Benefits of Reducing Electric System Losses

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Background

During the collaborative process before the administrative law judges (ALJs) in the Public Service Commission's (PSC, Commission) proceeding to establish an Energy Efficiency Portfolio Standard (EEPS), the NYISO commented that significant energy efficiency savings could be realized by making cost-effective equipment upgrades to New York State's electric transmission and distribution (T&D) systems. The NYISO suggested the installation of capacitors in strategic locations to reduce line losses as a primary example. The stakeholders, ALJs and the PSC agreed, and the Commission announced in its June 23, 2008 order[1] its plan to establish this system losses proceeding.[2] The Commission directed that "Staff should work with the [NYISO] and transmission owners to examine the potential loss reduction that could result from utilizing Optimal Power Flow technology in dispatching the bulk electric system in New York."[3]

The following is a summary of a number of months of collaborative work between the NYISO, PSC Staff and transmission owners (TOs) as well as two comprehensive studies on T&D line loss reduction in New York State.

The NYISO collaborated with PSC Staff, the New York TOs and other stakeholders in the EEPS proceeding's Working Group IV and at the July 17, 2008 Technical Conference in this proceeding to determine the potential benefits that could be achieved through the installation of capacitors on the State's T&D systems. Benefits identified were improved reliability and cost savings.

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[1] PSC Case 07-M-0548 – Order Establishing Energy Efficiency Portfolio Standard and Approving Programs (Issued and Effective June 23, 2008).

[2] PSC Case 08-E-0751 – Proceeding on Motion of the PSC to Identify Sources of Electric System Losses and the Means of Reducing Them, Order Clarifying Scope of Proceeding (Issued and Effective July 17, 2008).

[3] PSC Case 07-M-0548 – Order Establishing Energy Efficiency Portfolio Standard and Approving Programs (Issued and Effective June 23, 2008), at 62.

Although New York's T&D systems already meet applicable reliability requirements, an additional level of reliability can be achieved. Installing more capacitors would produce immediate and tangible benefits to the reliability of the power system. Adding capacitors to the T&D systems would reduce the need to call upon generators to increase their output of Volt-Ampere reactive power (VArs) to maintain voltages on the grid.

Adding static VAr compensation close to loads would reduce the losses that result from moving VArs over long distances, leaving room in the T&D systems to move more real power from generators to loads where it is needed. This is the best way to efficiently utilize the thermal capacity of the existing transmission system, resulting in cost savings. The cost savings are the result of reduced purchases of power from generators, reduced need for distribution capability, and potential increases in transfer limits for transmission interfaces that are limited by voltage.

The reliability benefits accrue from an improved T&D systems voltage profile, increased generator MVAr reserve under normal and equipment outage conditions, improved interface transfer limits, and reduced reactive power flow on the T&D systems. For instance, in the event of a bulk power system emergency with loss of transmission or generation, dynamic VAr capability from generating facilities will help to maintain the bulk power system voltage and stability operating limits. These benefits are very real. Historically, the lack of sufficient dynamic voltage compensation in a system emergency condition has been a major contributing cause of blackouts.

Real power losses are the amount of power consumed by the delivery system from electric current overcoming the resistance of the wires, transformers and other components of the power system that result in power being converted into heat (i.e., I^2R losses). In alternating current (AC) circuits, current that flows in electric and magnetic fields of the power system can be significant. This aspect of the system constitutes reactive power. Reactive current flow causes extra losses in the AC power system. Two to three percent of New York's electricity is consumed by transmission system losses before energy is converted into useful work at the consumer level. Similarly, an additional four to eight percent is consumed by losses in the distribution system. As stated in the EEPS Working Group IV Report:

> Of the 173,000,000 megawatt hours (MWh) of electric energy delivered to the state's transmission system in 2006, approximately 2.4% (4,000,000 MWhs) was consumed by losses in transmission system. Of the remaining 169,000,000 MWhs supplied to wholesale customers, a conservative estimate of 6% (10,000,000 MWh) was likely consumed by distribution system losses. In total, approximately 14,000,000 MWhs of New York's energy supply was consumed by losses in 2006.[4]

