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Power transformer failure management on the Eskom distribution network in Limpopo

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***Abstract*—**Power transformers are the crucial part of the power system network because they regulate the voltage either up or down on the electrical network for safe use by the consumers. Their reliable operation on the network is very critical because it directly impacts that of the entire electrical network connected to it. One of the major challenges power utilities face is the failure of power transformers on the distribution network. In this research, the dominating causes of transformer failures on the Eskom distribution Limpopo network were identified. Different power transformer failure management strategies are discussed. The current methodologies used in Eskom distribution to prevent power transformer failures are evaluated. Different solutions to improve the current transformer failure management strategies are proposed. The defined methods are based on literature and existing research on power transformer failure management strategies.

Keywords: **Power system reliability, distribution network, power transformer failure**

1. Introduction

Eskom is an electrical power - generation, transmission and distribution Company in South Africa, with growing demand and an ageing infrastructure. There has been increased pressure on electricity utilities to decrease outage time due to faults.

The System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index SAIFI are used reliability indicators by electric power utilities. SAIDI is the average outage duration for each customer served, and is calculated as:

$$SAIDI = \frac{\sum CustomerInterruptionDurations}{TotalNumberofCustomerServed} \quad (1)$$

The system average interruption frequency index is designed to give information about the average frequency of sustained interruptions per customer over a predefined area and is calculated as shown below:

$$SAIFI = \frac{\sum CustomerIn\ terruption\ Frequency}{TotalNumbe\ rofCustome\ rServed} \quad (2)$$

Plant performance report in the Limpopo network indicated the following number of transformer failures in the past four years:

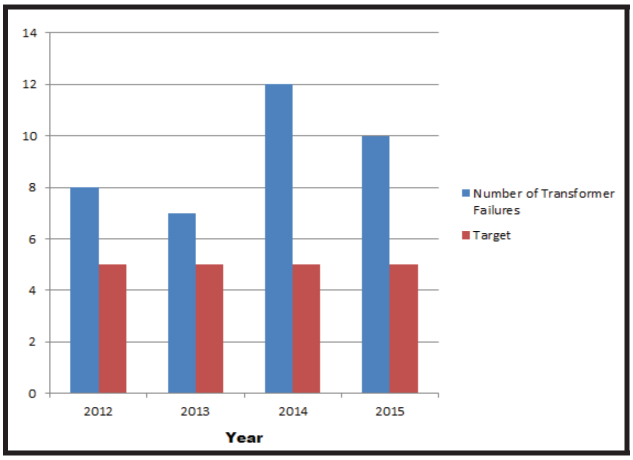

Figure 1: Number of Eskom distribution transformer failures from 2012 up to 2015 [1]

From the figure above, it can be observed that in the year 2012, there were eight transformers that failed. In 2013, the failure dropped down to seven failures; however in the year 2014, there were a total of twelve power transformer failures that were recorded and in 2015, there were ten failures recorded.

2. Problem Statement and Objective

2.1 Problem statement

The problem identified when a power transformer fails on the distribution network includes the following:

- Production loss for industries that consume huge amounts of power to run their machinery for bulk production. The machines will have to shut down until alternative source of electrical power is made available.
- Loss in the utility budget. The utility will have to find new ways of supplying their customers with power. A new power transformer may have to be purchased or spare transformer to be transported to site for commissioning.
- Loss of life for patient’s dependent on life support machines.

- Customer's safety. Once the power supply is off, the houses become prone to robberies because the alarms switch off.

In the past four years, there were a total of 37 transformers that failed on the Eskom distribution in Limpopo province. The total financial loss associated with the loss of all these transformers was R127.90 Million. The following bar-chart shows the cost of replacing the failed transformers each year from the year 2012 until 2015.

