Case Study of Dissolved Hydrogen Growth in Power Transformer Oil

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Background

The thermal energy generated by potential failures inside the power transformer will deteriorate the insulating oil or insulating paper and produce dissolved gases in the oil. Through dissolved gas analysis in oil (DGA), transformer status monitoring can be effectively achieved. In the case of 1212 Taipei #5 distribution transformer accident, it was found that when corona or any catalytic reactions occurred in the transformer, dissolved gas that mostly consists of hydrogen would be generated. If the hydrogen concentration rate or the generation rate is too high, there may be a risk of generating bubbles in the transformer, leading to arc discharge.

Therefore, exploring the causes and types of hydrogen growth brings the benefits of taking appropriate corresponding action quickly when transformers are abnormal, so as to strengthen the power grid resiliency.

Research contents

After 1212 Taipei #5 distribution transformer accident, Taiwan Power Research Institute (TPRI) revised the diagnosis benchmark of DGA for the fault of the power transformer in response to the risk of generation of hydrogen bubbles in the local area inside the transformer. In addition to the above measure, TPRI also investigated the historical data and their related maintenance of transformers with higher hydrogen concentration in the database to clarify the causes for the hydrogen generation of transformers.

According to the existing cases of Taiwan Power Company (TPC) and the investigation results of the laboratory analysis database, the causes for growth or high concentration of hydrogen can be roughly divided into three categories: (1) hydrogen growth caused by corona, (2) release of hydrogen from materials, (3) sample inhomogeneity, which will be described below.

(1) The cases of hydrogen growth caused by corona include: (A) poor construction of the connection component, (B) unopen of normally-opened oil valve, (C) impurities and foreign materials.

(A) Poor construction of connection component

It may cause the local strength of the electric field to be too large, resulting in corona in oil and continuous generation of hydrogen. Taking the connection of the high-voltage lead wire terminal of the transformer in Figure 1 as an example. The terminal was covered with aluminum foil longer than the design value, and the nuts were locked on the outside of the terminal during construction. Those resulted in more parallel parts of the bolt protruding from the terminal. The completion surface was thicker, so corona occurred and the value of hydrogen grew at a rate of more than 30 ppmv per month. The phenomenon of hydrogen growth stopped after the connection of the terminal and bandaging method were improved.

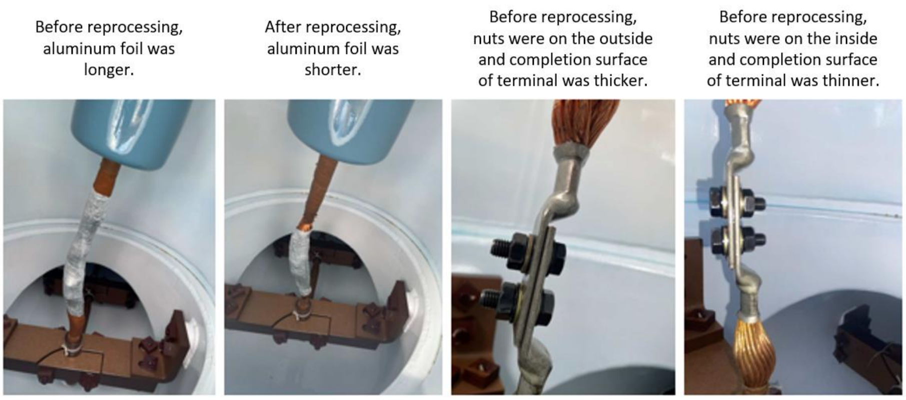


Figure 1 Connection of the high-voltage lead wire terminal

(B) Unopen of normally-opened oil valve

The connecting valve between the cable head (CHD) and the transformer will be closed during the construction of the transformer and should be reopened after construction. Otherwise, the insulating oil in the oil chamber of CHD will not be able to circulate with the transformer and lose the function of oil level adjustment, so the oil level of the oil chamber of CHD will be reduced when the shrinkage phenomenon of insulating oil occurs due to temperature change. It results in corona and hydrogen generation in charged parts unsoaked into the oil. The cases of TPC show that the phenomenon of hydrogen growth disappears after the connecting valve is opened.

(C) Impurities and foreign materials

If external impurities and foreign materials are brought into the transformer during construction, they may drift with the oil flow in the transformer, and cause corona when drifting to specific parts. It results in intermittent growth of hydrogen. In the cases of TPC, we have found that foreign materials are attached to the surface of the insulation paper of bandaged leads in the transformer. By identification, it is suspected that they are the pollutants of construction such as copper chips left over from the construction of CHD or silicone grease applied during the stress cone insertion. The phenomenon of hydrogen growth disappears after the source of pollution is removed.