Ratepayers ultimately pay for the energy consumed by T&D systems losses, which is reflected in the price of the power that is delivered to them. Accordingly, reducing real and reactive power losses in the T&D systems offers significant potential energy savings for New York consumers. These savings can offset the costs of making upgrades to the T&D systems, benefit consumers by lowering their electric bills, and benefit public health, the environment, and bulk power system reliability.

In support of the line losses proceeding, the NYISO has conducted a comprehensive transmission study based on power flow analysis conducted by its consultant, ABB, and input from certain New York TOs to identify the locations on the transmission and sub-transmission system (hereafter referred to as the transmission

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[4] PSC Case 07-M-0548 – Energy Efficiency Portfolio Standards Proceeding Final Report WORKING GROUP IV. December 5, 2007. Page 61

system) and at the interface between the transmission system and local distribution systems where losses are the greatest and where equipment upgrades will be most effective. The study focused on loss savings only; potential savings that would be attributable to capacity release (i.e., system capacity that is made available for future use such as distribution and transmission) were not explicitly modeled due to timing and budget constraints.

Because the NYISO models primarily contain the transmission[5] system, the potential savings on the distribution system were not investigated in the transmission study. To address the distribution system, the NYISO commissioned Quanta Technology to perform an analysis of the potential savings that could exist there. By combining the results of the two efforts, the NYISO presents information that can provide some guidance on the potential benefits of adding incremental capacitor compensation to both the transmission and distribution systems in New York State.

The focus of this report is: 1) to inform stakeholders on the potential for reducing system losses; 2) to identify the potential range of cost and savings that might be realized, and; 3) to identify power system locations, using non-linear optimization, where the potential for loss savings is greatest. This report is not intended to be the final determination for the locations identified. A final determination would require a physical inspection of the location and fine tuning of study assumptions to reflect location particulars that might not have been fully captured in the analysis, such as utility specific cost structure, available capacitor bank sizes, and generator reactive output.

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[5] There were a limited number of bus locations in specific zones modeled in the load flow cases with voltages as low as 13.2 kV to 13.8 kV.

Study Process

To determine the optimal locations and benefits of additional compensation, a study tool known as the Optimal Power Flow (OPF) was used by ABB for the assessment of the New York transmission system. The OPF is a power flow tool that utilizes optimization techniques such as non-linear programming to minimize an objective function. In this case, the objective is scheduling power system resources (generators, switchable shunt compensation, tap changing transformers, etc.) to minimize real or reactive power losses. The OPF can be used to identify those areas of the system where the installation of capacitors provides the most benefit and to determine the overall loss savings. The application of the OPF is described in detail in Appendix A of this report.

Before the analytical process can begin, base cases need to be developed. Since it is not practical to conduct OPF analysis on all of the 8,760 hours in a year, the first step was to parcel the annual load duration curve into seven segments. The study developed the load level and the number of hours (duration) of each segment. The seven load levels were designed to represent conditions ranging from peak through minimum load. The seven load levels resulted in seven power flow cases defined as load level case 1 through 7 or LDC1 through LDC7 (a.k.a. LD1 through LD7). Data from September 2005 through August 2008 was analyzed to develop the load levels. The historical data was also used to develop reactive loads, representative dispatches (i.e., load and generation balance) and interface flows, imports and exports. The Millwood 240 MVAr capacitor bank was assumed to be in service. The modeling assumptions are detailed in Appendix A.

As mentioned above, the NYISO's power flow models do not contain distribution facilities. Therefore, the OPF analysis quantified only the losses that can be saved on the transmission system. This qualification not withstanding, it is still possible to conservatively estimate the potential loss savings from equipment installations such as capacitors on the distribution system (illustrated in Appendix B), as well as environmental benefits in terms of reductions in CO_2 emissions.