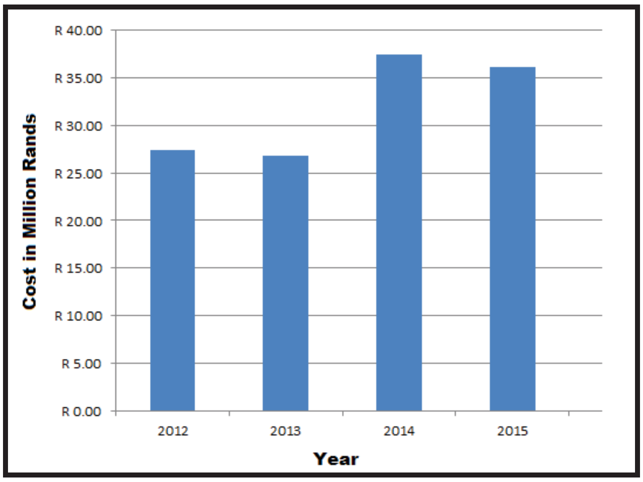

Figure 2: Cost associated with replacement of failed transformers from the year 2012 until 2015 [8]

From the above figure, it can be observed that failure of transformers is causing high financial loss for the utility. In 2012, the utility spent R27.45Million on power transformer failures. In 2013, R26.82Million was spent. In 2014, R37.44Million was spent and in 2015 the utility spent R36.18Million. The other concerns for Limpopo operations were the following:

- On networks with only one transformer installed in the substation, when that transformer fails; all the customers will be out of the electricity supply for the duration of that outage. In some cases back-feeding can be implemented to feed some or all customers affected. However, some substation feeders do not have that capability.
- In the commercial sector, the operations stops which result in zero production and hence no business for the duration of that outage.

Failure of transformers on the distribution network not only negatively impacts the reliability of the power system but also affect the power quality significantly.

There is therefore a need to identify the causes for these failures and the methods currently being implemented to prevent failure of these transformers.

2.2 Objective

The primary objective of this research is to identify factors affecting the performance of the power transformers on the Eskom distribution network in Limpopo. The secondary objective of this study was to:

- Analyse the performance of the power transformer failures in Eskom distribution network in Limpopo
- Determine ways in which Eskom distribution is currently preventing power transformer failures
- Study the factors leading to power transformer failure on the distribution network
- Recommend ways to mitigate the factors affecting the performance of power transformer failures in Eskom distribution in Limpopo.

3. LITERATURE REVIEW ON TRANSFORMER FAILURE

A power transformer, being one of the critical assets in the power system has remarkable effects considering maintenance and replacement from a reliability perspective. Its main function is to regulate the voltage either up or down on the electrical network for safe use by the consumers

Oil-filled power transformers consist of steel tanks, dielectric cooling oil, bushings, core-steel insulation and pressboard. Some degradation processes may affect various components of this equipment. There is a wide range of events that could lead to transformer failures. These include design defects, voltage surges, lightning strikes, structural damage, maintenance errors and rapid unexpected deterioration of insulation.

The following figure below shows the active part of a power transformer, consisting of the windings covered in cellulose insulation.

Figure 3: Active part of a power transformer [2]

3.1 Factors leading to power transformer failure

- Transformer overloading. When a power transformer is overloaded, its temperature can exceed 100 ^{0}C. Continuous overloading of a transformer results in a degree of risk and accelerated aging [3]. Overloading of a transformer causes generation of heat within the tank resulting in the burning of the winding insulation and ultimately causing the transformer to fail [4]. Under overloaded conditions, components such as load tap changer contacts and bushings connections may develop high temperature.

