Merchant Transmission and the Reliability of the New York State Bulk Power System
Part I: Thermal Transfer Limit Analysis

Mahmoud K. Elfayoumy[1], *Member, IEEE*, Ramon R. Tapia[2], *Member, IEEE*, and Roger Clayton[3], Senior *Member, IEEE*

Abstract--This paper is the first one in a series of papers that presents a reliability analysis of the New York State Bulk Power System (NYSBPS) with the addition of the Empire Connection, a major New York State 2,000 MW HVDC merchant transmission project developed by Conjunction LLC. The focus of this paper will be on the evaluation of thermal transfer limits for major NYSBPS interfaces relevant to the project. In evaluating the thermal transfer limit for the studied interfaces, the paper uses an incremental approach that determines the First Contingency Incremental Transfer Capability as a basis for calculating the thermal transfer limits, with and without the proposed Empire Connection Project. The thermal transfer limit analysis was conducted using PTI's Managing and Utilizing System Transmission (MUST) software package for FCITC calculations. The obtained results show that the thermal transfer limits for the intra NY State interfaces under study were substantially increased under normal and emergency conditions with the Proposed Empire Connection Project in service. The basis for this paper is the work done for the System Reliability Impact Study report for the Empire Connection approved by the NYISO on March 18, 2004 [1].

I. INTRODUCTION

The United States Congress Passed the Federal Power Act in 1992 and FERC in 1996 issued Order 888 [2] that promotes utility competition through open access based on Non-discriminatory transmission service by public utilities. FERC has encouraged merchant investors to undertake transmission projects however, in this newly deregulated power industry, few transmission projects are being proposed, merchant or otherwise because of regulatory uncertainty and risk aversion by investors.

In this regard, this paper is the first one in a series of papers that present a reliability analysis of the NYSBPS with a new HVDC merchant transmission project developed by Conjunction LLC. Conjunction's Empire Connection Project is designed to improve both the reliability and economic performance of NYSBPS. Thermal, voltage, and stability transfer limit analysis were undertaken to evaluate the impact of the Empire Connection Project on the transfer capability of major NYBPS interfaces. The focus of this paper will be on the evaluation of thermal transfer limits of the following NYSBPS interfaces: Total East (TE); Central East (CE); Upstate NY to South East NY (UPNY-SENY); Upstate NY to Consolidated Edison (UPNY-ConEd); and the New York City (NYC) Cable Interface. The Empire Connection Project is a 2x1000 MW, +/- 500 kV bipole HVDC project that will allow the economic exchange of power from power plants located in upstate NY to the major load located in NYC. The two 1,000 MW bipole circuits will be physically and electrically separate for reliability purposes.

According to the Federal Energy Regulatory Commission (FERC) order 889 issued in 1996 [3], it is mandatory that the Available Transfer Capability (ATC) for each control area is calculated and posted on a communication system called the Open Access Same-time Information System (OASIS). This represents a market signal of the capability of the transmission system for competitive energy delivery. In evaluating the thermal transfer limit for the studied interfaces, the paper uses an incremental approach that determines the First Contingency Incremental Transfer Capability (FCITC) [4] for the NYSBPS with and without the proposed Empire Connection Project. FCITC 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. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW). In order to calculate the FCITC limits [5], a linearized network model (for summer and winter peak conditions) that represents the Eastern Interconnection (EI) of the United Sates of America and participation factors are used. Generation shifts for the transfer analysis were chosen based on the NY Independent System Operator's criteria (NYISO). The New York State Reliability Council's Reliability Rules define the criteria used for the transfer analysis. The thermal transfer limit analysis was conducted using PTI's Managing and Utilizing System Transmission (MUST) [6] software package for FCITC calculations. The obtained results show that the thermal transfer limits for the intra NY State interfaces under study were substantially increased under normal and emergency conditions with the Proposed Empire Connection Project in service.

