



# Oiled and ready to go

Advanced application of ABB BIOTEMP® vegetable oil in a HV power transformer  
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Since its invention, the transformer has evolved in terms of added functionality and size to keep pace with rapidly changing and complex electric power systems. One thing that has remained virtually unchanged since it was first applied in Germany in 1890 is the use of mineral oil as an insulating and cooling media. However, the global crude oil crisis in the early 1970s and the ever increasing demand for environmentally friendly combustibles has seen the birth of several initiatives as well as extensive technology developments focused on finding alternative fuels, in particular for the automotive industry.

For their part, Brazilian electric power utilities have worked hard to develop insulating vegetable oil based on castor oil. However, an advanced high performance insulating vegetable oil for high voltage power transformers and apparatus, developed by ABB and known as BIOTEMP®, seemed just the solution these utilities were looking for. The first worldwide application of BIOTEMP® vegetable oil as an insulating and cooling fluid in a high voltage power transformer has been made by CEMIG, an electrical power utility based in the Southeastern region of Brazil and a key ABB customer.

## Power collaboration

Cost effective operation of electrical power generation, and transmission and distribution systems is related to reliability, availability, loading capability, extended useful life and reduced power transformer maintenance in connection with environmental preservation requirements. These factors have pushed many power utilities into searching for advanced technologies for both new and refurbished transformers.

In Brazil, for example, utilities and industries are increasingly interested in vegetable oil filled equipment not only for environmental reasons but also because of a government effort encouraging the use of vegetable related fuels<sup>1)</sup>. In addition, there is a drive to replace as much imported mineral insulation oil as possible because of (a) the problem of corrosive sulfur from foreign oil imports and (b) economic reasons. And finally, the Brazilian Standards Committee has already published an insulating vegetable oil specification similar to the corresponding ASTM<sup>2)</sup>.

One utility in particular has never been wary of trying new technologies. On the contrary, CEMIG **Factbox 1** has a long tradition of supporting the development and application of

advanced ABB technologies. For example, in the 1970s it was the first utility in Brazil to introduce ABB's<sup>3)</sup> 525 kV long transmission system, and in 1992 it was also the first to support ABB in the development and application of a project that focused on the on-site repair of large power transformers [1]. More recently, CEMIG has come up with a complete solution for a 525 kV shunt reactor diagnostic and complete refurbishment [2]. It should come as no surprise then that it was the first utility in the world to use BIOTEMP<sup>®</sup> [3] as an insulating and cooling fluid in its transformer type rated for a system voltage level of 145 kV.

BIOTEMP<sup>®</sup>, a superior performance renewable and biodegradable vegetable oil is compatible with solid insulating materials and is 97 percent biodegradable in 21 days.

### Let's work together

Besides its continued support in the development and application of new technologies, other factors contributed to its inclusion in the project. For ex-

ample, as a power utility, the company is constantly striving to increase power delivery reliability to its customers, and this means taking into account extreme and safe high transformer overload capability. Additionally, it is keen to be a lead supplier of environmentally clean and reliable energy and the use of a fully reprocessed, renewable and easily dispensable insulating oil is certainly a step in the right direction.

This joint project between ABB and CEMIG focused particularly on a transformer type delivered to CEMIG in 1974. Originally rated at 138/13.8 kV, 10/15 MVA, ONAN/ONAF, the application of advanced technologies involving hybrid solid insulation (DuPont Nomex<sup>®</sup> plus Cellulose) combined with ABB's BIOTEMP<sup>®</sup> vegetable oil as an insulating and cooling transformer fluid has increased the rated power to 25 MVA (ONAF). The refurbished transformer also includes:

- Up-to-date ABB TrafoStar<sup>™</sup> technology
- An extremely high overload capability – up to 70 percent above the rated power – without any loss of useful life
- ABB's advanced TEC transformer electronic control and on-line monitoring system

