PREVENTIVE MAINTENANCE TECHNOLOGIES FOR POWER TRANSFORMERS IN ALEXANDRIA ELECTRICITY DISTRIBUTION COMPANY

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ABSTRACT

Power transformers are among the most expensive and strategically important components of any power system so that their proper and continuous function is important to system reliability. Also, their failures can impose extraordinarily high costs on plants, factories and utilities. Therefore, early detecting the transformer abnormality and the ability to evaluate the problems can avoid damage on the transformer. Preventive maintenance is considered as one of the most important aspects to assure the reliability and integrity of electrical distribution systems. It is performed at regular intervals so that inspection, detection and correction of incipient failures either before they occur or before they develop into major defects are provided. This maintenance type includes tests, measurements, adjustments and part replacements, and is performed specially to prevent faults from occurring.

This paper will represent the preventive maintenance technologies adopted by Alexandria Electricity Distribution Company (AEDC) for power transformers. These technologies can be categorized into two categories. The first category is the infrared thermography which has been used for detecting temperature abnormalities on external surfaces of the transformer. The second one is the partial discharge testing which monitors the insulation breakdown of power transformer through the electromagnetic waves or the sound waves production.

Qualitative and quantitative analyses are carried out for each preventive maintenance technology and inspection results are presented after being processed by the diagnosis of real case studies that exist in electrical distribution system in AEDC network which covered about 7000 transformer point (T.P) and 115 network distribution points (D.P) distributed on five distribution zones. Finally, corrective actions taken by AEDC are evaluated in order to avoid transformer damage and consequently enhance the electric distribution system reliability.

INTRODUCTION

A preventive maintenance program is a schedule of regularly planned maintenance testing and actions that occurred in order to prevent breakdowns and failures. Finding and replacing worn components before they actually fail is the goal of the preventive service, as well as predicting useful life of existing equipment. Electrical preventive maintenance is cost effective because of the benefits it can provide, such as minimizing the system downtime, decreasing the frequency of replacing equipment, improving the system reliability and maximizing the equipment lifetime. AEDC has carried out several maintenance activities for power transformers as part of the preventive maintenance program. One of these activities is the infrared services implementation using the thermal image camera. The second one is the insulation breakdown of power transformer detection through the partial discharge measurements.

Infrared Thermography has evolved into one of the most valuable diagnostic tools used for preventive maintenance which is considered as a very important task that can prevent electricity blackout in large areas and reduces equipment damages in distribution systems. This non-destructive technique indicates a pinpoint location of system deficiencies and “hot – spots” in transformers that may cause fire and unnecessary downtime by detecting the infrared energy emitted from an object converting it to temperature, and displaying a high resolution image of temperature distribution with an accurate preventive maintenance report. The main advantage of thermal imaging is that the transformer electrical problems can be located quickly and accurately. This is highly beneficial, as the continuity of services without unnecessary equipment replacement and also leads to substantial savings.

Partial discharge monitoring is an effective preventive maintenance test for motors, generators, transformers as well as other electrical distribution equipment. The benefits of this testing allow for equipment analysis and diagnostics during normal production. Corrective actions can be planned and implemented, resulting in the unscheduled downtime reduction. An understanding of the theory related to partial discharge, and the relationship to early detection of insulation deterioration is required to properly evaluate this preventive maintenance tool. Data interpretation and corrective actions will be reviewed, in conjunction with comprehensive preventive maintenance practices that employ partial discharge testing and analysis.

This paper will describe the power transformer preventive maintenance program implemented by AEDC. A brief introduction has been provided in this section. The rest of this paper is arranged as follows. In section II, the basic concept of thermal image camera is explained. The thermal camera applications for transformers are analyzed in section III. In section IV, the partial discharge theory is described. The transformer partial discharge measurements are shown in section V. Finally, the concluding remarks are summarized.

BASIC CONCEPT OF THERMAL IMAGE CAMERA

The operation of thermal image camera can be explained by a nature phenomenon; every object always radiates infrared energy. The amount of energy radiated from an object is depending on its temperature and its emissivity. An object which has the ability to radiate the maximum possible energy for its temperature is known as a black body. Hence, emissivity is expressed as:

$$Emissivity = \frac{Radiation\ emitted\ by\ an\ object\ at\ T}{Radiation\ emitted\ by\ a\ black\ body\ at\ T}$$

Where: T refers to the temperature.
Emissivity is therefore an expression of an object's ability to radiate infrared energy. The value of emissivity tends to vary from one material to another. With metals a rough or oxidized surface usually has a higher emissivity than a polished surface. Here are some examples which are shown in table 1.

