

4 CONCLUSIONS AND RECOMMENDATIONS

The majority of the analysis was performed at the 2018 load level. Therefore, the conclusions and recommendations refer to 2018 conditions unless stated otherwise. Based on the 2018 results, there were no thermal or voltage criteria violations on the transmission system with all lines in, i.e. NERC category A events. There were no transmission overloads for single element contingencies, i.e. NERC category B events. However, there were many voltage violations, including local voltage collapse. Voltages were below 0.95 pu for many contingencies. All transmission overloads occurred for multi-element outages referred to N-2 or N-1-1. The transmission reinforcements are based on criteria violations under element-out conditions. Below is a summary of the concerns identified and the proposed conceptual solutions. Except for the St Johnsbury reliability concern, none of the deficiencies have a planned transmission solution at this time. More analysis is needed to better define the solutions and raise the solutions from a conceptual to a planned level. The proposed 46 kV line from Weybridge to New Haven can postpone the need for the second Middlebury transformer. Below is the description of individual deficiencies and proposed conceptual solutions. Section 5 includes the results of the non-transmission alternative screening for each of the solutions proposed.

Deficiency #1:

A 115 kV line contingency caused local voltage collapse of the St Albans load and low voltage in the Highgate area due to the radial condition. This concern occurs below the 900 MW Vermont load level. Breaker failure contingencies at Georgia failed to converge. The conceptual solution can be described as follows:

St Albans solution:

Construct a ring substation near the K-42 right-of-way with two 56 MVA transformers

Construct a ring substation at or near the Georgia substation.

Estimated cost: \$45M to \$90M

Timing of deficiency: Before 2009 (900 MW)

Priority: 3

Affected utilities: CVPS and VEC for St Albans. All DUs for Georgia.

The voltage collapse concern affects load served at St Albans and East Fairfax. Utilities supplied at these locations are CVPS and VEC.

Lead DU: CVPS

CVPS is directly supplied from St Albans and has the highest amount of load affected.

In conjunction with the above reinforcements, transmission lines may be required to address potential voltage stability concerns and improve the delivery of Highgate imports.

Georgia-St Albans voltage instability solution:

Construct a new 115 kV line between Georgia and St Albans

Estimated cost: \$15M to \$30M

Timing of deficiency: Before 2018 (less than 1275 MW)

Priority: 3

Affected utilities: CVPS, Swanton and VEC

The voltage instability concern affects load served at Highgate, St Albans and East Fairfax. Utilities supplied at these locations are CVPS, VEC and Swanton. The Newport, Irasburg and St Johnsbury station may also be affected. Additional studies are needed to determine how much wider the affected area is.

Lead DU: VEC.

The northern area is largely VEC's service territory.

Deficiency #2:

Loss of a transformer and breaker failure contingencies failed to converge. This concern occurs below the 700 MW Vermont load level. CVPS has proposed a new 46 kV line between Weybridge and New Haven to provide redundant service to load presently supplied radially. More analysis is needed to determine whether the voltage concern is totally resolved within the 10-year horizon. The conceptual solution, whose timing should be confirmed with the proposed 46 kV line installed, can be described as follows:

Middlebury solution:

Construct a ring substation at or near the existing Middlebury substation and install a 56 MVA transformer

Estimated cost: \$10M to \$20M

Timing of deficiency: Before 2009 (700 MW)

Priority: 2

Affected utilities: CVPS

CVPS is the only utility whose load is affected by loss of the transformer

Lead DU: CVPS

CVPS is the only affected utility

Deficiency #3:

Loss of a transformer solved with voltages below 0.7 pu, which is an indication of voltage collapse, and caused overloads of nearly 50% on 46 kV lines near West Rutland. Such overloads would likely cause the lines to sag and trip, which would then cause loss of load. This concern occurs at the 800 MW Vermont load level. The conceptual solution can be described as follows:

Blissville solution:

Construct a ring substation at or near the existing Blissville substation and install a 56 MVA transformer

Install reactive compensation, likely a 25 MVAr capacitor bank

Estimated cost: \$15M to \$30M

Timing of deficiency: Before 2009 (800 MW)

