On-site modernisation of power transformers

ABSTRACT

The paper presents technical and economic aspects of modernisation of transformers carried out on site. The decision-making process regarding the repairs or modernisation of transformers that have already exceeded their planned lifetime was analysed. The diagnostic process related to the assessment of the technical condition before the repair, and the use of these results to determine the scope of possible repairs and their cost-effectiveness were discussed. The scope of repair works that can be performed on site and the ways of verifying the quality of the completed works were also characterised.

KEYWORDS

diagnostics, regeneration, repairs and operation of transformers, transformer, unit lifetime extension

1. Introduction

At present, there are numerous technological possibilities related to carrying out advanced repair works at the place of installation of a transformer. Repair and modernisation operations include, among others: internal inspections of transformers, treatment or regeneration of transformer oil, sealing, modernisation of cooling systems, fitting of valves and gates, replacement of accessories, cleaning as well as painting, and application of anti-corrosion protection of transformers. An important part of the modernisation process is also the repair

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On-site service or repair works can extend the trouble-free lifetime of transformers by up to 15 years

or replacement of the on-load tap changer (OLTC) as well as the replacement of bushings [1-4].

However, the cost-effectiveness of modernising transformers after long service must be evaluated individually for each unit, with the assessment of the technical condition being an essential component. On its basis, the scope of the repair and the expected service life with the assumed parameters are determined [5].

The paper presents the technical possibilities of extending the lifetime of transformers by performing a repair or modernisation. Based on many years of experience of Energo – Complex, a decision-making algorithm has been developed to determine the profitability of modernisation, the scope of work and the technical feasibility of performing it on site. Issues related to the verification of the quality of the work performed before placing the unit in operation were also addressed.

2. Assessment of the technical condition of the unit

The main components of a reliable evaluation of the technical condition of a transformer are modern methods for diagnosing the condition of insulation, windings, bushings and the tap changer (Fig. 1).

2.1. Testing transformer oil

The degree of ageing and moisture in the insulation and the occurrence of many undesirable physicochemical processes in a transformer are assessed based on physicochemical tests of the properties and content of gases dissolved in oil. The determination of the electrical strength of the oil, the dielectric loss factor (tgδ) and the content of furans (especially 2FAL), makes it possible to assess the degree of ageing of the cellulose and oil [6, 7].

2.2. Testing moisture content in solid insulation using polarisation methods

The level of moisture content in solid insulation of transformers can be directly determined using different variants of measurements of polarisation phenomena. A widely used method is FDS, which uses the measurement of frequency characteristics tgδ and insulation capacity C in the range from 0.7 mHz to 5 kHz. In special cases where the paper-oil insulation is not in thermodynamic equilibrium or significantly aged with deposits on the cellulose surface, it is advisable to use the time characteristics of polarisation and depolarisation currents (PDCs) as well as recovery voltage measurement (RVM) [8].

2.3. Detection of winding deformation

Winding deformation detection can be carried out by means of the sweep frequency response analysis (SFRA). These measurements record the frequency characteristics of the winding admittance and transmission function mostly in the 100 Hz – 1 MHz frequency range [9].

Energo – Complex is continuously developing diagnostic methods in cooperation with the West Pomeranian University of Technology in Szczecin. The developed diagnostic technologies and methods of analysis of results have been implemented in the company's operating practice.

The diagnostic results that confirm the absence of internal defects, the absence of winding deformation and moderate ageing of the cellulose insulation show that the unit is suitable for modernisation and extension of its lifetime.

3. Characteristics of cost elements of modernisation

3.1. Insulation treatment, winding drying and oil regeneration

The effective extension of the remaining service life of old units depends on the reduction in the level of moisture

Based on many years of experience, Energo – Complex developed a decision-making algorithm to determine the profitability of modernisation, the scope of work and the technical feasibility