Study Results

Transmission Loss Savings

To determine the locations where installing capacitor banks provides the greatest benefit, transmission loss sensitivity analyses were conducted to identify how transmission losses can be reduced by injecting reactive power. For the OPF analysis, the objective function was defined as the minimization of MW losses, and the control variables were the incremental injection of MVAr at each of the New York Control Area (NYCA) buses. The analysis revealed the locations/buses where additional compensation would provide the greatest benefit. The output of this analysis is colorized contour maps that display the optimal locations, or most sensitive areas, for adding capacitors. The following contour maps (Figures 1 and 2 on page10) are the contour maps for the LDC1 or peak power flow case and LDC5 power flow case, which approximates the middle range of the load duration curve. The areas that appear in dark blue have the greatest potential for reactive power compensation and concomitant loss reductions.

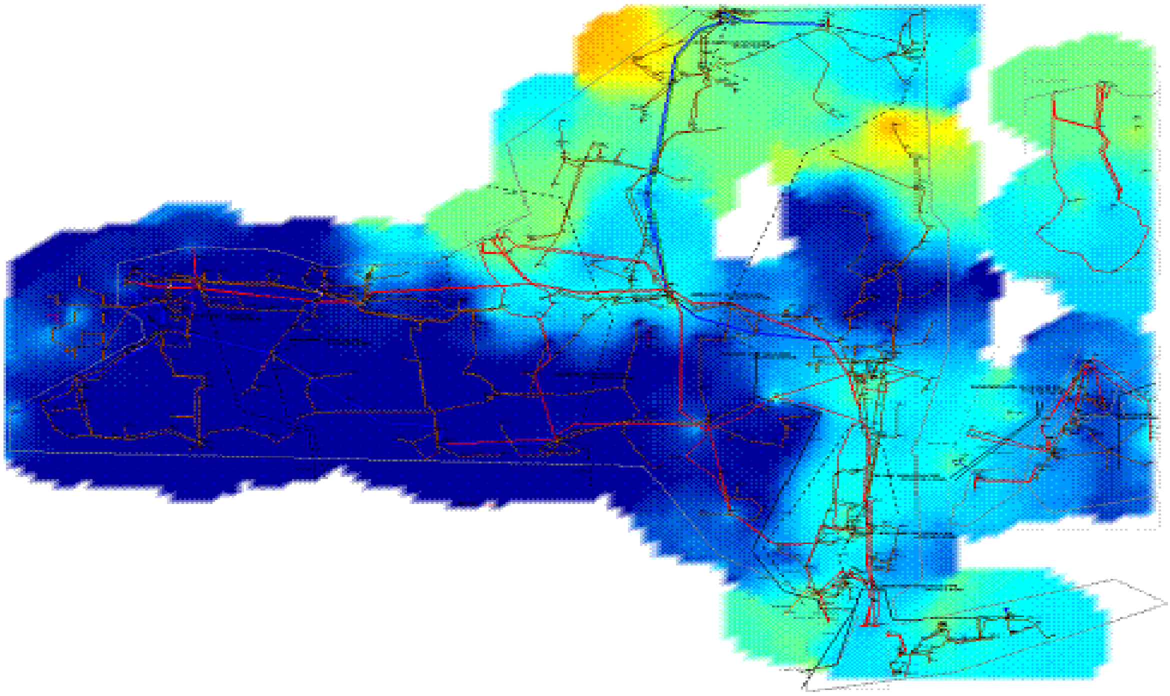

Figure 1 – Contour Map

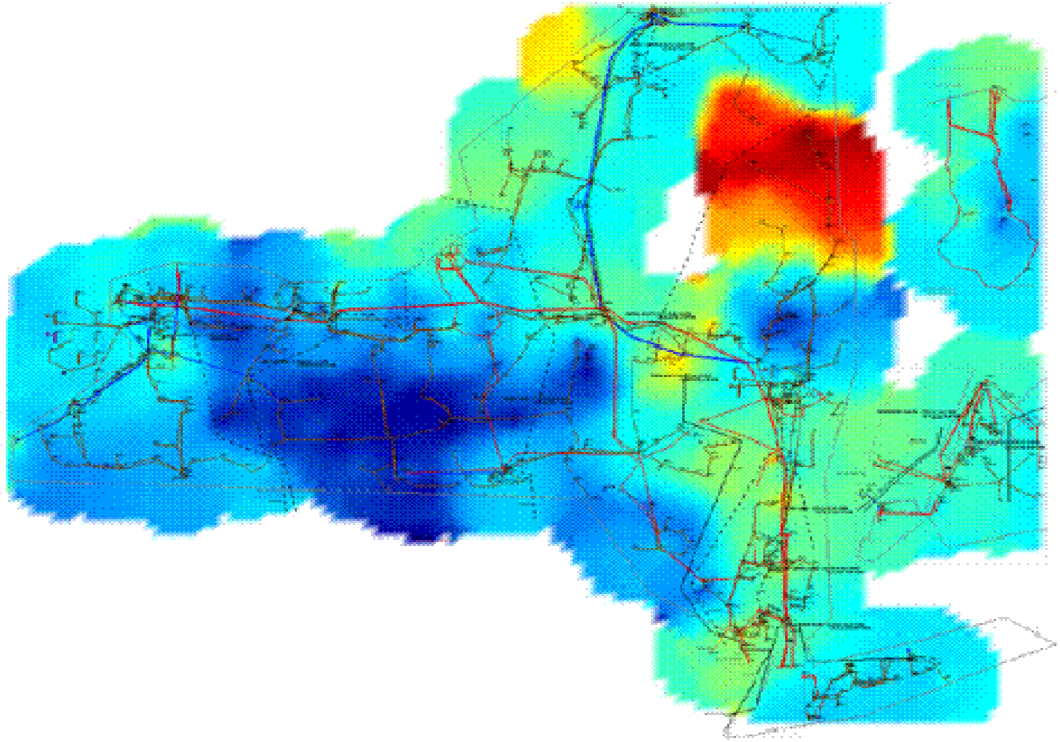

Figure 2 – Contour Map

As can be seen in the contour maps, the portion of the system where the addition of shunt compensation is most effective for loss reduction is present in the Upstate portion of the NYCA system.[6]

As capacitor banks are added to the system, loss savings gradually diminish in effectiveness. Sensitivity analysis is then used to establish the minimum amount the OPF model is willing to accept in terms of the MW of loss savings per MVAr of additional capacitors. For instance, the sensitivity can be set at a minimum of 1 MW of loss savings per 100 MVAr of capacitor banks added (Level I savings); or 0.5 MW of loss savings per 100 MVAr of capacitor banks (Level II savings). The Level I optimization will require adding fewer capacitor banks than the Level II optimization, and will result in lower MW loss savings. Nevertheless, the solution is more cost effective per MW of loss savings. Results were developed for both Levels.

The first step in developing loss savings sensitivity levels was to establish a reference point to evaluate the benefits of the incremental capacitors by identifying the amount of base line losses after optimizing existing reactive power control devices. The base cases for seven load levels were derived from a review of a range of observed operating conditions. During the real time operation, system operators constantly and continuously adjust system voltages utilizing: 1) generator terminal voltage control; 2) on-load transformer taps (LTCs) and; 3) switched shunts. To simulate these operation actions manually would be time consuming for the seven base cases, so the OPF is used to simulate this by adjusting reactive resources to meet criteria while minimizing losses. The simulation results show potential on transmission loss reduction via existing

