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DEFECTS AND DAMAGE TO SUPPORT STRUCTURES OF BIG POWER TRANSFORMERS AS A REASON OF SOIL CONTAMINATION

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Abstract
The paper presents selected problems of ecological safety of typical transformers footing structure. As a result of numerous faults caused by inappropriate design solutions as well as manufacturing and utilization, oil tanks being a part of support constructions very often do not meet conditions of tightness. Such a situation causes a threat of subsoil and underground water contamination with toxic oil. Based on many own observations, typical faults and damage have been presented and possibilities of their repair have been indicated.

Streszczenie
W artykule przedstawiono wybrane problemy ekologicznego bezpieczeństwa konstrukcji posadowienia typowych transformatorów. Wskutek licznych wad spowodowanych przez niewłaściwe rozwiązania projektowe, wykonawstwo i eksploatację, wanny olejowe wchodzące w skład konstrukcji wsporczych często nie spełniają wymaganych warunków szczelności. Taka sytuacja powoduje ryzyko skażenia toksycznym olejem podłoża i wód gruntowych. Bazując na licznych obserwacjach własnych, przedstawiono typowe wady i uszkodzenia oraz wskazano możliwości ich napraw.

Keywords: **Support structure; Oil tank; Transformer; Oil; Environment contamination.**

1. INTRODUCTION

Contemporary power industry, based on big power plants of different types, requires transmission of great quantities of power to significant distances. Only transmission lines of high voltage, most often 110 kV, 220 kV and 400 kV (in Europe), and additionally 800 kV (North America, Asia) can handle this problem. Higher voltages are not used in practice, however, construction of transmission lines of voltages 1000 kV and 1200 kV [1] is considered in China and India.

The need to use such high voltages results from the two basic reasons. First of them is concentration of power production in individual sources of great power, such as huge water-power plants or nuclear power plants. It causes a need for transmission of great quantities of power to long distances, ranging even up to hundreds or thousands of kilometers. The second reason, of economic nature, is often related to it and it is the cost of transmission. In case of relatively low voltages, parallel transmission is necessary, which requires construction of many transmission lines. Moreover, with low transmission voltages, power losses are much bigger than in case of EHV (Extra High Voltage) networks type. Obviously, power transmission with the use of EVH type of lines requires transformers, both “at the entrance”, when the power of relatively low voltages is generated as well as “at the exit” when the tension after transmission needs to be lowered to the value safe and useful for consumers.

First transmission system requiring transformers was presented already in 1891 during the exhibition in Frankfurt am Main. From the present point of view transmission line presented there was of relatively low voltage as it was only 20 kV, but already two years later a commercial solution was employed in Sweden, connecting water-power station with iron ore mine located 10 km away.

In the beginning transformers were used for local connections of power plants with big industrial consumers. In Europe the precursor of commercial transmission lines was Sweden, practically not having mineral fuels but having at disposal a great water-power potential, though substantially distant from the potential consumers. It was in Sweden in the 50s of the twentieth century where the first transmission line in the world of rated voltage 400 kV, length abound 1000 km and transmission power 500 MW was put to use. Soon lines of this type became standard in Europe.

In North America effective use of big water-power plants (Canada) and thermal power station (USA) required even higher industrial voltages which resulted in introduction of the transmission lines of voltage 735 kV (further standard 800 kV) in mid 60s by Hydro-Québec company and in USA 765 kV [1].

In Poland production of transformers began in the 20s of the twentieth century, whereas first transformers of the top voltage on the level of 150 kV were produced already in the 30 s. First transformers after the war of the voltage 110 kV were manufactured in Łódź in 1953. By mid-60s most of the net transformers were imported, however, after opening of a new factory in Łódź import covered only transformers of top voltage 400 kV and 750 kV as well as supplementary 110 kV. First Polish transformer of voltage 220 kV was made in 1967 and of the voltage equal 400 kV in 1971.

