FALIURE ANALYSIS OF MEDIUM VOLTAGE CAPACITOR BANKS:  
THE EGYPTIAN EXPERIENCE

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ABSTRACT

This paper describes the failure modes in the capacitor banks installed in the Egyptian Network over the past years. The study has focused on the capacitor banks installed at the MV side of the HV substations in the Egyptian Transmission Network. Failures of capacitor units/banks in substations can be detrimental to the supply of reliable power to consumers. Failure analysis, failure mechanism, failure origin and physical damage causes were studied, not only from the manufacturing point of view, but also from the utility prospective in order to enhance the utility reliability. The results of the study on 457 capacitor banks of about 2383 MVARs capacity revealed the main causes of capacitor accidents, and sum up experiences in the Egyptian Electricity Utility.

1. INTRODUCTION

Rapid development in Egypt, in late seventies and early eighties, led to fast expansion of the Egyptian Electrical Network. The Electric utility then faced a voltage reduction problem at some nodes of the network. A study had then been conducted in order to find the technical and economical benefits of reactive power compensation in the network. In order to maintain acceptable voltage levels and also to correct the power factor in the system, the study recommended installation of 1300 MVAR capacitor banks at the MV side of the HV substations. Nowadays, the total installed capacitors at these locations reach about 2450 MVARs.

System reliability depends on components’ reliability. Conditions of components directly affect system condition with respect to adequacy and security. Since capacitor banks play an important role in the power system operation, it is important to investigate and analyze their failure modes, reliability level, failure causes and mechanism, not only from the manufacturing point of view, but also from the utility prospective.

Power capacitor banks reliability evaluation through their failure modes, rates and mechanisms have been investigated at about 190 substations in the Egyptian Transmission Network, in which 2450 MVAR capacitor banks are installed. The study includes 9 vendors for whom the Capacitor Banks are installed during the period starting from the year of early installation in 1985 till now 2008.

2. CAPACITOR BANK INSTALLATIONS

Figure 1 shows the used in the Egyptian MV Networks typical capacitor bank installation consisting of two steps (1.8 and 3.6 MVAR). This arrangement allows three values of reactive power compensation (namely 1.8, 3.6 and 5.4 MVARs) depending on the load value and power factor (pf). The controller operation is determined by the pf of the main HV transformer and the voltage level at MV busbar.

Each step of the bank is connected in a double star arrangement. The connection between the two star points has a CT feeding an unbalance protection overcurrent relay to detect and protect the step against internal short/open circuit of capacitor elements. The feeder supplying the bank has normal overcurrent and earth fault protection.

Most of the used capacitor banks are fitted with internal fuses technology (see Figure 2). This technology is the perfect way to guarantee a reliable protection in case of having internal faults. The internal fuse disconnects the damaged unit instantaneously avoiding the loss of the complete capacitor.

In some cases, as an additional protection, the capacitor unit could be fitted with a pressure switch, which could disconnect the bank or give an alarm in case of having overpressure inside the can.
3. FAILURE MODES

In general, a bathtub curve may be used as an adequate representation of the capacitor unit failure modes against life time. The capacitor bank failure modes, as any electrical installation, can be divided into three main categories as shown in Figure 3: (i) early, (ii) random and (iii) wear out failure modes [1]. For capacitors specifically:

(i) Early Failures: Occur during the first year of energization and are usually caused by inherent defects due to poor materials, workmanship or processing procedures or manufacturer’s quality control besides installation problems.

(ii) Random Failures: Are produced by chance or by operating conditions such as a failure from lightning or switching surges or by harmonics threats. This failure mode is usually present in low percentages.

(iii) Wear out Failures: Are the results of dielectric material or component wear out. Normally, the wear out mode becomes dominant only after about 20 years of operation. This “normal” wear out period is characterized by an increasing failure rate.

4. CAPACITOR BANKS FAILURE RATES

Capacitor banks in the Egyptian MV networks are supplied by nine vendors. The following analysis of the failures covers only 5 of these vendors. The other four have smaller number of installations, and hence capacity, and exist in only one or two of the Egyptian Network 6 zones.

Table 1 shows the number of failures for the banks main components for each vendor. It also shows for each vendor the number of installations, total capacity, commissioning time and lifetime of the installations beside the number of zones in which these installations exist. Table 1 also shows the failure rates of the main three components of the installation (namely: Capacitor, Contactor and Control units) as a percentage of the total number of the installed banks.

The table indicates that the first three vendors are the most important since their banks exist in the majority of the zones (five or six) for a period of eighteen years (for vendors two and three) and twenty three years (for the first vendor).

Vendor four banks have only two years lifetime which means that the majority of the failures can be considered as early failures.

Although vendor five banks have twelve years of lifetime, they are installed only in one zone. Besides, the table illustrates the lack of failure data.