II. INTERCONNECTION PLAN

The study considered a 1,000 MW, +/- 500 kV HVDC bipole interconnection from a new substation (Albany), near the New Scotland 345 kV substation, on the New Scotland

[1] Mahmoud K. Elfayoumy is with Shaw Power Technologies Inc., Schenectady, NY12301 USA (e-mail Mahmoud.elfayoumy@shawgrp.com)

[2] Ramon R. Tapia is with Shaw Power Technologies Inc., Schenectady, NY12301 USA (e-mail Ramon.Tapia@shawgrp.com)

[3] Roger Clayton is with Conjunction LLC, Albany, NY USA, (e-mail rclayton@conjunctionllc.com)

345 kV to Alps 345 kV line to Con Edison's West 49th Street 345 kV substation and a 1,000 MW, +/- 500 kV bipole interconnection from a new substation (Greene), near the Leeds 345 kV substation, on the Leeds 345 kV to Gilboa 345 kV line, to Con Edison's Rainey 345 kV substation. Figure 1 shows a basic one-line interconnection diagram of the Empire Connection Project to the NYBPS.

III. INTRODUCTION TO TRANSFER LIMIT ANALYSIS

The reliability of a power network [7] can be characterized by its capability to carry power from one part to another. This is a characteristic which is very important when interconnections are involved, wherein close coordination to accommodate power transfers is required, and when wheeling and open access are supported.

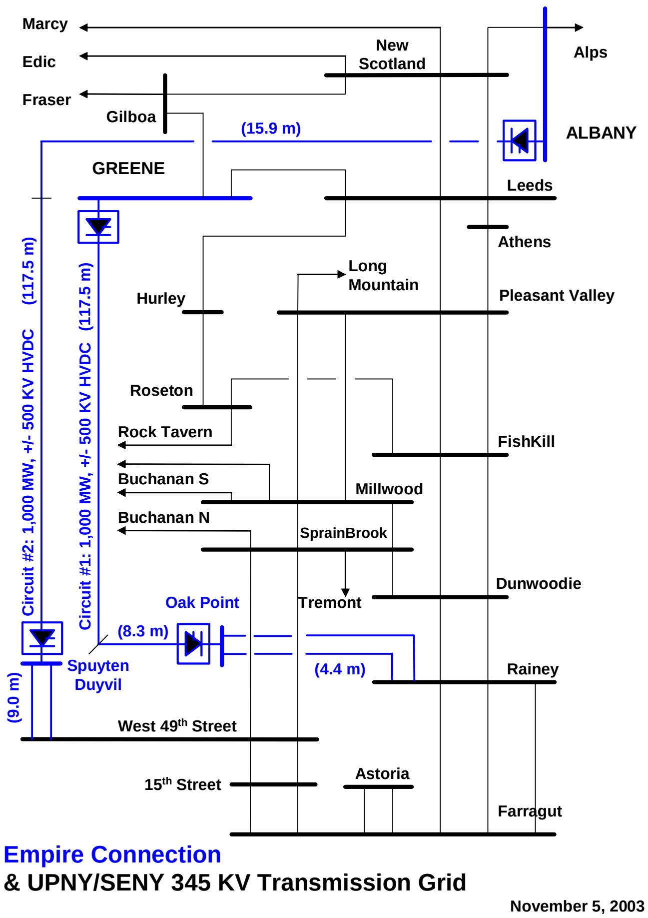

Figure1. Interconnection Plan

Figure 2 shows a power transfer from a sending area to a receiving area which is subject to transfer limits. These limits are a function of the reliability criteria applied for use of the transmission system.

The following definitions are commonly used for transfer limit analysis (Figure 3):

1. A *power increment*, ΔP, is transferred from A to B. A is the *sending* or *exporting area*, and B is the *receiving* or *importing area*.
2. The power flows on the *primary path* as well as the *parallel path* (via C).
3. Circuits on the primary path can be defined as the *interface*. In some situations, the interface may include output from generators (or portions of generators, in cases of shared ownership) located in A but owned by B.
4. P is the incremental import into B, and the algebraic sum of all power into B is the net import into B.