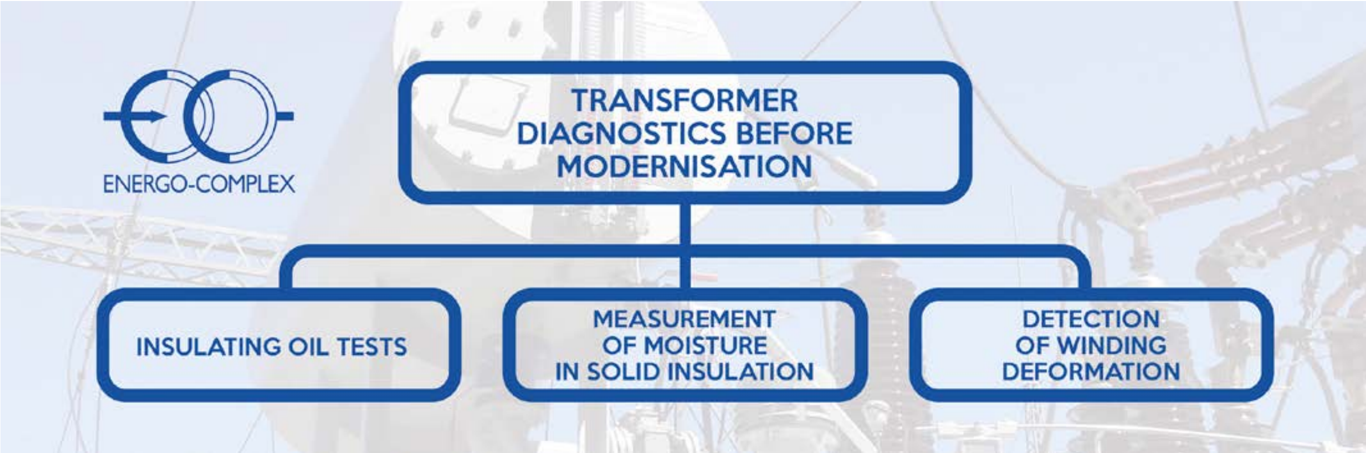


Figure 1. Transformer diagnostics before modernisation

The main components of a reliable evaluation of the technical condition of a transformer are modern methods for diagnosing the condition of insulation, windings, bushings and the tap changer

content in the insulation system and the restoration of the appropriate parameters of electrical insulating oil [10].

Mineral electro-insulating oils are exposed to numerous factors degrading their physicochemical and electro-insulating properties during operation. The main factors that intensify ageing processes are high working temperature, oxygen (oxidation), moisture, effects of electric field and catalytic action of metals. Oxidation and temperature play a dominant role in oil ageing processes. Physicochemical changes caused by the ageing process are indicated by the release of organic acids and the formation of alcohols, phenols and simple esters. In the initial ageing process, these products are dissolved in oil. Then, as a result of oxidation, oil-insoluble deposits, such as tar, asphalt and soap, precipitate. These products have a strong acidic reaction and significantly accelerate the cellulose depolymerisation. By precipitating on the surface of the windings, the resulting insoluble deposits limit the heat dissipation capacity, thus further accelerating the degradation process of the solid insulation.

Moisture is another accelerator of the solid insulation degradation process. The cellulose ageing process is five times faster with 3 % moisture content in the insulation than when with 1 % moisture content. Moisture also causes many other problems, such as the bubbling effect, which reduces the current carrying capacity of the unit.

Almost all moisture is contained in cellulose, and only its negligible part is cyclically transferred to oil during transformer temperature changes. The relatively frequent centrifugation of oil during transformer operation is not able to remove moisture from cellulose, and oil becomes moist again within a short period of time after treatment. On the other hand, the vacuum drying of insulation gives good results. In recent years, Energo – Complex has successfully applied the on-site insulation treatment technology, which includes drying of solid insulation and oil regeneration. Typical parameters of aged, new, and regenerated oil are shown in Table 1.

In order to achieve the drying effect of the transformer's solid insulation, a combination of different drying methods is used, i.e., the circulation and vacuum methods with the creation of a deep vacuum in the transformer tank. The insulation is cleaned of impurities by simultaneously regenerating the oil.

Table 1. Typical parameters of oil [11]

Parameter	Aged oil	New oil	Regenerated oil
Acid value (mg KOH / g)	~ 0.2	< 0.02	< 0.01
Water content (ppm)	> 10	< 10	< 10
Loss factor tg δ at 90 °C	~ 0.1	< 0.003	< 0.004
Resistivity at 90 °C (GΩm)	~ 1	> 100	> 150

The active part is heated by circulating hot oil with a temperature of 85 - 90 °C. Beyond the effect of obtaining the right temperature, the process of heating the active part by circulating the hot oil makes it possible to clean the accumulated ageing products from the cellulose insulation. This effect is achieved by simultaneously conducting the chemical regeneration of the oil to remove contaminants from the oil on an on-going basis. This process is usually continued until the moisture level is below 1.5 %.