- Thermal stress on transformer insulation. Most power transformers use kraft paper as insulation in the electrical windings of the core immersed in oil. When a transformer is in operation, the winding temperature can rise up to 85 ^{0}C. When electrical stress within the transformer increases, oil starts grabbing the properties of cellulose which leads to the acceleration of oil aging decomposition [5].
- Humidity in oil. High moisture level in the transformer tank causes low dielectric strength, decreased insulation and in a worst case scenario it can lead to the transformer breakdown [3]. It also accelerates oil aging and affects the insulating properties of the oil. If this is not tracked, the life expectancy of the transformer is affected and hence reduces the expected return on investment.
- Oil contamination can be in a form of metal, gases or liquid. The metal content in transformer oil may compromise the dielectric losses of the transformer insulating oils [3]. Contaminated oil has an effect such as corrosion on the transformer core insulating material; affecting the operation of the transformer. The core becomes in contact with oil and should there be any arc, fire will result. The breakdown of electrical insulating materials and related components inside a power transformer generates gases within the transformer.
- Lack of proper maintenance. The main objective of the power transformer maintenance is to ensure that the power transformer health is managed over their lifecycle [5]. This ensures optimal reliability, availability and life of the power transformer. Should maintenance be inadequate, both the plant performance and life expectancy are affected.
- Lightning strikes a power transformer, the lightning discharges resulting in phase-to-ground or phase-to-phase overvoltage. The induced voltage propagates along the network. During storms, lightning can blow fuses installed on the power transformer. If the power transformer is not fitted with the surge arresting equipment, there is high chance of the lightning damaging the transformer. Lightning causes internal localized overvoltage.
- Cooling system failure. As the power transformer operates, heat is generated within the transformer core. In the oil-filled power transformer, the oil acts as a coolant for the transformer core. The radiator, oil pumps and the cooling fans also form part of the cooling system to ensure that the transformer temperature does not rise above certain levels [1]. When the cooling system is not functioning properly, heat will build up within the transformer tank. This will affect the different transformer components such as the cellulose chains in the winding insulation paper, which will result in a decrease in the degree of polymerization [3]. Environmental effects such as corrosion, high humidity and sun radiation can affect the leakage in the oil/water pipes, which directly affects the transformer cooling system. Faulty thermostats will also show incorrect temperature causing the cooling system to operate in an undesirable manner.

- Aging. After a transformer has been in operation for a certain number of years, the different components within the transformer begin to wear-out which increases the failure rate. When a transformer is in operation, it is continuously subjected to thermal, electrical, mechanical and chemical stresses [6]. Upon purchasing of a power transformer, the manufacturers specify the life expectancy of that transformer. Once the transformer has been in operation for that specified period, the utility usually makes efforts to put the spares in place to ensure that if the currently installed transformer fails, it can be quickly and easily replaced.

3.2 Power transformer failure management strategies

Electrical transformers are filled with a combustible coolant (oil) and may therefore experience a breakage in electrical insulation which might result in an explosion or fire [2].

- One of the methods to manage transformer failure is the pressure and vapour sensor whose main purpose is to prevent fires and explosions resulting from the transformer fault inside the transformer tank. The pressure and vapor sensors are coupled together to monitor the vapor and pressure content in the transformer tank [4]. An increase in pressure of the transformer tank may indicate that an insulation breakdown has occurred. The control unit controls the operation of the entire fire and explosion prevention process. It is equipped with a data processing means which receives the signal from various sensors and can emit control signals intended for valves and the injection of nitrogen at the base of the power transformer thus preventing the power transformer from exploding.
- Dissolved gas analysis (DGA) method. The DGA method measures the concentration of the dissolved

gases within the sampled oil [6]. When a power transformer is in operation, there are certain gases that are generated into the insulating oil due to natural aging. Possible gases that can be injected include hydrogen, methane, ethane, ethylene, acetylene, carbon monoxide, carbon dioxide, nitrogen and oxygen. The DGA analysis results will give an indication of how much of each gas is there in the insulation oil. These results will be compared with the ones taken previously. Any sharp increase in any of the key gases is indicative of a potential problem within the transformer.

- On-line moisture analysis. Moisture in oil cooled power transformers and insulated power transformers has detrimental effects. High moisture level also causes low dielectric strength, decreased insulation and in a worst case scenario it can lead to the transformer breakdown [4]. It also accelerates oil aging and affects the insulating properties of the oil. An on-line moisture-in-oil probe will be inserted into the transformer to measure the moisture and temperature at the same time. This method enables one to track and monitor the moisture content. The online moisture analyser has to be placed in the cooling system and in such a way that the tip is in contact with the oil flowing transformer tank.

- Depressurization Strategy is the fast direct-tank depressurization method that activates as soon as the high pressure peak of the pressure wave reaches it [7]. During fault conditions, there is high pressure that is built up within the transformer tank. The pressure that builds up is between the gas bubbles and the surrounding liquid oil that generates a dynamic pressure peak which propagates and interacts with the tank. The depressurization strategy is intended to prevent the pressure build up within the transformer tank. Since transformers always rupture because of the static pressure at their weakest point, this strategy is designed to be the weakest point in terms of inertia to break with the dynamic pressure peak before the tank explodes.

