Life Extension Solutions for Ageing Power Transformer

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Abstract

Résumé:
Serventions on a transformer, beyond ‘normal’ maintenance and repair, to remedy its problems, restore the condition and postpone a predicted functional, economic or reliability end of life. It is applicable but not limited to the aged transformers (approaching their end of life) with or without defects or faults, functional or failed.
This paper will mainly focus on the life extension solutions for aged transformers which will slow down the ageing rate of their cellulosic / oil insulation system. This ageing rate is directly linked to the following factors:

- Temperature
- Moisture
- Oxygen

Some on-site life extension solutions are proposed in this paper, which are cost-effective, easy to implement and easy to maintain.

Authors
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Life Extension Solutions for Ageing Power Transformer Sihui CHEN GE Renewable Energy Grid Solutions Massy, France Abstract—Life Extension of transformers is defined as a set of major interventions on a transformer, beyond ‘normal’ maintenance and repair, to remedy its problems, restore the condition and postpone a predicted functional, economic or reliability end of life. It is applicable but not limited to the aged transformers (approaching their end of life) with or without defects or faults, functional or failed. This paper will mainly focus on the life extension solutions for aged transformers which will slow down the ageing rate of their cellulose / oil insulation system. This ageing rate is directly linked to the following factors: - Temperature - Moisture - Oxygen Some on-site life extension solutions are proposed in this paper, which are cost-effective, easy to implement and easy to maintain. Keywords—Power transformer; temperature, moisture, oxygen, cooling upgrade, drying, cost-effective, on-site I. INTRODUCTION Life Extension of transformers is defined as a set of major interventions on a transformer, beyond ‘normal’ maintenance and repair, to remedy its problems, restore the condition and postpone a predicted functional, economic or reliability end of life. It is applicable but not limited to the aged transformers (approaching their end of life) with or without defects or faults, functional or failed. There are several main factors that reduce the safety margin of transformers: moisture, oxygen, temperature, particle contaminations, electrical and mechanical stresses. A better control of these factors will reduce the rate of insulation deterioration and could be part of life extension. This paper will mainly focus on the cost-effective on-site life extension solutions for aged transformers which will slow down the ageing rate of their cellulose / oil insulation system. This ageing rate is directly linked to the following factors: - Temperature - Moisture - Oxygen Temperature: one of the key ageing factors for cellulose insulation system of power transformer is temperature. If it is possible to reduce the oil and winding temperature, the ageing rate of transformers will be slowed down. This is one of the potential life extension solutions which is not too difficult to carry out and in most of the cases not very costly. Thus, cooling upgrade solution on external coolers is one of the efficient solutions for life extension. Moisture: water is also an important ageing factor for cellulose system. Keeping the transformer dry is an efficient way to slow down the cellulose ageing, for example: - Upgrading the oil preservation system to a modern (sealed) one - change to new type of breathers - On-line dryers Oxygen: low oxygen environment will not only slow down the ageing process. Retrofit of oil preservation system will also help to reduce the oxygen content in the oil. These on-site life extension solutions are easy to implement, quite cost effective and will allow asset managers to optimize CAPEX, extend aged transformer life and better manage the replacement planning of transformers. II. TEMPERATURE CONTROL AND COOLING UPGRADE As mentioned before, temperature is one the key aging factors for cellulosic paper. The good control of oil / winding temperature will avoid the excessive aging of solid insulation structure and extend the transformer life. Either degraded operation mode (reduced rating) or cooling upgrade by keeping the same rating can reduce the oil / winding temperature and slow down the ageing process. The inconvenient point of degraded operation mode is that the transformer will not be able to deliver the target power and is not really expected by operators. As for cooling upgrade solutions, the most cost-effective solutions are upgrade of external coolers and cooling control cubicles. There are three types of coolers in application of power transformers. Radiator /fan bank (on-tank or separated), air blast cooler and water cooler. The advantage of the radiator bank is that it would be simpler to design in spare capacity and the cooling could be staged (AN and AF). Of course, when there is at least one ON cooling mode, radiator option will then become the only choice. The design of air blast coolers will generally follow the philosophy of one cooler redundancy. They would be smaller and therefore more suitable to the space constraint. The same for water cooler. The air blast coolers/water coolers