Priority: 5

Affected utilities: CVPS

CVPS is the only utility whose load is affected by loss of the transformer

Lead DU: CVPS

CVPS is the only affected utility

Deficiency #4:

Loss of a transformer solved with voltages below 0.7 pu, which is an indication of voltage collapse. Breaker failure contingencies failed to converge, particularly with the F-206 line out of service. The area supplied by the Chelsea transformer is winter peaking. Therefore, more severe voltage concerns are expected near Chelsea in the winter. Loss of a line caused voltages to drop below 0.8 pu. This concern occurs at the 1000 MW Vermont load level, assuming the Bradford 5.4 MVAR capacitor bank can be subdivided into smaller capacitor banks. This concern can occur at the 700 MW load level because the capacitor bank cannot be dispatched pre-contingency at its current size. At the 1000 MW load level, the low voltage concern exists even with the capacitor bank dispatched. The conceptual solution can be described as follows:

Hartford solution:

Construct a ring substation at or near the existing Hartford substation and install a 56 MVA transformer

Estimated cost: \$15M to \$30M

Timing of deficiency: Before 2009 (1000 MW)

Priority: 6

Affected utilities: CVPS and GMP

The low voltage concern affects load served from Hartford. The utilities supplied at that location are CVPS and GMP (Norwich load).

Lead DU: CVPS

CVPS is directly supplied from Hartford and has the highest amount of load affected

Chelsea solution:

Construct a ring substation at or near the existing Chelsea substation and install a 56 MVA transformer

Estimated cost: \$15M to \$30M

Timing of deficiency: 2018 (1275 MW) assuming the second Hartford transformer is installed. Otherwise the timing is 2013 (1210 MW).

Priority: 17

Affected utilities: CVPS and WEC

The low voltage concern affects load served on the 46 kV system between Silverlake, Chelsea and Taftsville. Utilities served from this system are CVPS and WEC.

Lead DU: CVPS

CVPS is directly supplied from Chelsea and has the highest amount of load affected.

Deficiency #5:

Loss of a transformer caused overloads in excess of 50% on 46 kV lines from Blissville to Cold River. Transformers overloaded in excess of 30% for loss of a transformer. Such overloads would likely cause the lines to sag and trip, which would then cause loss of load. This concern occurs at the 1000 MW Vermont load level. The conceptual solution can be described as follows:

North Rutland solution:

Construct a ring substation at or near the CVPS South Rutland substation and install a 75 MVA transformer

Estimated cost: \$15M to \$30M

Timing of deficiency: Before 2009 (1000 MW)

Priority: 4

Affected utilities: CVPS

CVPS is the only utility whose load is affected by loss of either transformer

Lead DU: CVPS

CVPS is the only affected utility

Deficiency #6:

Loss of a transformer solved with voltages approaching 0.8 pu, and caused overloads of nearly 10% on 46 kV lines from Windsor. Such overloads would likely cause the lines to sag and trip, which would then cause loss of load. The transformer itself overloaded for loss of nearby transformers. This concern occurs below the 700 MW Vermont load level. However, 46 kV upgrades can postpone the need for a transformer solution. Ascutney breaker failure contingencies failed to converge. Such voltage collapse may extend beyond the local Ascutney 46 kV system as more remote transformers would try to support the load. The conceptual solution can be described as follows:

Ascutney solution:

Construct a breaker-and-a-half 115 kV substation at or near the Ascutney substation and install a 56 MVA transformer.

Estimated cost: \$20M to \$40M

Timing of deficiency: 2013 (1210 MW) assuming 46 kV capacitor banks are installed now and 46 kV lines are reconductored now. Otherwise the timing is now for the 115 kV substation upgrade and second transformer (700 MW).

Priority: 7 for station, 15 for transformer

Affected utilities: CVPS, Ludlow, GMP

The voltage collapse concern affects load served on the 46 kV system between Cold River, Windsor, and Bellows Falls. Utilities served from this system are CVPS, Ludlow, and GMP following relocation of the Bridge Street substation.