The oil regeneration process comprises particulate filtration, separation of polar particles using an absorbent, vacuum drying and degassing. The decisive factor of the whole cycle is the physicochemical process of purifying the oil flowing through sorption columns, which are formed by fuller's earth. Regeneration is carried out until the obtained physicochemical parameters of the oil are similar to those of new oils.

The parallel processes of oil regeneration and drying and cleaning of the insulation create an excellent and long-lasting effect of improving the condition of the transformer's insulation system. Fig. 2 shows a device for regeneration and treatment of insulating oil used by Energo – Complex.

3.2. Replacement of the cooling system

During many years of a transformer's operation, sludge is gradually deposited on the internal walls of the transformer coolers. As a result, the cross-section of the heat sink decreases, cooling conditions deteriorate, and corrosion processes and mechanical degradation (vibration) lead to oil leaks. Therefore, before starting repairs, one should proceed from the assumption that heat sinks are worn out and plan their replacement. Although the cost of new heat sinks is by no means low, the repair of rusty and inefficient heat sinks is virtually uneconomic.

Fig. 3 shows the view of the transformer before and after modernisation.

3.3. On-load tap changer

An important component of modernisation costs is the purchase or

The extension of the remaining service life of old units depends on the reduction in the level of moisture content in the insulation and the restoration of the parameters of electrical insulating oil

Figure 2. View of the device for regeneration and treatment of insulating oil

Before starting repairs, one should proceed from the assumption that heat sinks are worn out and plan their replacement

Figure 3. View of the transformer before and after modernisation

OLTC can be replaced on site, and currently Energo – Complex performs this type of modernisation as a standard part of extending the lifetime of medium and high voltage transformer units

general repair of the existing on-load tap changer (OLTC). The cost of a new changer constitutes a significant percentage of the unit's value.

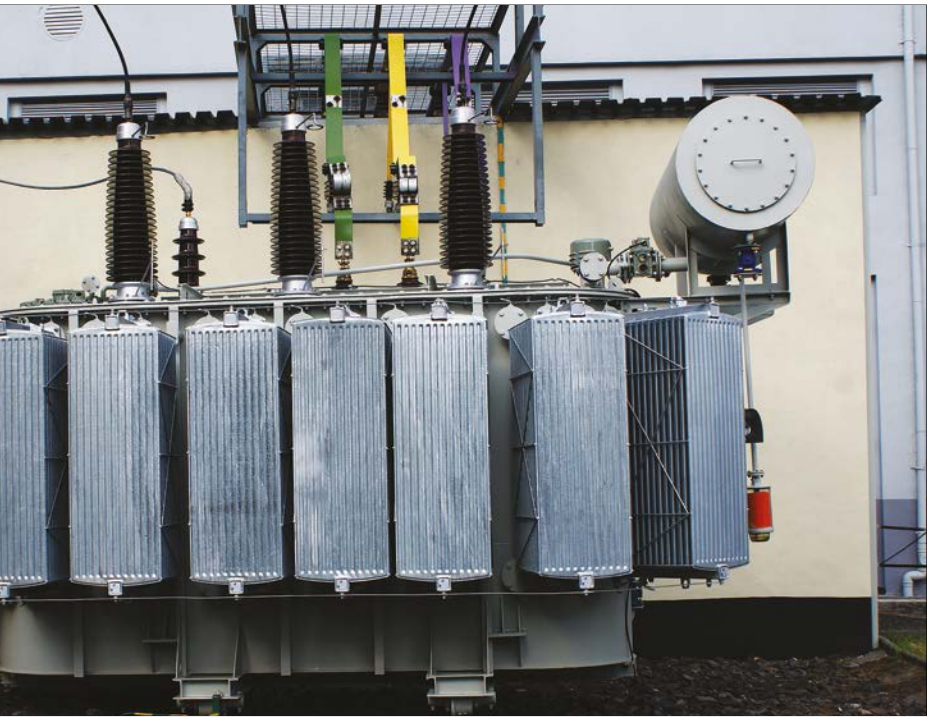
OLTC can be replaced on site, and currently Energo – Complex performs this type of modernisation as a standard part of extending the lifetime of medium and ultra-high voltage transformer units (Fig. 4).