#### Factbox 1 CEMIG

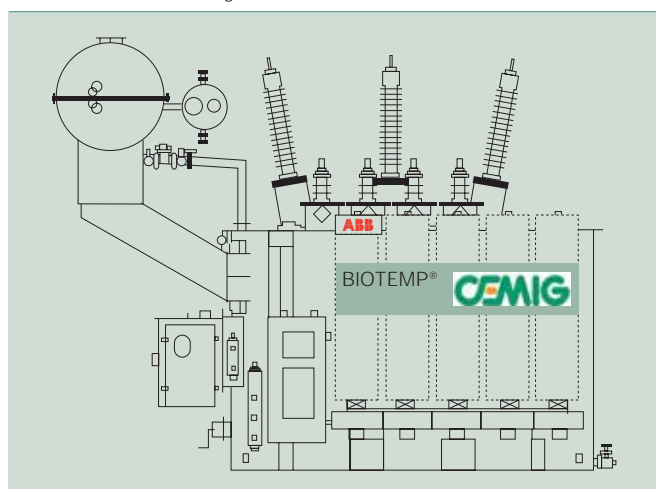
CEMIG (Companhia Energética de Minas Gerais) is the electrical power utility of the State of Minas Gerais in the Southeastern region of Brazil. CEMIG has an installed capacity of 6113 MW, a transmission system comprising more than 21,000 km of lines (4,912 km of line are reserved for the extra-high voltage level from 230 kV to 500 kV) and a distribution system extending over more than 379,400 km. It supplies electricity to an area equivalent to a country the size of France (or roughly 568,000 km<sup>2</sup>). This area includes 774 cities and a population of about 17 million people.

#### Factbox 2 Typical transformer insulating fluid properties.

Note: H.T.H = High Temperature Hydrocarbon Fluid (ASTM D5222)

TYPICAL PROPERTIES OF INSULATING FLUIDS				
	BIOTEMP	Mineral Oil	H.T.H.	Silicone
<b>Electrical</b>				
Dielectric Strength, kV (ASTM D877)	45	30	40	43
<b>Physical</b>				
Viscosity, cSt. 100°C	10	3	11.5	16
(ASTM D445) 40°C	45	12	110	38
0°C	300	76	2200	90
Flash pt. °C (ASTM D92)	330	145	285	300
Fire pt. °C (ASTM D92)	360	160	308	330
Specific Heat (cal/g/°C) (ASTM D2766)	0.47	0.43	0.45	0.36
Coefficient of Expansion (per °C) (ASTM D1903)	6.88 x 10 <sup>-4</sup>	7.55 x 10 <sup>-4</sup>	7.3 x 10 <sup>-4</sup>	1.04 x 10 <sup>-3</sup>
Pour pt. °C (ASTM D97)	-15 to -25	-40	-24	-55
Sp. Gravity (ASTM D1298)	0.91	0.91	0.87	0.96
Color (ASTM D1500)	<0.5	0.5	0.5 – 2.0	<0.5
<b>Environmental</b>				
Aquatic Biodegradation Rate (%) 21 day test using CEC-L-33-A-93/94	97.0	25.2	27.1	0.0

- 1 The new regulating transformer rated at 25MVA, 145kV and filled with ABB's BIOTEMP® vegetable oil



- Low voltage on-load regulation using ABB's UZ type on-load tap changer filled with BIOTEMP® vegetable oil
- High voltage ABB GOB type bushings also filled with BIOTEMP® vegetable oil

The benefits provided by such a transformer as seen by CEMIG include:

- High transformer reliability
- High transformer availability due to reduced maintenance needs
- Reduced installation costs
- The risk of an explosion and the consequent ground and underground water contamination is significantly reduced when compared to a mineral oil filled transformer. Even if an explosion were to happen, the vegetable oil would generate much less hazardous non-toxic by-products.

**BIOTEMP®: a superior vegetable oil**  
BIOTEMP® is the brand name of an advanced biodegradable electrical insulating fluid made of high oleic vegetable oil and extracted from renewable natural agricultural sources. The fluid has excellent dielectric characteristics with high temperature stability and superior flash and fire resistance: 330 °C and 360 °C respectively while mineral oil has flash and fire temperatures of 145 °C and 160 °C. BIOTEMP® is very compatible with solid insulating materials and is 97 percent biodegradable in 21 days. It is an inhibited oil and has been approved according to both ASTM D2440 – which con-

cerns the “Standard Test Method for Oxidation Stability for Mineral Insulating Oil” – and ASTM D3487 type II [4] – it does not contain any PCBs. A comparison of BIOTEMP® with other insulating fluids is given in **Factbox 2**.

The development of advanced new materials means utility services can upgrade old transformers, thus allowing increased safety, low maintenance and increased product lifetime.

