HAZARD IDENTIFICATION AND RISK ASSESSMENT OF POWER TRANSFORMERS DURING ERECTION, OPERATION AND MAINTENANCE

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ABSTRACT

The aim of the project is to carry out a study on Hazards identification, making a risk assessment of the identified hazards and recommend actions to eliminate or minimize the effect of identified hazards. Modern electric power system is made of capital-intensive assets such as alternators, power transformers, electrical switchyards, and other supporting equipment’s. Power transformers are at the heart of the electrical power generation, transmission, and distribution system. The Electrical power plants are required to ensure quality power without interruption and disturbances. This task becomes challenging due to the increasing demand for electrical power and also due to the increased competition within the energy sector. It is very essential that power transformers give quality and reliable performance with cost effectiveness. Any malfunctioning/ internal or external defects in the transformers may cause damage to the property, injury to the personal or damage to the environment. The consequences of major failures in power transformers includes, fire, explosion, electrocution, etc. The Unidentified hazards and risks may lead to accidents and business interruption may adversely affect the reputation of the organization. This project deals with the evaluation of the potential hazards related to the operation and maintenance of power transformers. This project also deals with the risk reduction measures which ultimately avoids the tangible and in tangible loss to the organization and enhances the safety of equipment, personal and environment. Recommendations shall be made to eliminate or control it for all the hazards identified during the hazard assessment. The recommendations should include the specific actions required to correct the problem.

Keywords: Modern electric power system, Electrical power plants, Hazards identification, risk assessment

INTRODUCTION

Hazard assessments and controls help build safe and healthy workplaces. They are at the core of every organization’s occupational health and safety management system. Modern electric power systems made of power transmission and distribution grids consist of copious number of distributed, autonomously managed, capital-intensive assets. Such assets comprise: Power plants, Transmission lines, Power transformers and supporting equipments. Power transformers are at the heart of electrical transmission and distribution system and as competition increases within the energy sector, so does the pressure on transformer manufacturing industry to improve safety ,reliability and reduce costs of transformers. Usually power transformers have a 20-35 year design life. In practice, a transformer can reach 60 years of useful life if it is properly operated and maintained. With the normal aging, their internal condition degrades, which increases the risk of failure. Traditionally, the evolution of these faults was accompanied with preventative maintenance programs combined with regular tests. With deregulation, it has become necessary to reduce maintenance costs and equipment inventories, thus there is a trend in the industry to move from traditional time-based maintenance programs to condition based maintenance.

