On-site transformation

TrafoSiteRepair™ combines the old with the new to improve power transformer availability

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A reliable supply of electric power is essential and a failure of any one of the installed equipment is expensive not only for utilities but also for the manufacturing industry. A power utility may lose revenues and incur penalties for non-delivery, while the failure of an industrial transformer, for example, may lead to lengthy and therefore costly downtime. Using dedicated solutions, ABB has been helping power utilities and electricity intensive industries to improve equipment and production efficiency as well as reliability by minimizing the number of failures, and if one does occur, by getting the equipment back into service in the shortest possible time.

However, outage time has been reduced even further by newly developed ABB processes which allow transformer repair, refurbishment or retrofit to be carried out completely on-site. Packaged and marketed globally under the name of TrafoSiteRepair™, it is a combination of years of experience and state-of-the-art technology, and some 200 units in 25 countries are evidence of its success.

A transformer fails in an aluminum smelter plant but production isn't immediately affected because the plant owner had the foresight to build redundancy into the system. However, he knows that the loss of another key component will be expensive in terms of downtime and loss of output, and therefore the transformer must be repaired or replaced as soon as possible.

Normally a power transformer can be maintained and retrofitted on-site. However, major repairs, such as repairing or replacing the windings, mean the transformer must be transported to a factory where the required space and equipment are available. If the transformer is large and the distance to the factory great, the time it takes the component to get there, not to mention the costs and risks involved, will strongly influence when the transformer can resume normal operation. Unfortunately this could take anywhere from 2 to 24 months before it is fully back up and running. To overcome these problems, ABB began work some years ago to develop processes that allowed engineers to perform major repairs on-site.

The result is an innovative process that combines the old with the new. With it ABB can now not only repair and have the transformer back in operation, on average, in less than seven months, but the quality of the repair work done can even be improved. Known as TrafoSiteRepair™, it is a solution for repairing, refurbishing and retrofitting transformers on-site. It includes verified repair processes that are of the same quality and standard as those used in a factory environment. To date, some 200 units, which include utility, industrial and HVDC transformers and reactors, have been repaired or refurbished – and in many cases the latest transformer technology has also been applied, resulting in devices with a higher rating.

The TrafoSiteRepair™ process

A typical factory and workshop that manufactures and repairs high voltage equipment is characterized by its orderly layout, cleanliness and well-controlled atmosphere. It also possesses heavy lifting equipment, special tools and fixtures, high voltage test laboratories, and experienced operators for each step of the process. The same indoor environment must exist on-site if various transformer repair scenarios are to be successfully carried out. A temporary workshop, equipped with the same type of tools and equipment as used in a factory, will be set up if a repair area is not immediately available at a customer site. Heavy lifting equipment, if needed, will also be supplied. This is required because the largest transformers, with a weight of up to 400 metric tons, need their active parts to be untanked and tanked.

While the factory can be brought to the transformer as opposed to the other way round, certain obstacles had to be overcome to make this possible. The first centered on the need for reliable transformer testing during the different stages of repair, refurbishment or retrofit. However it was the high-voltage test, the final test performed before installation and commissioning, that created somewhat of a challenge. In the past, motor-generator sets were used for high-voltage testing of power transformers on-site. Motor-generator sets are quite heavy and therefore difficult to transport. They also lack the flexibility to adapt to the test frequencies of different transformers, requiring instead a high rating relative to the test power required. Additionally, on-site maintenance requirements have to be taken into consideration. To overcome the portability and flexibility problem, ABB has developed a sophisticated *Mobile High-Voltage Test System* together with test system suppliers and suppliers of high power electronic converters.

TrafoSiteRepair™ is a solution for repairing, refurbishing and retrofitting transformers on-site and is a combination of years of experience and state-of-the-art technology.

The second hurdle concerned the drying system. Moisture is the enemy of organic insulation (eg, insulation paper) in power transformers because it speeds up the degradation process, which in turn affects the reliability of the transformer and reduces its technical lifetime. It is therefore of the utmost importance to dry the insulation paper in a transformer whenever it has been exposed to air. To do this successfully, ABB developed an innovative on-site transformer drying system based on a low frequency current. Known as the *Low Frequency Heating drying system*, it is used in combination with the hot oil spray method, and when compared to other drying methods it reduces drying time considerably to provide a more than satisfactory moisture level of below one percent.

These two innovations are discussed in greater detail in the following paragraphs.

Mobile High-Voltage Testing System

ABB's Mobile High-Voltage Testing System can be used to test even the largest power transformers available. A complete testing laboratory is contained within a 40-foot (about 12 m) container that can easily be transported over land sea and air 1a-1c. At the heart of the system is a powerful static frequency converter which can generate the required test power in the frequency range between 40 and 200 Hz. This enables tests to be performed at the most favorable frequency – as determined by internationally agreed-upon standards to minimize the required power for the test. The mobile test system performs applied and induced voltage tests, which can be combined with the partial discharge (PD) measurements to evaluate the integrity of the equipment. In addition, measurement of no-load losses and impedance may also be performed.