3.3 Factors affecting power transformer failure on the Eskom distribution network in Limpopo

On the Eskom Distribution LOU network, there are a total of 249 substations with a total of 378 substation power transformer of different MVA size and voltage level.

From the substation transformers that failed, the causes of failure were as follows:

- Transformers failing due to aging
- Failure due to overloading
- Failure due to poor maintenance
- Failure due to poor security at substations in remote areas
- Failure due to internal faults

3.4 Eskom distribution power transformer failure prevention approach

Eskom distribution has put in place, various methodologies to avoid power transformer failure. These methods will be explained in sections below.

- Maintenance Engineering Strategy

Maintenance Engineering Strategy refers to the engineering performed during the design process (logistic support analysis) to define the maintenance requirements of the System, Structure or Component that serves as primary input to the maintenance execution strategy [5].

Eskom maintenance engineering strategies includes the preventative, corrective, testing and inspection maintenance activities based on the outcome of FMEA and RCM analyses. The operating unit plant department will capture the asset operation, condition and performance information required in the asset performance management tool to develop asset specific execution strategies.

The process of monitoring is in place for the Zone manager to be accountable for the implementation of the maintenance engineering strategies. The maintenance engineering strategy ensures that the power transformer health is managed over their lifecycle to ensure optimal reliability, availability and life of the transformer.

Challenges faced by the Limpopo region with this method include the following:

- In certain Limpopo areas such as Modimolle in Lephalale Zone, there are not enough resources at the customer network centres to manage the daily line faults, do the substation and pole-mounted transformer maintenance, customer queries, network maintenance etc. As a result, maintenance of the power transformers ends up being rescheduled for a later period. Faults that cause the utility to increase the SAIDI are prioritised over routine maintenance activities because there are penalties.
- When there’s overload of work, the field services officers take short-cuts instead of performing the lengthy maintenance activities.

- Degradation review and health index

Transformers mostly operate under many extreme conditions such as high oil temperature and overloading. There are conditions that affect the degradation process affecting various components of the transformer. Overloads cause above normal temperatures; through faults can cause displacement of coils and insulation; and lightning and switching surges cause internal localized over-voltages.

Moisture particles and acids degrade the transformer insulation. These conditions degrading the transformer insulation eventually can lead to transformer failure. In order for Eskom distribution to avoid degradation of the transformer winding insulation, periodic dissolved gas in oil analysis, oil temperature monitoring, gas accumulation and core leakage current testing are performed on the distribution power transformers.

Components such as the Load Tap Changers (LTC) have moving parts that are subject to wear and stress. The LTC make or break high currents and undergo arcing that accompanies such operations. Excessive arcing causes overheating, contact burning, insulation oil contamination and short-circuit failure.

Eskom performs a special LTC maintenance to ensure reliable operation. Should the LTC fail, there will be severe consequences which include loss of customer supply, costs of replacement, safety of the persons entering the substation and environmental problems such as oil spill. While LTC reliability has improved over the years, they are still a major cause of transformer outages [5].

In Eskom distribution, this method has shown improvement over the past 4 years. The degradation review and the health index method was performer correctly on 80% of the transformers. The other 20% were analysed after their date had passed.

- Visual assessment

Power transformers have visible and accessible components that make visual inspection effective. Visual inspection can detect external contamination, corrosion, misalignment, evidence of overheating, oil leakages and cracks on bushings, tank, fans, radiator, pipes and fittings [6].

Visual inspections can also verify the condition of gaskets and seals. Power transformers have mechanical features such as the winding and oil temperature indicators which are accessible visually. In Eskom distribution, visual assessment on the power transformer is done by the substation owner.

- Oil Analysis (DGA, Furan, moisture and metals)

DGA determines the quantities of various gases dissolved in oil. DGA often serves as a primary means to assess insulation and to identify faults such as insulation aging and overheating, arcing in oil and partial discharge damage.