The general configuration of a modern power system is that power Sources and loads are hundreds of miles away. Hence by proper maintenance and operation the hazard will be eliminated and safety of the transformer increase in-turn the life of the transformer increase. The risk of a catastrophic fire with a properly inspected, tested, and maintained transformer is small. Proper maintenance and thorough testing of the transformer will prevent or detect many events that could lead to explosion and/or fire. However, unforeseen events such as design defects, voltage surges, lightning strikes, structural damage, rapid unexpected deterioration of insulation, sabotage, and even maintenance errors can and do lead to transformer fires and the consequences can be severe. A transformer fire that involves several thousand gallons of combustible insulating oil can result in severe damage to nearby power plant structural components such as concrete walls and damage or destroy electrical components such as nearby transformers, bus work, and circuit breakers. K. Gowri, et al, (2013) said that the Transformers play an important role in the efficient transmission of electricity. Regular monitoring and maintenance can make it possible to detect flaws before much damage has been done. Current systems can provide information about the state of transformer but they are either offline or expensive to implement. The Health monitoring equipment that can acquire process, analyze & communicates the critical parameters to the concerned officials who is at remote place with the help of Auto dialing unit. Not only the conventional
technical data, such as current, voltage, etc, but also other critical information such as frequency, oil temperature, oil level etc. of transformers is required by the operators to ensure safe power delivery and to assist the day to day decision making activities. A.U. Adoghe et al (2012) said that the purpose of maintenance is to extend equipment lifetime or at least the mean time to the next failure. Maintenance too incurs expenditures that result in very costly consequences when not performed or performed too little, and it may not even be economical to perform it too frequently. Therefore the two costs must be balanced. In the past, this balance had been estimated by extrapolating the experience obtained from existing systems and using the rule of thumb methods. Nowadlys, the tempo of advanced and sophisticated research in that direction has rendered such rule of thumb methods obsolete. The literature works describing the reliability centered maintenance methods for managing distribution assets have grown until the papers can now be numbered in thousands. This paper presents critical review of the various existing methods that have been developed by different researchers and proposes a probabilistic model that will provide a quantitative connection between reliability and maintenance, a link missing in all the heuristic approaches. Andrew Kim et al (2009) said that the Power transformers play an important role in making communities function by distributing the power. Power transformers deal with high voltage electric power and there is a strong possibility of accidental fire incidents in the power transformer. Because of the high possibility of fire occurrence and the important role they play in the maintenance of normal life in the community, the power transformers must have a proper fire protection system in place to provide the best fire protection. Current fire protection systems for power transformers using sprinklers require a large quantity of water, which may cause a problem to their electrical function as well as creating water damage and environmental effects. Also, clean-up after fire suppression is another problem. Power transformers contain hazardous materials, and any run-off water from the fire suppression activities has to be collected. It is a costly proposition to provide infrastructure to contain the run-off water resulting from the fire suppression of a power transformer. Another fire protection approach is to use an air-aspirated foam system. However, current air-aspirated foam systems produce poor quality foam, therefore a large quantity of foam is needed to provide proper fire protection to the power transformers. This again creates a clean-up problem afterwards, delays the re-start of the power transformers and prolongs the power shutdown to the community. The National Research Council of Canada (NRC) has developed a means of producing Compressed-Air-Foam (CAF) in a fixed pipe system. This system provides superior quality foam with uniform distribution and high momentum. In previous studies, NRC has proven by full-scale tests that CAF has superior fire suppression performance compared to current foam or sprinkler systems. Therefore, CAF may be an ideal solution in providing fire protection for power transformers, with its superior fire suppression performance and low water requirement, thus minimizing the clean-up problem. Zoran Gajic (2008), describe how to provide standardized, current based, differential protection for any three-phase power transformer, including the phase-shifting transformers with variable phase angle shift and transformers of all construction types and internal on-load tap-changer configurations. The use of standard transformer differential protection for such applications is considered impossible in the protective relaying standards and practices currently applied. He provides the background for different types of power transformers and the differential protection schemes currently applied. After that a complete mathematical proof for the new, universal transformer differential protection principle, based on theory of symmetrical components, is derived. He shown how to correctly calculate differential currents by simultaneously providing on-line compensation for current magnitude variations, on-line compensation for arbitrary phase angle shift variations and settable zero-sequence current reduction on any power transformer side. By using this method differential protection for arbitrary power transformers will be ideally balanced for all symmetrical and non-symmetrical through-load conditions and external faults. The method is independent of individual transformer winding connection details (i.e. star, delta or zigzag), but dependent on having the correct information about actual on-load tap-changer(s) position if they are built-in within the protected power transformer. Thierry Paillat et al. (2009) analyzed that In high power transformer, oil flowing on pressboard surface is suspected to be responsible of electrostatic hazards and failures. Different methods of risk assessment have been proposed to understand and prevent it: mini-static tester in the Westinghouse protocol, mini-static tester in the spinning disk measurement, monitoring of tangent delta and dissolved gases measurement. At P institute of Poitiers an original sensor was developed used for quantification of the electric charge generated and of accumulated charge for an oil flow onto the surface of a transformer pressboard insulated from ground. Operational for 10 years, this bench has been used to study over a hundred couples of oil / pressboard, pairs of new oil and pressboard, pairs of aged oil and pressboard, pairs of suspicious oil and pressboards. The paper presents a comparative analysis of these 10 years of experience. This analysis provides, among other results, a critical electrostatic hazards assessment in transformers and an attempt of discrimination tentative of a suspected transformer. Anthony Kwok-lung Ng (2002), studied that the requirement of fire safety protection systems for distribution substations is not provided in the compliance document for fire safety to the New Zealand Building Code. Therefore, the New Zealand Fire Service (NZFS) has proposed a list of fire safety protection requirements for distribution substations in a letter, dated 10th July 2002. A review by Nyman, has considered the fire safety requirements proposed by the NZFS and discussed the issues with a number of fire engineers over the last three years. Nyman concerned that one of the requirements regarding the four hour fire separation between the distribution substation and the interior spaces of the building may not be necessary when considering the risk exposure to the building occupants in different situations, such as the involvement of the sprinkler systems and the use of transformers with a lower fire hazard. Fire resistance rating (FRR) typically means the time duration for which passive fire protection system, such as fire barriers, fire walls and other fire rated building elements, can maintain its integrity, insulation and stability in a standard fire endurance test. Based on the literature review and discussions with industry experts, it is found that failure of the passive fire protection system in a real fire exposure could potentially occur earlier than the time indicated by the fire resistance rating derived from the standard test depending on the characteristics of the actual fire (heat release rate, fire load density and fire location) and the
characteristics of the fire compartment (its geometric, ventilation conditions, opening definition, building services and equipment). Hence, it is known that a higher level of fire safety, such as 4 hour fire rated construction and use of sprinkler system, may significantly improve the fire risk to health of occupants in the building; however, they could never eliminate the risk. Harkishan Jashnani (2011), said that the primary objective of the Transformer Protection is to detect internal faults in the transformer with a high degree of sensitivity and cause subsequent de-energization and, at the same time be immune to faults external to the transformer i.e. through faults. Sensitive detection and de- energization enables the fault damage and hence necessary repairs to be limited. However, it should be able to provide backup protection in case of through faults on the system, as these could lead to deterioration and accelerated aging, and/or failure of the transformer winding insulation due to overheating and high impact forces caused in the windings due to high fault currents. In addition to the internal faults, abnormal system conditions such as over excitation, over voltage and loss of cooling can lead to deterioration and accelerated aging or internal failure of the transformer. Hence protection again these failures should be considered in as part of the comprehensive transformer protection scheme. Ahmed Elsayed Bayoumy et al., (2011), said that the main goal of this research was to assess the health and remaining lifetime of a working transformer. This information plays a very important role in the planning strategies of power delivery systems and in the avoidance of the potentially appalling effects of unexpected transformer outages. This thesis presents two different methods of assessing transformer end of life and three distinct methods of determining the health index and health condition of any working transformer. The first method of assessing transformer end of life is based on the use of Monte Carlo technique to simulate the thermal life of the solid insulation in a transformer, the failure of which is the main reason for transformer breakdown. The method developed uses the monthly average ambient temperature and the monthly solar clearness index along with their associated uncertainties in order to estimate the hourly ambient temperature. The average daily load curve and the associated uncertainties in each hourly load are then used to model the transformer load. The inherent uncertainties in the transformer loading and the ambient temperature are used to generate an artificial history of the life of the transformer, which becomes the basis for appraising its remaining lifetime.

