Hidden assets

A new range of submersible solid insulation distribution transformers

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People resist the idea of distribution transformers being sited in or close to residential areas for a variety of reasons: They consider them unsightly and they see a possibility of soil or groundwater contamination, even an explosion, in the event of serious failure. Putting the same transformers underground is only a partial answer. Also, it is costly and can harbor new risks.

New submersible solid insulation distribution transformers rated from 25 to 167 kVA, developed jointly by ABB and Canadian utility Hydro-Québec, provide a total solution to the problem. A major breakthrough in distribution transformer technology, they allow underground networks to be installed and operated which are economical, safe *and* environmentally sound. Over 400 units are currently installed all over North America, many of them buried directly in the ground or operating in saline water.

The obvious advantages of the early underground residential distribution (URD) installations, many of which were designed to be submersible, quickly led to their widespread acceptance in urban areas. However, the hope placed in them soon faded as the installed equipment began to show signs of corrosion and subsequently failed. Consequently, much of the industry went over to using pad-mounted distribution transformers.

Conventional pad-mounted transformers, however, have two major disadvantages. First, they are perceived as being an eyesore – and therefore unsuited for above-ground installation in a residential area. Second, they have the (unquantified) drawback that they pose an environmental hazard by threatening to contaminate the soil and groundwater in the event of severe failure.

What was clearly needed was a new, totally submersible transformer that, besides having neither of these disadvantages, would stand up to the harshest underground conditions as well as all the usual electrical phenomena that can occur.

Joint venture

Canadian utility Hydro-Québec (HQ), an internationally renowned technological leader in electric power distribution, Technical data of SDT

Type		single phase
Power	kVA	25 to 167
Primary voltage	kV	14.4
Secondary voltage	V	240/120
Cooling		AN
Frequency	Hz	60
Max temp rise	°C	100

Typical performance data

Power	kVA	50	100	167
Impedance	%	4.0	3.2	3.4
No-load losses	W	140	270	395
Load losses	W	275	415	600
Width	mm	600	600	660
Length	mm	510	770	930
Height	mm	535	535	600

is continually investing in new technologies to improve the reliability of its services while also preserving the environment. HQ was prompted to intensify these efforts by the damage to its above-ground distribution infrastructure caused by an ice storm that hit the north-eastern part of North America in 1998. These included an expansion of Hydro-Québec's underground systems, which currently make up about 9% of its total network.

To this end, HQ and ABB entered into a joint venture, CITEQ (see panel), to develop a new solid insulation distribution transformer (SDT). To date, more than 50 of the new transformers have been installed by HQ below ground. The results have been very positive and suggest that this technology has a promising future.

Unique design

The new SDT (see tables 1 and 2) features a unique design 1 in which solid insulation and a composite-material outer shell play the key roles. The solid electrical insulation system essentially comprises insulating film and hardened epoxy resin; no liquid or gas dielectric medium is used. The windings are fully impregnated and the magnetic core fully coated with epoxy resin, which serves as the dielectric medium. A composite of fiberglass and epoxy resin is used for the SDT's outer shell, which is waterproof, corrosion-resistant and requires no maintenance. The shell, although light, also adds to the structural strength of the transformer. SDTs built in this way are very compact and can be installed in any position.

Characteristics intrinsic to the SDT offer system designers several new possibilities:

- The primary bushing well(s) can be directly molded into the unit, eliminating the need for a separate part.
- Secondary flexible cables can be integrated in the unit, so there is no need for separate secondary bushings.
- Lifting and support brackets can be integrated in the outer shell for a completely corrosion-free unit.

1 The new SDT features solid insulation and an outer shell made of composite material.

Pilot projects point up benefits

CITEQ is currently participating in several large-scale pilot projects, involving over 300 homes in Ontario and Québec, in which pad-mounted transformers have been replaced by SDTs buried either in small fiberglass vaults or directly in the ground. The transformers are now in their third year of trouble-free operation, during which time they have had to withstand extreme cold as well as very hot and humid weather.

These projects are confirming the benefits of using SDTs, including:

- Freedom from corrosion over their entire service life.
- Loading capability, surge withstand and partial discharge levels remain unchanged.
- No visual/physical impact on the environment; complete freedom of movement for people and vehicles.
- Performance unaffected by weather conditions, including solar heat.
- No risk of catastrophic explosion.
- No absolute need to remove old units, as no risk of soil/groundwater contamination.
- Economic direct, vault-less burial; can be adapted for burial in mini-vault.
- Total installed system cost comparable or better than with conventional equipment.

SDT test behavior

The SDTs used in the pilot projects were subjected to a series of routine and type tests, as well as the following special tests:

- Demonstration test for direct buried transformers
- Heat runs and cold load pick-up tests
- Short-circuit withstand
- Impulse withstand
- Low temperature and thermal shock
- Internal fault withstand performance
- Fire behavior
- Accelerated aging

Demonstration test for direct buried transformers

Three 100-kVA units, each of them encased in a fiberglass envelope, were buried in the ground without any other kind of protective enclosure. The units

2 Three 100-kVA SDTs are buried (beneath the three bushes) in front of this CITEQ facility.

feed a CITEQ facility with a 300 kVA, 24,940/14,400GrdY-600 V supply.