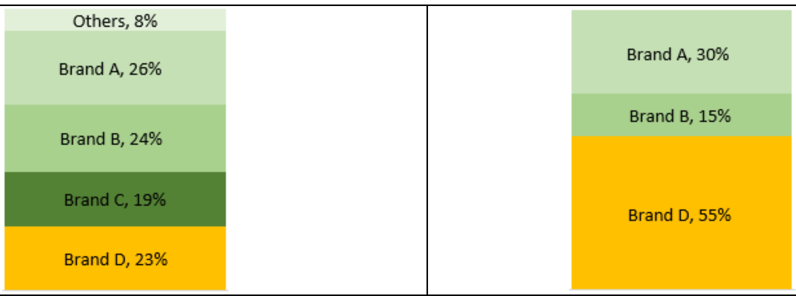
(2) Release of hydrogen from materials

Hydrogen could also be released when the materials used in the transformer is not compatible with insulating oil or the surface of the stainless steel is in contact with insulating oil which has not been dehydrogenated. In the cases of TPC, transformer cooler of a specific brand was suspected of using stainless steel materials whose surfaces had not been treated with special coatings or dehydrogenation. It results in starting to significantly grow in hydrogen of about 40% of transformers after installation, with concentrations of up to 800 ppmv or more. Most hydrogen concentration of them would slowly decline after reaching the peak in 1 to 2 years. This phenomenon is caused by material properties, not by electrical faults, so the growth rate of hydrogen should not be significantly risky if it is within the benchmark that must be noticed.

(3) Sample inhomogeneity

Due to the poor compatibility of hydrogen with insulating oil, hydrogen is easy to accumulate at the end or the upper of pipeline with poor oil flow. It affects the accuracy of transformer status diagnosis. In some cases, if insulating oil with poor circulation at the end of the pipeline is not fully discharged but directly sampled, hydrogen concentration can be as high as 7000 ppmv. However, the hydrogen concentration value is only 16 ppmv after full release. The distribution of gas compositions in poor oil flow may be extremely inhomogeneous, too. Taking the vertical distribution of dissolved gases in oil in the Bucholz relay of transformer as an example, it can be observed that compared with the oil of the transformer (hydrogen concentration value of 203 ppmv), the hydrogen concentration value at top of pipeline is higher (297 ppmv), and the concentration value at the bottom is lower (104 ppmv). In addition, the design of CHD structure may cause the inhomogeneous distribution of gas. With a poor fluidity of insulating oil in the pipeline between the transformer and CHD, the longer the distance between CHD and oil channels of each phase (farther away from the transformer) it is, the more inhomogeneous the distribution of gas is. In one case, hydrogen concentration in oil is only 32 ppmv, but as the oil channels in three-phase of CHD are farther away from the transformer, the hydrogen concentration rates increase to 81 ppmv, 112 ppmv, and 150 ppmv, respectively.

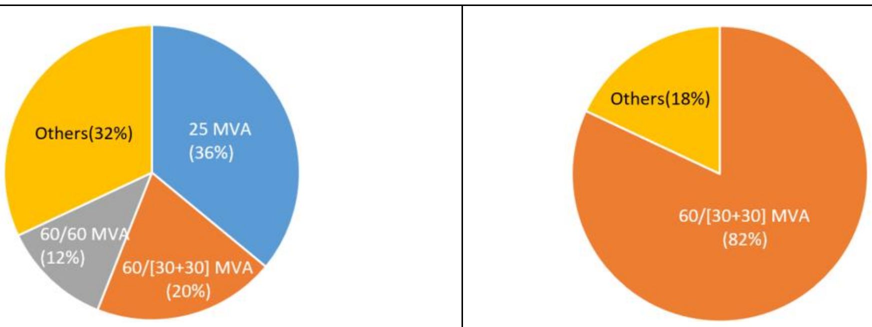
In addition to the above sources, the different designs of transformers and materials from different companies may also lead to differences in hydrogen concentration. According to the statistical data of TPC's above-10 MVA transformers, it can be found that although the transformer of brand D only accounts for 23% of total transformers, the proportion of transformers of brand D with hydrogen concentration greater than 100 ppmv is as high as 55% (Figure 2). By further analysis, it can be found that transformer of 60/[30+30] MVA accounts for only 20% of all transformers of brand D, but among those with hydrogen concentration of greater than 100ppmv, this type accounts for up to 82% (Figure 3). Compared with the design or materials of other manufacturers, transformers of brand D have a significantly higher probability of hydrogen growth, and the type of 60/[30+30] MVA is the most prominent.



(a) All transformers

(b) Transformers with hydrogen concentration higher than 100 ppmv

Figure 2 The proportion of transformers above 10 MVA of each brand of TPC



(a) All transformers

(b) Transformers with hydrogen concentration higher than 100 ppmv

Figure 3 The proportion of specifications of transformers in TPC of brand D above 10MVA

In general, when hydrogen-dominated growth patterns come from corona or some catalytic reaction, the risk is low. However, the case of 1212 incident shows that if the source of hydrogen occurs in local area of a transformer, the actual concentration of hydrogen in this local area may be much higher than the measured value, or even exceed the saturated solubility of insulating oil (about 5%). Furthermore, if bubbles in the oil are generated, the dielectric strength will decrease and the apparatus will be in a high-risk state. Therefore, when it is found there is the phenomenon of obvious growth of hydrogen, in addition to paying attention to the status of other medium and high energy key gases (such as ethylene and acetylene), the risk of bubble generation in the local area should also be considered. In addition, according to the investigation of TPRI, hydrogen may also come from other factors such as material release or sampling errors. If we only consider whether hydrogen concentration meets the benchmark and take excessive maintenance actions directly (such as shutting down for internal inspections), it will increase the operation cost and will not bring benefits of diagnosis of the status of transformer. Therefore, in addition to establishing appropriate benchmarks, further investigations should be undertaken to clarify the causes of hydrogen generation and provide panel of experts as a reference for comprehensive diagnosis, so as to effectively maintain the strength of power grid and reduce costs.