**Power Transformer**

Power transformer is a static electric device which is used to change the nominal voltage level either step –up or step -down.

**PRINCIPLE**

If an alternating e.m.f is applied to the terminals of the primary winding of a transformer with the secondary winding open circuited, a very small current will flow in the primary circuit only, which serves to magnetize the core and to supply the iron loss of the transformer. Thus an alternating magnetic flux is established in the core which induces an e.m.f in both primary and secondary windings. The magnetizing ampere- turns are given by the product of the magnetizing current and the primary turns. The no- load current is given by the total no- load ampere turns divided by the primary turns. As the primary winding and secondary winding wound on the same core and as magnetizing flux is common to the two windings, obviously the voltage induced in a single turn of each winding will be the same and the induced voltages in the primary and secondary windings are therefore in direct proportion to the number of turns in those windings.

$$E=4K\Phi Nf$$

Where,

- \(E\) = rms value of the induced e.m.f in the winding.
- \(K\) = form factor of the e.m.f.
- \(\Phi\) = frequency of the supply in hertz.
- \(N\) = number of turns in the windings.

The above formula holds good only for the voltage induced in either primary or secondary windings.

**MAIN COMPONENTS OF POWER TRANSFORMER**

The main components of power transformer are given below,

1. Transformer Tank
2. High Voltage Bushing
3. Low Voltage Bushing
4. Radiator
5. Cooling Fans
6. Conservator Tank
7. System Ground terminal
8. Drain Value
9. Dehydrating Breather
10. Oil Temperature / Pressure Gauges
11. Bushing Current Transformers
12. Control Panel

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Image references:
- Fig 1 principle of transformer
- Fig 2 General Power Transformer
OPERATION OF POWER TRANSFORMER

Power Transformer should be initially inspected and pre-commissioned, after successful completion of the above the transformer can be energized at no load. Oil settling duration of 2 days for transformers up to 245 kV class and 3 days for 400 kV and above class are recommended after completion of hot oil circulation and before energizing. Excessive vibration if any on part of the transformer shall be located and rectified. Transformer shall be observed for abnormality. If any gas is collected inside the Buchholz Relay, it shall be analyzed for its combustibility. If gas is not combustible then air is trapped inside the transformer. All instruments should be checked for abnormality. Check winding temperature and oil temperature readings at least once in every shift. Check and conform that tap position indicators is same in local and remote indicators. Check and confirm that none of the alarms are indicated. Ensure that cooler power supply isolator is ON. Ensure that cooler control is in AUTO. Ensure that pumps and fans are running smoothly as temperature dictates. After watching the operation of the transformer at no load or 24 hours and conforming that everything is normal the transformer is taken in load. Observe the temperature indicators, fan and pump operation while raising and lowering temperature.