In Eskom distribution, the oil samples are taken at the substation and will be submitted to a private company for assessment. Records on Eskom system showed that the transformer oil samples were taken from the substations on time.

- Tan-delta Test

This test involves application of voltage to the bushing terminals and measuring the capacitance and loss angles using a bridge technique [6]. The aim of this test is to help detect deterioration of the bushing insulation and other internal components such as support insulators. The tan delta methodology has been successfully implemented in Eskom distribution

- *SCADA and online monitoring control system*

A careful monitoring system is required to remotely control and monitor the electrical equipment on site via a remote terminal unit. This will ensure the visibility of the substation plant equipment for control. There are appointed network controllers at the Network Management Centre who continuously monitor the network under normal and abnormal conditions remotely.

4. Discussion and Conclusion

The aim of the study was to identify the dominating factors causing the power transformer failures on the Eskom distribution network in Limpopo. These factors were found to be aging, overloading, poor maintenance, internal faults and poor security at substations in remote areas.

The proposed methods to improve the performance of power transformers on the Eskom distribution network in Limpopo were:

- Installation of the online monitoring system on the power transformers.

This method will assist management in monitoring the status of the oil in the transformer tank which will enable the network operations team to make any plan of action required.

- Effective Maintenance Schedule

The maintenance schedule that is currently being implemented is effective, however due to shortage of resources and vast maintenance work that needs to be conducted on a daily basis, transformer maintenance sometimes gets rescheduled for a later period. This study provides improvement in this method. The different Customer Network Centres (CNC's) must liaise with each other to make sure that they avail their staff member to help other CNC's with maintenance.

- Installation of backup transformers

For all the substations with single transformers, it is suggested that projects must be initiated to install a second transformer for reliability purposes. Alternatively all the medium-voltage feeders must be back-fed from other substation feeders.

- Improve security measures at substations in remote areas

Eskom substations are always locked to avoid unauthorised access. Installation of the security cameras at substations located in remote areas is recommended.

- Plan for aging transformers

As the transformer age, the internal condition degrades resulting in the increase in the risk of failure. Paper insulation degrades due to heat that leads to polymerization of the cellulose chains. The paper covering the windings will start to become brittle over time. The tensile strength of the paper will drop to a level where it will not be able to withstand the transformer tank internal faults. It is therefore recommended that as soon as that time approaches, a plan must be put in place to ensure that a spare transformer is readily available to be installed.

- Avoid overloading of the power transformer

Overloading of the power transformer cause high temperatures within the main tank which can cause the transformer to fail. In certain areas, Eskom distribution transformers overload during period when the overall system peaks. During this period, the cooling system must be improved at those particular substations.

5. References

[1] Eskom Holdings Limited. *Eskom Distribution Limpopo Operating Unit Plant Performance report*, Limpopo Province: *http://dt.eskom.co.za/distribution/plantperformance.htm.*

[2] M. Foata. "Transformer fire risk and mitigation", *CIGRE A2 Transformers Session*, 2010

[3] H. Borsi, E. Gochenback, V. Wasserberg, "Lifetime Extension of transformers by online Drying," in *19th International Power System Conference* (PSC), 2004, Iran-Tehran.

[4] M. Minhas, J. Reynders, P. de Clerk. "Failures in large power transformers" in *proceeding of Cigre conference on large high voltage electric system*, 1997, Cairo, Egypt.

[5] M. Minhas, J. Reynders, P.J. de Clerk. "Failures in power system transformers and appropriate monitoring techniques", *High voltage engineering symposium 22-27 august 1999*, conference publication no. 467, © IEE 1999.

[6] J. Endrenyi and G.J. Anders. "Aging, maintenance and reliability approaches to preserving equipment health and extending equipment life," *IEEE Power and Energy Magazine*, vol. 4, no.3, pp. 59-67, 2006.

[7] T. Suwanasri, E. Chaidee, C. Adsoongnoen. "Failure Statistics and Power Transformer Condition Evaluation by dissolved gas analysis Technique" in *International Conference on condition monitoring and diagnosis,* 2008, Beijing China.

[8] Eskom Distribution Limpopo Operating Unit Plant Performance report, Limpopo Province South Africa.