ON-SITE REFURBISHMENT AND HV TESTS OF LARGE POWER TRANSFORMERS IN THE HUNGARIAN TRANSMISSION GRID

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Abstract:

Abstract: Transformers are one of the key elements in the power grid. In the current climate of deregulation and the opening of the electricity market, methods of maintaining and operating transformers are increasingly aimed at reducing costs while still ensuring the best possible operation. Our activities are mostly dedicated to the area of transformer on-site refurbishment and diagnostics. The time and the cost of the transportation of the transformer to the factory is very considerable, therefore the place of the refurbishment is very important. Number of technical and economical aspects must be assessed. The difficulty here is to express all these quantities in money units in order to compare different scenarios. The paper presents a short view of on-site routine processes, high voltage electric test and on-site repairs of large transformers installed in the Hungarian national grid with special regard to the on-site disassembling with a special lifting technology. The paper describes three failure incidents, the decision process, the on-site tests and the repair actions on three large transformers with respects to the on-site diagnostic procedures and on-site HV test including PD measurements.

1 INTRODUCTION

The repair of a power transformer in a manufacturing facility is a good alternative, especially when the dimensions and weight allow transportation by road, implying a quick and reasonable cost solution for shipment. Performing on site repair works is a different option with similar reliable and quality results, requiring an adequate preparation and conditioning of the environment, special equipment, processes, testing and experienced personnel. The main advantages related to on site repair works are shorter repair time and lower cost when compared to shipment to a repair location, especially for bigger size transformers. To maintain serviceability of transformers at the desired level, it is necessary to conduct major repair in due time. To good decision making it is essential that advanced suitable on-site refurbishment techniques and diagnostic tools have to available. The successful use of on-site refurbishment several testing techniques have to us to check to efficiency of the refurbishment.

2 TRANSFORMER REFURBISHMENT POLICY AT HUNGARIAN TSO

Specific details are provided in the following sections. Nowadays, fast and cost-effective transformer repair and modernization are recommended. On-site routine and small repair operations of power transformers have been performed for many years in Hungary. However, only lately that successful case of on-site complete repair of transformers has been performed. The choice of repair site depends on a structured technical and economical evaluation of possible alternatives, namely: technical viability of performing on-site repair; available time for repair; time for site-factory-site transportation, actual cost of transportation; cost and risk of additional damages associated with transportation [1], [2].

Very important aspects are the ageing conditions of the corresponding insulation. Transportation of transformers with insulation polymerization degree (DP) below 450 is not recommended, because the risks of mechanical damage (which might occur during transportation, including the active part (core, windings) and major insulation, tap changers, the reduction/loss of winding block pressing, etc.). It is important to point out that even after approval on factory acceptance tests, the transformer state condition can be compromised due to efforts associated with occurrences during transportation [1], [2].

The failure rates of large power transformers are dependent upon the highest winding voltage, history of transformer, service and load (temperature) conditions, etc. which significantly influence the ageing process and the reliability of the transformers. Before a catastrophic failure occurs inside a large power transformer, preventive actions, but if failure occurs remedial actions must be introduced.

The owner of the transformer must select - based upon technical, operational and economical considerations - one of the following alternative possibilities [4], [5]:

- Repair or refurbishment of damaged or poor condition unit in factory,
- Replacement of damaged unit with a new or spare transformer,
- Repair or refurbishment of the damaged or poor condition unit in a workshop,
- Repair or refurbishment of damaged or poor condition unit on-site.

The time and the cost of the transportation of the transformer to the factory is very considerable, therefore the place of the refurbishment is very important. Number of technical and economical aspects must be assessed. The difficulty here is to express all these quantities in money units in order to compare different scenarios.

To good decision making it is essential that advanced suitable on-site diagnostic tools are readily available to assess the condition or localise the damage in the transformer. Lots of on-site test, refurbishment and repairs on power transformers have been performed since many years. However, it is only recently that induced AC test, various new diagnostic methods and low-cost refurbishment or repair of large transformers have been carried out.

