load are 87173.7 MW and 84961 MW, respectively. By summing up the export and import of the 13 CAs, we assume that the RTO's export and import are 9886 MW and 7673.3 MW, respectively. After the generation adjustment for export and the load adjustment for import, the CA native and transfer portions can be calculated by comparing the adjusted generation with the adjusted load, as shown in Table I. The native and transfer impacts for each RTO unit can then be calculated and are summarized by CA. The RTO A's market flow on the constraint is 61.817 MW after summing up all the native and transfer impacts.

For the non-market operating entities of the remaining 51 CAs, they are operating as individual BAs. There are tagged interchange transactions among these CAs, where the total export and import transactions are 15087.5 MW and 17300.2 MW, respectively. It can be calculated that the GTL impacts of the 51 CAs are 216.307 MW. The tag impacts of the tags within the 51 CAs and between them and the RTO A are 13.782 MW and -4.993 MW, respectively. Therefore, the sum of the market flow, the GTL impacts of non-market BAs and the tag impacts is $61.817 + 216.307 + 13.782 - 4.993 = 286.913$ MW, which is exactly the same as the total generation impacts (or UDS flow [3]) assuming the whole system is operating as a single BA. The line flows of DC and AC power flow solutions are 286.8 MW and 284.8 MW (measured at the sending end). It can be seen that the calculated generation impact result is very close to the DC flow solution. The minor difference is caused by the transmission losses which are not considered in the DC flow calculation.

TABLE I RTO A'S MARKET FLOW INFORMATION

CA No.	L_i (MW)	P_i (MW)	Native (MW)	Transfer (MW)	Native Impact (MW)	Transfer Impact (MW)
5	16316	16504.6	14632.9	0	−36.840	0
9	2319.4	2470.6	2109.9	80.5	−2.029	0.410
20	90.6	8110.6	82.4	7108.4	0	30.504
21	2060.2	3268.6	1874.2	1023.8	−0.051	5.770
22	1666.7	1550.6	1374.7	0	0.077	0
23	3082	2053.4	1820.5	0	−0.002	0
24	4423.2	3647.8	3234.1	0	0.068	0
25	6203	4617.1	4093.4	0	−0.202	0
26	8842.2	6693.6	5934.5	0	−0.638	0
27	4387	2468.4	2188.4	0	0.022	0
28	4257.4	4157.5	3686	0	−0.116	0
47	16236.7	16299	14450.6	0	67.724	0
50	15076.6	15332	13593.2	0	−2.879	0

It should be mentioned that when more CAs join RTO and the energy market expands, the previously tagged transactions among the RTO's CAs will disappear and become part of RTO's market flow. This will affect the export and import of RTO and therefore, the RTO's market flow and tag impacts on any constraint. However, since the whole interconnected system is still balanced, the equivalence between the actual line flow and the sum of the market flows of all RTOs, the GTL impacts of all non-RTOs, and the total tag impacts among them still exists. Based on this information, we will be able to identify the loop flow and its causes on any transmission constraint.

B. Multiple RTOs

Assume the system contains two RTOs, the RTO A remains the same and the RTO B consists of seven CAs (10, 16-19, 48 and 64). The RTO B's generation and load information is shown in Table II. The RTO B's total generation and load are 54542 MW and 55006.6 MW, and its export and import are 318.3 MW and 782.9 MW, respectively.

For the RTO B, the CA native and transfer portions together with the impacts are also given in Table II. The RTO B's market flow on the constraint is 186.947 MW. It is calculated that the total GTL impact of the remaining 44 CAs is 31.614 MW and the impact of the tagged transactions is 6.535 MW. As a result, the sum of market flows of RTO A and B, the GTL impact of non-RTOs, and the tag impacts is $61.817 + 186.947 + 31.614 + 6.535 = 286.913$ MW. It is the same as the actual line flow. It can be seen that regardless of the number of RTOs, the market operations will not cause unidentified loop flow issue as long as the market flows, GTL impacts and tag impacts are calculated in a proper manner.

TABLE II RTO B'S MARKET FLOW INFORMATION

CA No.	L_i (MW)	P_i (MW)	Native (MW)	Transfer (MW)	Native Impact (MW)	Transfer Impact (MW)
10	1599.9	1590.4	1577.1	4	−0.047	−0.133
16	2105.2	2103	2075.2	15.5	−6.418	−0.392
17	2662.7	2259.4	2246.2	0	196.587	0
18	5356.7	5359.4	5280.5	47.7	1.092	−0.338
19	7590.4	7904.9	7482.4	376.4	−3.251	−4.608
48	6443.6	6444.7	6351.9	55.2	−2.887	−7.329
64	29248	28880.2	28711.6	0	14.668	0

IV. CONCLUSION

In this paper, the assessment of parallel flows for both market and non-market entities is provided in order to identify the potential loop flow issue due to methodologies such as in the market flow calculation. It shows that the market flow methodology will not cause the loop flow issue as long as the market flow is calculated in a consistent manner with the tagged transaction impact, regardless of the number of RTOs. To better mitigate the loop flow in the real-time operations, the actual data together with the real-time system information needs to be adopted to calculate parallel flow impacts. The GTL impacts need to be evaluated similar to the market flow methodology. Furthermore, the tag impacts should be calculated based on generation-to-load instead of generation-to-generation. The numerical results are demonstrated to verify.

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