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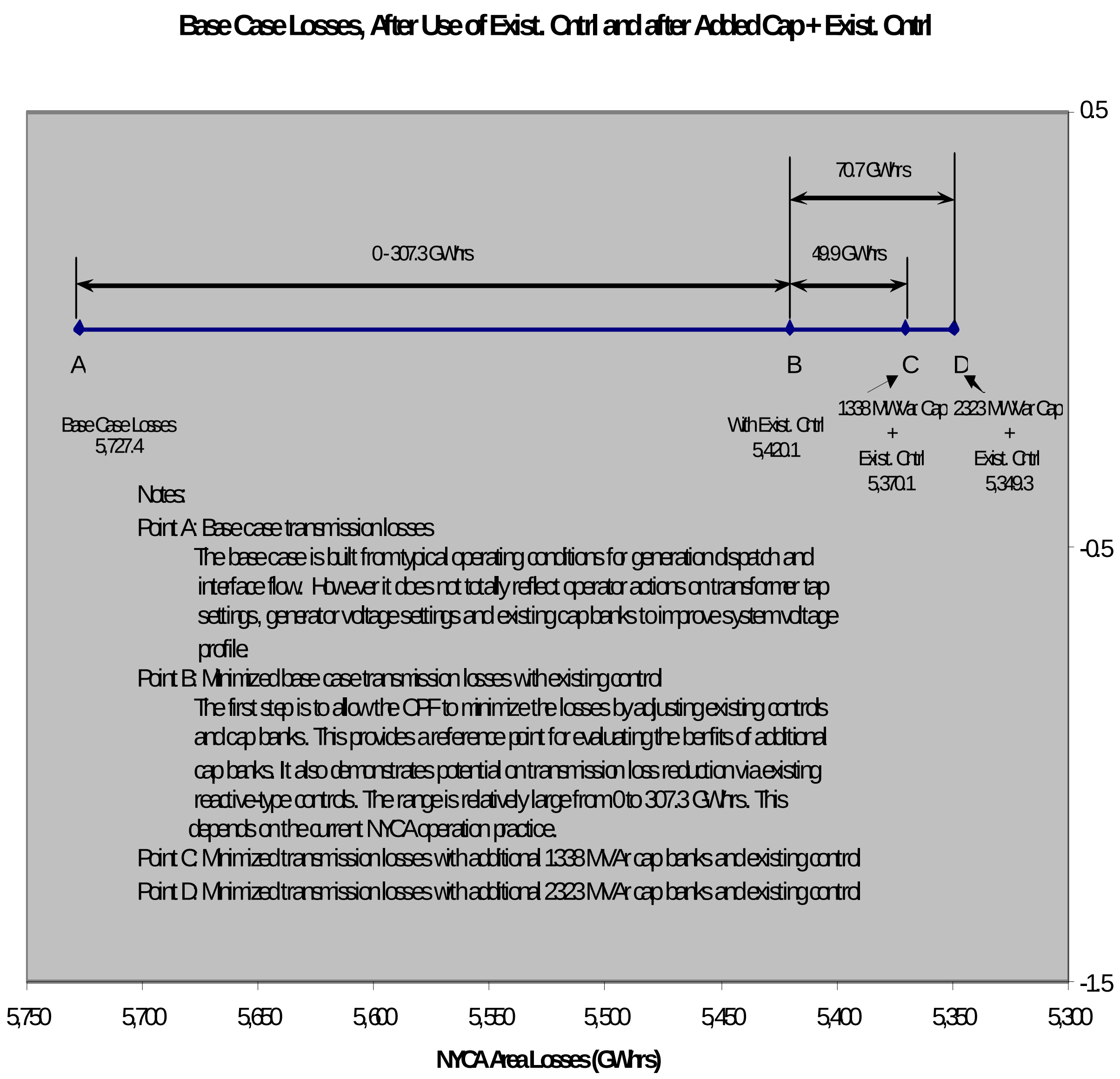
[6] Different system states such as facility outage conditions can results in different outcomes.

reactive-type controls (transformer taps, existing switched shunts, and generator voltages). The range for this potential transmission loss reduction is from 0 to approximately 307 GWh/Year as shown in Figure 3. The actual loss reduction via existing controls will depend on current NYCA operational practices. The application of the OPF concept in real time operations was investigated in Working Group 2 of the Losses Proceeding. Working Group 2 has identified the issues associated with implementing OPF technology on-line but has not issued its report.