At present professional power industry utilizes over 230000 of transformers. This number includes around 3300 nos. of devices of top voltage 110 ÷ 400 kV including around 80 nos. of transformers 400 kV, a bit over 200 nos. of transformers 220 kV and about 3000 nos. of transformers 110 kV [5]. All these devices use transformer oil, playing the role of both the insulator as well as coolant. The amount of oil in the transformer of top voltage 110-400 kV is 60 ÷ 80 tons. In most cases mineral oils are used in comparison to less often used synthetic ones. Transformer oil may include highly toxic substances such as biphenyl polychloride, furans and dioxins, very often of carcinogenic properties. Moreover, as all oils, it is inflammable.

2. DESCRIPTION OF THE PROBLEM

Data referred to in the introduction show that in Poland amount of oil only in the transformers of the top voltage 110 kV or higher is estimated on the level of a quarter million of tones. In case of the used oil, of substantial harmfulness and toxicity, a failure of a single device may cause very serious in its consequences contamination of soil within many meters radius. In case of oil penetrating into ground water the reach of adverse effect may substantially increase, and the results – in situation of oil penetrating into local water intakes (wells) – may be very dangerous.

In order to protect the environment against effects of such failures a transformer foundation is encased with so called oil tank (pit or oil tray), the function of which is to catch, in case of failure, the whole amount of oil which could leak out from the device. Due to considerable combustibility of oil, thus a danger of fire in case of a leak, total capacity of an oil tank needs to exceed oil capacity by 20% – such an excess is for extingushing substance. The plausibility of leaking oil catching the fire is reflected in the example of fire which broke out in September 2008 in Radlna near Tarnów where over 80 tons of oil leaking from the transformer 400/110 kV burned down. Luckily, in this case the soil was not contaminated as the reinforced concrete tray turned out to be tight.

3. PROTECTION OF WATER AND SOIL AGAINST OIL CONTAMINATION

According to legislation binding in European Union power branch enterprises are part of the group of subjects having impact on the environment. The consequence of such a provision is obligation to follow standards regarding natural environment protection as well as to run strict wastes management.

The basic requirement resulting from law regulations [6, 9, 10] and regarding safe utilization of big power transformers, as devices containing over 1000 liters of oil-derivative substances, is their double protection. External protection has got the form of reinforced concrete oil tank, whose monolithic structure shall take over oil leaking from a transformer separating it, at the same time, from ground and ground waters. In the past problems with tightness of oil tanks used to cause numerous soil contaminations due to contaminated storm water outflow [3, 4]. At present, according to Environment Protection Minister's Decree [8] maximal limit has been determined for contamination of storm or melt waters with oil-derivative hydrocarbons before mixing with other water or waster water on the level of 15mg/l. In some European countries this value has been limited to 5 mg/l [2, 3]. Additional requirement for storm water included in the Decree [8] is provision that the water shall not contain regular slurries whose amount would exceed 100 mg/l.

As quality tests of soils located in direct vicinity of working transformers oil tank [2] as well as the paper authors' own experience (based on prepared reports on technical condition) show, inappropriate construction or faults from an oil tank structure stage may also cause soil contamination. The most dangerous contamination may be caused by BTX compounds (Benzene, Toluene, Xylene). Environment Protection Minister's Decree [7] determines maximum threshold values for these substances. Depending on the quality of soil as well as its function (present and planned one) groups A, B and C of soils were distinguished. For instance, boundary value of soil contamination for soils in group C (brownfields, mining lands, communication areas) amounts to 100 μg/kg of dry matter.

4. DESCRIPTION OF TYPICAL FOUNDATION

Typical support structure of a transformer (fig. 1) consists of three elements: foundation itself, approach continuous footing and oil tank.

