Transmission Loading Relief (TLR) and Hour-Ahead ATC

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Abstract

In open-access electricity markets the reservations of transmission services are based on data resulting from the off-line computation of Available Transfer Capability (ATC). When ATC data is inaccurate or misused, security violations can emerge and cause operators and operations planners to invoke Transmission Loading Relief (TLR) procedures. This paper illustrates the relationship between TLR and ATC, and presents possible approaches to reducing the need to invoke TLR procedures while improving the utilization of the transmission system.

Keywords: Transmission loading relief, off-line ATC, hour-ahead ATC.

1. Introduction

The North American Electric Reliability Council (NERC) has developed an Operating Manual that addresses a multitude of issues associated with electric power system operations [1]. This manual includes the Transmission Loading Relief (TLR) procedure for dealing with issues that focus primarily on the relationship between interchange transactions and security violations. Since interchange transactions are typically created through the use of Available Transfer Capability (ATC) information, there should be a very close relationship between the need for TLR and the accuracy and use of ATC information. In other words, if the ATC information is accurate at the time a transaction is arranged, and it is used properly, then the need for TLR should be due only to unanticipated changes in system conditions. Such changes could be system loading patterns, the status of lines and facilities, generation scheduling, and model parameter values.

This paper examines two important aspects of ATC accuracy and use. The first considers the non-simultaneous nature of posted numbers. The second considers the chaining of numbers between areas with connecting paths.

2. Background on ATC

Quantifying the capabilities of a transmission system for interchange has been of interest for over 25 years [2-4]. These earlier methods focused primarily on Simultaneous Interchange Capability (SIC) rather than wheeling capabilities. The application of SIC was more of an emergency capability in case local generation was lost and massive import was required. The terminology of Available Transfer Capability (ATC) was created to quantify open access to transmission facilities [5,6]. As such, it is used to reserve transmission services needed for economic transactions between suppliers and consumers. The theoretical foundations and computational burdens of ATC are essentially identical to those of SIC.

A large percentage of ATC calculations performed today utilize linear load flow techniques to approximately predict changes in line loading in response to transfers and line outages. In their simplest form, these linear methods rely exclusively on distributions factors [7]. The Power Transfer Distribution Factor (PTDF) is a “power” version of traditional linear circuit analysis with current division. The Line Outage Distribution Factor (LODF) also uses traditional linear circuit analysis to compute these “large-change” sensitivities. While some work has been done on including dynamic constraints on transfers [8], the core ATC computation considers static constraints only. References [9-11] provide additional analysis of errors associated with ATC calculations.
Currently, the following procedure referred to as off-line ATC, is used to provide ATC information for commercial purposes:

1. The security coordinator builds a regional model for the expected peak conditions. The model includes power flow base case, contingencies, monitored elements and directions.

2. The security coordinator computes firm and non-firm ATC based on the set of proposed directions on a monthly, weekly and daily basis, and posts the results on the Open Access Same-time Information System (OASIS).

3. Marketers use ATC data to propose transactions and make reservations of transmission services.

4. Control areas verify and debug the OASIS values for the day, including specific system changes and operational considerations.

5. As the time for transaction implementation approaches, control areas perform security analysis to identify potential problems.

The process has been implemented within a daily framework due to important technical reasons related to the fact that ATC is a massive and complicated computational task, and that making its results available demands a large data integration effort. The same reasons have left many ATC issues unsolved, and set challenges regarding ATC procedures and computational methods.

3. TLR and ATC

Transmission loading relief (TLR) is a sequence of actions taken during operations planning or during real-time operation to avoid or remedy security violations associated with the transmission system. Informal or "local" TLR has been in existence for as long as transmission lines have been subject to limitations. System planners and operators have developed systematic procedures to assist in the avoidance or elimination of transmission loading problems. These procedures are typically unique to each control area and may vary widely across the interconnected grid. Formal TLR procedures are identified by NERC in [1] as a mechanism to ensure certain consistencies and fairness in resolving issues of security that arise due to financial transactions. These procedures are briefly summarized below.