BIOTEMP® vegetable oil can absorb water thus greatly increasing the life of the insulation paper immersed in it. In fact a study based on tensile strength and degree-of-polymerization measurements has shown that Kraft paper immersed in BIOTEMP® lasts twice as long as paper in transformer oil derived from petroleum sources. This property combined with BIOTEMP®'s superior thermal properties means a transformer can support a higher hot spot temperature in its winding. Because of these thermal properties, transformer installation requirements become a little less complicated in that:

- Fire walls in the substation bay are no longer required
- Fire liability and insurance costs are reduced

- Factbox 3 Transformer data before and after the revamp

	Original	Refurbished
Serial Number	54381	
Manufacturer	ASEA	ABB
Year	1974	2006
Frequency, Hz	60	60
Phases	3	3
Voltages	138 ± 2 x 2.5% / 13.8 ± 16 x 0.625 kV	
Rated Power, MVA	15 (ONAF2)	25 (ONAF2)
Overload, MVA	-	37.5 (6h, 150%) 42 (4h, 170%)
OLTC	UZERN 250	UZF 250
Insulation	Cellulose	Hybrid (Nomex + Cellulose)
Oil Type	Mineral	BIOTEMP®

- Fire extinction system requirements in the substation bay can be effectively optimized
- The distance between the transformer and adjacent equipment and/or buildings becomes less critical

#### Putting it all together

The electrical and mechanical redesign of the transformer was fully developed by ABB Brazil. Engineering efforts concentrated in particular on:

- **Winding insulation dimensioning** using Nomex® paper and board insulation. The dielectric permittivity of these impregnated in insulating vegetable oil is very different to that of standard cellulose paper in insulating mineral oil. As a result, a specific electrical potential distribution exists based on the combined insulation structure formed by the cellulose or Nomex (paper and/or pressboard) impregnated in the insulating oil
- **Internal winding connections** using paper insulated cables for electrical

#### Footnotes

- <sup>1)</sup> Nowadays Brazilian cars use a flexible fuel automatic control system that allows cars to run on a natural gas, gasoline, sugarcane ethanol and a mixture of gasoline and ethanol in any percentage of each combustible. Additionally biodiesel is used in trucks.
- <sup>2)</sup> ASTM International is an international standards development organization that develops and publishes voluntary technical standards for a wide range of materials, products, systems, and services.
- <sup>3)</sup> In the 1970s, both BBC (Brown Boveri Corporation) and ASEA contributed – as separate companies – to CEMIG's 525 kV System



## Power collaboration

and thermal dimensioning for overload conditions

- *External cooling system dimensioning and temperature rise evaluations*, taking into account differences in the viscosity of the vegetable and mineral oils and the extreme high overload requirement

The revamped transformer is shown in **1** and the main data before and after redesign are given in **Factbox 3**. The transformer manufacturing process was carried out in accordance with the well-established TrafoStar™ regulations. A specially adapted vegetable oil filling process, comprising a separate temporary oil system and dedicated oil processing machines such as a thermo-vacuum plant, filters, heaters and hoses, was used. Other factors such as conditioning, vacuum time, oil filling under a vacuum process, oil circulation time and

final standing time before tests have been defined and applied were also considered. Quality control was carried out during each stage of the process in accordance with internal ABB Six-Sigma procedures<sup>4)</sup>. ABB high voltage GOB bushings were also filled with BIOTEMP® vegetable oil and rigorously tested.

### A great performer

**2** shows the assembled transformer sitting in the test bay of the ABB Brazil High Voltage Laboratory. All standard routine tests [5, 6], together with a set of specially designed ones were performed. Dielectric, thermal and operational tests included:

- Lightning (full and chopped waves) and switching impulse tests in all windings terminals
- Short duration AC applied tests
- Long duration induced voltage tests – including Partial Discharge mea-

surements – before and after the heat run ( where oil and winding temperature rise measurements were taken) as well as overload thermal tests

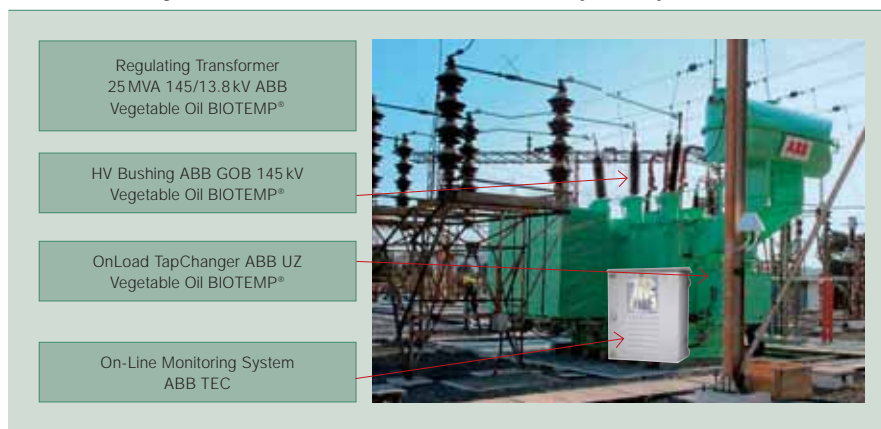
- No-load and load sound level measurements tests, including octave-band noise spectrum measurement
- A long duration overload test
- Power frequency long duration over-excitation tests
- A Frequency Response (FRA) test

All dielectric and thermal tests were monitored by oil dissolved gas analysis (DGA). The oil DGA test results showed there was no significant variation in gas concentration before and after the electrical and thermal tests, a clear demonstration of the transformer superiority and reliability [7].

