

Six Steps to Improve Distribution Voltage Quality

Hydro-Québec has optimized its distribution-planning process by taking an integrated approach to prioritize the corrective measures necessary to control undervoltage, overload and losses.

By Jean-Pierre Laflamme and Georges Simard, Hydro-Québec

In recent years, many engineers have increased the use of sophisticated tools and software to improve the distribution-planning process. Network data and ancillary information has brought new emphasis to the modern study of the distribution system. While the new tools are powerful and can handle significant amounts of data, it became clear that the planning process needed some revamping because planning practices differed from region to region and younger engineers lacked the experience to interpret the software results.

As a result, a general review of the planning standards was conducted and a practical step-by-step planning approach was developed. The following proposed corrective measures are listed in order of priority of application and cover most situations:

1. Load transfer
2. Load unbalance corrections
3. Shunt capacitor installation
4. Line conductor replacement
5. Rebuilding a single- or double-phase section of the feeder into a three-phase circuit
6. Installation or relocation of voltage regulators.

This order should not be considered absolute in all cases. It is also possible to apply more than one of these measures on the same feeder to correct different problems or to obtain more loss reduction.

The optimization approach is based on minimizing distribution losses. Each

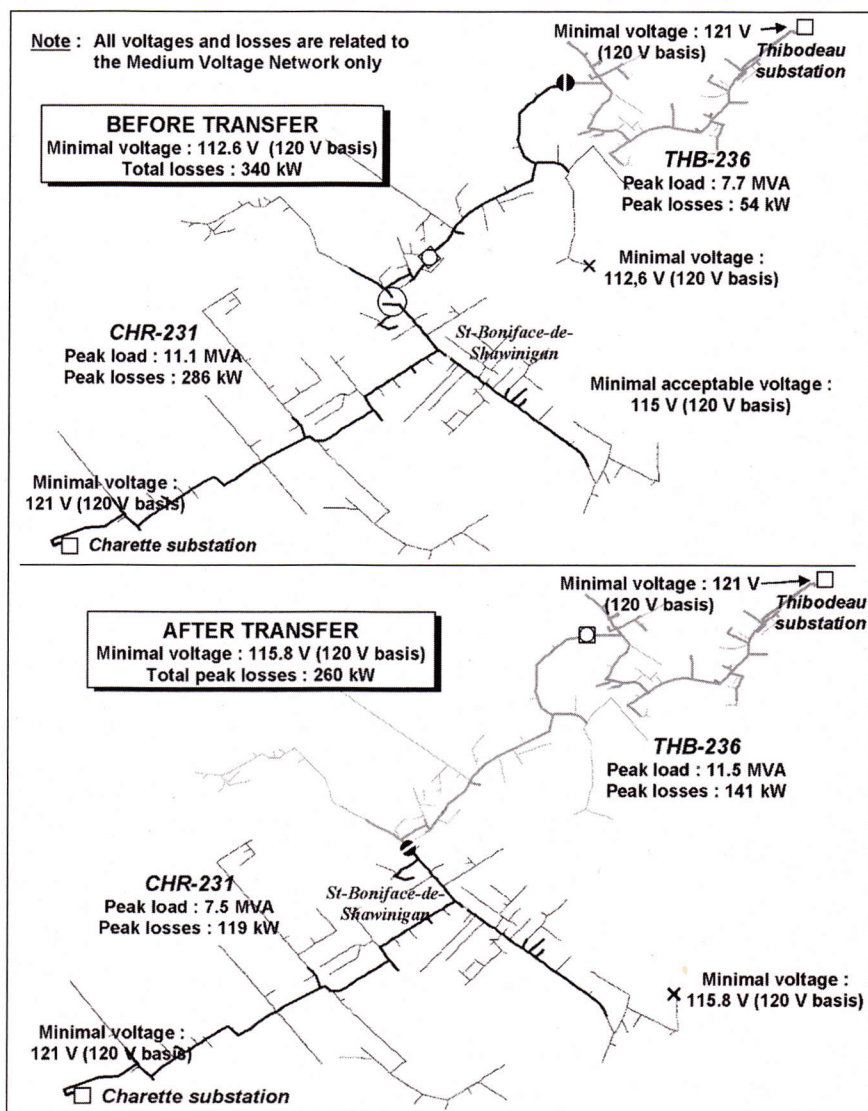


Fig. 1. Example of a load transfer.

measure described can return significant loss reductions with the exception of relocating voltage regulators. By using a network software simulator, losses can be calculated rapidly. By trial and error, it is possible to quickly find the best solution by comparing simulated scenarios against actual situations. Distribution-planning software often provides optimization functions to assist in this task.