Lead DU: CVPS

CVPS has the highest amount of load affected

Install reactive compensation, likely two 25 MVAR capacitor banks

Estimated cost: \$2M to \$4M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 8

Affected utilities: All DUs

115 kV voltage levels affect imports into central and northern Vermont. Therefore all Utilities are affected by Ascutney voltage violations, except for utilities supplied from the Southern loop connected to Bennington and Brattleboro.

Lead DU: CVPS

CVPS has the highest amount of load affected

Deficiency #7:

Bennington breaker failure contingencies failed to converge. The conceptual solution can be described as follows:

Bennington solution:

Construct a breaker-and-a-half substation at or near the Bennington substation

Install reactive compensation, likely two 12.5 MVAR capacitor banks

Estimated cost: \$10M to \$20M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 14

Affected utilities: All Vermont DUs. NGRID is also affected by this deficiency.

The voltage collapse concern affects load served on the 46 kV system between Bennington and Newfane. GMP load will be served by a radial connection to the NGRID Harriman station with acceptable voltage. Ties to NGRID in MA and NY will be disconnected.

Lead DU: CVPS

CVPS is the only affected utility

Deficiency #8:

With all lines in, loss of a line reduced the Blissville 115 kV voltage below 0.95 pu. This deficiency is addressed by reactive compensation proposed at Blissville.

With a facility out of service, loss of another facility caused voltages to drop below 0.95 pu. The conceptual solution can be described as follows:

Voltage support solution (complementing capacitor banks at Blissville and Ascutney):

Install reactive compensation at Queen City, likely one 25 MVAR capacitor bank

Install reactive compensation at West Rutland, likely two 25 MVAR capacitor banks

Estimated cost: \$3M to \$6M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 8

Affected utilities: All Vermont DUs and NGRID

For Queen City, the low voltage concern affects load served from East Avenue, Gorge, Tafts Corner, Queen City, Shelburne, Charlotte, North Ferrisburg, Vergennes, New Haven, Middlebury, Florence, Blissville, North Rutland, Cold River, and New York. The utilities supplied at these locations are BED, GMP, VEC, CVPS, Vermont Marble, and National Grid NY.

For West Rutland, the low voltage concern affects load served from Shelburne, Charlotte, North Ferrisburg, Vergennes, New Haven, Middlebury, Florence, Blissville, North Rutland, Cold River, and New York. The utilities supplied at these locations are GMP, CVPS, Vermont Marble, and National Grid NY.

Lead DU: GMP for Queen City, CVPS for West Rutland

For Queen City, GMP is directly supplied from Queen City and has the highest amount of load affected near Queen City

For West Rutland, CVPS has the largest amount of load affected

Deficiency #9:

Based on operating experience, additional reactive compensation is needed for light and moderate load levels. At light to moderate load levels, voltage at the 345 kV stations in Vermont can exceed 1.05 pu if generators are out of service. Power factor surveys in the past two years have shown that the winter shoulder point was over the high power factor curve. This condition is expected to be aggravated when the Coolidge Connector is placed in service. The conceptual solution can be described as follows:

Voltage support solution:

Install reactive compensation at West Rutland 345 kV, likely one 40 MVAR shunt reactor

Install reactive compensation at Coolidge 345 kV, likely one 40 MVAR shunt reactor

Estimated cost: \$5M to \$10M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 8

Affected utilities: All Vermont DUs
All load contributes to high voltages

Lead DU: CVPS
CVPS has the largest amount of load affected

Deficiency #10:

Loss of a line reduced the voltage near St Johnsbury below 0.94 pu. This voltage concern also occurred for other outages. The planned solution can be described as follows:

St Johnsbury solution:

Efforts are underway to construct a four-breaker 115 kV ring substation at or near the Lyndonville substation with a 56 MVA transformer. 248 filing is expected in the next few months.