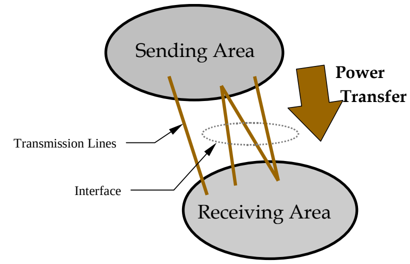

Figure 2 Power Transfer Limits

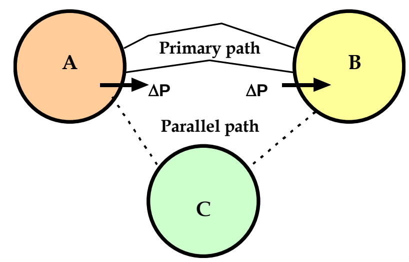

Figure 3 Primary and Parallel Paths

As ΔP is increased, flows on the primary path, as well as the parallel path increase. The *incremental transfer limit* is the value of ΔP when one of the following conditions is reached:

1. Flow on a monitored circuit reaches the limit for acceptable loading
2. Voltage on a monitored bus is at the minimum acceptable value
3. The network reaches a state of voltage instability leading to collapse
4. Flow on a monitored circuit would be at the limit for acceptable post-contingency loading if a contingency were to occur
5. Voltage on a monitored bus would be at the limit for acceptable post-contingency voltage if a contingency were to occur
6. The system is not voltage stable if a contingency were to occur
7. The system does not meet dynamic response criteria (stability) if a disturbance such as a fault were to occur

The *total transfer limit* is the sum of the incremental transfer limit and the transfer in the base case. The *interface transfer limit* is the flow on a selected interface when the incremental transfer limit is reached. Similarly, the *maximum import* can be determined by gradually increasing import until one of the conditions given above is reached. All the preceding refer to non-simultaneous transfers; i.e., between two regions at a time. Another kind of transfer is the *simultaneous transfer* wherein both A and C transfer power to B concurrently. The transfer limit from A to B at any time depends on the transfer from C to B, and vice-versa. There is no numerical relationship between simultaneous and non-simultaneous transfer limits.

Linear methods are widely applied [8] where the transfer limits of interest are thermal in nature; i.e., limits are due to loading of circuits and transformers. In these methods the following assumptions apply: MVAR flows are negligible, voltage support is not a problem, and a DC Power Flow can be applied. For a linear system, a change in power injection in a network node causes a linear change in all branches of the network. For each branch, the power flow can thus be defined by:

$$PFLOW_i = BASFLO_i + \sum_{j}^{L} \Delta PINJ_j \bullet \left(\frac{dFLOW_i}{dPINJ_j} \right)$$

Where:

PFLOWi = flow on line i
BASFLOi = base flow on line i
ΔPINJj = change in power injection (positive if generation increase) at bus j
L = total number of buses
$\left(\frac{dFLOW_i}{dPINJ_j} \right)$ = power injection distribution factor (PIDF) for line i due to power injection at bus j.

The application of a PIDF is illustrated in Figure 4.

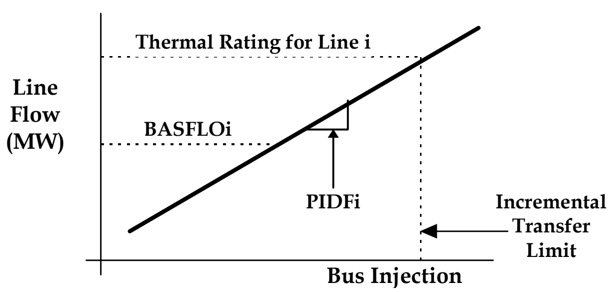

Figure 4 Incremental transfer limit determined using distribution factor

Using the same technique, overload transfer limits can be determined for each monitored branch. The individual transfer limits are ordered according to increasing transfer limit. The *constraining* transfer limit is the lowest in this order. The process of selection is shown in Figure 5. The constraining transfer limit can be attributed to a particular branch that might indicate a weak spot in the system.