GENERIC HAZARD TYPE

The general types of hazards prompt participants to begin considering the risks relevant to the hazard in area under review.

Exposure

The possible event that could occur if control of the hazard is lost.

Hazard – Overview

Hazard are grouped into 4 common sources

1. Visible Hazards
   - Posture/Repetition
   - Lifting, pushing, pulling
   - Slips, trips and falls

2. Hidden Hazards
   - Those not readily sensed without prompting a more detailed search.
   - Dust, Radiation, Ergonomic stressors.

3. Developing Hazards
   - Those which get worse over time may not be detected without measurement.
   - Integrity of plant (corrosion), design failure Mine Bench (Loose Digging Face)

7. Planning and Conducting of Hazard Assessment:

The purposes of Hazard Assessment are as follows:-

1. To identify all the factors that may cause harm to employees and others (the hazards);
2. To consider what the chances are of that harm actually be falling anyone in the circumstances of a particular case and the possible severity that could come from it (the risks); and
3. To enable employers to plan, introduce and monitor preventive measures to ensure that the risks are adequately controlled at all times.

8. Hazard Assessment activities shall be planned and conducted:

   a) For situation:
      - Where hazard appear to pose significant threat;
      - Uncertain whether existing controls are adequate; or/and
      - Before implementing corrective or preventive measures.

   b) By organization intending to continuously improve OSH Management System. It should be the duty of the employer to assign trained personnel to lead a team of employees associated with one particular process or activity to conduct hazard assessment.

9. Process of Hazard Assessment requires 4 simple steps:

   1) Classify work activities;
   2) Identify hazard;
   3) Conduct risk assessment (analyze and estimate risk from each hazard), by calculating or estimating
      1) Likelihood of occurrence, and
      2) Severity of hazard

   Decide if risk is tolerable and apply control measures (if necessary).
10. Flow Chart of Hazard Assessment:

![Flow Chart of Hazard Assessment](image)

*Fig 4. Example for methodology of Hazard Assessment*

11. Controlling Risk:

It is the actions or measures taken to avoid or reduce the exposure to a hazard such that the potential for negative consequences are minimized to an acceptance level.

12. Hierarchy of Hazard control:

- **Eliminate:** Redesign the task to eliminate the Hazard?
- **Substitute:** Replace materials, equipment or processes with less hazards ones?
- **Engineering / Isolation:** Is it possible to provide mechanical aids, barriers, guarding etc. to isolate the hazard?
- **Administration/ Training:** Use training and procedures to inform people how to avoid the hazard?
- **PPE:** Use personal protective equipment to avoid impact with hazard.

13. Hazard Evaluation Methods

Past incidents are analyzed for basic causes to prevent or mitigate the incidents. The analysis of past data can be varied depending on the resources and details of data. Analysis of accidents in industry typically shows that all of them result from one or more of following causes, most of which can be controlled such as,

- Design/ construction failure.
- Operating error.
- Equipment failure.
- Maintenance weakness.
- Insufficient supervision and training.

There is a need for formalized techniques to assess the level of risk to life, property and environment before the plant is commissioned and in existing units. In other words, HAZARD ANALYSIS and RISK ASSESSMENT is essential for the purpose of judgment on potential risk and its management from the said industrial unit. The main purpose of hazard analysis is, of their possible consequences.

- To review suitability of sitting, layout and design.
- To determine suitable modifications.
- To ensure that appropriate contingency plans are made, and
- To promote ongoing safety awareness.

14. Conclusion

The effects of major malfunctions in electrical transformers includes, fire, explosion, electrocution, etc. Unidentifiable hazards and risks may cause accidents and business interruption could adversely influence the reputation of the organization. This project addresses the assessment of the potential hazards relating to the operation and maintenance of transducers. This project also deals with risk mitigation measures which eventually evades tangible and in tangible loss in the organization and improves the safety of appliances, personal and environment. Recommendations must be made in order to remove or to control it for all the hazards identified during the hazard assessment. The recommendations should include the specific actions necessary to correct the problem.

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