Install reactive compensation, likely two 12.5 MVAR capacitor banks

Estimated cost: \$22M

Timing of deficiency: 2009 (400 MW for transformer, and less than 1170 MW for cap banks)

Planned in service date: 2011

Priority: 1

Affected utilities: For transformer: CVPS and Lyndonville are the only utilities whose load is affected by loss of the transformer due to the radial nature of the system
For capacitor banks: the voltage collapse concern affects load served at St Johnsbury, Irasburg and Newport. Utilities supplied at these locations are CVPS, Lyndonville, and VEC

Lead DU: Lyndonville

Lyndonville is the utility that requested the reliability improvement

Deficiency #11:

The K-186 line (VY-Chestnut Hill 115 kV) overloaded for loss of an autotransformer, particularly with another facility out of service. The conceptual solution can be described as follows:

K-186 overload solution:

Rebuild the Vermont Yankee to Vernon Road Tap 115 kV line section

Estimated cost: \$5M to \$10M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 10

Affected utilities: All Vermont DUs. However, NGRID and NU loads are also the primary contributors to this deficiency.

This overload is caused mostly by regional transfers and New Hampshire load. A reduction of 50 MW in Vermont west of Ascutney does not reduce the flow on the line. Disconnecting the GMP load (about 9 MW) fed out of Bellows Falls reduced the overload by 0.6% at the 2009 load level. Comparatively, reducing the Vernon Road load by 9 MW reduced the line flow by 2.9%, which eliminated the overload at the 2009 load level. Therefore, the affected utilities are CVPS, GMP, and mostly NU and NGRID whose load affects the violation.

Lead DU: CVPS

CVPS has the highest amount of load affected

Deficiency #12:

With the F-206 line out of service, the Granite PARs could not be adjusted to reduce south to north flows. As a result, a number of lines overloaded. The conceptual solutions can be described as follows:

K-31 overload solution:

Rebuild the Coolidge to Ascutney 115 kV line

Estimated cost: \$25M to \$50M

Timing of deficiency: 2009 (less than 1170 MW)

Priority: 9

Affected utilities: All Vermont DUs. NGRID and NU.

This overload is caused mostly by regional transfers and New Hampshire load. A reduction of 50 MW in Vermont west of Ascutney does not reduce the flow on the line. Disconnecting the GMP load (about 9 MW) fed out of Bellows Falls eliminated the overload at the 2009 load level. Therefore, the affected utilities are GMP and those that are in the vicinity of the 115 kV line (CVPS and Ludlow), and mostly NU and NGRID whose load affects the violation. Ludlow and CVPS will also be affected during the rebuild of the line because the 46 kV line that connects to Ludlow and CVPS will be overloaded.

Lead DU: GMP

Of the Vermont utilities, only GMP load can affect this overload

Deficiency #13:

K-149 overload solution:

Rebuild the Ascutney to Ascutney Tap 115 kV line section

Estimated cost: \$5M to \$10M

Timing of deficiency: 2013 (1210 MW)

Priority: 12

Affected utilities: All Vermont DUs. However, NGRID and NU loads are also the primary contributors to this deficiency.

This overload is caused mostly by regional transfers and New Hampshire load. A reduction of 10 MW in Vermont west of Ascutney reduced the flow on the line by 0.5%. Disconnecting the GMP load (about 9 MW) fed out of Bellows Falls reduced the flow by 4.7%, which eliminated the overload at the 2013 load level. Therefore, the affected utilities are CVPS, GMP, and mostly NU and NGRID whose load affects the violation.

Lead DU: CVPS

Upgrade is in CVPS' service territory.

Deficiency #14:

With one autotransformer out of service, loss of another autotransformer overloaded the T-198 line. The conceptual solution can be described as follows:

T-198 overload solution:

Install a 345/115 kV autotransformer at Vernon

Estimated cost: \$15M to \$30M

Timing of deficiency: 2010 (1185 MW)

Priority: 11

Affected utilities: All Vermont DUs. However, NGRID and NU loads are also the primary contributors to this deficiency.

This overload is caused mostly by regional transfers and New Hampshire load. A reduction of 50 MW in Vermont west of Ascutney does not reduce the flow on the line. Disconnecting the GMP load (about 9 MW) fed out of Bellows Falls does not reduce the overload. Reducing the Vernon Road load by 11 MW reduced the overload by 2.2%. Therefore, the affected utilities are CVPS, and mostly NU and NGRID whose load affects the violation.

Lead DU: CVPS

Upgrade is in CVPS' service territory

Deficiency #15:

With a line out of service, a number of lines exceeded their normal rating prior to the next contingency, and were overloaded significantly for many contingencies, particularly for loss of each other.

