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EVALUATION OF THE CONDITION AND THE PERFORMANCE OF UNDERGROUND FLUID FILLED HV LINKS AT HYDRO-QUÉBEC

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ABSTRACT

As with most major utilities around the world, many transmission underground links in Hydro-Québec are approaching their expected end of life. With current budget restrictions, it is imperative that asset managers should be able to assess the actual condition and performance of each link, and prioritize the necessary actions.

*The **Gl**obal **P**erformance **I**ndex (**GPI**) developed at Hydro Quebec has proven to be an efficient tool for evaluating the condition and performance of underground links with fluid filled cables installed in a duct and manhole system. It provides asset managers with the necessary data to identify and prioritize retrofitting and replacement projects.*

KEYWORDS

Fluid filled cables; Condition assessment; Performance evaluation; Asset management. Ducts and manholes

INTRODUCTION

Hydro-Québec –TransÉnergie has over one hundred and eighty (180) High Voltage Underground Links, mainly rated 120 kV and 315 kV. The network also includes one link operated at 450 KV DC. These links are mainly installed in major urban areas but a number of them are also installed in hydroelectric generating stations.

More than seventy (70) of these links, representing 60% of the network in length, were installed in the sixties and the seventies, using Fluid Filled Cables installed in duct banks and manholes. Since 1989, all new links are built using XLPE insulated cables and pre moulded accessories.

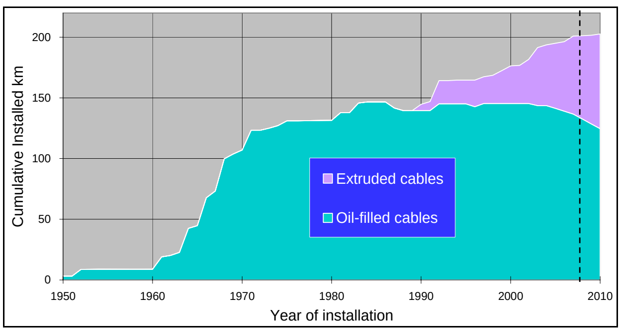

Figure1. Cumulative installed HV underground links at Hydro-Québec (km)

As with most major utilities around the world, the older links have been in service for more than forty (40) years and are approaching their expected end of life. The replacement of these links represents a major investment. With current budget restrictions, it is imperative that asset managers should be able to assess the actual condition and performance of each link, and prioritize the replacement projects in their annual action plan.

ASSET MANAGEMENT DECISION MAKING PROCESS

The asset management process can be described by the following four steps, as illustrated in figure 2.

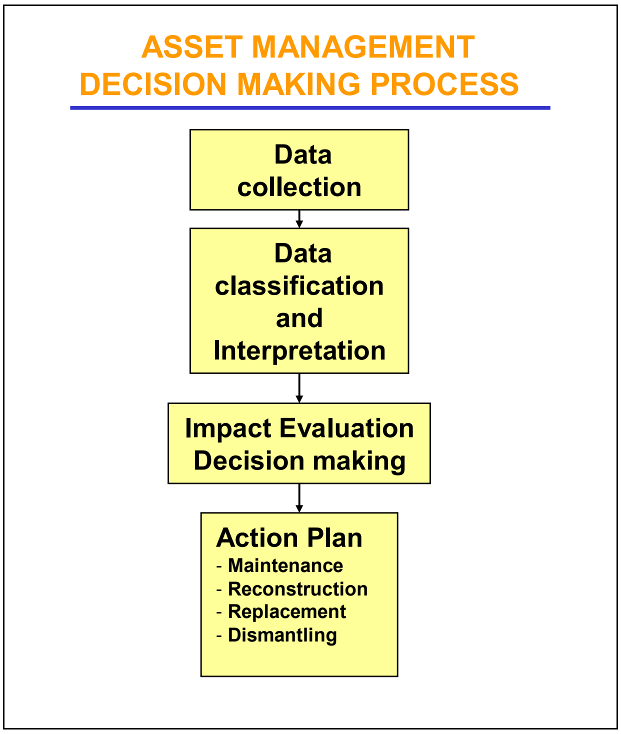

Figure 2. Asset management simplified process

- Step 1. Data collection. This includes all existing data, available from records, and operational data that are collected mainly by maintenance crews. In order to collect useful data, one must have a very good knowledge of the links to be evaluated.
- Step 2. Data classification and interpretation. This step consists of the organisation of data to filter out the most useful information from all the available data.
- Step 3. Impact evaluation and decision making. The evaluation of a link should take into account not only the available data, but also other factors like the strategic importance of a link. Each decision should be made taking into account its global impact on the system.
- Step 4. Action plan. All the decisions taken in step 3 will result in a global action plan; that will help achieve the expected goals of reliability of the network.