For measures such as adding or replacing conductor, the optimization approach is based on the minimum cost of the solution, taking into account all the costs and savings, including loss reduction. The following describes the listed corrective measures.

Load Transfer

The first thing to check is load transfer where overload or undervoltage exists, or where the goal is to reduce losses. Load transfer can provide a fast long-term and generally low-cost solution to overload and undervoltage problems. Typically, load transfer also returns significant loss reductions.

In optimizing load transfer, consider the following account constraints:

- Capacity of the receiving feeder or substation
- Localization of the load breaker and switch
- Limitations and risks associated with the network protection
- Effects on the losses in the substation and on high-voltage lines.

In some cases, load transfer may cause the displacement of a recloser or a load break switch. Often, the protection of the corresponding feeder should be revised or adapted to the new network configuration. In other cases, it may be necessary to add or replace some sections of conductor on the receiving feeder. In this situation, the relocation of equipment and the saved losses should be considered in a cost-benefit analysis where evaluating the profitability of the transfer.

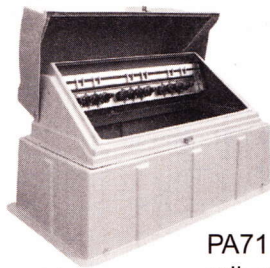
Remember that load transfer can also affect other measures such as load unbalance correction or adding shunt capacitors.

Load Unbalance Correction

On a four-wire wye-feeder connection, unequal currents cause a zero-sequence current, which returns to the source via both the neutral line and by the earth. This current rise may cause some problems when it reaches a

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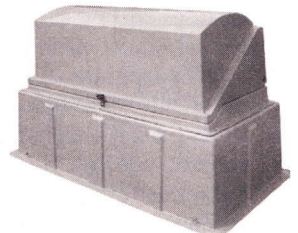
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Note : All voltages and losses are related to the Medium Voltage Network only