The process starts when a security coordinator (such as a NERC council - MAIN, ECAR, etc.) identifies a transmission facility within its security area that is about to, or has exceeded the operating security limit. At this point the security coordinator may invoke local TLR or NERC TLR. This NERC TLR procedure involves the following “levels” (Detailed explanations of the actions associated with each of these levels if given in [1]):

Level 1: Notify security coordinators of situation
Level 2a: Hold interchange transactions at current levels
Level 2b: Reallocate Firm Transmission Service
Level 2c: Reallocate Nonfirm Transmission Service
Level 3: Curtail Nonfirm transactions
Level 4: Reconfigure transmission and generation
Level 5: Curtail Firm transactions
Level 6: Implement emergency procedures

The transmission relief procedure depends on the results of off-line ATC, which has a number of limitations:

a) Off-line ATC does not include in the computation information about the actual transactions that will take place in the region and the impact of those that take place out of it. It is a non-simultaneous computation.

b) The operating conditions of the system at non-peak hours can considerably differ from those at the peak hour. Presumably, but not necessarily, the magnitude of the flows in the system will in general be larger at the peak hour and ATC would be computed for the most restrictive condition. While this is safe, ATC can be largely underestimated for non-peak hours, which will result in a sub-utilization of the system transmission capabilities.

c) Numerical errors are present in off-line ATC because it often neglects the influence of reactive power, uses linear models and assumes constant distribution factors. The current practice attempts to account for these errors through the transmission reliability margin (TRM).

These limitations create the following problems in TLR:

a) TLR decisions can be inaccurate as they are based on the planning results of daily ATC and PTDFs from the off-line computation.

b) The implementation of TLR to relieve and overload can originate new constrained facilities in the system.

c) TLR is an iterative process that requires large amounts of data and precise and fast coordination among the security coordinators and other participants in the operation of the grid. The
procedure requires the area holding the constrained facility to interact with all the agents involved in a transaction, and notify them every time the procedure changes from one TLR level to another.

d) The procedure opens opportunities for economic gaming, which can reduce the efficiency of the market.

The following section focuses on the problems associated with the fact that ATC numbers are non-simultaneous.

4. Non-simultaneity of day-ahead ATC

Virtually all of the current ATC postings on the various Open Access Same-time Information Systems are computed offline. In addition, they are usually non-simultaneous in nature and valid for peak load on a one-day-ahead basis. To illustrate that the use of these numbers leads to the need for TLR, consider the 3-area system in Figure 1.

Figure 1: 7-bus System

ATC values at the initial operating point are shown in column t1. For each direction, ATC is shown in MW with the corresponding limiting element. For example, for a transfer between area A to B, bus 4 to 6, ATC is computed to be 200MW. If a 200MW transfer occurs, the system will end up with line 4-5 at its loadability limit.

Table 1: 7-bus Case, ATC Data

<table>
<thead>
<tr>
<th>Transfer Areas</th>
<th>Transfer Buses</th>
<th>ATC (MW)</th>
<th>Limiting Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>1-6</td>
<td>87</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>2-6</td>
<td>200</td>
<td>2-6</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>200</td>
<td>4-5</td>
</tr>
<tr>
<td>A-C</td>
<td>1-7</td>
<td>90</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>2-7</td>
<td>138</td>
<td>2-5</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>142</td>
<td>4-5</td>
</tr>
<tr>
<td>B-C</td>
<td>6-7</td>
<td>182</td>
<td>6-7</td>
</tr>
</tbody>
</table>
Case A: Simultaneous transactions

Given this system data, suppose that the following transmission reservations occur (which are all possible after the initial posting):

- Direction 1-6: 50MW
- Direction 2-6: 150W
- Direction 4-6: 180MW

If these transactions are implemented, line 4-5 will have an overload of 17% and line 2-6 will have an overload of 80%! When this schedule is analyzed prior to implementation, TLR will have to be invoked to relieve the overloading of these lines. Each participating control area for the transaction will implement a local TLR procedure, which would imply the rearrangement of its own resources, or ask the security coordinator for a NERC TLR procedure, which would require the rearrangement of the resources of all the interconnection entities involved in the transaction.

Note that TLR becomes necessary because ATC values were not obtained from a simultaneous simulation. This is a serious shortcoming of current ATC computations.

Once TLR is initiated, the process determines for each type of transaction the impact of those that affect the loading of the facility in 5% or more based on PTDFs. Then transactions are curtailed in a progressive, prioritized manner. If no more transactions can be curtailed, the process goes to the next TLR level.

Case B: Sequential transactions: off-line ATC

As an alternative approach, consider a sequence of transactions starting at the initial operating point used above. The results for the sequence are shown on Table 2. In this case, ATC values remain as those computed by the off-line ATC process as the transactions take place.