In the following sections, the application of those four steps is detailed in the case of underground high voltage fluid filled links at Hydro-Québec.

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COMPONENTS OF HYDRO-QUEBEC UNDERGROUND TRANSMISSION NETWORK

Each underground fluid-filled link can be subdivided in four main systems, namely electrical system, civil infrastructure, hydraulic system and sheath bonding and protection system. Good operation (performance) of a link depends on the satisfactory behaviour of all four systems. The global performance analysis of a link has therefore to consider every important component of these systems, in order to give the most significant results.

For each component, it is useful to analyse the deterioration process due to aging, as well as failure statistics and maintenance records, in order to identify proper indicators for the condition and/or performance of the component.

Electrical system

The electrical system consists of high voltage cables, joints and terminations. The most evident indicator of a problem in the electrical system is certainly an internal failure that can occur in any part of the system; cable or accessories.

Cables

Many types of cables are installed in our network. The main distinction is the type of insulation. As the extruded cables are more recent, only the oil-filled cables are considered in the **GPI** evaluation process.

Oil-filled cables installed in the system may have different type of metallic sheaths: pure Lead, Lead-alloys and Aluminium. For Lead-sheathed cables, different types of reinforcements have been used, leading to diverse limits of the maximum allowed internal operating pressure.

The degradation mechanisms of oil-filled cables are well documented: paper and oil degradation, evolution of gases in oil, partial discharge, oil leakage, and sheath corrosion (particularly for aluminium sheaths).

A specific problem is encountered with the duct and manhole system, namely cable movement in the manholes. Excessive bending of cables in the manholes often leads to the development of cracks in the lead sheath and consequently undesirable oil leakage.

Joints

More than 1000 joints are in service at present, ranging from the simple straight-through joints to more complex designs, such as sectionalized joints, oil-feeding joints and oil-stop joints.

The most common problem encountered with joints in the network is oil leakage at the wipes. This could be attributed to the thermo mechanical movements of the joints in the manholes, as the joints are free to move in our system.

In case of sectionalized joints, a fault may be caused by a flashover across the casing insulator, due to excessive transient voltages.

In oil-stop joints, leakage can occur between the two sides of the joint, eventually leading to a hydraulic fault.

Figure 3. 120kV sectionalized joints in a manhole

Terminations

Terminations in the network are of the outdoor type with porcelain insulator, oil-immersed type in transformers and gas-immersed type in case of SF6 substations.

Terminations are subject to oil leaks due to gasket degradation, breakage of the supporting insulators, and flashover caused by pollution accumulation on the insulators.

Civil infrastructure

The civil infrastructure consists of the ducts and manholes, foundations, and the supporting structures for terminations.

Duct banks

In urban areas, the cables are mostly installed in duct banks of 4 or 8 conduits. In older circuits, the conduits were made of asphalt saturated cardboard. These were eventually replaced by PVC conduits and more recently by **FRE** (**F**ibreglass **R**einforced **E**poxy) conduits, ensuring much lower friction during cable pulling as well as high durability.

Most of the urban network was originally installed in a double circuit in the same duct bank. Although this arrangement reduced the initial construction cost, it decreased the line availability for maintenance and created the risk of double-circuit simultaneous damage in case of dig-ins.

Concrete

Concrete is used to build the duct-bank covering the conduits, mainly for mechanical protection. It also provides a good thermal environment. Concrete is not reinforced except in special cases such as crossing under a railway,

A very common problem with older duct banks is a lack of concrete around the bottom layer of conduits. As the older conduits were soft, mechanical vibration of concrete was not allowed during construction; to avoid any damage to the fragile conduits. This is confirmed as we commonly find conduits completely exposed; lacking the expected mechanical protection during interventions made near an existing older duct bank.

Manholes
There are over 380 manholes in the high voltage underground network. They have the following dimensions: 5,7 m in length x 1,6 m in width x 2,1 m in height. In the double circuit configuration, joints for both circuits are installed on opposite walls of a single manhole. However, this resulted in very low opportunity for maintenance as workers are not allowed to enter manholes having energized cables, for safety reasons.

In older manholes, cracks could develop in the shorter walls or in the floor, as the old design did not allow for reinforcement in those elements. This resulted in cave-ins of manholes, particularly in the case of nearby excavations.

Corrosion of the metallic elements in the manholes is also frequently observed, for example on cable and joints supports or on the grounding copper wires.