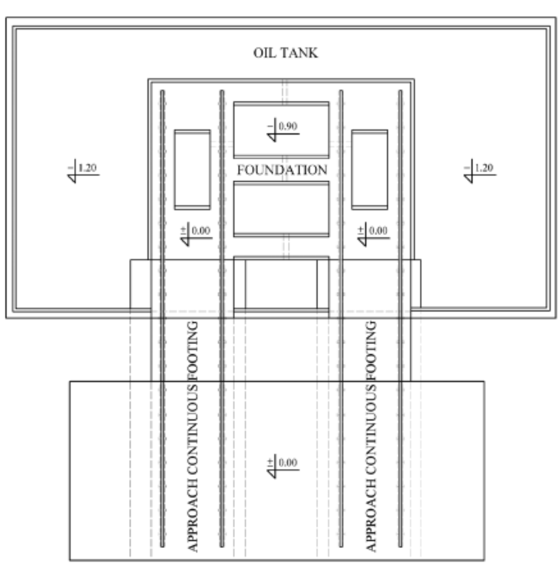

Figure 1.
Typical support structure of a transformer 220/110 kV

A specific foundation constitutes transformer's target support construction during its use and most often it is constructed as reinforced concrete block with a few big hollows. Its task is to safely carry loads resulting from the transformer's weight including technological oil to the subsoil, with account to slight dynamic and external loads. Hollows used in most cases reduce mass of the foundation block, serving at the same time as spaces allowing collection of oil or water. In appropriately constructed foundation particular hollows are of different depth with sloping bottom and they are connected with drains which enable carrying the oil or water away to the oil tank surrounding the foundation.

There are rails installed on the foundation crown (most often railway, regular-truck ones) on which a transformer is set and stabilized. In few cases foundations are constructed as full blocks or reconstructed to such, by means of filling originally constructed hollows with concrete.

Approach continuous footing is mostly constructed in the form of two reinforced concrete continuous footings based on one slab and adjusted to the foundation edge. There are rails installed on the top surface of continuous footings being extension of rails on the foundation and connected to it in the spot of the construction joint. After the approach continuous footing is used to set transformer on the specific foundation, theoretically it happens to be used as temporary parking place during repairs of the transformer or its support structure. In practice, however, most of the repairs are done without moving the transformer. In case of many structures the authors of the paper were preparing expert opinions for, transformers were not moved to the approach continuous footing .

Third of the elements i.e. an oil tank, from the load bearing capacity point of view, is a secondary structure as it carries relatively little soil and possible ground water pressure as well as load from steel grate covered with mesh or platform crates and extinguishing stone layer (fig. 2). In case of typical tank the walls were constructed as reinforced concrete monolithic walls, and the bottom as a concrete or reinforced concrete slab. In most of transformers used in Poland, of top voltage equal 110 kV or more, a typical solution with an oil tank described above was employed.

In contemporary solutions under-transformer tanks are more and more often made of stainless steel or plastic which almost automatically ensures their appropriate leaktightness. Such tanks are usually connected to underground retention tanks whose task is to catch and collect oil.

In everyday utilization, the oil tank role is to catch oil leaking from the uptight transformer's installation.

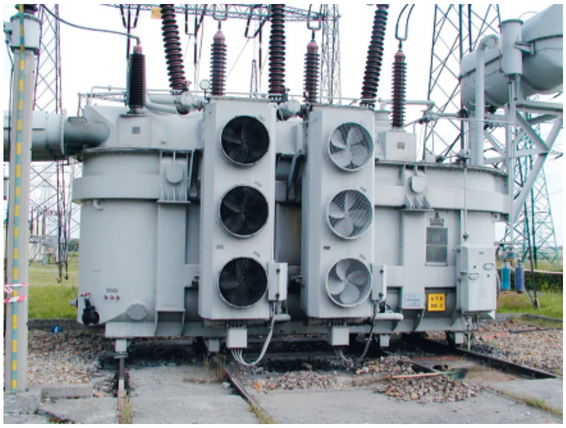

Figure 2.
220/110 kV transformer on a work station

5. CONSTRUCTION AND TASK OF TYPICAL OIL TANKS

As it was mentioned before, an oil tank is of secondary importance as a superstructure, however, from environment protection point of view it is the most important component of the whole supporting structure.

In practice there are two typical functional solutions of an oil tank. In both cases it has got inclined bottom canalizing liquid in the lowest point, but there are various ways of carrying it away.

In typical case a tank is furnished with adjustable outlet, leading to an oil separator and then to sewerage system. However, there are also tanks without outlets, supplied with sink enabling drainage of collected water.

