VOLTAGE STABILITY CONSTRAINED AVAILABLE TRANSFER CAPABILITY CALCULATION USING MATLAB

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ABSTRACT

The Available Transfer Capability (ATC) of a transmission system is a measure of unutilized capability of the system at a given time and depends on a number of factors such as the system generation dispatch, system load level, load distribution in the network, power transfers between areas, network topology, and the limits imposed on the transmission network due to thermal, voltage and stability considerations. This paper describes a method for determining the ATC between any two areas in a transmission system (multiarea) under a given set of system operating conditions. The method used here provides ATC between the two areas in a transmission system on the basis of voltage magnitude limits at the buses and static voltage stability limits. In addition, the method can be used to compute ATC between two areas based on including thermal limits also. The proposed method is illustrated using two IEEE test systems.

Index Terms: Available Transfer Capability (ATC), Total Transfer Capability (TTC), Tie Lines.

1. INTRODUCTION

The computation of ATC is very important in the deregulated power system because Electric utilities would be required to post information on ATC’s of their transmission networks so that such information will help power marketers, sellers and buyers in planning, operation and reserving the transmission services [1]. Utilities would have to determine adequately their ATC’s to ensure that system reliability is maintained while serving a wide range of transmission transactions. ATC between and within areas of the interconnected power system and ATC for critical transmission paths between these areas would be continuously updated and changes in scheduled power transfers between the areas are posted.

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Power system transfer capability indicates how much inter area power transfers can be increased without compromising system security. Transfer capability computations play a role in both the planning and operation of the power system with regard to system security. One benefit of interconnected power systems is the potential for increased reliability.

In an interconnected system, the loss of generation in one area can be replaced by generation from other areas. Thus, several systems interconnected can survive contingencies that the individual systems could not. Transfer capability computations are useful for evaluating the ability of the interconnected system to remain secure following generation and transmission outages.

Determining the adequacy of the transmission system in allowing external generation to replace internal generation is a typical application for transfer capability computations. For this purpose, a model of the network reflecting the anticipated conditions is assumed. Several generators within one area are selected as sinks. The power injected to the network at these locations is systematically reduced or eliminated to reflect the planned or unplanned loss of the units. For each generation outage scenario, several external generators are selected as potential sources.

The choice of sources and the participation of each source depend upon the assumption concerning the time frame of the response. The purpose of the transfer capability computation is to determine the quantity of lost generation that can be replaced by the potential reserves and the limiting constraints in each circumstance. In addition to varying the assumptions regarding the generation sources and sinks to reflect different outages and reserve locations, the computations are often repeated assuming different loading conditions or increasing loads and coincident branch element outages.

Transfer capability is the measure of the ability of interconnected electric systems to reliably move or transfer power from one area to another over all transmission lines (or paths) between those areas under specified system conditions [3]. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW). In this context, “area” may be an individual electric system, power pool, control area, sub region, or NERC Region, or a portion of any of these. Transfer capability is also directional in nature. That is, the transfer capability from Area A to Area B is not generally equal to the transfer capability from Area B to Area A [3].

Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses [3]. Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre and post-contingency system conditions [3].

The system-limiting factors that limit a power system’s ATC are many. Among them are the line current limits, voltage magnitude limit, generator reactive power limit, and voltage collapse limit, etc.
The line current limit usually is a line’s thermal limit. Too much current flow in a line may cause a line to droop or damage nearby connected equipments. DC power flow has been widely used to calculate thermal limit with great speed.

But DC power flow can not deal with other limiting factors. The bus voltage magnitudes also need to be kept within reasonable limits. Voltage over-limit may cause damage to system equipments, and reduce the power quality to the customers. Low voltage sometimes is also an indication that the system is near a voltage collapse. Both high voltage and low voltage are regulated by system circuit breakers and pose limits to the power transfer.

Generators have reactive power output limits. After a limit is reached, a generator will not be able to regulate its bus voltage. It is degraded from a PV bus into a PQ bus. This may cause voltage collapse or system instability [6].