Termination supporting structure
The galvanised steel structures supporting the terminations represent the main civil infrastructure within the substations. As with all other metallic components, these structures are subjected to corrosion.

Over the years, different models of cable clamps have been used, ranging from treated wooden blocks to metallic clamps. These elements are also subjected to degradation (rotting or corrosion).

Hydraulic system

The hydraulic system main purpose is to maintain a positive oil pressure in the cable system, at all times, to preserve its electrical insulating properties.

Each link has a dedicated oil feeding system. The system would meet all oil demands under normal operating conditions. Most links also have backup hydraulic reserve, which is either dedicated or shared with other nearby links.

The hydraulic system is composed of the oil, oil tanks, piping and other components such as valves, gauges, pressure switches and oil line insulators.

Oil
The best known indicator related to oil quality is the result of dissolved gas analysis carried out on samples.

Oil feeding tanks
There are more than 600 oil tanks on the network. Fifteen (15) different models are used, depending on the required oil capacity and pressure range of the link.

Oil tanks suffer mostly from corrosion of the outer shell leading to oil leaks. Corrosion is usually more severe on tanks located in underground vaults where they are exposed to severe conditions, such as high humidity, and corrosive polluted water.

Oil piping and accessories
Oil piping is generally made of copper. Stainless steel has been used on the more recent systems.

Older systems are fitted with pressure gauges with contacts for alarm relaying. In some cases, the pressures gauges have been replaced by pressures switches and transducers, connected to an electronic monitoring system called **PASCAB**. The new monitoring system greatly increased the reliability and performance of many links by permitting earlier detection of abnormal conditions.

Piping and accessories are also subjected to corrosion and oil leaks.

Figure 4. Automated oil pressure monitoring system.

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Sheath bonding and protection system

Cable sheaths of all our underground links are transposed and well protected with SVL's at the appropriate locations.

Figure 5 shows an example of cross-bonding in a manhole, using submersible SVL's at the cross-bonding point for sheath protection.

Figure 5. Cross bonding system in a manhole.

Cable jackets including the outer covering at joints as well as the SVL's are periodically tested to ensure their integrity.

Damage can occur on some SVL's due to water ingress or high voltage transients. Water ingress in joint coverings is sometimes observed, usually combined with oil leakage at the joint.

SELECTION OF INDICATORS

The above four systems were analyzed in order to determine their importance and their impact on the condition and performance of a given link.

Many possible indicators were identified, covering all aspects of the four systems. Finally, only nine (9) indicators were selected as most pertinent. Each indicator is a well defined and measurable quantity, thus ensuring repeatable results and an objective evaluation of each link.

The selected indicators are separated in two categories; namely **Cumulative indicators** and **Operation based indicators**.

Different weight factors were assigned to these indicators to reflect their relative impact on the global evaluation of a given link.

Cumulative indicators

These indicators require good knowledge of the link since its original inception; design and construction.

1. Age (0 to 10 points)
The first indicator selected is the age of the link. In order to better discriminate between older links, a non linear scale was adopted for this indicator: the first 40 years of a link have a weight of 5 points. The next 10 years (between 40 and 50 years) have an equal weight of 5 points.

2. Internal failures (0 to 10 points)
This indicator takes into account internal failures requiring replacement of cables and/or accessories. Faults due to external aggressions are not considered in this indicator.

3. Automated oil pressure monitoring system; PASCAB (0 to 3 points)
This indicator is related to the presence or absence of the automated oil pressure monitoring system, PASCAB. Long lines and those with multiple hydraulic sections, not equipped with this monitoring system, can be more at risk.

4. High risk technology (0 to 3 points)
This indicator was selected to identify links with specific cable technology or an unusual cable installation technique that are related to many problems in the network. Some examples are links that are equipped with oil tanks at one end only and links using cables installed in a vertical shaft.

Operation based indicators

The second category of indicators summarizes the performance of the link over the **last five years**. Data for these indicators are mainly collected by maintenance personnel during periodic inspection.

5. Dissolved gas analysis (0 to 10 points)
Both the evolution of gas levels as well as the tendencies (stable evolution or accelerating evolution of gas levels) are taken into consideration.

6. Oil leaks (0 to 10 points)
Oil leaks in any component of the links are considered. The maximum score for this indicator corresponds to oil leaks in the system that can not be located and would require regular addition of oil in the system.

7. Repairs (0 to 8 points)
This indicator summarizes the corrective maintenance that was required on a specific link over the last five years. Each kind of repair is given a specific weight, according to its impact on the operation and reliability of the link.