Collecting of liquid in the oil pit results from ongoing utilization of a transformer. Approximate exploitation data show that yearly several liters of transformer oil leaks out from a typical transformer 220/110 kV. Practically, all of this amount leaks on the foundation or extinguishing stone layer and then it is washed away with storm water to the tank inside. In effect a mud layer being a mixture of oil, water and impurities precipitates on the tank bottom.

Depending on the intensity of precipitation as well as external temperature (having impact on intensity of water evaporation) part of sediments moves toward outlet or sink, and part of it permanently covers the tank bottom.

Regardless of the conditions of ongoing exploitation, a tank task is to catch all oil which could leak out from the transformer in case of its failure. It is then assumed that an oil tank, with hollows in a foundation (if such were made) needs to hold not only whole oil inside a transformer (in case of typical transformer of big power it is from 60 to 80 tons) but also extinguishing medium whose amount corresponds to 20% of an oil volume.

As it can be concluded from the above description, the basic requirement a construction of oil tank needs to meet is full tightness which guarantees impossibility of transformer oil, harmful for the environment, getting into the soil. Review of supporting structure carried out by the authors of the paper show however, numerous defects and flaws of oil tanks resulting in lack of appropriate tightness.

6. TYPICAL EXAMPLES OF FLAWS AND DEFECTS OF OIL TANKS STRUCTURES

Examples described below are based on observation and research of several support structure of 220/110 kV transformers, after around 30 years of operation.

Practically in all cases it can be noted that structure of an oil tank does not meet the requirement of tightness. The whole range of typical flaws and defects reiterated many times in the subsequent tested structures. Some of the most frequent irregularities are listed below and illustrated with photos.

The most often encountered design and constructional flaw is lack of any insulation from a tank inside side – it refers to both walls (fig. 3, 4, 5) as well as a bottom. Such a situation causes penetration of oil into the smallest cracks in concrete as well as supersaturation of the surface layer of uncracked concrete.

In practice it makes execution of any repairs or a construction tightening much more difficult as it almost entirely eliminates remedial mediums adherence to original concrete. Similarly, in most cases there was no wall insulation provided from the ground side, which in case of high level of underground waters causes leaking of underground water into a tank inside (fig. 3) and fast destruction of almost permanently damp concrete.

Generally the walls and bottom are made of very poor concrete – in best of the tested cases the concrete class was C12/15, very often , however, concrete corresponded to class C8/10. Regardless of bad concrete strength parameters, particularly shoddy was construction of a tank walls – numerous roughnesses, honeycombings in concrete were noted (mainly at joints of concreting stages) as well as parts of left

Figure 3.
Lack of a wall insulation, visible defective contact between concrete layers and dampness

Figure 4.
Lack of insulation, visible numerous irregularities, honey-combings in concrete and fragment of left shuttering

Figure 5.
Lack of insulation, visible defects of concreting

shutterings. The examples of such flaws have been shown in figures 4, 5.

In some of the structures different intensity of cracks in the walls (fig. 6, 7) and in the oil tank bottom was observed, sometimes with traces of underground water intensively leaking into a tank. It is obvious that in case of transformer failure and filling a tank with oil it would end up with reversed direction of flow and oil would immediately get into the ground around the structure.

Figure 6.
Heavy horizontal cracking of an oil tank wall, traces of ground water leakage

Figure 7.
Heavy vertical cracking of an oil tank wall, concrete sorting out, traces of leakages

Lack of an oil tank tightness in many cases resulted also from improper construction and protection of joints between basic constructional elements constituting part of foundation as a whole. The worst point here is almost always contact between an oil tank and construction of an approach continuous footing. This point is presumably faulty because in a typical construction a continuous footing disturbs continuity of a wall. It needs to be emphasized that in any of tested foundations, a contact of these two elements was properly sealed, and in individual cases (fig. 8) vertical gap on the whole height of the wall reached the width of 10 cm. Similarly, in all cases proper seals were missing at contact of continuous footing and proper foundation as well as at contact of a tank bottom with a foundation vertical planes.

Figure 8.
Gap at contact of an approach continuous footing and an oil tank wall

A separate issue is the problem of a tank capacity, essential in case of a transformer unsealing.