1. At time t1 marketer M1 proposes a transaction T1 of 150 MW from A-B in the direction 4-6. As ATC is 200MW, the transfer should create no problem and there should be 50MW available for direction 4-6 after the transaction is implemented.

2. At time t2 marketer M2 reads ATC for direction 6-7 to be 182MW and proposes a transaction T2 of 150 MW. As a result, line 4-5 presents an overload of 8% that needs to be relieved.

3. At time t3 marketer M3 reads ATC for direction 2-6 as 200MW and proposes a transaction T3 of 150 MW. The final results will be overloads of 5% in line 2-5, 12% in line 2-6 and 26% in line 4-5. TLR must be applied in order to relieve the loading of these lines.

Table 2: Sequential ATC data

<table>
<thead>
<tr>
<th>Transfer</th>
<th>t0</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-B</td>
<td>1-6</td>
<td>87</td>
<td>1-2</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>2-6</td>
<td>200</td>
<td>2-6</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>200</td>
<td>4-5</td>
<td>50</td>
</tr>
<tr>
<td>A-C</td>
<td>1-7</td>
<td>90</td>
<td>1-2</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>2-7</td>
<td>138</td>
<td>2-5</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>142</td>
<td>4-5</td>
<td>142</td>
</tr>
<tr>
<td>B-C</td>
<td>6-7</td>
<td>182</td>
<td>6-7</td>
<td>32</td>
</tr>
</tbody>
</table>

Note in this case that for proposed transactions the values of unreserved ATC do not change and therefore the capability for each direction is assumed to be the one that was computed for the base case. As this is a non-simultaneous process, new transactions can overload the system. TLR will be needed even though the transactions were based on posted ATC values.

Note also that TLR for line 4-5 for example can involve the curtailment of transaction T1, which was proposed on actual ATC values and did not create any overload in the first place.

If all the ATC numbers were computed after t3 the results would be as shown in Table 3. The negative values indicate that ATC was computed for an overloaded base case. For example for 1-6, a 135MW reduction of the current transfer will be needed to relieve the loading of line 4-5. The “NE” tags stand for “Non-existing” value of increase or decrease that would relieve the loading for a specific direction.

Table 3: ATC for final conditions

<table>
<thead>
<tr>
<th>Transfer</th>
<th>t3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td></td>
</tr>
<tr>
<td>A-B</td>
<td>-135</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>2-6</td>
<td>-212</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>A-C</td>
<td>-62</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>2-7</td>
<td>-74</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>4-7</td>
<td>-45</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
</tr>
<tr>
<td>B-C</td>
<td>NE</td>
</tr>
<tr>
<td></td>
<td>2-6</td>
</tr>
</tbody>
</table>
Even though this is a very simple case, the presence of negative values and “NE” tags give us a feeling of why TLR levels and generation re-dispatch are needed in the implementation of TLR procedures.

**Case C: Sequential transactions - updated ATC**

Start again with the system at the initial operating point shown in Figure 1. Let us perform a sequence of transactions and write down the results on Table 4.

1. As in Case B, at time t1 marketer M1 proposes a 150MW transaction T1 from areas A-B in the direction 4-6 whose ATC is 200MW. 50MW must remain as shown in column t1. Other ATC values are recomputed and updated in column t1. Note that constraining elements can also change. For example, for transaction 2-7, line 2-5 has been replaced by line 4-5 as the new constraining element.

2. At time t2 marketer M2 proposes a transaction from area B-C in direction 6-7 of 100MW. As ATC is 123 there should be no problem. At t2 23MW remain available in that direction. All other ATC values are recomputed.

3. At time t3 marketer M3 proposes a 30MW transaction from areas A-C, direction 2-6. As ATC is 42, this is possible and there are 12 MW remaining in that direction. All other ATC values are recomputed.