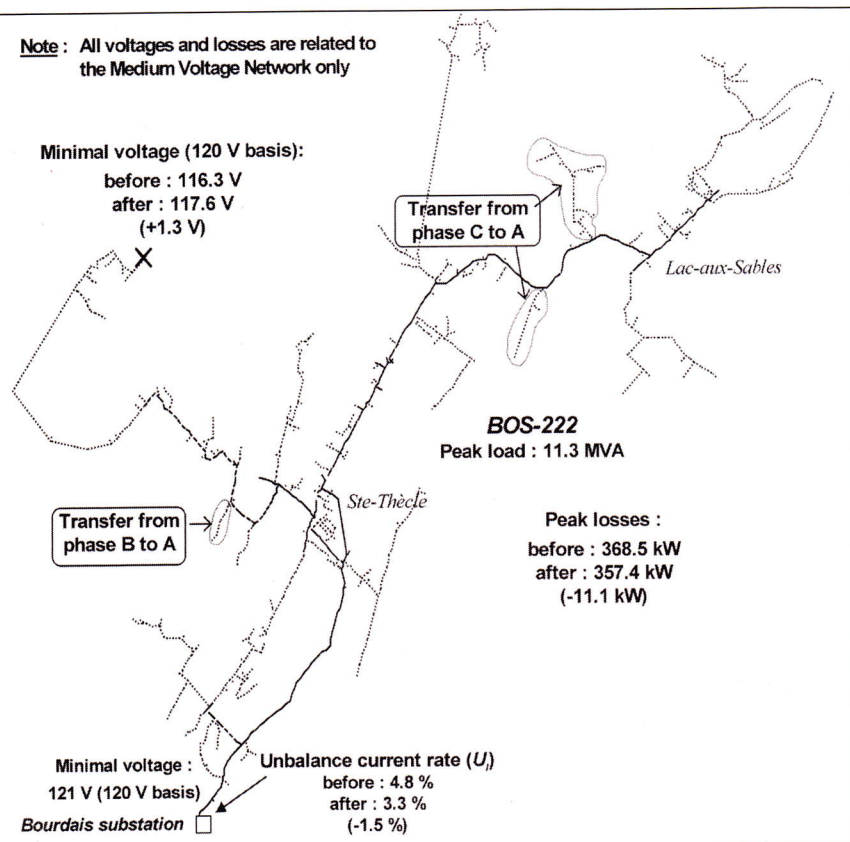


Fig. 2. Example of a load unbalance correction.

certain level, including:

- Increase in voltage drop on heavier loaded phases
- In certain cases, overload of conductors or equipment on heavier loaded phases
- Increase in losses (unbalance related losses increase proportionally to the squared zero-sequence current)
- Increase in problems related to high-level ground current (local increase of ground voltage, stray voltage, phone interference)
- Increase in negative-sequence voltage (beyond a certain level, may cause overheating of three-phase motors).

For these reasons, and because it can be done at low cost, correcting the load unbalance should be considered early in the optimization approach. The importance of this correction increases with the amplitude of the unbalance.

Rebalancing the loads requires the transfer from phases with the highest loads toward those with lesser loads. Losses are minimal when currents are equal on each phase. Performing these transfers maximize loss reduction and, in most cases, voltage improvement. Optimization functions

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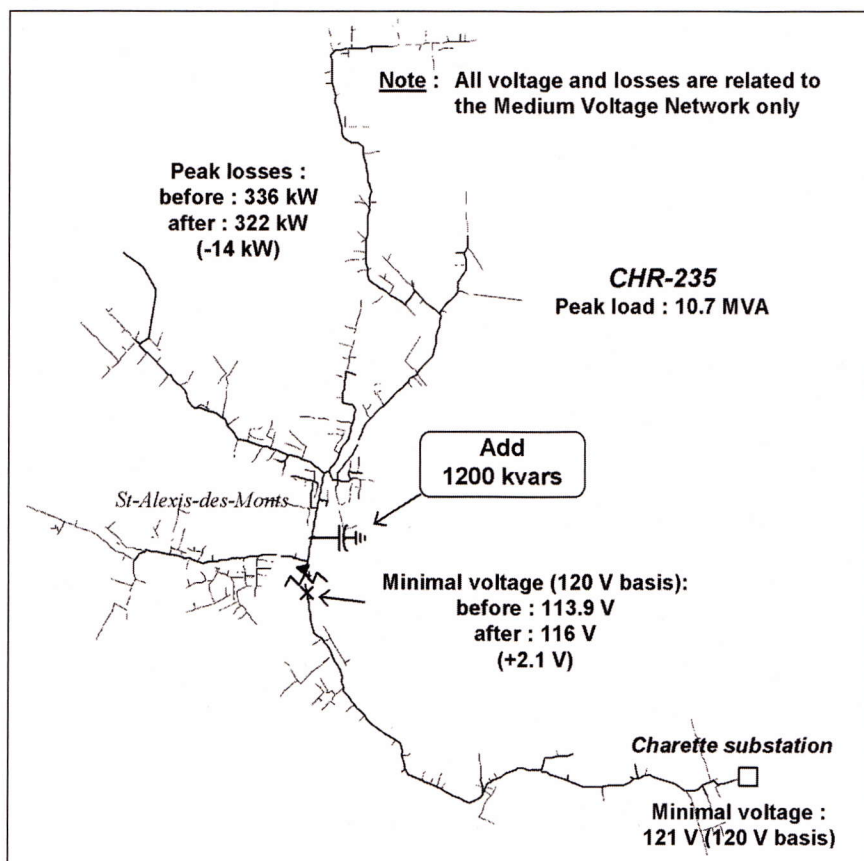


Fig. 3. Example of a capacitor installation.

are available on most network simulators to ease the task, and the best option can be determined by trial and error.