TABLE 1 – Emissivity values

Material	Emissivity
Aluminum Weathered	0.83
Copper Polished	0.05
Copper Oxidized	0.78
Nickel	0.05
Stainless Steel Polished	0.16
Stainless Steel Oxidized	0.85
Steel Polished	0.07
Steel Oxidized	0.79

THERMAL CAMERA APPLICATIONS FOR TRANSFORMERS

Infrared thermographic inspection of electrical distribution system in AEDC network offers a pinpoint location of system deficiencies and "hot-spots" while at the same time remaining very affordable to company budgets. Thermal image camera has the ability to produce a visual representation of thermal patterns as the heating systems components are identified and recorded. Maintenance strategies are then planned and carried out before system breakdowns occur. Heating components are generally noted as white or lighter colored areas in an infrared image. Transformer secondary connections, transformer overheating, ground current and transformer bushing heating are examples of unwanted conditions that thermography can locate and provide early warning signs for maintenance departments.

CASE STUDY NO.1

Thermal image camera can identify overheating components such as the transformer shown in figure 1 (800 K.V.A) and its temperature reaches 100.1°C. Transformer overheating increases transformer losses, weaken the insulation and may result in reducing transformer lifetime. The principal reasons for transformer overheating are classified as follows:

- Excessive transformer loading.
- Excess current in the neutral of the transformer.
- Problems in the cooling system.
- High harmonic content in the power supply.
- Sustained overvoltage which exists for a long period of time.

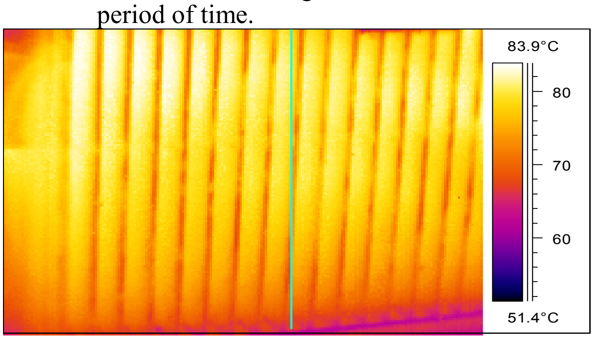

Fig. 1 shows an increase in temperature in the transformer that reaches 79.9°C at T.P 652 in Saba Basha at East Zone.

Since transformers are a critical and expensive component of the power system, it must be protected against faults and overloads. The type of protection used should minimize the time of disconnection for faults within the transformer and to reduce the risk of catastrophic failure to simplify eventual repair. Any extended operation of the transformer under abnormal condition such as faults or overloads compromises the lifetime of the transformer. This means that an adequate protection should be provided for quicker isolation of the transformer under such conditions.

CASE STUDY NO.2

This case study shows transformer insulator bushing heating which breakdown over time due to its high temperature as shown in figure 2.

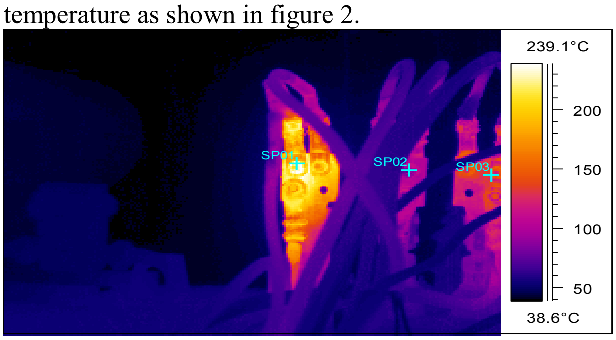

Fig. 2 shows an increase in temperature in transformer bushing phases (R, S, T) that reaches (146 °C, 76.5 °C, 242.6 °C) at T.P 2805 in Abu- Kir at Montaza Zone.

If it is not replaced in proper time, catastrophic failures can develop. Thermography can locate overheating transformer bushings to provide early warning so that repairs can be planned before failure. This deficiency can be avoided by scheduled cleaning the equipment and also by preventing looseness in connections.

CASE STUDY NO.3

Thermography can locate overheating transformer secondary line connections as shown in figure 3. This overheating type may be due to the presence of moisture which can cause connection failure, so precautions should be taken to minimize the entrance of moisture.