To maintain serviceability of transformers at the desired level, it is necessary to carry out the required refurbishment or repair in due time. The used diagnostic systems permit to disclose and assess the real condition of transformers, and to show the danger level of developing defects.

Our and international experiences show that only a small number of transformers demanded an immediate repair and "as a rule". An individual approach is necessary to the repair or refurbishment of each transformer, that are strict observation of technology requirements, a permanent control the oil parameters and insulating properties of windings, as well as accumulated experience in repair on the basis of advanced technologies.

The Hungarian MAVIR Ltd. - as the owner of the HV transformers - very often repairs or refurbishes the damaged or poor condition transformers in factory. But this paper shows three failure incidents and the decision processes with the Hungarian transformers when the final decision was "the on-site refurbishment".

This paper describes the failure incident, decision process and on-site repair actions on two 400/120 kV, 250 MVA transformers and a 220/120 kV, 160 MVA unit with particular attention to the on-site diagnostic and high voltage testing procedures. As it well known that in the older transformers with oil-paper insulation always significant winding shrinkage occurs after a long-term service, leading to reduction in clamping pressure and short circuit withstand strength.

In the first case study the optimal decision was also the on-site repair. Thanks the effective diagnostic methods it was clear that some thermal fault would be in the transformer, and it was also obvious that the windings were not damaged. Because the transportation is too expensive, and it was available the above mentioned new on-site disassembling technique and on-site HV test, the optimal decision looked was also the on-site refurbishment.

In the second case study apart of winding shrinkage (winding and core loosening) there were not any other problems with this transformer. Since the transportation would be too expensive so the on-site refurbishment looked cost effective comparing with the factory repair. For the good decision it was very important that there were available some relatively new processes, for example low cost un-tanking technique and the on-site AC test with PD measurement to help the on-site repair.

The third case study presents that how far important the on-site high voltage AC test with electrical PD measurement. In this case it looked that the optimal decision was also the on-site repair. The main target of the repair was the re-pressurising the windings and the core. After the refurbishment all parameters of transformer, including its dielectric loss factor, RVM spectrum, the reduction of vibration, etc. meet the requirements, but during the on-site induced HV test they have realised that within one of the three phases the PD was very high: over some hundred thousands pC at 10 % of nominal voltage. Without the induced HV test with PD measurements it would be impossible discover this defect.

3 ON-SITE REPAIR WITH SPECIAL UNTANKING TECHNOLOGY

The on-site repair of high voltage transformers involves complex operations. They require a combination of a set of special processes supported by a group of transformer specialists. Among the transformer repair process, involving lots of various steps, the special un-tanking technology with using the "CRAB lifting system" was the most important (Figure 1).

The CRAB lifting equipment allowed to open the transformer and to carry out the repressing on the windings and cores and various repairing works on-site in the substation. The on-site works start with hot oil circulation to increase the insulation temperature, and then it continues with removing the hot oil, with opening the transformer, lifting and fixing the active part successively.

Figure 1: Un-tanking with CRAB lifting system

After a close visual inspection some cleaning activities had to be performed inside the tank to remove all debris and the pieces metallic and cellulose insulation, which have been distributed inside the tank during the installation and service years.

A critical element in all on-site repair activities of large power transformers is the drying procedure. It is well known that, due to the long time exposure (several days) of oil impregnated cellulose insulation to the air humidity, both the thermal and dielectric properties can be degraded. During service local humidity causes enhanced dielectric losses and free gas may be produced (bubbles) leading to dangerous partial discharge (PD) activity. But our case the temperature of insulation was over 50°C and the tank was open approximately 8 hours. After the closing the tank vacuum and drying processes were applied to the active part with hot oil circulation for extraction of the absorbed water mostly from the surface of cellulose insulation (approximately 3 days treatment).

To check the condition of insulation, before and after the on-site transformer repair, the following test were carried out: DGA, oil screen (testing of physical and chemical properties of oil), winding resistance, insulation resistance, tg delta and capacitance (windings and bushings), frequency response (FRA), vibration measurements, RVM, degree of polymerization of paper (DP), induced voltage with monitoring of Partial Discharges (PD) up to 130% of rated voltage [2].