Minor repairs such as replacement of corroded cables clamps would have a low weight of 1 point. However, major repairs like reconstruction of a complete manhole would have a maximum weight of 8 points. Cable repairs due to dig-ins would also be considered in this indicator, with the same maximum weight of 8 points.

8. Sheath protection system faults (0 to 8 points)
Data for this indicator is collected during periodical testing of the cable sheath and protection system.

Sometimes, sheath defects can be identified but not repaired. These can eventually lead to cable failure over time. Since aluminium sheaths are subject to faster rate of corrosion than lead ones, sheath faults on those systems are deemed more serious (more points are allowed).

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9. Bending radius and cable movement in manholes (0 to 6 points)

This indicator is based on the observation of thermo-mechanical movement of cables in manholes. Excessive bending of cables in manhole can lead to oil leaks and eventually insulation failure. In some cases, excessive bending is observed, but the situation has stabilised. Those cases are considered less severe than those where the cable bending radius continues to deteriorate .

Figure 6: Measuring bending radius during inspection

GLOBAL PERFORMANCE INDEX (GPI)

The rigorous application of the nine point evaluation procedure covering the history of a given link and its recent performance in the network yields a "**G**lobal **P**erformance **I**ndex"; **GPI**. The value of the **GPI** would vary from 0; for new links, to the very serious and unacceptable level of 68.

As illustrated in figure 7, the results of **GPI** are divided in three zones to better prioritize the required actions:

- Orange zone: **GPI ≥ 40** points. Immediate action is required on the link. Refurbishment, reconstruction or replacement has to be considered.
- Yellow zone: **25 points < GPI ≤ 40 points**. Links should be followed closely. A thorough investigation should be planned in the following year to confirm the condition of the link. The result of the investigation would lead to the precise action plan for that link.
- Green zone: **GPI ≤ 25 points**. No special action is required. Regular maintenance should be continued.

The last two columns in the table are an additional tool to better interpret the **GPI** results. The first one identifies the number of indicators that have been measured: a low number of measured indicators leads to an insufficient knowledge of the actual condition of a link. The last column identifies the date of the last update to the **GPI** for each link. Older results could mean that the actual condition of a link may have changed since its last evaluation.

		Cotes attribuées aux différents indicateurs											
CIRCUITS	Année de mise en serv.	Âge	Claquage interne	PASCAB	Technologies à risque élevé	Fuites d'huile	Gaz dissous	Réparations & anomalies	Défauts de gaine	Rayons de courbure & migration de câbles	INDICE GLOBAL	Nb d'indica-teurs définis	Date de la dernière modif.
1281	1964	6	6	3	3	7	0	8	6	2	41	9/9	2006-05-03
1250	1968	5	0	0	3	7	6	8	6	2	37	9/9	2006-07-06
1282	1965	6	0	3	3	7	0	2	6	2	29	9/9	2006-06-07
1215	1971	5	0	0	n.d.	7	0	8	6	2	28	8/9	30-03-06
1469	1983	2	0	0	3	7	0	8	n.d.	6	26	8/9	30-03-06
1230	1971	5	0	0	3	7	0	8	n.d.	2	25	8/9	2006-12-06
1297	1970	5	0	2	n.d.	7	0	2	6	2	24	8/9	2006-04-06
1280	1961	7	0	2	2	3	0	8	n.d.	2	24	8/9	2006-12-06
1212	1970	5	6	0	2	3	3	2	n.d.	2	23	8/9	2006-07-06
1299	1968	5	0	0	3	3	6	3	n.d.	2	22	8/9	30-03-06
1295	1966	6	0	3	3	0	6	2	n.d.	n.d.	20	7/9	2006-07-06
1296	1966	6	0	3	3	3	3	2	n.d.	0	20	8/9	2006-07-06
1247	1971	5	0	0	3	7	0	2	n.d.	2	19	8/9	2006-12-06
3043	1981	3	4	0	2	0	6	0	n.d.	n.d.	15	7/9	2006-07-06
1298	1968	5	0	0	3	3	0	0	n.d.	2	13	8/9	30-03-06
1232	1974	4	0	0	2	3	0	n.d.	n.d.	2	11	7/9	2006-12-06
3042	1981	3	0	0	2	0	0	0	n.d.	n.d.	5	7/9	2006-07-06
1468	1990	1	0	n.d.	n.d.	n.d.	n.d.	0	n.d.	0	1	4/9	2006-06-04