The transformers were buried in a mixture of sand and crushed stones, and the location afterwards covered with soil and grass 2. This installation has performed successfully since going into service in December 1999.

Heat runs and cold load pick-up tests

Each of the unit sizes was subjected to a series of heat run tests simulating normal and overload conditions. These showed that the average internal temperature rise at full load and voltage is limited to 100°C. Even with an ambient temperature of 40°C and a hot-spot margin of 20°C, the maximum hot-spot temperature will not exceed 160°C, which is well below the rated temperature limit of 200°C for the insulating material.

In addition to regular heat-run tests, Hydro-Québec specified cold load pick-up tests for the SDTs. These were performed to simulate the kind of severe operating conditions that could occur during a power loss in the winter. The transformers were subjected to five cold load pick-up cycles 3, each comprising the following steps:

- Heat-run at 100% load until the temperatures reached equilibrium
- Simulation of loss of power for 1.5 hours
- SDTs run at 240% overoad for half an hour
- Overload at 200% for one hour
- Ramping-down for one hour to 100% load
- Hold at 100% until temperatures reached equilibrium

Partial discharge measurements were performed between each cycle. Afterwards, the transformers were subjected to a series of low-frequency, impulse and induced withstand tests. The results confirmed the suitability of the SDTs for this kind of duty.

Short-circuit withstand

Short-circuit tests performed on the submersible distribution transformers have shown that the only noticeable change in impedance voltage occurred as a result of the increase in winding temperature after each short-circuit test. The impedance voltage measured before,

What is CITEQ?

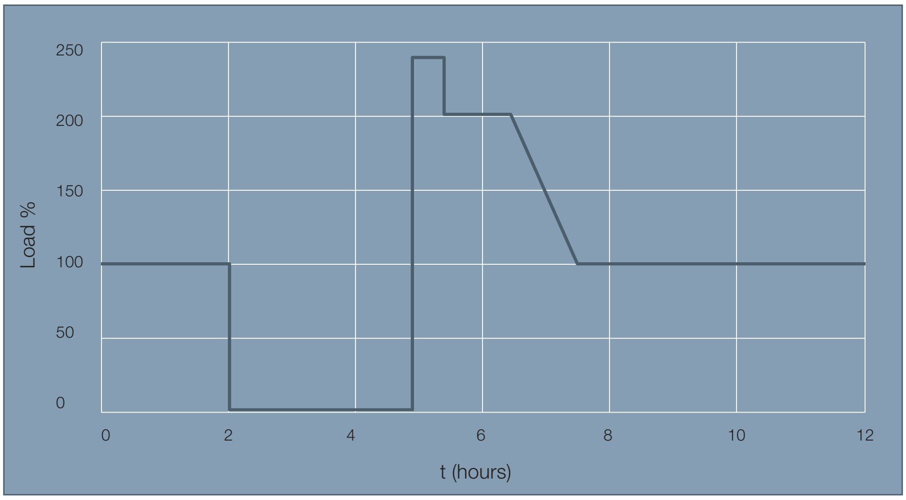
CITEQ stands for centre d'innovation sur le transport d'énergie du Québec (Québec power transmission innovation center). A joint venture between Hydro-Québec and ABB, CITEQ focuses on research and development in the area of new electrical power transmission and distribution equipment.

CITEQ is strategically located at Varennes, close to ABB's power transformer plant and the Institut de recherche en électricité du Québec IREQ (Québec electricity research institute).

The synergy generated by this profitable partnership between ABB and Hydro-Québec benefits both customers and suppliers.

In August 2002, CITEQ transferred to ABB the manufacturing and marketing rights for the new transformer technology. Since then ABB has been using this advanced technology to produce SDTs in its new transformer factory near Varennes.

3 Cold load pick-up test. This special test, required by Hydro-Québec, subjects the transformers to five heat-run cycles corresponding to extreme service conditions. During the test, the transformers are energized at their nominal voltage.



Two SDTs have been operating under salt water at the Charleston Historical Center in South Carolina since May 2000.

during and after the short-circuit test was practically constant, with a maximum variation of less than 0.15%.

Impulse withstand

It was shown that SDTs withstand repetitive impulse tests. For example, prior to the short-circuit test a 50-kVA unit withstood 2 reduced waves at 60 kV, 2 chopped waves at 125 kV, and 3 full waves at 125 kV; then 2 full waves at 95 kV and 2 full waves at 125 kV. Impulse tests performed immediately after a heat-run test confirmed that the SDT can withstand impulses at an elevated temperature. One unit withstood a total of 4 full waves at 125 kV at a temperature of 92°C.