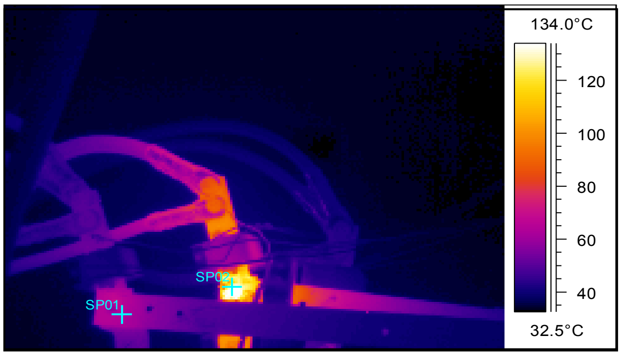

Fig. 3 shows an increase in temperature in transformer secondary line connections in both R, S phases that reaches 136.4 °C and 63.4 °C at T.P. 1285 in Ibrahimeya at Central zone.

CASE STUDY NO.4

A large ground current which may trip the protective devices is detected in figure 4.

Fig. 4 shows a large ground current due to the unbalanced loads between the three phases R, S, T which reaches 79.9 °C at T.P 2784 in Kabary at West Zone.

This is considered as a sign of the unbalanced loads between the three phases R, S, T. This phenomenon is very dangerous since the system power quality is affected. For example, the unbalanced loading causes unbalanced voltages even the voltage at source is balanced. Lower, higher, or unbalanced voltage reduces efficiency and may damage appliances. Furthermore, this phenomenon must be prevented by balancing loads in distribution systems.

PARTIAL DISCHARGE THEORY

Partial discharge theory includes the analysis of materials, electric fields, arcing characteristics, pulse wave propagation and attenuation, sensor spatial sensitivity, frequency response and calibration, noise and data interpretation. Partial Discharge can be described as an electrical pulse or discharge in a gas-filled void or on a dielectric surface of a solid or liquid insulation system. This pulse or discharge only partially bridges the gap between phase insulation to ground and phase to phase insulation.

These discharges might occur in any void between the copper conductor and the grounded motor frame reference. The voids may be located between the copper conductor and insulation wall, internal to the insulation itself, between the outer insulation wall and the grounded frame, or along the surface of the insulation. The pulses occur at high frequencies; therefore they attenuate quickly as they pass to ground. The discharges are effectively small arcs occurring within the insulation system, therefore deteriorating the insulation, and can result in eventual complete insulation failure.

The possible locations of voids within the insulation system are illustrated in figure 5.

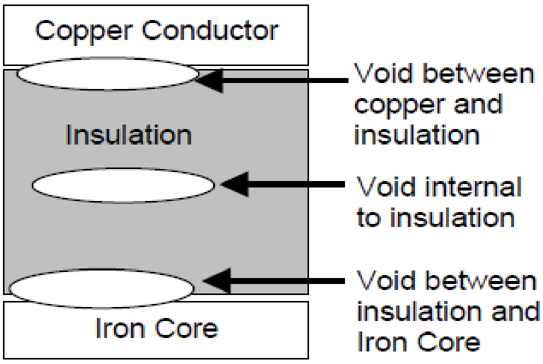

Fig. 5 shows the partial discharge within Insulation System

The other area of partial discharge, which can eventually result, is insulation tracking. This usually occurs on the insulation surface. These discharges can bridge the potential gradient between the applied voltage and ground by cracks or contaminated paths on the insulation surface. This is illustrated in figure 6.