In case of a typical structure theoretical capacity of a tank includes hollows in a foundation as well as capacity limited by a top section of a circumferential wall, above the ground surface. Practically, in all cases evaluated by the authors upper, substantially thinner section of a wall was constructed without reinforcement and thus considerably weaker. The effect of it is great number of cracks, and in extreme cases almost entire destruction of this element (fig. 9) which results in substantial reduction of an oil tank capacity.

Moreover, due to the requirement of ensuring transformer movement, upper section of the wall on the railway subgrade width was not constructed but completed later by means of brick wall. In practice such missing part of a wall was never completed (fig. 9) or it is in very bad condition (fig. 10)

In individual cases structure of an oil tank was made only "for show" replacing monolithic bottom with sidewalk slabs laid loose on sand bed.

Figure 9.
Substantial damage to upper section of an oil tank wall, lack of the drivable section filling

Figure 10.
Damaged brick filling of transit section of the wall

7. POSSIBILITIES OF PREVENTIVE ACTIONS

Diagnostics of technical condition of oil tanks under transformers is a very difficult task. It usually takes place when a transformer is switched on, on a very limited space, with steel grate at the top, on which there is a layer of thick broken stone on steel meshes or platform grits. The structure itself is heavily dirtied with mixture of oil and permanent dirt, and many times additionally flooded with water. In effect, it is possible to notice and assess only basic, the most intensive flaws and defects, allowing to make decision about possibility and legitimacy of a potential repair.

Formulation of detailed recommendations is thus possible only after removal of broken stone and grate as well as thorough cleaning of walls and bottom surface.

An alternative activity to the repair of an oil tank is its demolition and reconstruction, in case when we want to keep a structure as reinforced concrete one.

More and more often, in case of lack of possibility or legitimacy of the repair and sealing of the existing tank, decision is made about installation of a steel or plastic tank – completely independent (after demolition of the old one), or installed in its inside. A solution frequently used at present is a tank clearly set outside a transformer outline which enables getting required capacity easily.

Therefore, a factor which decides about keeping original structure is not only its technical condition but also meeting or not meeting a requirement of appropriate capacity.

In case when technical condition of an oil tank makes its repair impossible, and at the same time it satisfies requirements of minimal, required capacity, a typical remedial and repair recommendations include: thorough cleaning of the whole structure, filling the cracks, reprofiling of defects in the selected PCC system, sealing of all structural contacts, and then – application of chemically resistant putty on the whole surface of all elements from the tank inside. It is also recommended to provide typical water insulation at the contact of structural elements and ground. Also possibility of safe removal of sludge accumulated inside an oil tank needs to be ensured every time. In many cases mixed solution is justified, with repair of walls and construction of a new bottom. Very often removal and reconstruction of upper thinner section of wall is recommended.

Finally, decision about repair or replacement of structure is often based on financial and time conditions and only then on technical premises.

A very important aspect of performing any works is a requirement to properly utilize all wastes, and in particular debris from demolished elements as well as products of concrete sand-blasting. These materials are supersaturated with used and harmful oil.

At the same time repair or replacement of a tank is usually accompanied by required repair and protection of a foundation itself and approach continuous footing - it is particularly essential due to the requirement of maintaining continuity of surface insulations.

8. SUMMARY AND CONCLUSIONS

In a typical support structure of a transformer, an oil tank is, in constructional respect, a secondary element, however, it plays an important role of protection against soil and underground waters contamination with toxic oil.

The paper presents examples of typical damages and defects of oil tanks reinforced concrete structures, observed in the structures made in 1970's and 1980's. Tanks were considered to be secondary elements and they were usually designed and constructed very carelessly.

In many actual cases both the designers as well as contractors of this part of the support structure did not think of protecting it against cracking or appearance of other kinds of leakages, and also did not provide any surface insulations. In the course of utilization most of walls and bottom structures were difficult to access and nobody was very eager to inspect them thoroughly. When bad condition became visible already in above-ground section, ineffective repairs were carried out with the use of improperly chosen materials and methods of construction.

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