4 ON-SITE INDUCED TESTS WITH PD MEASUREMENT

On-site tests on high voltage power transformers is of increasing interest as part of transformer commissioning, as a diagnostic tool for condition assessment and as an acceptance test just after transformer repair or refurbishment. The internal insulation of HV power transformers is subject to defects due to several reasons associated to bad material, design, manufacturing or repairing processes, resulting from shipment, etc. On-site induced voltage tests are to simulate on the transformer under testing the equivalent stresses which may be established during service condition.

In our practice the on-site HV voltage electrical routine test may be commissioning or diagnostic test. The commissioning test is part of the on-site equipment commissioning procedure in order to demonstrate that shipment and erection have not caused any new defects to HV insulation, that repair or refurbishment have been successfully completed and HV insulation is free of dangerous defect. The diagnostic is part of the on-site diagnostic procedure in order to check correct manufacture of HV insulation, provide reference values to further tests or to confirm results obtained from other types of test [2], [3].

Off-line electrical tests such as the measurement of dielectric loss, frequency response, resistance etc, which use voltages much lower than the normal working voltage, have in many cases been useful in diagnosing a fault following a trip or assessing the general condition of the transformer. Unfortunately these low voltage tests do not normally provide any useful diagnostic information about partial discharge faults which tend to be voltage related. Up to date, on-site high voltage tests - including partial discharge monitoring and measurements - are the most significant tests in order to quantify HV insulation quality. The use of a separate HV source is more informative than measurement at normal operation voltage, as it allows investigation of the HV insulation performance with voltage.

Alternating voltages are most important for on-site tests. In our cases after the on-site refurbishment induced AC test was performed with electrical PD measurements. But in “case study of PD”, during the final HV induced test the PD was high it was necessary to apply acoustic and electrical PD measurement to localise the source of PD.

To perform on-site HV tests, a complete test container was built. It contains the necessary excitation and the measuring instrumentation for the on-site PD testing of transformers (Figure 2).

The hart of the equipment is a Diesel motor-generator set providing 400V 50-60Hz 3 phase output voltage with a 430A continuous and 600A short time current output [2].

To adjust the generator output to the test object input voltage an intermediate set-up transformer is built into the container with selected voltage ratio. The internal switching cabinet controls the output voltage and the step-up transformer ratio.

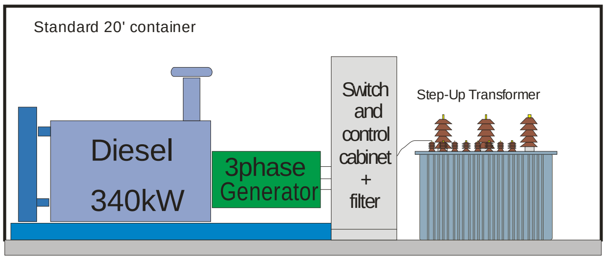

Figure 2: Test container for on-site induced HV test on transformer with PD measurement.

A special filter is placed between the generator output and the step-up transformer to eliminate the electrical noise of the generator excitation.

Inside the container in separate cabinet is the place of the PD multiplexer, PD meter and voltage/current measurement.

The generator can be set to 60 Hz which enables testing of 50 Hz transformers with 120% of the rated voltage. In the factory the acceptance tests and PD measurement are carried out all bushings at 130% U_N during 60 min. If the transformers possess regulating winding the induced test can be also carried out at 130% U_N, as in factory if we drive the OLTC to the extreme position. The noise level originating from a diesel generator and from surrounding area is usually not higher than 50-80 pC on the injection side [2].

These transformers were energised from the tertiary winding using a three-phase supply from a diesel generator connected via a intermediate transformer to the tertiary winding (Figure 2, Figure 3). In our cases the capacitor bushings with tap-off connectors are available and the measuring impedance is directly connected to the bushing tap-off.