The voltage collapse is the upper physical limit that a power system can function properly. Beyond this point, no mathematical solution exists. This situation usually happens after a bus voltage has a significant drop or when a generator’s var limit is reached.

The limitations on power system performance that we consider in this paper are transmission voltage magnitudes and voltage collapse. All these limits can be handled in an AC load flow power system model.

2. STATIC VOLTAGE STABILITY

Static voltage instability is mainly associated with reactive power imbalance. Reactive power support that the bus receives from the systems can limit loadability of that bus. If the reactive power support reaches the limit, the system will approach the maximum loading point or voltage collapse point [7].

In static voltage stability, slowly developing changes in the power system occur that eventually lead to a shortage of reactive power and declining voltage. This phenomenon can be seen from the plot of the voltage at receiving end versus the power transferred. The plots are popularly referred to as P-V curve or “Nose” curve. As the power transfer increases, the voltage at the receiving end decreases. Eventually, the critical (nose) point, the point at which the system reactive power is out of use, is reached where any further increase in active power transfer will lead to very rapid decrease in voltage magnitude. Before reaching the critical point, the large voltage drop due to heavy reactive power losses can be observed. The maximum load that can be increased prior to the point at which the system reactive power is out of use is called static voltage stability margin or loading margin of the system [8].

In static voltage stability study, mainly two analysis techniques, namely Continuation Power Flow and Optimization technique (or direct) methods are used [8].
(a) Continuation Power Flow Method
Continuation Power Flow presents a way to plot complete PV curves by automatically changing the value of Loading Factor (LF or $\hat{e}$). It involves predictor and corrector steps to guarantee a well-behaved numerical solution of the related equations. PV curves are currently in use at some utilities for determining proximity to collapse so that operators can take timely preventive measures to avoid voltage collapse. The CPF method uses the successive power flow solution to fully compute the voltage profiles up to collapse point to determine the loading margin. Tangent vector which is a byproduct of the CPF process can also be used as an index to identify the weakest bus of the system. Mathematically, the CPF procedure can be summarized in two steps, namely predictor and corrector steps. A third step known as parameterization is introduced to avoid some convergence problems.

(b) Optimization Technique Method
Optimization technique provides a more accurate solution and it is able to handle power system constraints in a simple way. However, it gives only the solution at the optimal point, which may not be useful in the operation of an intermediate loading point, between base case and collapse point.

3. PROPOSED METHOD OF ATC ASSESSMENT
The basic idea in the ATC calculations is to determine for a given set of system conditions (generation dispatch, load level, network topology, and its limits), the maximum amount of power that a transmission system can transfer, in addition to the already committed transmission services, when power is injected at one location and the same amount of power is extracted at the same time at another location without the violation of transmission constraints. This additional amount of power is referred to in this paper as the ATC between the two locations in the network.

Injecting power at one location in the network and extracting it at another location affects system flow patterns. As the injected power increases between the two locations, some transmission elements or interfaces become limiting, and therefore no more additional power can be transferred between the two locations. If there is one transmission path between the two locations, the ATC between them will be equal to the ATC for the path and is given by the difference between the flow limit on the limiting element or the interface and the flow on the element or interface before the injection of power (base case). If there is more than one transmission path between the two locations, the ATC between them is equal to the sum of ATC’s for all transmission paths between the two locations. In this case, the ATC for a certain path between the two locations is given by the difference between the flows on the path after and before the injection of power.
The simulation process used in this paper is illustrated using the flow chart given below. The ATC is limited by the voltage magnitude at the buses and the static voltage stability limit. Thermal limit checking is not accounted in this ATC computation and is assumed to be infinity.

As the flowchart shows, a transfer case is selected first. The variables, which are going to be used for the simulation, are chosen. For example, after identifying the tie lines connecting the two areas, the power of the generator of an area and the load of another area is increased so that power is transferred from an area to another. The branch flow of the line or lines connecting the two areas will then be recorded. If the power flow solution of the transfer case cannot be converged, the simulation will be stopped, go back a few steps, and continue running again with smaller steps, just to increase the accuracy of the simulation. The reason for running the simulation in a bigger step comparing to the second stage is to reduce the time consumption. The ATC is then the total power flow increased between the two areas before the system plunge into instability.