Figure 7: Global Performance Index Table, in 2006

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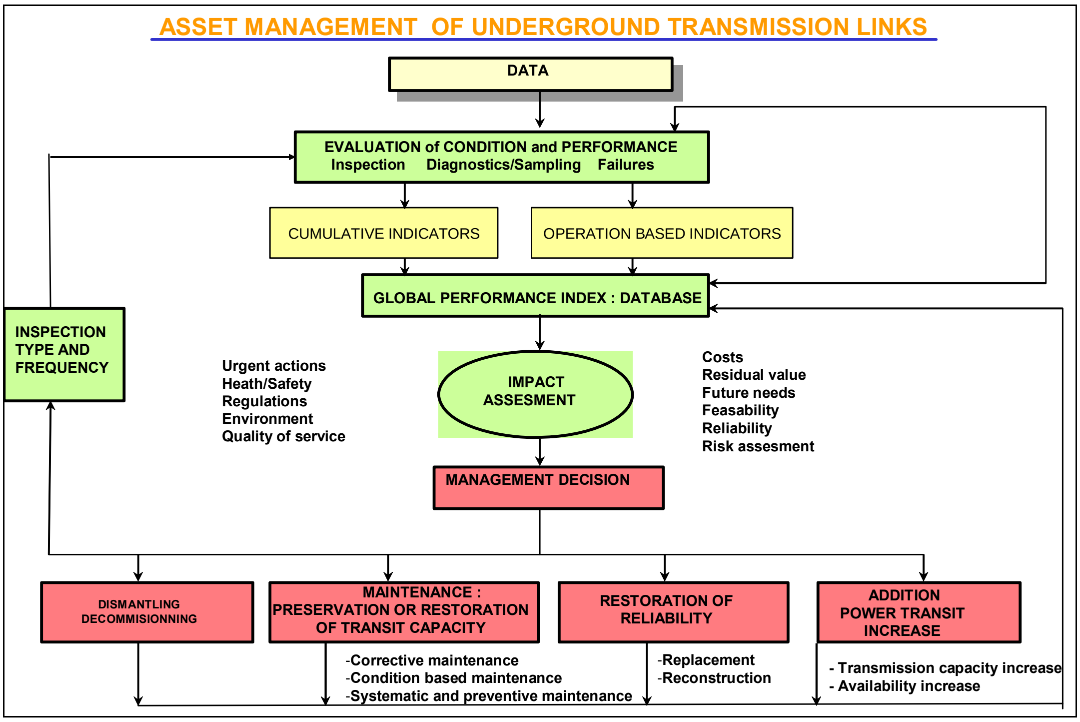

Figure 8: Asset management decision process for HV underground links

PREPARING THE RECOMMENDATION

The use of **GPI** clearly identifies the links that have to be acted upon. However, selecting the appropriate action for each link requires a much more global approach, taking into account the evolution of the whole network. It is imperative to take the following points into consideration when building the case and preparing the recommendation.

- The required reliability level and the importance of a given link depend on its location as well as on the architecture of the network.
- It is of utmost importance to verify the required link future capacity. In other words, it is simple to replace the existing link by an "equivalent" one without considering future needs. This may be the wrong solution. A reconfiguration of the network should also be considered and studied at this stage.
- Apart from the technical aspects, the residual (book) value of the link can play a major role in the decision whether to retrofit or to replace a given link. Some regulatory organisations would require that this value be added to the total cost of the replacement project.

All local and national regulations such as the need for public hearing, required permits as well as those related to public health and safety should be respected.

A well documented evaluation taking into account the above aspects is usually needed in order to justify the required budgets, and gain acceptance from regulating agencies.

ACTION PLAN BASED ON GPI

In 2006, the GPI identified one link in the orange zone and four links in the yellow zone. Strategic evaluation of the five links has lead to diverse solutions:

- The single link (No.1281) in the orange zone will be replaced in 2008.
- One link (No. 1215) will be replaced in 2007.
- One link (No. 1282) which was in the same duct bank as a link scheduled to be replaced (No. 1281) is deemed less urgent.
- The other two links (No. 1250 and No. 1469) share the same duct bank. A thorough investigation will be required to determine the first to be replaced as network operators would not allow for both circuits to be simultaneously out of service.

CONCLUSION

The **GPI** developed at Hydro Quebec has proven to be an efficient tool in evaluating the condition and performance of underground links with fluid filled cables installed in a duct and manhole system. It provides asset managers with the necessary data to take important decisions concerning link replacement.

Similar indices developed by other utilities are equally efficient. They are well adapted to analyse their specific underground network. This approach could also be adapted to other utility assets.

GLOSSARY

GPI: Global performance index
FRE: Fibreglass reinforced Epoxy
SVL: Sheath Voltage Limiters