Figure 3: On-site induced HV test on transformer

Figure 3 shows a large 250 MVA, 400/120/18 kV transformer under dielectric testing in a substation when the high voltage electric AC tests was perform with a motor-generator mobile group built into a container.

The partial discharge measurement is sensitive tool to verify the insulation of power transformer. The PD source is decoupled via a capacitive sensor on the bushing bottom through measuring impedance. The signals will be amplified via wide band amplifier; each bushing has its own sensor. These signals are then transferred shielded cable the measuring equipment.

The IEC 60076-3 standard prescribes a maximum allowable limit of 100 pC for partial discharge noise level according to the IEC 60270 during induced voltage testing. The PD measuring system was Tettex 9120 in wide band mode (40-200 kHz). The PD impulse was done from test tap of HV bushings.

5 CASE STUDY OF THERMALFAULT

This “Case Study” is really illustrating the on-site refurbishment of transformer with thermal fault. This transformer (22 years old, 250 MVA, 400/120/18 kV core type autotransformer) from 1984 to 2006 was in parallel service with a similar unit, but the temperature of this unit was always higher than “the neighbouring unit temperature”. The dissolved gas-in-oil-analysis (DGA) signatures had been always indicating a high temperature overheating failure involving cellulose insulation material (thermal fault between 300-700°C or over).

Regarding the diagnostic data it was obvious that the windings weren’t damaged but they have got local overheating area therefore at first step it had to try to repair on-site and not in the factory. After the removing the oil the un-tanking technique was used with the CRAB lifting system. After the un-tanking processes, it was found that the paper insulation on a short section of the OLTC connections was almost burned out, the insulation was carbonised and the copper conductors were consumed in a great extent (Figure 4).

Figure 4: paper carbonisation and burning out phenomena on the OLTC connection

Regarding the special profile of the copper conductor and the carbonised insulation it was obvious that during the short opening hours it is impossible to change this part that's why it had to open the transformer once more. During the first part of the overhaul, the iron core and the coils were retightened. After consulting the OLTC factory a decision was taken about the prefabrication of the insulated copper conductor with special profile and building in to the transformer during the second opening of the transformer.

6 CASE STUDY OF WINDING LOOSENING

This "Case Study" is really illustrating the on-site refurbishment of transformer with "winding loosening problem". In this case study the investigated unit was 28 years old, 250 MVA, 400/120/18 kV, core type autotransformer, consequently it sustains a number of short circuits during its service life, mostly during the switching-on process. The "classical diagnoses" of the transformer didn't predict any fault but vibration measurements (sensors on wall of the tank and hydrophone used directly through the oil), the FRA (Frequency Response Analysis) and endoscope pictures indicated that the mechanical condition of transformer has been changed. Vibration measurements (sensors on wall of the tank and hydrophone used directly through the oil) were carried out in the "no-load" and "load" mode, and during the "switch-on" process and the results show looseness of the core and windings.

After a long-term service of transformer it was obvious the reduction in clamping pressure but in this case the loosing of core and the winding was relatively large (Figure 5). In this case, the main goal is to extend the lifetime of the active part through targeted maintenance operations on the repressing the windings and core. But if the transformer is open the main equipment parts, namely, the OLTC and its control panel, the cooling system, the cabinets have been refurbished, too.

Figure 5: strong looseness in the core of transformer

After the opening the transformer the first inspection always consists in checking that the transformer's active part does not suffer from an incipient fault, the geometric deformation of the windings, displacement of winding (significant displacement in the axial direction), buckling of winding (significant displacement in the radial direction). It is important to have an estimation of the residual tightening of the windings as this significantly conditions the mechanical withstand of the transformer at the time of a short circuit. During the overhaul, the iron core and the coils were retightened. At the end all parameters of transformer after the repair, including its dielectric loss factor, RVM spectrum, the reduction of vibration, etc. meet the requirements. The decision to carry out onsite repairs of this transformer at the stations has resulted in considerable time and cost saving and helped in maintaining desired availability. After five months repair the transformer was switched back into service and has operated without any further problem ever since.