K-32 overload solution:

Rebuild the Coolidge to Cold River 115 kV line

Estimated cost: \$35M to \$70M

Timing of deficiency: 2013 (1210 MW)

Priority: 13

Affected utilities: All Vermont DUs. NY load also affects this deficiency.

Moving the Newport Block load into Vermont advanced the timing of this violation. A reduction of 10 MW in the Burlington area reduced the flow on the line by 1.5% of the normal rating. A reduction of 10 MW at Ludlow does not reduce the flow on the line. However, Ludlow and CVPS will be affected during the rebuild of the line because the 46 kV line that connects to Ludlow and CVPS will be overloaded.

Lead DU: CVPS

CVPS has the highest amount of load affected

Deficiency #16:

Coolidge autotransformer overload solution:

Install a 345/115 kV autotransformer at Coolidge

Estimated cost: \$20M to \$40M

Timing of deficiency: 2016 (1245 MW)

Priority: 16

Affected utilities: All Vermont DUs. NY, NU and NGRID loads also affect this deficiency.

Moving the Newport Block load into Vermont advanced the timing of this violation. A reduction of 10 MW in the Burlington area or in NH reduced the flow on the transformer by 0.4%. A reduction of 10 MW at Ludlow reduced the flow on the transformer by 0.3%. All Utilities are affected by Ascutney voltage violations, except for utilities supplied from the Southern loop connected to Bennington and Brattleboro.

Lead DU: CVPS

CVPS has the highest amount of load affected

Deficiency #17:

There were loop flow concerns on the sub-transmission system. As the Vermont load level increases and as transmission line flows increase, the sub-transmission system is increasingly exposed to loop flow concerns, where the sub-transmission system becomes an alternate path for transmission scale flows when transmission lines open. For some of those outage events, sectionalization of the sub-transmission system may cause loss of load, particularly if automatic sectionalization schemes are utilized. Except in one case, loss of load was avoided in the analysis by carefully opening the sub-transmission system after the first contingency but before the next contingency. No solutions are proposed at this time because the system concerns were removed by opening sub-transmission lines. The opening of sub-transmission lines following a transmission contingency is somewhat risky because it is not always intuitive where sectionalization should occur.

Deficiency #18:

The sub-transmission system lacks voltage support in many areas. Below the 1170 MW load level (year 2009), voltages were below 0.9 pu for loss of a single element near Middlebury, Blissville, Hartford, Ascutney, Cold River, Rutland, St Albans, and East Fairfax.

At the 1275 MW load level (year 2018), voltages were below 0.95 pu with all lines in near Ascutney, Blissville, and St Johnsbury. Voltages were below 0.9 pu for loss of a sub-transmission line or with a sub-transmission breaker open near St Albans, Chelsea, Hartford, Ascutney, Rutland, Cold River, and Blissville. Voltages were below 0.9 pu for loss of a step-down transformer near St Albans, Chelsea, Hartford, Ascutney, Rutland, Cold River, Blissville, and Barre. Voltage collapse occurred for loss of a transformer. Voltages were below 0.9 pu for loss of a transmission line, with no other transmission element out of service, near St Albans, Chelsea, Hartford, Ascutney, Rutland, Cold River, Blissville, Barre, and St Johnsbury. Voltage collapse could occur near Chelsea. The solutions proposed for the transmission system postponed the need to address some of these voltage concerns. However, additional reactive compensation is recommended at the sub-transmission and distribution systems near the substations noted above. Existing and new capacitor banks need to be equipped with switching equipment to dispatch capacitor banks off when the load level is lower than peak. Recent ISO-NE power factor surveys showed that the Vermont power factor is higher than desired during shoulder load levels, particularly during the fall and winter seasons. Too many distribution and sub-transmission capacitor banks remain on line during shoulder load levels, while additional capacitor banks are needed for peak load levels.

Deficiency #19:

Below the 1170 MW load level (year 2009), loss of a single element caused overloads near Blissville, Hartford, St Albans, North Rutland, Cold River, Ascutney and Barre.