The decision to replace or repair an OLTC is obviously guided by financial issues, however, from the technical point of view, the most important factor is the number of switching operations performed by the changer. The new tap changer designs provide users with tangible benefits, in terms of both reliability and operating costs, by increasing maintenance intervals and, for vacuum designs, even by eliminating costly servicing operations entirely. Therefore, the choice of the path to be followed for OLTC is made on a case-by-case basis. For key units and units operating under conditions of large load and voltage fluctuations and the associated large number of OLTC switching operations, it is recommended to replace the device with a new one and, in justified cases, with one made in vacuum technology.

For units operating under conditions of small voltage fluctuations and, consequently, with relatively small numbers of switches, the repair and modernisation of the existing OLTC produce satisfactory results. Operational practice proves that the drive units of OLTCs get damaged the most often. Therefore, the replacement of the drive unit with a new one and the repair of other OLTC com-

Table 2. Typical inspection and servicing intervals for different OLTC types [11]

OLTC	The number of switches between servicing operations	Time	Contact life
PO 250 – VEL 110	15,000	3 years	~ 80,000
MR OILTAP VIIIY – MIIIY	100,000 – 150,000	7 years	~ 400,000
MR VACUTAP VVIIIY - VMIIIY	300,000	-	600,000



ponents are, in many cases, sufficient to achieve a satisfactory improvement in operational reliability. In this way, for a relatively low price, it is possible to obtain a device whose service life will be comparable to the expected lifetime of a repaired transformer.

Fig. 5 shows the scope of transformer renovation on site.

4. Verification of the quality of works performed as part of the repair or modernisation of the unit

Tests carried out after the completion of repair works play a very important role in the process of revitalising the technical condition of transformers. The tests are usually extensive.

Based on many years of operational experience, Energo – Complex recommends the extension of the scope of acceptance tests for ultra-high voltage transformers by adding a voltage test with simultaneous measurement of partial discharges.

Even relatively simple repair works, such as a replacement of bushings or repairs of an on-load tap changer with a selector cage, are not without risk of damage to the components of the insulation system, contamination, and moisture in the elements of the active part of the transformer. In the operating practice, there were cases of transformer failures after repairs. These failures did not occur immediately after the voltage was applied, but usually in the first 72 hours after the start-up. In these cases, the basic post-installation tests did not reveal any irregularities. Removal of such failures is additionally associated with very high costs and operating difficulties for the owner of the unit. There is, therefore, an economically reasonable and technically feasible need to verify repair works by means of systems that enable PD measurements on site. This can be done with the mains power supply, which results in a measurement without the possibility of voltage adjustment, but significantly reduces the cost of testing. A much better solution is to carry out the measurements using an external source.