In the long term, the utility can expect a reduced risk of explosions, less maintenance and extended transformer useful lifetime.

The use of BIOTEMP® vegetable oil also has its advantages when it comes to transportation. Because the transformer can be shipped filled with BIOTEMP®, costs and the amount of paperwork needed are reduced. This is in stark contrast to mineral oil

**2** BIOTEMP® vegetable oil filled transformer at the HV laboratory test bay (ABB Brazil)



### Footnote

<sup>4)</sup> ABB Six-Sigma procedures are in compliance with ISO 9001 and ISO 14001 standards.

**3** The newly revamped BIOTEMP® vegetable oil filled transformer in operation at a CEMIG substation bay



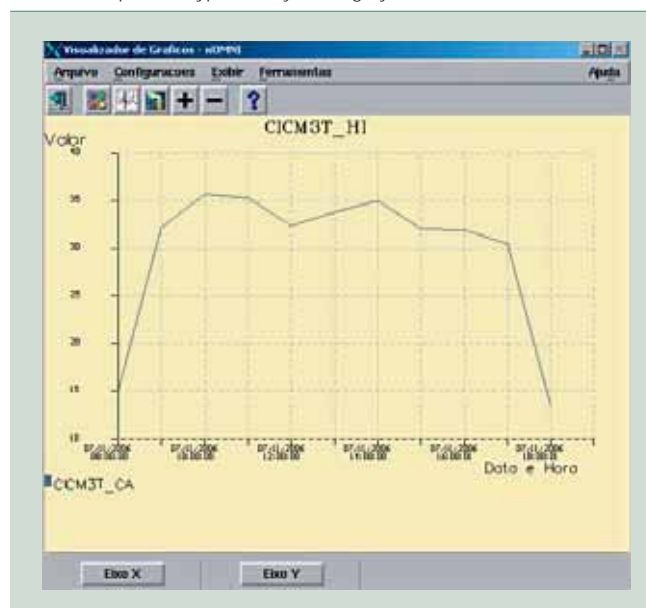
which must be shipped in a separate container to that of the transformer. Therefore transporting the transformer over 500 km from the ABB factory to the CEMIG Cidade Industrial substation was relatively straightforward. Once installation and commissioning were completed [3], the transformer began commercial operation at the end of July 2006. Since then it handles peak overloads of up to 42 MVA (170 percent) almost everyday [4].

Transformer operation is monitored by ABB's TEC on-line monitoring system as well as by conventional oil tests, oil and winding temperature monitoring and periodic infrared scanning. The aim is to follow, as closely as possible, the performance of both the transformer and the BIOTEMP® vegetable oil. So far the results have shown very reliable transformer performance especially under severe overload conditions.

#### From here on

The development of advanced new materials is a significant step forward in transformer technology. This also means utility services can upgrade old transformers and reap the rewards of these developments such as increased safety, low maintenance and increased product lifetime. Well-established development cooperation projects, such as that between ABB and CEMIG, create ideal conditions for the application

4 An example of a typical daily loading cycle.



of new and advanced transformer technologies, resulting in benefits not only to both companies, but also to the power industry and society as a whole.

To explain this further using the ABB/CEMIG development project as a direct reference, the thermal properties of new materials, for example, enabled the rated power of the original transformer to be increased. Additionally, transformer reliable overload capacity was also increased from 150 to 170 percent of its rated power. The benefits of using BIOTEMP®, a superior performance renewable and biodegradable vegetable oil from ABB brought about increased safety and reduced costs during installation at

CEMIG. In the long term, the utility can expect a reduced risk of explosions, less maintenance and extended transformer useful lifetime.

There remains, however, much to be done for the utility industry. Finding ways of further simplifying and optimizing future substation design will keep engineers busy for a long time. A first step towards this goal would be to review today's transformer installation standards and local legislations. In any case, the work of applying this new transformer technology at voltage levels greater than 145 kV is well and truly underway.

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