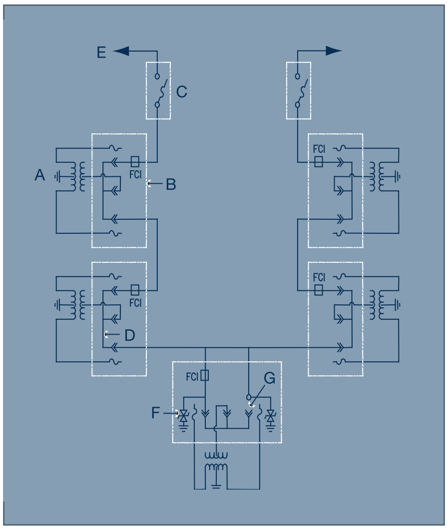
Low temperature and thermal shock

Each of the unit sizes was placed separately in a climatic chamber and subjected to a thermal shock test in which the temperature was reduced in five steps to 0°C, −10°C, −20°C, −30°C and −40°C.

At each step, when the temperature had reached equilibrium, the transformer under test had the full voltage and 200% load applied to it for one hour. Afterwards, the transformers were subjected to a series of applied voltage, impulse and induced withstand tests. Partial discharge measurements before and after each test showed that no changes had taken place.

> Results with the new solid insulation distribution transformers installed below ground suggest that this technology has a promising future.

4 The new SDTs are well suited for use in conventional URD loop-feed circuits.



- A SDT, buried direct, 14.4 kV
- B Shallow vault with fault-circuit indicator (FCI), elbow switching device and fusing compartments
- C Pad-mounted switch and fuse compartment
- D Three-way junction
- E URD cable
- F MOV arrester, 21 kV
- G Normally open elbow

The Bois-Franc project

This project is part of a vast scheme being developed by Bombardier Aéronautique Inc on a 20-million square feet site in Montréal. When finished, the Bois-Franc project will have as many as 8000 dwellings, including town houses, condominiums and single-family houses.

To date, a total of 40 transformers (100 kVA, 24,940/14,400-240/120V) have been installed in residential loops on the site. The loops, each with 10 SDTs, have their ends attached to pad-mounted switchgear with fuse protection.

The SDTs are installed in fiberglass and polymeric cement coffers measuring 1.8 by 1.2 meters by 1 meter deep, which are able to withstand occasional loads of up to 9050 kg.

Internal fault withstand performance

Fault withstand tests were conducted on an SDT prototype using a fuse wire to simulate an internal fault to ground. Two consecutive faults were simulated, the first at 8 kA and the second at 10 kA symmetrical rms, for one cycle. The tests demonstrated that there was no risk of parts detaching themselves and flying off, or of fire, as a result of such faults. The fault re-established itself just as soon as the circuit conditions were applied again.

Fire behavior test

Fire behavior tests were performed on test samples in accordance with ASTM standards E 162 (surface flammability of material using a radiant heat energy source) and E 662 (specific optical density of smoke generated by solid materials). These tests demonstrated that the SDT makes only a small contribution to the thermal energy of a fire, to its smoke emissions, and to the toxic substances it generates.

Submersion and chemical resistance test

A transformer was submerged in a chloride-rich solution to verify the protective shell's resistance to chemicals that could be found in a typical Hydro-Québec underground installation.

Courtyard at Ile de la brunante, a cluster of town houses that is part of the Bois-Franc project in Montreal. The photo on the left shows the interior of a fiberglass/polymeric-cement coffer used for the SDT installation.

Accelerated aging test

Accelerated aging tests, simulating 15 and 30 years of aging, were performed on 12 SDTs. Comparison of the dielectric's withstand capability before and after the tests showed no apparent aging. An analysis of the partial discharge measurements before, during and after the tests also indicated that no notable changes had taken place.

SDT technology is an interesting option for prestigious residential areas, where pad-mounted transformers stand no chance because of their visual impact.

SDTs for URD loop-feed circuits

Among the distribution configurations for which the new SDT has been designed are conventional loop-feed systems. Features of such a system with SDTs 4 can include:

- Full use of separable insulated connectors, positioned for easy operation on conventional three-way junctions.
- Secondary terminals and cables that include single and dual element fuses.
- 'Visible' fault-circuit indicators at each transformer location.
- No need for a primary fuse in each vault, since failure will not cause an explosion. Alternatively, a polymer-encased primary fuse can be installed at each transformer location or at the beginning of the loop.

Applications abound

SDT technology has advantages for a whole range of applications in all sorts of environments. For example, the SDT's unique features are allowing Hydro-Québec to cut back on its civil substructures to smooth the acceptance and integration of high-density urban developments. And SDT technology represents an interesting option for prestigious residential areas, where pad-mounted transformers stand no chance because of their visual impact. Coastal areas represent another environment for which the SDT is predestined. Like most other kinds of aggressive atmosphere, sea air attacks and easily corrodes the metal enclosures of transformers. The SDT, with its corrosion-free polymer casing, is the perfect answer. Ever since the idea of underground residential distribution systems was first mooted, the totally submersible distribution transformer has been on utility engineers' 'wanted' list as the ideal design for such an application. Commercial success of the SDT could well provide impetus for new investment in the development of an all-submersible URD system.

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