4. At time t4 transaction T1 is cancelled relieving 150 MW in direction 4-6. All other ATC values are recomputed.

**Table 4: Case C: ATC is updated.**

<table>
<thead>
<tr>
<th></th>
<th>t0</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Bus</td>
<td>ATC</td>
<td>Lim</td>
<td>ATC</td>
<td>Lim</td>
</tr>
<tr>
<td>A-B</td>
<td>1-6</td>
<td>87</td>
<td>1-2</td>
<td>59</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>2-6</td>
<td>200</td>
<td>2-6</td>
<td>59</td>
<td>2-6</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>200</td>
<td>4-5</td>
<td>50</td>
<td>4-5</td>
</tr>
<tr>
<td>A-C</td>
<td>1-7</td>
<td>90</td>
<td>1-2</td>
<td>61</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>2-7</td>
<td>138</td>
<td>2-5</td>
<td>81</td>
<td>4-5</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>142</td>
<td>4-5</td>
<td>35</td>
<td>4-5</td>
</tr>
<tr>
<td>B-C</td>
<td>6-7</td>
<td>182</td>
<td>6-7</td>
<td>123</td>
<td>4-5</td>
</tr>
</tbody>
</table>

Case C is an ideal case in which ATC is updated each time a transaction takes place, is proposed, or a reservation is made. Note that ATC values remain positive. This occurs because transactions T1, T2, T3 and T4 were based on true ATC values. For this ideal case, no TLR procedure is required.

If a continuous ATC computation is possible, and transactions are based on true ATC data we can think of transactions as moving within a secure transactional space. The boundaries are given by facilities security limits and the distance to a boundary in the direction of a specific transaction is given by the value of ATC for that direction. This is represented in Figure 2 for Case C for t0, t1 and t2.

**Figure 2: Secure Transactional Space**

For the transactional space shown in Figure 2, the coordinates are the transactions in directions 4-6, 6-7 and 2-6. The center of coordinates (0,0,0) represents the initial operating point where no transactions take place. At this point the secure transactional space is given by cube t0 with dimensions [200,200,182]. Then T1 moves the operating point to (150,0,0) and ATC results in a secure transactional space given by cube t1 with dimensions [50,123,59]. T2 moves the operating point to (150,100,0) and ATC results in a secure transactional space given by cube t2 with dimensions [9,23,42]. T3 moves the operating point to (150,100,30) and so on.

As it can be seen, each time a transaction is proposed, the secure transactional space changes (it can be reduced or augmented) after ATC values and the distances to each boundary are given by the ATC value for that direction.
5. Chaining ATC numbers

When a transaction involves several control areas and associated ATC postings, the need to reserve transmission services along a contract path can result in a misuse of ATC numbers. For example, if transmission services are required between areas A, B and C for an A to C transaction, reservations might be made based on the minimum capability posted for A to B and B to C. This is a logical assumption, but can result in a TLR procedure because this chaining is not normally valid. One of the primary reasons why it is not valid is because ATC numbers are based on maximum allowable transfers subject to numerous contingencies. It is very likely that the limiting transfer will occur because of a proposed contingency. Since the A to B transfer might be limited by one contingency and the B to C transfer might be limited by a different contingency, it is not correct to use the minimum of these two ATC numbers to determine the A to C maximum transfer. It may well be that the A to C transfer is actually limited by a completely different contingency than the A to B and B to C. Furthermore, the ATC numbers may be the result of different limiting elements. There is one case where the ATC number for A to C can be obtained from the ATC numbers for A to B and B to C, but the result is not simply the minimum of the two. Consider the following new line ij flows in response to a transaction of P from A to B, B to C and A to C:

\[
P_{ij,AB}^{\text{new}} = P_{ij}^{\text{old}} + T_{ij,AB} P \\
P_{ij,BC}^{\text{new}} = P_{ij}^{\text{old}} + T_{ij,BC} P \\
P_{ij,AC}^{\text{new}} = P_{ij}^{\text{old}} + T_{ij,AC} P
\]

For a maximum allowable line ij flow of \( P_{ij}^{\text{max}} \), the maximum P which can be used for each transaction is:

\[
P_{\text{maxAB}} = (P_{ij}^{\text{max}} - P_{ij}^{\text{old}})/T_{ij,AB} \\
P_{\text{maxBC}} = (P_{ij}^{\text{max}} - P_{ij}^{\text{old}})/T_{ij,BC} \\
P_{\text{maxAC}} = (P_{ij}^{\text{max}} - P_{ij}^{\text{old}})/T_{ij,AC}
\]

Where all of the \( P \)'s and \( T \)'s are assumed to be positive numbers. In this case, \( P_{\text{maxAC}} \) is the correct ATC for a transaction from A to C. If only the ATC postings for A to B and B to C are given, the ATC for A to C can be computed from the other two as (by inspection from above, since \( T_{ij,AC} = T_{ij,AB} + T_{ij,BC} \)):

\[
P_{\text{maxAC}} = (P_{\text{maxAB}} P_{\text{maxBC}})/( P_{\text{maxAB}} + P_{\text{maxBC}})
\]

Note that this is not normally the same as the minimum of \( P_{\text{maxAB}} \) and \( P_{\text{maxBC}} \). Also note that this computation may need to be revised when one or more of the T’s are negative numbers, or a line flow maximum is reached through a negative flow. Also note that this is for the special case where all ATC numbers are determined by the same limiting line and the same contingency.