At the 1275 MW load level (year 2018), a line overloaded in the Montpelier area with all lines in. Overloads occurred for loss of a sub-transmission line or with a sub-transmission breaker open near St Albans, Rutland, and Montpelier. Overloads occurred for loss of a step-down transformer near St Albans, Hartford, Ascutney, Rutland, Blissville, and Montpelier. Overloads occurred for loss of a transmission line, with no other transmission element out of service, near St Albans, Ascutney, Cold River, Montpelier and Barre. The solutions proposed for the transmission system postponed the need to address some of these thermal concerns. Insufficient sub-transmission transfer capacity exists between transmission substations. Additional transformers were proposed to prevent the overloads between substations as adjacent transformers attempt to compensate for loss of transformer. If sub-transmission lines between substations cannot carry the post-contingency flows adjacent transformers cannot backup each other effectively. Overloads due to sub-transmission contingencies were unaffected by the proposed transmission upgrades.

Barre solution:

Construct a ring substation at or near the Barre substation and install a 75 MVA transformer

Estimated cost: \$10M to \$20M

Timing of deficiency: 2009, or 2018 if the 34.5 kV system is reinforced

Priority: 17

Affected utilities: GMP, WEC

The low voltage and overload concerns affect load served on the 34.5 kV system between Berlin, Marshfield, Websterville, and McIndoes Falls. Utilities served from this system are GMP and WEC.

Lead DU: GMP

GMP is directly supplied from Barre and has the highest amount of load affected

Deficiency #20:

There were no additional overloads on the Vermont system due to VY being removed from the system. However, overloads in southwestern NH were significantly higher. In addition, reactive margins were significantly reduced. High voltage is a present concern. The selection of a solution will need to involve not only VELCO, but also ISO-NE, NGRID, and NU. Severe overloads occurred on the 115 kV lines in Southwest NH. Voltage collapse occurred for certain Category C contingencies in New Hampshire and Massachusetts. Those thermal and voltage concerns affect the Vermont system.

Deficiency #21:

With the Highgate converter removed from the system, the performance of the system was very poor. The conceptual solution can be described as follows:

Solution to multiple overloads and voltage violations:

Construct a 230 kV line in parallel with the existing PV-20 line.

Estimated cost: \$200M to \$300M (Vermont portion)

Timing of deficiency: The timing depends on multiple factors, including the remaining life of existing facilities, recent operating events, ISO-NE interests, as well as regional coordinated planning between New England and New York. For example, if Highgate remains available for dispatch even if the contracts are not renewed, the year of need would be approximately 2021. If Highgate is unavailable, the timing is 2016. However, if the condition of the underwater cables is such that they need to be replaced, the upgrade may be needed sooner.

Priority: Unknown. Depends on the factors noted in the above paragraph.

Affected utilities: All Vermont DUs

The overload and voltage concerns are systemwide, except for the southern Loop system connected to Bennington and Brattleboro.

Lead DU: GMP

GMP has the highest amount of load in the area where this upgrade would be constructed.

Deficiency #22:

With the above reinforcements in service, except the 230 kV upgrade, there were additional overloads on the transmission system between years 2018 and 2023, and there were indications that voltage performance was becoming a concern. The performance of the system was poor. With the Highgate converter out of service, several lines overloaded and the loading on some lines were close to 100% of their rating. Voltages fell below 0.95 pu. A number of contingencies failed to converge. With a line out of service, a number of lines reached their normal rating prior to the next contingency. The conceptual solution is the same as the one described for deficiency #21.

Deficiency#23:

At the 2028 load level, numerous 46 kV buses (30+) had sub 0.95 pu voltages even with all facilities in-service. These buses were located predominantly in central Vermont beneath the 115 kV network between Chelsea, Hartford, Ascutney, Bellows Falls and Cold River, with a small number of stations in the 46 kV network beneath the Highgate and Newport substations. With all facilities initially in service, loss a line failed to converge. Loss of some facilities reduced voltages below 0.9 pu. Loss of other facilities reduced voltages below 0.95 pu. With a facility out of service, the performance of the system was significantly worse. Many 115 kV lines overloaded from the Rutland area to the north and from the Granite area to the west. The conceptual solution is the same as the one described for deficiency #21.