To handle overload transfer limits due to contingencies, the assumption of linearity can be applied similarly as follows: the outage of a branch causes a linear change in flows in all other branches. The flow on a branch following an outage is:

$$PFLOW_i = BASFLO_i + POUT_k \bullet \left(\frac{dFLOW_i}{LINE_k} \right)$$

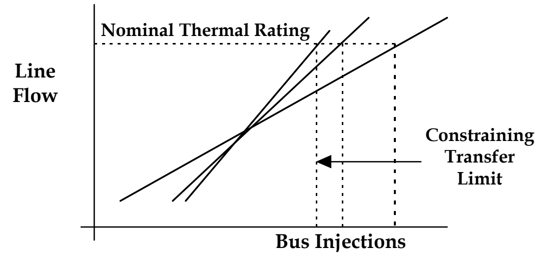

Figure 5 Selecting the Constraining Transfer Limit

Where:
PFLOWi = flow on line i
BASFLOi = base flow on line i
POUTk = flow on line k
k = line outages
$\left(\frac{dFLOW_j}{LINE_k} \right)$ = line outage distribution factor (LODF) for line i due to outage of line k.

Note that the LODF is obtained by interpolating the high and low transfer conditions for each contingency. If there are *m* monitored branches and *n* contingencies, then there are (*m* x *n)* contingency overload transfer limits. As before, these are ordered from lowest to highest. Since the distribution factors may be viewed as sensitivities, one may consider some sensitivities to have less impact than others. A factor called the *cutoff* defines a value for the distribution factor below which the factor is ignored. A typical range for the cutoff is 2-3%.

IV. TRANSFER LIMIT ANALYSIS FOR THE PLANNED SYSTEM

A comprehensive analysis of the impact of the Empire Connection Project for summer and winter base cases was conducted. Normal and emergency thermal limitations on transfers on the intra NY State interfaces were performed with regard to Long-Term Emergency Rating (LTE) as well as Short-Term Emergency Rating (STE). Generation shifts used for the transfer analysis were implemented according to the NYISO specifications. The New York State Reliability Council's Reliability Rules define the criteria used for the transfer analysis:

1. Under normal criteria, an interface is found to be limited to the transfer level at which:
    a. A branch has reached its Normal Rating for pre-contingency system, or
    b. A branch has reached its LTE Rating following a contingency.

2. Under emergency criteria, an interface is found to be limited to the transfer level at which:
    a. A branch has reached its Normal Rating for pre-contingency system, or

b. A branch has reached its STE Rating following a contingency.

The emergency limits are used when the NYISO declares that the NYSBPS is in an emergency state. However, the New York in-City cable system is allowed to operate up to its STE Rating for post-contingency normal conditions.

A summary of the summer analysis results for normal and emergency thermal transfer limits is tabulated in Table 1 and Table 2. A summary of the winter analysis results for normal thermal transfer limits is tabulated in Table 3. The intra NYS interface transfer limit analysis includes five interfaces: NYC Cable; UPNY-Con Ed; UPNY-SENY; Central East and Total East. . It is noted that actual NYISO operating limits for these interfaces may vary as a function of year of analysis (load growth & system changes) and generation dispatch assumptions. From Tables 1, 2, and 3, the following findings are observed:

A. New York City Cable

The summer base case transfer limit for this interface was 4,897 MW. The same value is obtained under Normal and Emergency Transfer Criteria, as the limiting element involves the New York cables that can be loaded up to STE. The normal and emergency transfer limits are increased by 1,625 MW when the Empire Connection Project is in service.

For the winter base case, the normal transfer limit for the NYC Cable interface is 5,155 MW. With the addition of the Empire Connection Project, the transfer limit is increased by 1,409 MW to 6,564 MW.