are generally more expensive than radiators in dissipating the same heat losses. Moreover, the main constraint for water cooler is that the big quantity of water should be continuously available. To have mineral oil "close" to water source doesn’t always meet the safety requirement of some industries since any leakage of mineral oil could pollute the water source. For radiator / fan type coolers, adding fans either on the bottom or on the side of radiators is quick and cost-effective solutions to improve the cooling efficiency (fig. 1). The fan speed and radiator panel size should be studied to reach an ideal coverage of blown surface of radiator panels. Speed variable fans could also used to optimize the temperature control and noise in function of loading. If the surrounding space is adequate, adding radiators is also possible solution for cooling upgrade. Radiator header collectors could be used to replace the on-tank design. In this case, on-site oil treatment system kit will be necessary for oil treatment and filling after upgrade. Cooling control logic could be also part of upgrade project. A good on / off point for pump and fan control will be essential for smooth transformer temperature evolution despite the variable transformer loading profile. This will also help to avoid overheating period and slow down the ageing process of solid insulation system. OTI and WTI are used to switch on / off the pumps and fans, also to activate the alarms and trip off. When the loading variation is big and fast, WTI should be used to control both pumps and fans. Double gradient type could be used. An earlier start of pumps and fans could greatly reduce the overheating period between cooling stage transition. Fig. 1. Example of adding fans, on the side and bottom of radiators As for compact coolers (air blast coolers and water coolers), the solution is simpler. Adding coolers or replacing old ones by more efficient ones can easily reduce the transformer temperature. For aged transformers, the total oil flow should be maintained to the similar level as before, since the transformer solid insulation could be aged and fragile. Even a small increase of oil flow could lead to winding insulation failure. Therefore, an upgrade of pumps is not really
recommended in many cases. Generally, the cost of cooling upgrade is only 10% to 40% of a replacement by a new transformer. Depending on the original design, cooling upgrade solution can reduce the top oil temperature and winding temperature by a range of 3-10K. The outage time on site is generally less than 1 week. III. TRANSFORMER MOISTURE CONTROL A. oil conservator retrofit The moisture in transformer could enter in different ways: - The tank and cooler gaskets by diffusion - The insulation degradation - Oil / Air interface in the conservator during load cycles. Free breathing transformers are generally much wetter than those sealed ones due to the free contact between conservator oil and free air. The traditional breathers are often saturated and requires regular replacement. These transformers are generally aging much faster than others. For new transformers, it is recommended to install the sealed type (with rubber membrane or rubber bag, fig.2) oil conservators. For old transformers, a retrofit of air bag to the oil conservator could stop moisture ingress from conservator breathing system and greatly extend the transformer life. However, the retrofit of air bag should be done together with drying of transformer if the transformer is already very wet. If retrofitting the air bag without drying the transformer, the life extension effect could be very limited. This retrofit work requires certain outage time, a strict on-site replacement process and very qualified people. Fig. 2. Example of air bag inside oil conservator The advantage of air bag is that it can both control the moisture ingress and the oil contact with free air (restricted oxygen exposure). B. Breather retrofit 1) Refrigeration breather Another retrofit solution for free breathing transformers is to replace the traditional breather by Drycol refrigeration breather. This is a simpler and cheaper solution which requires less outage and less qualified workers. Fig. 3. Example of Drycol refrigeration breather How Drycol works, referred to fig 4: - Act directly and continuously on air in the conservator tank - A series of thermostatic elements tuned to alternately cool and heat the units vertical duct cyclically in continuous repeated cycle extracting moisture as frost and ice and melting it to escape via a drain tube - Dryness of air in conservator tank causes moisture to migrate from the oil to air in the conservator, resulting dryness of the oil causes moisture to migrate from the insulation to the oil and air for removal Fig. 4. Mechanism of Drycol 2) Auto rechargeable silica gel breather The auto rechargeable silica gel electrical breather has the following advantages compared to the traditional silica gel breather: - Automatic recharge with self-learning system (improve the setting of recharge by humidity monitoring) - Maintenance free - Quick and easy installation - Heating system for silica gel regeneration Fig. 5. Auto rechargeable breather C. On-site drying solutions There are many existing methods for on-site transformer drying. Not easy to choose an ideal on-site drying solution. Hot Oil Circulation + Vacuum: Diffusion