From Table 1, it can be seen that vendor 1 has the highest number of failures for all the three components. However, its failure rates as a percentage of the number of units is the highest only for the contactors (19% compared to 11% for both vendors two and three). This result shows that the contactor is the component most vulnerable to the effect of aging. In fact, contactors are affected by high stresses sense it frequently switches on and off the capacitors. Note also that vendor 1 capacitors have the longest lifetime.
Table 1 shows also that:

- Capacitor failure rates of vendor V3 is the worst, V2 is the best and V1 is moderate, but V1 can be considered better since its long lifetime (twenty three years) introduces additional aging effect.

- For controller failures, V2 is the worst, while V3 is moderate and V1 is the best. Although V1 rate is the same as for V3, it has the longest time period.

In the above mentioned analysis, the failure of main bank components is considered. However, each of the main components consists of other subcomponents. Table 2 shows an example of the failure numbers for some subcomponents at one of the zones covering four vendors.

<table>
<thead>
<tr>
<th>Sub Component</th>
<th>Vendor 1</th>
<th>Vendor 2</th>
<th>Vendor 3</th>
<th>Vendor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuses</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Over-voltage relay</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Unbalance protect.</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Bushing</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Control cables</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

5. EXAMPLES OF FAILURE MECHANISMS

In 2008, EETC noticed two types of problems in the newly delivered medium voltage capacitors from a specific vendor.

These two problems were:
1. Observation of oil leakage from some capacitor bushing
2. Decline in capacitance values which leads to tripping of the bank by the unbalance protection.

Due to the importance of the problem, an investigation task force has been formed on the highest level of the vendor company together with the utility personnel. The start point was to measure the harmonic level at the installation sites. It worth to mention that the harmonic levels at those sites were within the permissible limits. The findings and observation about these two problems are as follow:

5.1 Oil leakage from the bushing

This problem has been traced down to the quality of adhesive material used to seal the bushing with the capacitor unit tank. This material is purchased from a world leader supplier. The material was examined in the laboratories of the supplier and it was found that the material has a contamination problem with silicon that leads to change in its characteristics by time and as a result it causes incomplete adhesion between the bushing and the tank (Figure 4).

The vendor added to his production process a step of 100% checking the quality of adhesion by applying double the tightening torque on the bushing in order to detect any inconsistency in adhesive material bonding characteristics.

5.2 Capacitance value decline

An autopsy of faulty capacitor units were done at the vendor testing laboratories. An investigation by Scanning Electron Microscope has been performed on the internal elements inside the capacitor units. The investigation showed a contamination of the capacitor metal film by the materials used for soldering the capacitor units to the connection leads. This contamination was found to be responsible for the reduction in insulation properties.

The soldering materials were also purchased from a world leader supplier known for high quality. The vendor has officially informed the supplier of soldering material with these findings and he has started an internal investigation on the product. The vendor is now performing further detailed analysis to better understand how this contamination flows in the capacitor film and why this contamination has appeared in order to eliminate it definitively (Figure 5).
6. UTILITY MAINTENANCE PRACTISES

It is well known that power capacitors are unrepairable components, so the failed components are always replaced from those in the existing spare parts stock under the responsibility of both the utility maintenance crew and the technical staff of the vendor, and sometimes spare parts, such as fuses, contactor coils, auxiliary relays, timers…etc, are obtained from the local market.

As mentioned before, the utility side perform detailed measurements concerning the harmonics level at those locations of failed capacitor as well as locations where capacitor banks are intended to be installed.

The utility also conducts many tests on the banks at the factory before acceptance. Also commissioning tests are conducted on site before putting the banks into operation. Some periodic tests are also done periodically including measurements of harmonics at the substation.

7. CONCLUSION AND RECOMMENDATION

Capacitor bank failure mode and failure rate analysis is important to reveal their reliability and goodness of all stages starting from putting specifications, designing, testing, installing, operating, and maintaining the banks. Such analysis can help also in selection of good manufacturers of capacitors, contactors, fuses, controllers, bushings …etc.

All substation shunt capacitor bank failures require a follow up investigation and root cause analysis. Too often in the past, capacitor failures were viewed more as routine annoyances that just had to be accepted. The trend today is to approach each capacitor failure as the potential result of a design, operation or maintenance defect.

An in-depth investigation should be conducted by an investigator familiar with the capacitor bank and performed before any potential evidence is disturbed. Once the root cause of the failure is determined, the information can then be passed on to the responsible department(s). Relevant information can be obtained and shared through this process and appropriate changes can then be made where applicable.

Substation shunt capacitor banks are becoming increasingly important in the reliable and economic operation of electric systems. The experiences associated with the increased use of these capacitor banks have made it apparent that these static devices are extremely vulnerable to a multitude of system abnormalities.

It is essential to fully understand the operating characteristics of shunt capacitors and to apply good engineering principles in their design, operation, and maintenance.

The two problems identified in this paper illustrate that there are many potential sources that can lead to or cause capacitor failures. It is therefore essential that each substation shunt capacitor failure be thoroughly investigated so that a root cause can be identified and the resulting information used to improve the reliability of both the current and future capacitor banks.

8. REFERENCES


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