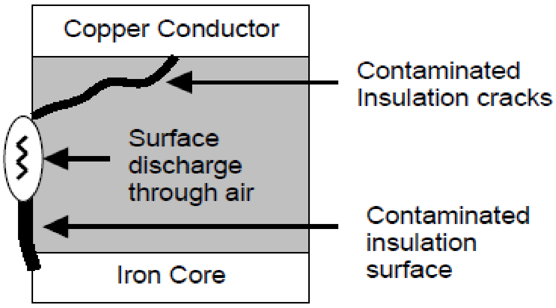

Fig. 6 shows the surface partial discharge

PARTIAL DISCHARGE MEASUREMENTS FOR TRANSFORMERS

Nowadays, the PD measurements play a critical role in determining the health of electrical assets in utilities such as transformers. The accurate measurement of a PD signal is the key to implement a detection system for deterioration of transformer insulation which is a frequent cause of transformer failure. It also provides power utilities to target maintenance plans to the areas that require the most attention. AEDC is one of these power utilities using the Ultra Transient Earth Voltage (TEV) Plus for PD testing that is based on the detection of the radio frequency part of the electromagnetic spectrum and ultrasonic emissions. Both TEV and surface discharges can be detected and are displayed as numerical values on a colour screen. Also, this instrument has the ability to display the number of PD pulses per cycle, severity levels, maximum levels for internal discharges, and a numerical value for ultrasonic emissions which can be heard with the supplied headphones. Therefore, AEDC has carried out preventive maintenance programs using Ultra TEV Plus to prevent electricity blackout in large areas and to reduce the equipment damages of distribution systems. These programs are adopted in all distribution zones in Alexandria. In addition, the corrective actions are taken by AEDC in order to avoid unexpected outages. Table 2 shows the PD measurements in coast zone for transformer points and kiosks that contain transformer which need to be maintained. This zone contains five areas: hanovil, bitach, abou talate, borg el arab and el hamam as shown in the following table.

TABLE 2- PD measurements in coast zone

Area	Transf. Point (T.P) or Kiosk No.	Magnetic Test	Ultrasonic Test
Hanovil	2838	5 dB	19 dB
	2902	5 dB	33 dB
	3067	4 dB	23 dB
Bitach	2867	6 dB	18 dB
	703	5 dB	35 dB
	691	5 dB	18 dB
Abou Talate	2628	7 dB	28 dB
	2670	5 dB	30 dB
Borg El Arab	Khadamate Mogawra 3	8 dB	22 dB
	C1	6 dB	29 dB
El Hamam	El Moustashfa	3 dB	17 dB
	Amn Dawla	5 dB	35 dB
	Seka Hadid	5 dB	30 dB
	El Gazar	5 dB	17 dB

If the magnetic test values are between (0 dB: 20 dB) this means that this transformer is in normal condition and need no maintenance. If the values are between (20 dB: 29 dB) this means that this transformer needs maintenance. If the values are greater than 29 dB this means that this transformer is in dangerous zone.
If the ultrasonic test values are between (-9 dB: 0 dB) this means that this transformer is in normal condition and need no maintenance but if the values are between (0 dB: 47 dB) this means that this transformer is in dangerous zone.
The results mentioned in table 2 prove that the ultrasonic measurement is most powerful on a comparative basis and can significantly increase the reliability of partial discharge detection when used with other partial discharge testing technologies such as the magnetic test. This is due to the measured transformers values which are located in the dangerous region according to ultrasonic test although they are considered normal in the magnetic test. The discharge analyses identify the insulation deterioration main causes which are due to the presence of moisture and the high humidity that characterize the coast zone in the Mediterranean city, Alexandria. Consequently, these transformers must be maintained and measured till their values are normal which is shown in table 3.

TABLE 3- PD measurements in coast zone after maintenance.

Area	Transf. Point (T.P) or Kiosk No.	Ultrasonic Test
Hanovil	2838	-2 dB
	2902	-2 dB
	3067	-1 dB
Bitach	2867	-3 dB
	703	-1 dB
	691	-2 dB
Abou Talate	2628	0 dB
	2670	-4 dB
Borg El Arab	Khadamate Mogawra 3	-2 dB
	C1	-3 dB
El Hamam	El Moustashfa	-2 dB
	Amn Dawla	-3 dB
	Seka Hadid	-1 dB
	El Gazar	-2 dB

CONCLUSION

Unscheduled outages of transformers can cause huge power system problems, social disorder and financial losses. The only way to avoid unexpected shutdowns by failures of any kind in transformers is through a good maintenance strategy which can be done with the help of a number of technology tools such as the infrared thermography and the PD testing.
AEDC has used the thermal image camera to inspect the system deficiencies for distribution systems especially for transformers by detecting the loose in connections, the

unbalanced loads and overload conditions. Also it can potentially be used for diagnostics of other problems. These infrared inspections of electrical systems are beneficial to reduce the number of costly and catastrophic equipment failures and unscheduled plant shutdowns leading to the improvement of system efficiency and power quality.
Also, AEDC use the partial discharge detection and measurement which is considered as an effective preventive maintenance. This is due to the early detection of failures in the insulation of power transformers which is considered as the most important reason of the fault. Consequently, corrective actions can be planned and investigated, leading to minimizing the equipment malfunction, power outages, or interruptions to operations or services.
Concluding, AEDC enhances and preserves the system reliability and reduces the transformer maintenance costs by adopting its preventive maintenance program which leads to a high level of continuity and quality of supply to customers.

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