For a given system state, the ATC from one area (Area 1) to another area (Area 2) and ATC’s for selected transmission paths between them will be calculated using following procedure:

1. Establish a base case power flow using AC power flow in which the system load is supplied without violating any transmission limits.
2. Identify the tie lines between the two areas.
3. Obtain from the base case, power flows in these selected tie lines or transmission paths between the two areas.
4. Check for presence of loads at the receiving ends of these tie lines.
5. If so, increase the load in larger steps.
6. Again obtain the power flows in these tie lines between the two areas by running AC power flow.
7. Repeat step 5 until system conditions are violated.
8. Now go back one step and decrease the load by one step.
9. Now by increasing the load in smaller steps run the power flow until system conditions are violated and obtain the power flows in tie lines.
10. The difference between the flows computed in steps 9 and 3 on a particular transmission path or tie line would give the required ATC for that path or tie line.
11. The sum of ATC’s computed for tie lines between two areas will give the ATC between those two areas.
Select transfer case and variables to be changed

Step increase variables

Check if Bus voltages are stable

Yes

Step back and increase variables in smaller steps

Check if Bus voltages are stable

Yes

No

ATC

End

Fig. 1: Flow Chart for The Simulation

The above procedure can be used to compute ATC’s of multiple-area systems as a function of time. Hourly or daily ATC’s can be calculated as the power system goes through its moment by moment changes.

4. RESULTS AND DISCUSSION

The methods described in the preceding sections for computing the ATC of a transmission system are illustrated using two IEEE bus systems as shown in figures 2 and 5. That is using IEEE 30 bus system and IEEE 118 bus system [10] and [11].

ATC’s were computed between three areas using power flow program in MATLAB. The ATC’s of the transmission lines and the ATC’s between the areas for the IEEE 30 Bus Test system shown in figure 2 are as given in the following tables I and II. The maximum power that can be transferred between the two areas 1 and 2 without any violations of transmission constraints was found to be 23.15 MW and between areas 1 and 3 and 2 and 3 the ATC values
are found to be 38.52 MW and –13.71 MW respectively. The negative sign indicates that the ATC is in reverse direction.

Figure 3 shows the PV curves of receiving end load buses of tie lines of IEEE 30 bus test system with only voltage collapse limit applied. Figure 4 shows the PV curves of receiving end load buses of tie lines of IEEE 30 bus test system with both voltage limit and voltage collapse limit applied.

Similarly the ATC’s between the areas for the IEEE 118 Bus Test system shown in figure 5 are as given in table III. The maximum power that can be transferred between the two areas 1 and 2 without any violations of transmission constraints is found to be 19.09 MW and between areas 1 and 3 and 2 and 3 the ATC values are found to be –21.97 MW and –345.29 MW respectively.
Fig. 3: PV Curves of Receiving End Buses of Tie Lines of IEEE 30 Bus Test System with Only Voltage Collapse Limit

Fig. 4: PV Curves of Receiving End Buses of Tie Lines of IEEE 30 Bus Test System with Both Voltage Limit and Voltage Collapse Limit
### Fig. 5: Modified IEEE 118 Bus Test System

### Table I

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<th>to Bus No.</th>
<th>ATC (MW)</th>
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<tr>
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<td>2</td>
<td>41.39</td>
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Table II

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<tr>
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Table III

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<th>ATC (MW)</th>
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<td>2</td>
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</tr>
<tr>
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<td>3</td>
<td>-21.97</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-345.29</td>
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</table>

5. CONCLUSION

In this paper a simple, efficient and practical method for determining the ATC between any two areas in the transmission system has been proposed and the ATC’s for transmission paths between two buses and ATC’s between two areas interconnected by tie lines are calculated. The results obtained from the application of the above method of ATC assessment to the two IEEE test systems demonstrated that ATC was limited mainly due to the violation of voltage magnitudes at the buses.

REFERENCES