Further investigation into the use of posted ATC for chaining needs to be done. It may be that numbers other that ATC should be used. For example, perhaps PTDF’s should be posted rather that the ATC. Then ATC can be computed when needed for any transaction.

As a compromise between offline ATC computation and real-time ATC, the implementation of hour-ahead ATC would be consistent with hourly market decisions. This would solve a large number of the problems discussed in the last two sections. The following section gives a framework for this.

6. Hour-ahead ATC

Hour-ahead ATC performs the same computation as off-line ATC. It operates through the planned model for the next few hours. It would be used intensively within the Energy Management System (EMS) study mode, imposing hard performance and data integration challenges.

Current ATC solvers are able to provide accurate results for systems with thousands of buses, and hundreds of directions and contingencies in few minutes. The difficult part of hour-ahead ATC is data management and modeling.

To accurately compute ATC, the following information must be provided to the solver:

a) System and Transaction data: network topology, equipment parameters, control settings, load profile, generation profile, external model description, interchange schedule, contingency description, subsystem description, monitored element description, direction description.

b) ATC function control data.

c) Output filter description and posting method.
From existing technologies, ATC for the next hour can be computed as follows:

1. Obtain a base system case from the real-time state estimator solution. This would give a base topology description, generation schedule and base power flows.

2. Include in the system model modifications to loads using system and bus load forecast functions. Update generation settings using generation schedules and update base flows using information for schedules and transmission services.

3. Solve the power flow for the next hour case and compute PTDFs and LODFs matrices.

4. Compute ATC for confirmed reservations using a transaction analyzer based on linear methods which could also be used for other computations such as contingency analysis, sensitivity analysis, interchange distribution calculations, transaction arrangement and transmission loading relief.

Hour-ahead ATC would run cyclically (every hour) over future hour models. It could also run on operator request and when new reservations have been confirmed. The function would be the core of the information system, serving both the economic and reliability goals of the hourly-market. A sketch of the function is shown in Figure 3.

7. Conclusions

TLR procedures are implemented to relieve overloading in the transmission system. TLR is required because proposed transactions are based on ATC values that do not necessarily reflect the actual transfer capabilities, either due to the non-simultaneous nature of ATC, or improper chaining. In order achieve an efficient and stable performance of the hourly market, the participants need to have accurate ATC information. A way to increase the quality and meaningfulness of ATC data is to compute it in such a time framework that the model included in the computation is the closest to the real situation. In the ideal case, marketers would have updated information each time a reservation is confirmed.

With existing technologies it may be possible to incorporate hour-ahead ATC functions that minimize the need for TLR as well as enhance the utilization of transmission resources.

The reduction of the need for TLR may also be achieved by minimizing misuse of ATC numbers, or through alternative concepts that are more accurate and flexible for use in reserving contract paths.

8. Acknowledgements

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9. References

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Peter W. Sauer obtained his Bachelor of Science degree in Electrical Engineering from the University of Missouri at Rolla in 1969, the Master of Science and Ph.D. degrees in Electrical Engineering from Purdue University in 1974 and 1977 respectively. From 1969 to 1973, he was the electrical engineer on a design assistance team for the Tactical Air Command at Langley Air Force Base, Virginia, working on design and construction of airfield lighting and electrical distribution systems. He has been on the faculty at Illinois since 1977 where he teaches courses and directs research on power systems and electric machines. His main interests are in modeling and simulation of power system dynamics with applications to steady-state and transient stability analysis. From August 1991 to August 1992 he served as the Program Director for Power Systems in the Electrical and Communication Systems Division of the National Science Foundation in Washington D.C. He is the Chairman of the IEEE Power Engineering Society (PES) Working Group on Dynamic Security Assessment, and Chairman of the IEEE Central Illinois Chapter of PES. He is a registered Professional Engineer in Virginia and Illinois and a Fellow of the IEEE.