Figure 4. OLTC replacement in a transformer on site

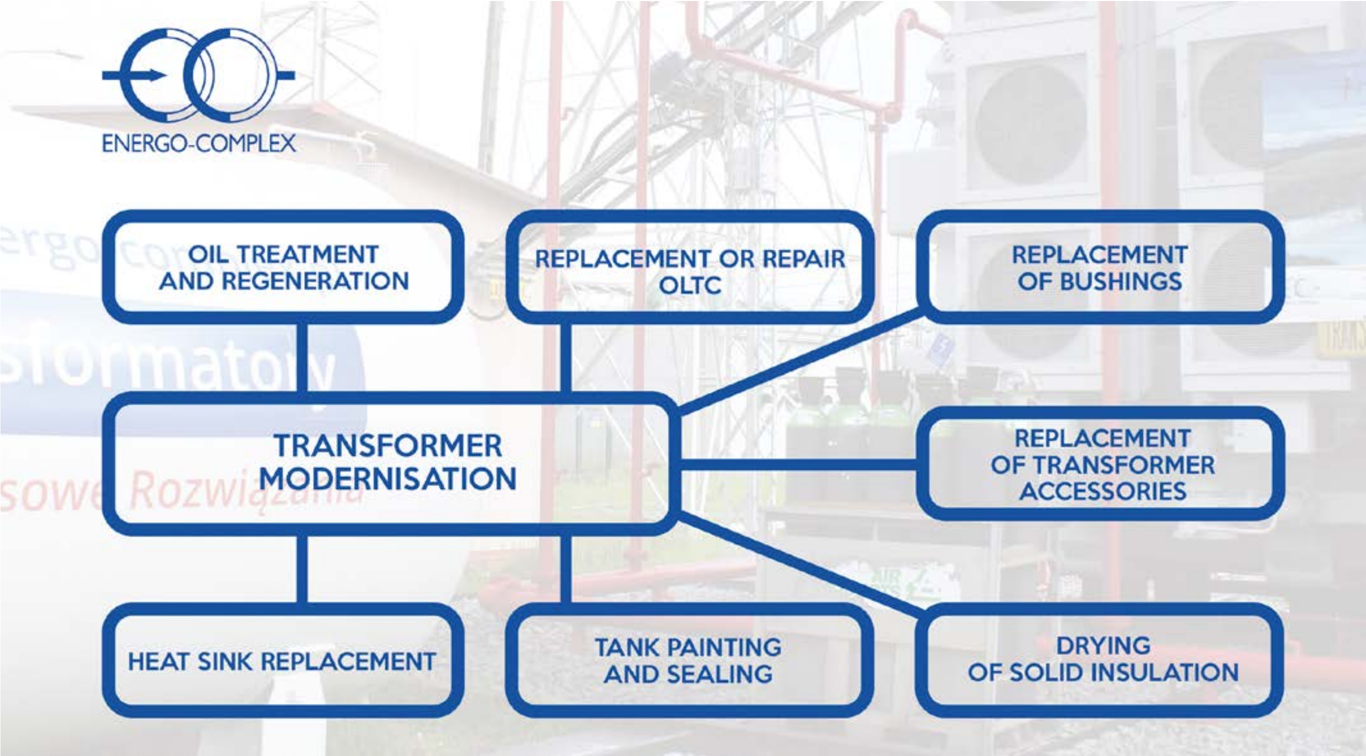


Figure 5. Elements of transformer modernisation on site

Tests carried out after the completion of repair works play a very important role in the process of revitalising the technical condition of transformers

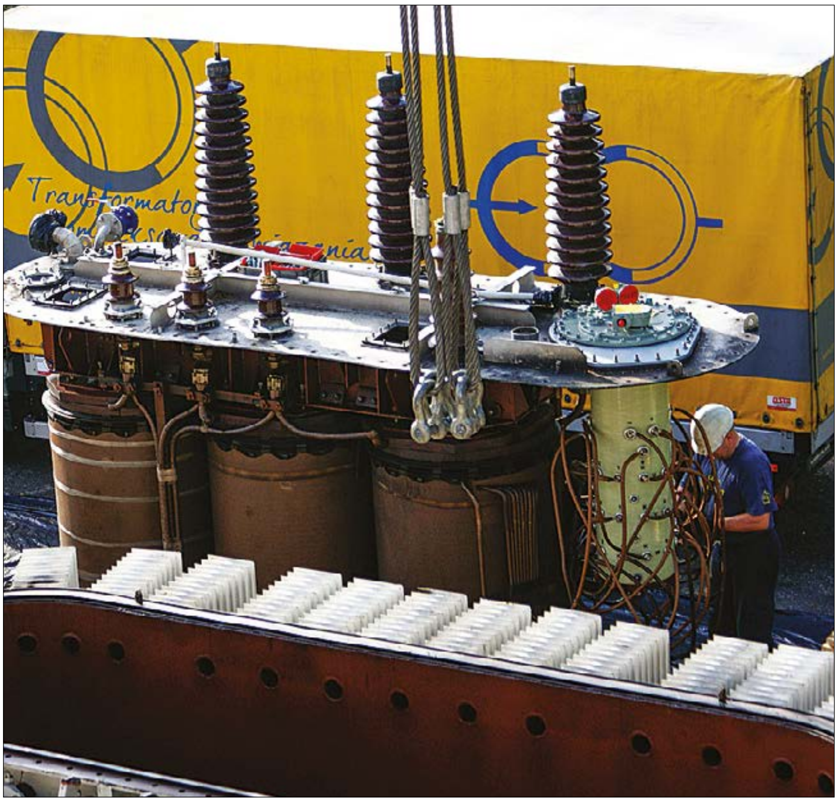


Figure 6. View of the active part of the transformer during renovation on site

Apart from the possibility of adjustment and performing a full voltage test, a measurement carried out under these conditions is significantly less exposed to the influence of interference from the power network. Such a measurement is also significantly safer, as the short-circuit power of a mobile source is much lower than that of a rigid network.