Typically, a voltage gain of about 1 V to 2 V on a 120-V basis, and a load reduction of about 10% on the most heavily loaded phase, can be expected. On a 25-kV feeder, loss reductions of 5 to 10 kW are possible.

Feeder Reactive Compensation

The two main advantages to applying reactive compensation are increased line voltage and reduced losses. Typically, on a 25-kV semi-urban or rural feeder, this measure may give a voltage increase from 1 V to 3 V and a loss reduction of 5 to 15 kW.

To apply reactive compensation, first determine the quantity of capacitors needed. When reactive compensation is required, the typical choice consists of installing one fixed capacitor bank per feeder. Then, apply the two-thirds rule to obtain the maximal loss reduction by installing kVAR capacitors equal to two-thirds of the total reactive load at two-thirds of the feeder length. This allows a theoretical reduction of eight-ninths of the losses related to reactive load flow on the feeder.

If we strictly apply the two-thirds

rule to the peak-load period, too many capacitors will be installed for the off-peak period. We must make a compromise between the peak value and the average value of the reactive load when selecting the number of capacitors. By experience, the average value of the reactive load is approximately 75% of its peak value. So an adequate quantity of capacitors is approximately 88% of the quantity determined by the two-thirds rule. That represents approximately 60% of the peak reactive load of the feeder.

The same consideration applies when selecting the location of the capacitor bank. If the reactive load is constant, the best way to obtain maximal reduction of the losses will be to install the capacitor at a place where the reactive load is half of its nominal kVARs.

In practice, if this rule is strictly applied to the peak-load period, the capacitor bank will be located too far down the feeder when taking into account the off-peak periods. That may cause overvoltage problems at the end of the feeder during the low-load periods. Thus, to achieve the higher loss saving, the capacitor must be

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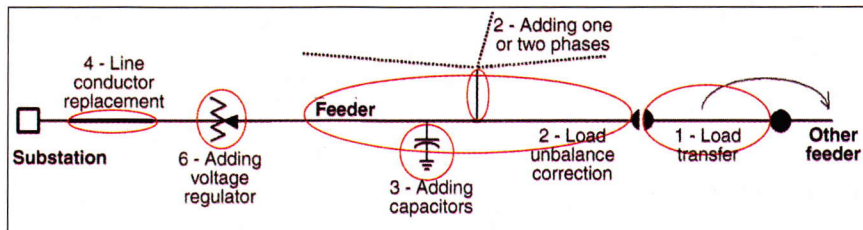


Fig. 4. Typical sequencing of the corrective measures.

located at a place where the reactive load at the peak period is slightly higher than half. At Hydro-Québec, that represents about 60% of the peak reactance required. The last step consists in checking the results with a load flow simulation. If this capacitor bank size and location cause overvoltage during the low-load period, generally a location nearer to the source would be found to slightly reduce the voltage gain.

Figure 4 is an example of capacitor installation on a Hydro-Québec 25-kV feeder.

Line Conductor Replacement

Conductor overloads appear when the current in a conductor exceeds the conductor's allowable limit. In the case of three-phase lines, this may occur on only one or two phases, depending on the magnitude of the load unbalances between phases. This situation may lead to excessive overheating or damage to the conductors when backing up other feeders or during cold-load pickup. This is especially important when these overloads occur during the summer when the warmer ambient air makes it more difficult to discharge excess heat. This situation usually requires that corrective measures be implemented.

In some cases, the increase in voltage resulting from the upgrading of highly loaded conductors may allow substantial costs to be avoided in correcting voltage situations further down the line (such as by adding a regulator). These costs, combined with costs saved through loss reduction, are such that the cost of replacing a highly loaded conductor may prove to be the most economical approach. This solution also contributes to overall improvement of the distribution system.

Since this corrective measure may be expensive, it is necessary to consider it after the measures previously mentioned.