The second step was to determine the incremental MVArs that are needed to produce additional loss savings on the transmission system based on the seven optimized load flow cases. The Level I optimization resulted in 1,338 MVArs of cap banks being added with approximately 49.9 GWh of annual energy savings. The Level II optimization resulted in 2,323 MVArs of cap banks being added with approximately 70.7 GWh of annual energy savings. Figure 3 presents the overall process:



Notes:

Point A: Base case transmission losses

The base case is built from typical operating conditions for generation dispatch and interface flow. However it does not totally reflect operator actions on transformer tap settings, generator voltage settings and existing cap banks to improve system voltage profile.

Point B: Minimized base case transmission losses with existing control

The first step is to allow the OPF to minimize the losses by adjusting existing controls and cap banks. This provides a reference point for evaluating the benfits of additional cap banks. It also demonstrates potential on transmission loss reduction via existing reactive-type controls. The range is relatively large from 0 to 307.3 GWhrs. This depends on the current NYCA operation practice.

Point C: Minimized transmission losses with additional 1338 MVAr cap banks and existing control

Point D: Minimized transmission losses with additional 2323 MVAr cap banks and existing control

Figure 3 – Overall Study Process

Table 1 – Transmission Loss Reduction with 1338 MVAr Additional Cap Banks

Load Step	Hours	Added Cap (Mvar)	Loss Reduction Due to Added Cap (MW)	Loss Reduction (MWHrs)
LD1 (90%-100%)	48	1338	31.2	1,498
LD2 (80%-90%)	178	442	13.2	2,356
LD3 (70%-80%)	665	185	6.5	4,331
LD4 (60%-70%)	1958	193	6.3	12,251
LD5 (52.5%-60%)	2633	276	7.4	19,526
LD6 (40%-52.5%)	3036	166	2.8	8,367
LD7 (37.5%-40%)	242	305	6.4	1,554
Total	**8760**			**49,884**

Note: Level I energy saving on transmission loss reduction due to additional 1338 MVAr cap bank.

Table 2 – Transmission Loss Reduction with 2323 MVAr Additional Cap Banks

Load Step	Hours	Added Cap (Mvar)	Loss Reduction Due to Added Cap (MW)	Loss Reduction (MWHrs)
LD1 (90%-100%)	48	2323	40.4	1,939
LD2 (80%-90%)	178	920	18.8	3,346
LD3 (70%-80%)	665	528	8.4	5,586
LD4 (60%-70%)	1958	608	8.4	16,447
LD5 (52.5%-60%)	2633	746	9.7	25,540
LD6 (40%-52.5%)	3036	629	5.2	15,787
LD7 (37.5%-40%)	242	660	8.3	2,009
Total	**8760**			**70,654**

Note: Level II energy saving (1.3%) on transmission loss reduction due to additional 2323 MVAr cap bank.

The ABB Report (Appendix A) provides the location for the compensation that was added for the two levels of optimization. These locations are the electrical buses which are modeled in the OPF. The OPF does not consider physical limitations that might exist at a particular location. Also, the OPF does not take into consideration the unit size of capacitors that would be available for installation. In addition to the energy savings, reducing losses results in more capacity available for use on the system (i.e., reduced need for generating and transmission facilities) as well as environmental benefits due to reduced emissions of carbon dioxide.