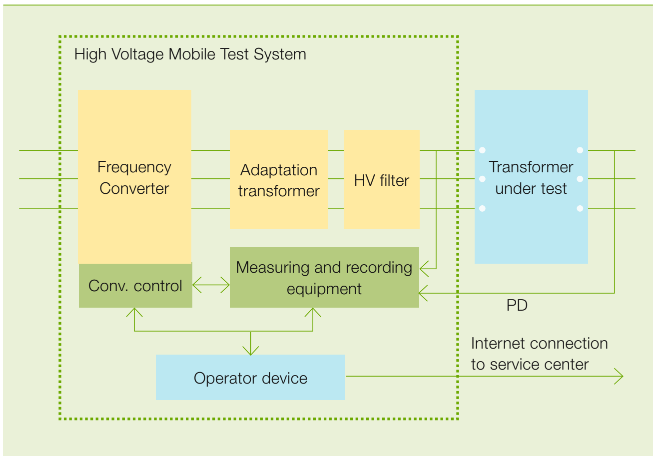
The set-up of an induced voltage test is shown in 2. In this scenario the frequency converter can be tuned to the self-compensating frequency of the test set-up, and in the case of a

1a The Mobile High-Voltage Test System, built into a 12 m container, arrives on-site

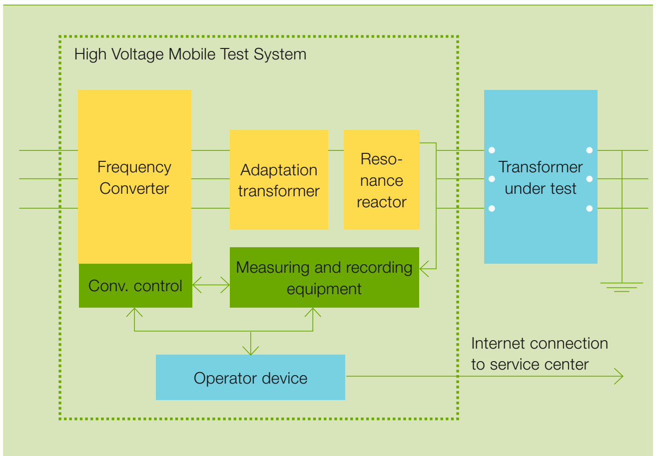
1b A typical set-up for transformer testing at a nuclear power plant

1c Mobile High-Voltage Test System control room

2 Induced voltage test set-up



3 Applied voltage test set-up



power transformer, this is normally in the range between 70 and 120 Hz. By performing the test at this frequency, the power required for the test circuit will be limited only to the active losses. The adaptation transformer is designed to match the normal voltage range applied to the tertiary voltage windings of power transformers.

For an applied voltage test, a resonance circuit is formed by the capacitance of the test object and the resonance reactor of the test set-up 3. These two components define a certain resonant frequency which is automatically detected by the static frequency converter control system.

Drying power transformers on-site

Maintaining the dryness of the insulation is of the utmost importance. Windings and insulation components are manufactured at one of ABB's transformer factories and are then vapor-phased and impregnated. Prior to shipping and assembly, they are carefully packed to maintain the required level of dryness. However, during the repair process, the insulation paper and cellulose components are affected by exposure to air during assembly and must therefore be properly dried. Moisture not only speeds up the degradation process but it can also have a direct impact on the reliability of the transformer as water droplets can lead to an internal short-circuit.

A typical drying process for power transformers uses vacuum and heat, ideally at the same time. But a vacuum thermally insulates the inner part of the transformer (much like the workings of a thermos flask) making heat transfer to the windings virtually impossible with external heating. Instead, conventional site drying processes normally include a heat cycle followed by a vacuum cycle. These processes can last up to several weeks before the correct moisture content is reached. Other disadvantages include:

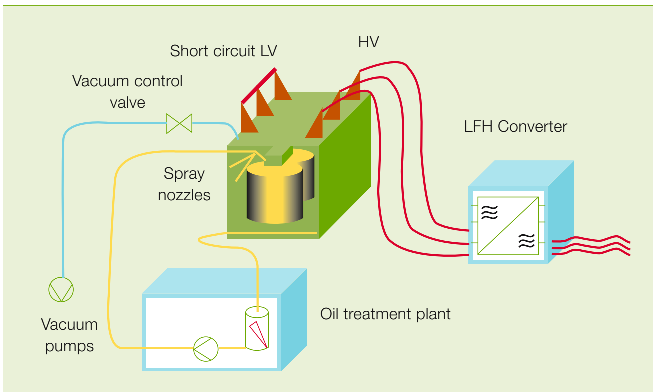
- Limited drying temperature as the heat transfer media is oil.
- A substantial temperature drop during the vacuum cycles because of the energy needed to evaporate the moisture.
- Several heating cycles are needed which expose the insulation paper to heat and oxygen, stressing the insulation.
- Oil spray processes cannot reach the inner part of the windings because of a protective cover.