7 CASE STUDY OF HIGH PD

The investigated unit was 36 years old (160 MVA, 220/126/10,5 kV, made in 1971), 3 phase, core type autotransformer, consequently it sustains a number of short circuits during its service life, mostly during the switching-on process because it works for a high current research institute. The "classical diagnoses" of the transformer didn't predict any fault but vibration measurements (sensors on wall of the tank and hydrophone used directly through the oil), the FRA (Frequency Response Analysis) and endoscope pictures indicated that the mechanical condition of transformer has been changed.

The main target of the repair was the pressurising the windings and the core and at the end of refurbishment the other parameters don't change or should be better. During the overhaul, the iron core and the coils were retightened. At the end all parameters of transformer after the repair, including its dielectric loss factor, RVM spectrum, the reduction of vibration, etc. meet the requirements.

But after the on-site refurbishment during the induced HV test they have realised that PD within one of the three phases was over some hundred thousands pC at 10 % of nominal voltage. Regarding the electrical PD results it can be realised that the PD source would be in phase „B" and it was suspected to be partial discharge on the top of the 120 kV winding. But in order to localize the possible sources of acoustic emission signals, an Acoustic Emission test was performed using 20 piezoelectric sensors distributed on the transformer tank and a real time three dimensional (3D) location software help to find the location of faults. By the help of the electrical and acoustic PD measurement the source of fault was localized basically in the conductor near the winding of phase “B” of the autotransformer tank. It was proved that the electrical and acoustic PD technique was very effective way to find the PD source. After opening and disassembling the transformer it was observed that the conductor which makes the connection with the electrostatic shield has wrong connection (it was brittle connection but now flexible). Due to this deficiency the shield was not connected during the 100 Hz vibration and large discharges generation could appear.

If the transformer is not energised (in no-load case), when the test voltage was below the 30 kV, the vibration of the active part is relative low, it can be measured a continuity in the contacts. But during higher test voltage level, when the vibration was growing step by step, it can be realised that this contact was getting worse step by step and it can be measured electrical PD over hundred thousand pC. It was also discovered that in the same time the AE test indicated large signals near the above mentioned regions. After disassembling joint and cleaning the copper conductor covered with paper, it can be seen the wrong contact which might give the large PD. In several cases, HV induced voltage with partial discharge electrical and acoustic monitoring has been successfully used to detect and locate partial discharge in large power transformers.

We have to pay attention that electrical PD measurement could indicate the internal PD but unfortunately this method does not indicate the location of the partial discharge generation, only that a problem exists. Acoustic emission (AE) test is a non-destructive and non-quantitative testing technology that may be used to detect and locate PD in oil-immersed power transformers. The strength of the AE method is its ability to calculate the location of the fault in 3D and to assess the type of fault present at this location.

8 CONCLUSION

There is no long tradition in Hungary of the on-site repair and refurbishment of 220–400 kV transformers. But nowadays there is an important reason for utilities to be able to carry out on-site maintenance, refurbishment, repair and on-site high voltage tests which were carried out previously only in the factory. To maintain serviceability of transformers at the desired level, it is necessary to conduct major repair in due time. To good decision making it is essential that advanced suitable on-site refurbishment techniques and diagnostic tools have to be available. The successful use of on-site refurbishment several testing techniques have to us to check to efficiency of the refurbishment.

The refurbished transformers have been in serviced for years without difficulties. These cases have demonstrated that advanced on-site diagnosis methods, the induced HV tests the applied repairs were effective, reliable and economical, therefore it is promising in the future to save cost.

The results show that on-site tests, including high voltage tests, on high voltage power transformers is fully possible and reliable. It can be selected as a proven method for diagnosis and final acceptance of new and repaired or even refurbished power transformers.

Economic evaluation of repair or refurbishment of a transformer needs to take into consideration a number of factors which are not simple for precise financial estimation. Regarding the very simple estimation: the comparison the cost of new transformer and higher risk of failure a possibly higher running costs and others, the above mentioned two cases show that these on-site repair or refurbishment of a transformers probably were economic (the on-site repair cost was approximately 13-15% of new transformer price).

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