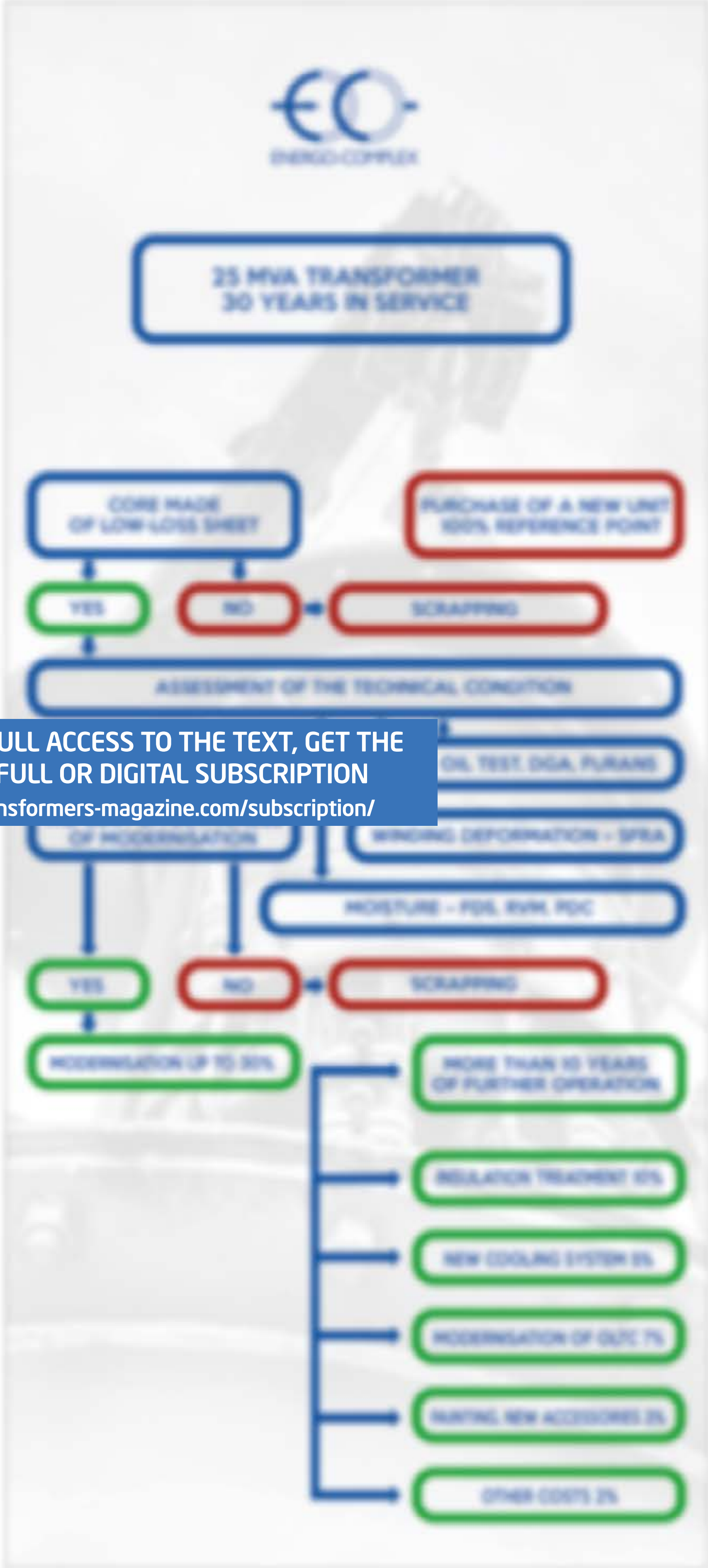
In the measurement practice, Energo – Complex uses Montesto 200 [12] measuring and recording system, which enables simultaneous analysis of electrical signals as well as the signals recorded in the ultra-high frequency band by a UHF probe.

Fig. 6 shows a view of the active part of the transformer during renovation on site.

5. Analysis of modernisation costs depending on the technical condition of the transformer

The procedure for deciding whether to modernise a transformer can be presented on the example of a typical 25 MVA, 110 / 15 kV transformer, which operated for 30 years in a grid at low load and had no major failures. The order of the decision-making activities and the estimated cost of modernisation are presented in the form of an algorithm shown in Fig. 7.

6. The final decision: replacement or modernisation?



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The cost of modernisation of a 30-year-old 25 MVA, 110 / 15 kV unit which would enable operation for another 10 – 15 years, is estimated to be 15 – 20 % of the value of the new transformer

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