These limits are very much a function of NYC generation dispatch. For example, the summer normal and emergency transfer limit is 4,916 MW in the base case without the proposed Bergen project interconnected at West 49th Street and without the Empire Connection project. The corresponding limit with the Empire Connection project is 6,981 MW, showing an increase of 2065 MW.

B. UPNY-Con Ed

The summer base case transfer limits for UPNY-Con Ed interface (open and closed) are 4,073 MW and 5,603 MW, respectively, under Normal Transfer Criteria. Under Emergency Transfer Criteria, the base case transfer limits for UPNY-Con Ed interface (open and closed) are 4,729 MW and 6,258 MW, respectively. With the Empire Project in service, there is an increase of 2,523 MW and 2,522 MW in the transfer limits for UPNY-Con Ed (open and closed), respectively, under Normal Transfer Criteria while under Emergency Criteria there is an increase of 2,648 MW for both UPNY-Con Ed interfaces (open and closed).

For winter, at the UPNY – ConEd interface (Open and closed) under Normal Transfer Criteria, the winter base case transfer limits with the re-dispatch are 5,143 MW and 6,673 MW, respectively. This interface will see an increase in transfer limits of about 2,147 MW with the Empire Connection Project in operation for the open and closed interfaces.

C. UPNY-SENY

The summer base case transfer limits for UPNY-SENY interface (Open and Closed) are 4,328 MW and 4,418 MW, respectively, under Normal Transfer Criteria. Under Emergency Transfer Criteria, the base case transfer limits for UPNY-SENY interface (open and closed) are 4,984 MW and 5,074 MW, respectively. With the Empire Connection Project in service, there is an increase of 2,606 MW and 2,605 MW in the transfer limits for UPNY-SENY (open and closed), respectively, under Normal Transfer Criteria. Under Emergency Criteria there is an increase of 2,158 MW and 2,157 MW for UPNY-SENY interface (open and closed), respectively.

For winter, the transfer limits for the UPNY-SENY interface (open and closed) in the winter base case with re-dispatch are 5,184 MW and 5,833 MW, respectively. With the Empire Connection Project in service, there will be an increase of 2,101 MW and 1,801 MW, respectively, in the transfer limits for the UPNY-SENY interface (open and closed).

Table 1 Summer NY Intra Interfaces Normal Transfer Limit (MW) Analysis

LF #	Case Description	NYC Cable	UPNY-Con Ed (O/C)*	UPNY-SENY (O/C)*	Central East	Total East
1	Summer Base Case (Empire O/S)	4,897	4,073/ 5,603	4,328/ 4,418	2,308	4,072
2	Summer Base (Empire I/S)	6,522	6,596/ 8,125	6,934/ 7,023	3,038	5,078

*: Open/Closed

Table 2 Summer NY Intra Interfaces Emergency Transfer Limit (MW) Analysis

LF #	Case Description	NYC Cable	UPNY-Con Ed (O/C)	UPNY-SENY (O/C)	Central East	Total East
1	Summer Base Case (Empire O/S)	4,897	4,729/ 6,258	4,984/ 5,074	2,626	4,361
2	Summer Base (Empire I/S)	6,522	7,377/ 8,906	7,142/ 7,231	3,311	5,091

Table 3 Winter Interface Normal MW Transfer Limit Results

LF #	Case Description	NYC Cable	UPNY-ConEd (O/C)	UPNY-SENY (O/C)	Central East	Total East
1	Winter Base Case (Empire O/S)	5,155	5,143/ 6,673	5,184/ 5,833	2,949	5,959
2	Winter Case (Empire I/S)	6,564	7,290/ 8,820	7,285/ 7,634	3,110	6,057