To overcome these disadvantages, ABB developed its new on-site transformer drying system known formally as Low Frequency Heating (LFH). LFH, together with the hot oil spray method 4 and 5, uniformly heats the transformer low- and high-voltage windings in a vacuum using a low frequency (of approximately one hertz) current. The LFH system heats the windings from the inside while the hot oil spray method heats the outer parts of the insulation system. The main advantage of this process is the speed at which drying can be achieved. When compared with effective systems like hot oil circulation or hot oil spray, LFH increases drying speed by a factor of between two and four. The hot oil and vacuum or hot oil spray processes are still used with TrafoSiteRepair™ and add to the quality of the repair work, but LFH is considered the most effective solution when repair time is critical.

The DFR method

Once drying has taken place, the remaining moisture level in the cellulose insulation of a transformer needs to be determined. This has traditionally been done on samples and test blocks taken out of the

4 Plant concept for a mobile LFH drying process in combination with hot oil spray

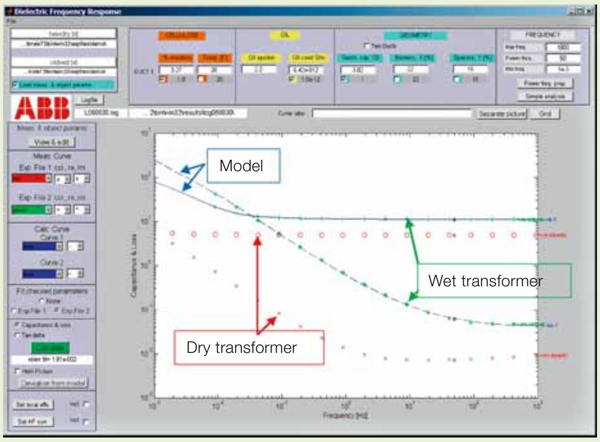


transformer using the Karl Fisher method (KF). ABB has developed an alternative method using a recently developed diagnostic tool, a Dielectric Frequency Response test (DFR) for transformer insulation system testing. This new method compares power factor measurements over a wide frequency range – provided by the DFR test – with a transformer model that is based on the dielectric properties of oil-impregnated cellulose at various conditions. The detailed information required for the model is obtained from transformer insulation system manufacturing drawings.

Since the effect of moisture and ionic contamination on the dielectric properties of the insulation system is more pronounced at low frequencies, the preferred measurement frequency range is between 1 mHz and 1 kHz. The dielectric properties evaluated by the DFR test are the real and imaginary capacitances (or permittivities) and the dissipation factor. In 6, an example of a DFR measurement for a transformer with 0.5 and 3 percent moisture is shown.

This DFR measurement is then compared to the model that represents the transformer insulation materials and structure that has been measured. In the modeling procedure, the design information and DFR test data described above are the inputs. An algorithm calculates the response of the composite system model and the “moisture in cellulose” and “oil conductivity” values are then optimized to form a best-fit of the calculated response curve to the measured DFR data.

6 Graphical representation of a Dielectric Frequency Response (DFR) test for a transformer with 0.5 and 3 percent moisture. The model is fitted to the transformer with 3 percent moisture



5 On-site drying of a 750 MVA/500 kV core type autotransformer with LFH heating combined with hot oil spray

The two main advantages of this method over the KF one are:

- The condition of the insulation may be assessed without having to open the transformer.
- Measurements taken at multiple frequencies provide more information which makes it possible to distinguish properties of both the cellulose and oil insulation separately.

In addition, DFR is a non-destructive test that provides an overall evaluation of the moisture within the bulk insulation more precisely than KF tests on local paper samples. The assessed moisture is more representative than that of a dew point measurement, which is sensitive to surface moisture rather than the moisture of the bulk insulation. The DFR test, when compared with a power factor test, can better differentiate between moisture versus contamination, and moisture in the paper versus higher oil conductivity. And finally, assessing the moisture on a unit after repair and before it is put back into service is difficult with an oil sample since the accuracy of the evaluation is poor at low temperatures. The DFR test has also proved useful in discovering other transformer insulation defects such as bad core grounding or carbon tracking deposits. For these reasons, ABB uses DFR as a quality control tool after repair.

The on-site advantage

Repairing, refurbishing or retrofitting power transformers on-site, irrespective of whether they are located in transmission or distribution substations, power generators or power-consuming industries, has long been accepted as the best method of getting units back into service in the shortest possible time. ABB’s TrafoSiteRepair™ offers greater speed than ever before by minimizing the outage time of the transformer, the unavailability of the power supply and more importantly, the loss of revenues for the owner. It is the result of innovative processes created in an innovative environment by innovative people.

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