Adding One or Two Phases

In the case of single-phase or two-phase lines (since currents cannot be

balanced between three phases), a neutral current occurs that may reach the same value of the phase current. This neutral current can become particularly high on single-phase and two-phase lines with high loads.

The effects of single-phase and two-phase lines with high neutral currents are often difficult to determine. However, some problems may occur, such as:

- Localized increase in ground voltage resulting from a greater flow of current in the ground
- Interference with communication circuits
- Difficulty in coordinating the protection systems of these lines
- Increased losses
- Increased voltage drops
- Localized increase in load unbalances.

The first two problems described may be aggravated when a more sizable portion of the current returns via the ground as a result of neutral conductor failure, or even high-ground conductivity. Note that these problems also may apply to highly unbalanced three-phase lines.

Installation of Voltage Regulators

In some cases, the only viable solution is to add voltage regulators because the other solutions are too costly. However, this solution is not favored due to the increased losses caused by this equipment. Voltage regulators also require more maintenance and can be relatively expensive, especially for three-phase and high-load applications. Nevertheless, the use of regulators has some advantages. For instance, they usually provide a greater gain in voltage than the other solutions, and they allow undervoltage problems to be corrected over an extended period in the future.

Voltage regulators are usually considered a last resort and are primarily only used when there are significant voltage drops caused by long lines or smaller-sized conductors with a relatively small load.

Typical Effect and Cost of the Corrective Measures

Measure	Effect on the Reduction of the			Cost of the measure
	Load	Voltage drop	Losses	
Load transfer	medium	medium to high	negligible to low	negligible to low
Unbalance load correction	low to medium	low to medium	low to medium	negligible
Adding capacitors	negligible	medium	low to medium	low
Line conductor	high	low	high	high
Adding one to two phases	high	low	medium to high	medium to high
Adding voltage regulator	nil	high	nil	medium to high
Considered scale		(120-V basis)		(2001 Canadian dollars)
Negligible	< 2%	—	—	< \$2000
Low	2 @ 10%	< 1 V	< 5 kW	2 @ \$15,000
Medium	10% @ 30%	1 @ 3V	5 @ 15kW	15 @ \$30,000
High	> 30%	> 3 V	> 15 kW	> \$30,000

Note: The considered scale for the voltage drop and the losses are related to a 25-kV network.

The table gives the influence of the previous corrective measures on overload, undervoltage and losses typical of most situations.

Figure 4 gives a visual representation of the sequence of corrective measures typical for most situations. It is

possible to follow a different sequence, depending on the situation.

This article proposes alternatives to optimize a medium-voltage system. The approach suggests a sequence of corrective measures, starting with the less expensive and moving to the more

costly solutions. Losses on the medium-voltage network serve as a guide to optimize corrective measures because, in general, a system with the lowest losses has the best performance. ▀

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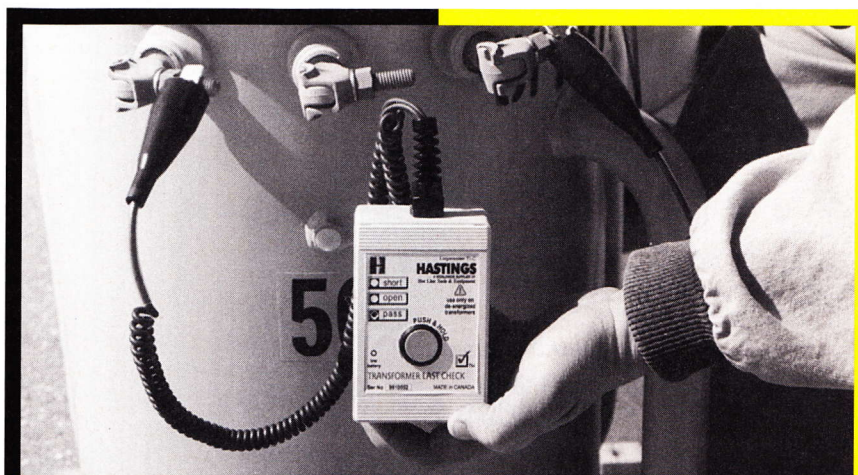
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