D. Total East & Central East

The summer base case transfer limits for Total East and Central East interfaces are 4,072 MW and 2,308 MW, respectively, under Normal Transfer Criteria. Under Emergency Transfer Criteria, the base case transfer limits for Total East and Central East are 4,361 MW and 2,626 MW, respectively. With the Empire Connection Project in service, there is an increase of 1,006 MW and 730 MW in the transfer limits of Total East and Central East, respectively, under

Normal Transfer Criteria. Under Emergency Criteria, there is an increase of 730 MW and 685 MW for Total East and Central East, respectively. The winter base case transfer limit for the Central East interface is 2,949 MW under normal transfer criteria. For the Total East interface, the transfer limit is 5,959 MW. With the addition of the Empire Connection Project, there would be an increase in the transfer limit for the Central East interface of 161 MW and an increase of 98 MW for the Total East interface. The increase in transfer limits of the Central East and Total East interfaces due to the Empire Connection project are interesting because those interfaces are not parallel to the project. In this case, the increases are due to the project redistributing NYSBPS power flows and thus removing a previously limiting constraint.

IV CONCLUSION

The paper presents a thermal limit transfer analysis of the NYSBPS with a major HVDC transmission project developed by Conjunction LLC. An incremental approach is used in evaluating the thermal transfer limit for the studied NYS intra Interfaces. The incremental approach determines the FCITC as a basis for transfer limit analysis for the relevant NYSBPS intra interfaces with and without the proposed Empire Connection Project. The thermal transfer limits introduced in the paper are for: normal summer and winter peak load conditions; peak load summer emergency conditions. The thermal transfer limit analysis was conducted using PTI's Managing and Utilizing System Transmission (MUST) software package for FCITC calculations. The obtained results show that the thermal transfer limits for the intra NY State interfaces under study were substantially increased under normal and emergency conditions with the proposed Empire Connection Project in service.

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VI. BIOGRAPHIES

Dr. Elfayoumy (M'02) received his B. Sc. and M. Sc. degrees in Electrical Power Engineering from Alexandria University, Alexandria Egypt, in 1991, and 1994 respectively with final grades of Distinction with degree of Honor. He received his Ph.D. in Electrical Power Systems from Howard University, Washington, D.C. in May 2000. Currently he is with Power Technologies, Inc. working as a consultant in the areas of transmission analysis and modeling. His current area of focus is in interconnection planning, reliability assessment, transfer limit calculations, security constrained unit commitment, security-constrained dispatch, and AI applications to power systems. Dr. Elfayoumy is a member of IEEE and PES society. He is also a member of TAU BETA PI professional engineer's honor society chapter of Washington DC and a member of Sigma Xi professional Scientific Research society. Dr. Elfayoumy published over 21 IEEE (IEE) journal and conference papers.

Ramon Tapia received a B.Sc. degree in Electrical Engineering from Universidad Catolica Madre y Maestra, Santiago, Dom. Rep. in 1976, a MS in Electrical Engineering from Union College, Schenectady NY in 1983 and a ME in Electric Power Engineering from Rensselaer Polytechnic Institute, Troy, NY in 1989. He also completed the General Electric Power Systems Engineering Course in 1982. Currently he is an Associate Director with Shaw Power Technologies in Schenectady, NY. In 1977 he joined Dominican Republic's national electric utility, Corporation Dominicana de Electricidad (CDE) as a Power System Analyst. In 1982, Mr. Tapia joined the New York Power Pool (NYPP) as an Engineer. In 1987 he was promoted to Senior Engineer. He is a member of the IEEE Power Engineering Society (PES).

Roger Clayton received his B.Sc. (Hons) in Electrical Engineering and his M.Sc in Power System Engineering from Aston University, Birmingham, U.K. He is presently Senior Vice President, Electrical Engineering for Conjunction LLC. He has previously worked in the electric utility consulting business for PG&E National Energy Group, GE Power System Energy Consulting, Electric Power Consultants, Inc. and Power Technologies, Inc. Mr. Clayton is a Registered Professional Engineer in the State of New York and a Senior Member of IEEE.