coefficient of humidity through cellulosic material is drastically increased if we add vacuum and temperature in the drying process. For this reason, this method is extensively used for drying transformers at site. Hot Oil Spray + Hot Oil Circulation + Vacuum: In certain types of transformers (for example shell type transformers), it is difficult to heat some parts of the solid insulation with the previous method. For this reason, in these cases it is common to add Hot Oil Spray Phases in the process, to assure a proper drying in the whole mass of cellulosic material. Low Frequency Heating (LFH) + Hot oil circulation or Hot Oil Spray: Keeping a high and homogeneous temperature in the solid insulation (limited by depolymerization of the cellulose) is essential to reduce the total duration of the drying process and to assure the result. Low Frequency Heating consists of the injection of a percentage of the rated current through the windings in short-circuit condition, at a very low frequency (usually below 1 Hz), in order that the applied voltage is only a small percentage of the Short-Circuit Voltage of the transformer. Current injection is completely supervised by the LFH control equipment. During the complete drying process, Low Frequency heating phases are combined with other Hot Oil Circulation and / or Hot Oil Spray phases. Total process duration is minimized, and the final quality of the drying is assured. However, all the process above can take from days to weeks: - Unit stays de-energized - Afterwards, must be refilled with oil and electrically tested - Vacuum in the tank could lead the failure in the sealings - High outage costs All the solutions above require specific on-site equipment and well qualified people to execute the drying process. Thus, generally high outage costs. On-line drying technologies: On-line drying device is a small device connected to the operating transformers directly via existing valves to continuously remove water and particles from the oil. It also acts as the transfer medium to extract water from the paper insulation in a power transformer. There are several types of on-line drying filtering technologies. In this paper, we mainly focus on two methods: - Cellulose cartridge filters - Molecular sieve filter The advantage of on-line drying is that the transformer is heating up itself. The moisture will move from solid structure, especially the thick insulation structure to oil due to moisture equilibrium between oil and paper. This is dynamic and long process. On-line process is more adequate for a continuous drying process without overheating transformers. It is recommended to keep oil temperature over 50°C to guarantee a good efficiency of the drying solution. The installation requires generally very short outage. No special qualification is required for the on-site installation. Moreover, no requirement on tank vacuum resistance, it is applicable for all types of power transformers, especially for aged transformers with out-of-date design. An advantage of the cellulose cartridge system is that the cellulose cartridges can be automatically regenerated at set intervals, thereby avoiding the need for replacement. For molecular sieve filter, more and more drying device are equipped with warning system to inform users of the saturation of filter bottles and then necessity of replacement. Now, it also exists molecular sieve model with auto regeneration, which is less common than cellulose cartridge filter In this case, the filters could be also regenerated automatically. Zero maintenance is required. The on-line drying solution with different filtering technologies, could be fixed (fig 6) or mobile (fig 7). The users could choose to install the device to one transformer permanently or share several mobile devices within one fleet. Permanent / short (up to 3 months) / long term system (18-24 months) is available on the market. The molecular sieves saturated quickly when the initial WCP exceeded 4% and requires regular replacement besides auto regeneration type. Their lower rate of water removal suggests that they are more suitable for keeping a transformer (<3%) dry than for drying a very wet transformer. The cellulose cartridge filters were more efficient in drying a wet transformer (>3%), i.e., they lowered the WCP faster than the molecular sieves because they operated with a pump using a higher flow rate. These two on-line drying technologies are cheap, quick, easy and low risk solution for on-site transformer moisture management and transformer life extension, applicable for all types of power transformers and...
CONCLUSION

With an ageing installed base worldwide and operational/financial constraints to replace a transformer, asset and operation managers are looking for solutions to optimize the performance of their installed assets and to extend their life with a minimum cost. The ageing of cellulosic insulation system of power transformers is an irreversible process and refurbishment of windings could generally lead to a replacement of transformers. Therefore, all the solutions which help to slow down this process could be considered as life extension solutions. This paper presents the most cost-effective on-site life extension solutions for power transformers. Generally, they are cheap, easy to install and easy to maintain.


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