Distribution Loss Savings

In general, the closer the compensation is located to the load the greater benefit in terms of losses savings. The analysis for the transmission system primarily added capacitor banks at the 115 kV and lower transmission voltages. For example, the Level II optimization would reduce the transmission losses by 70.7 GWh, which is about 1.3% of the total losses. If the losses savings are achieved by installing capacitor banks on primarily the distribution systems instead of at the transmission system, this should result in at least an equal amount (1.3%) reduction in distribution losses. As discussed above, the EEPS Working Group IV report estimated that distribution losses totaled approximately 10,000 GWh. Compensating for those losses would result in additional savings of approximately 130 GWh of energy and total peak reduction of approximately 114.7 MW. The Quanta Technology Report in Appendix B, which estimated potential loss reductions on the distribution system as high as 30% (see page 13 of the report), implies that these estimates of distribution loss savings are conservative.

Estimating Energy and Demand Savings

Energy and demand savings through line loss reductions result in both monetary and environmental benefits. To determine the monetary benefits, averages of historical locational based marginal price (LBMP[7]) wholesale electric prices for 2006 were developed by load level and were applied to the energy savings by load level. The use of historic LBMP wholesale electric prices for calculating the monetary benefits from loss reductions was agreed upon by the participants in EEPS Working Group IV. Although the savings elements such as energy and capacity used in calculating the benefits are consistent with those identified in the EEPS, the NYISO believes its approach for calculating those savings more accurately aligns with potential market outcomes (e.g., LBMP by load level and ICAP auction impacts) than the average dollar values used in the EEPS analysis.

To determine the value of the estimated energy savings for the distribution system, the average dollar value savings from adding 2,323 MVAr of reactive compensation was calculated and applied to the energy savings estimated for the distribution system. Savings attributed to reductions in peak demand for supply/generation capacity release is based on the NYISO's summer ICAP market auction results (see note 5 of Table 3). Capacity release savings attributed to T&D savings require a more complex analysis and were not determined for this assessment. The Quanta Technology report (Appendix B) provides examples of such benefits for the distribution system (see section three, starting on page 12 of the Quanta Technology Report).

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[7] The NYISO's LBMP market design consists of three pricing components which are energy, transmission congestion and system losses. A reduction in system losses results in an overall positive feedback on LBMP which potentially could result in overall lower prices which has not been reflected.

Given the importance of CO_2 reductions, the environmental benefits were quantified in terms of the tons of CO_2 emissions that were avoided. The CO_2 savings were calculated based on the assumption that gas fired generation would be the generation at the margin for most hours (a conservative approach). Table 3 summarizes the potential benefits that can be realized by reducing system losses.

Table 3 – Summary of Potential of Savings

Quantity	**1338 MVArs of Cap Banks ABB Study**	**2323 MVArs of Cap Banks ABB Study**	**2323 MVArs of Caps Installed on the Distribution System**	**Totals**
Energy Savings (GWh)	49.8[1]	70.7[1]	200.7	49.8 – 202.4
CO2 savings (tons)[2]	60,900	86,800	252,800	60,900 – 252,800
Energy Dollar Value[3] (millions of dollars)	5.0	6.9	19.6	5.0 – 19.6
T & D Savings[4] (millions of dollars)	TBD	TBD	TBD	TBD
Generation Capacity Savings[5] (millions of dollars)	6.0	7.8	21.7	6.0 – 21.7
Total Potential Dollar Savings (millions of dollars)	11.0	14.7	41.3	11.0 – 41.3

Note 1: From ABB report (Appendix A)
Note 2: Based on gas at the margin which resulted in CO2 reductions of 1,200 tons/GWh saved
Note 3: Based on 2006 LBMP prices by load level. Reflects wholesale electric prices only. Does not reflect retail prices
Note 4: Estimate not provided because such estimates would be complex to calculate and require additional data
Note 5: ICAP savings based on Summer Capability Period, NYCA clearing price of \$2.50/kW-month, demand curve slope of \$0.20/100 MW, 18,000 MW exposed to market price, 31 MW reduction in real power losses:

- Without cap banks, capacity payments are \$2.50 * 18,000,000 * 6 months = \$270M
- With cap banks, capacity payments are \$2.44 * 18,031,000 * 6 months = \$264M
- Savings due to cap banks = \$6M (summer only)

Besides the savings identified above, there are additional reliability benefits which can be quantified from the benefits they provide to the electrical system. As an example, ABB ran a sensitivity case for the peak load case or LDC1. An outage condition was used to investigate the additional benefits of added capacitor banks on the NYCA system voltage profile. The base case was adjusted by turning off generation from the Poletti unit in New York City (approximately 891 MW of generation and reactive output of 175 MVArs). To make this a stressed case, available internal Zone J generation (MWs) were not allowed to adjust. Adjustment of MVArs was accomplished through the application of the OPF which limits generating units to .98 power factor. This required increased MW flows into New York City to offset the MWs from this unit being unavailable. In order for the case to solve and to maintain voltages within reliability criteria under the increased transfer conditions would require an additional 630 MVArs of capacitor banks. The increased transfer case was rerun with the 2,323 MVArs of capacitor from the level II optimization available to the system and the voltages stayed within criteria. The contingency loss of the Ravenswood 3 unit (approximately 940 MW of generation and reactive output of 250 MVArs) was then tested against the case with the additional MVArs and increased transfers. Voltages for this contingency with the additional MVArs available stayed within criteria. This is a result of the stringent assumptions regarding reactive reserves utilized in deriving base case solutions in these analyses (see section 16 of the ABB report). Notwithstanding this illustrative example, the Con Edison system does meet first and second contingency design without the 630 MVArs of the example.

The addition of capacitor banks improved transfer capability under outage conditions and on voltage limited interfaces. Section 4 of the Quanta Technology Report in Appendix B expands on the reliability benefits that derive from the installation of additional capacitor banks.

Conclusion

The analysis presented herein in conjunction with the supporting ABB and Quanta Technology reports demonstrate substantial benefits to adding reactive compensation to New York's T&D systems. Further, the NYISO believes that the stated estimates of these benefits can be characterized as conservative. For example, the energy dollar saving estimates are based on wholesale electricity prices, capacity savings were only based on the summer auction savings, carbon benefits are based on gas fired generation being the marginal unit, and the kW and kWh distribution system savings were extrapolated from the transmission system, while the Quanta report indicates the potential for much greater savings.

Depending on the location of the capacitor banks (transmission versus distribution) and based on TO provided input, the NYISO has estimated that the cost of capacitor banks can range from 20,000 dollars per MVAr up to 50,000 dollars per MVAr. This would result in an estimated potential capital investment ranging between $46 on the lower end up to $105 million on the higher end for the installation of 2,323 MVArs of capacitors. Using a mid range cost of approximately $75 million and the 15% carrying cost used in the ABB report results in an annual cost of $11.25 million over the useful life of the equipment. If the mid-range of the estimated annual cost of the capacitor banks is compared to the mid-range of the estimated annual savings ($26 million), the result is a ratio that exceeds two dollars in savings for every dollar of cost, or a payback of a little over three years. The utilities and PSC Staff can make such calculations more accurately since costs and rate recovery – and therefore savings – associated with specific installations will vary. Again, it should be noted that cost savings for increasing available transfer capability or T&D capacity release were not included in the savings numbers. Finally, given the growing cost of managing carbon emissions and additional savings that would result in full retail electric rates, the NYISO has concluded with substantial certainty that the addition of capacitor bank compensation to New York’s T&D systems can potentially provide substantial benefits to the electricity consumers of New York.

Appendix A: NYISO/ABB Study – Transmission System Losses Exploration Study

See enclosed CD

Appendix B: NYISO/Quanta Technology Study – Benefits of Adding Capacitors to the Electric System

See enclosed CD

Appendix C: EEPS Working Group IV – Final Report

See enclosed CD