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Characteristics of the Reactive Power Output of Metallized Polypropylene Capacitors at Thermal Stability Conditions

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Abstract

The nature of loads in the Low Voltage (LV) systems is predominantly inductive. This leads to a lagging power factor in LV networks and hence it is essential to compensate for the lagging power factor with suitable LV capacitor banks. Low Voltage power factor compensation is done with shunt capacitors to maintain a power factor closer to unity. For LV shunt power factor compensation, LV capacitors of the Metallized Polypropylene (MPP) type are predominantly used. When used in LV systems, these capacitors are operated under full load and generally operate at maximum operating temperature. A study was undertaken to identify the reactive power output under such conditions in MPP-type capacitors of similar voltage and different power ratings and the results of the study are discussed in this paper.

Keywords: Capacitor, Capacitance, Kvar, LV Networks, MPP, Self-Healing APFC Panels, Tan Delta, Thermal Stability, Watt Loss

1. Introduction

In distribution networks, the quest is for the reduction in power losses and improved system efficiency in the distribution network. Significant changes are happening in load-side management in the distribution sector. Industrial loads have become very dynamic with the increased usage of power electronics in motors and drives. As the nature of loads in the Low Voltage (LV) systems are inductive, it is essential to compensate for the lagging power factor with suitable LV capacitor banks. Capacitors with Polypropylene as dielectric and coated with metallization also termed MPP type are mostly used in the LV networks. These capacitors are of the self-healing type.

2. Self-Healing Process

Self-healing is a process by which voltage breakdown of dielectric, heals in a matter of microseconds and hence does not produce a short circuit. The breakdown can occur as a result of weakness or pores in the dielectric film and with evaporation created by the plasma on account of the breakdown in the channel region thus created, the metal edges get removed by evaporation, and insulation areas are formed in this region. The rapid expansion of plasma extends beyond areas of insulation, which leads to rapid cooling in low electric field areas, allowing faster extinguishing, and hence healing takes place. All of this tends to happen in a few microseconds. The areas of insulation thus created tend to become highly resistive and can withstand higher voltage stress. The advantage of these self-healing capacitors is that all the Self-Healing process happens so fast, that the capacitor is functional without any breakdown during this SH period.

3. Advantages of SH-Type Capacitors

These SH-type capacitors are almost 2.5 times more compact by volume and lesser in weight than the non-self-healing type of capacitors used in shunt compensation. Further, with advancements in design, nowadays SH type

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capacitors for shunt compensation come without any liquid fill with dry inert gas fill.

With increased emphasis on automation in the LV networks power factor shunt compensation is done with LV Automatic Power Factor Correction (APFC) panels which are gaining popularity. Here again, these types of capacitors are used due to their low weight and low volume.

4. Usage-Challenges

As space availability for electrical panels is a major issue in cities multiple units of SH-type capacitors are housed in cramped compartments of panels wherein there is limited space for ventilation. Hence the capacitors operating in such spaces are operated at almost elevated temperatures due to constricted spaces of the installations.

As the output of the capacitors plays an important role in deciding the kvar requirement it is important to access the output of SH-type capacitors at elevated temperatures. Hence it is essential to study the output of the SH-type capacitors that are operated at elevated temperatures. To access and create such operating conditions a study was undertaken to understand the variation in output of the SH-type capacitors.

5. Details of Test Samples Used for the Study

Three test samples of the same voltage rating were used for the study and the details of the samples are listed in Table 1.

Table 1. Details of test sample used for the study

Sl. No.	Rating of the Test Sample	Design Max. Ambient Temperature	Identity of test Sample
1.	28.1 kvar, 440V, 3Φ, Δ connected, 50Hz MPP Gas filled LV Capacitor	60°C	Sample 1
2.	28.1 kvar, 440V, 3Φ, Δ connected, 50Hz MPP Resin filled LV Capacitor	60°C	Sample 2
3.	75 kvar, 440 V, 3Φ, Δ connected, 50Hz MPP LV Capacitor- dry type- Gas filled	55°C	Sample 3

6. Criteria and Guidelines for the Study

Studying the output of the SH-type capacitors used in such constricted spaces under demanding ambient conditions is important to ensure the reliable performance of capacitors in delivering the required output. The thermal and electrical stress was carried out based on the criteria specified in the IEC 60831-1 for the thermal stability test[1].

To simulate the thermal stresses the test sample was to be placed in an oven set to the maximum ambient for which the capacitor was designed.

For simulating the electrical stress the capacitor was stressed to 1.44 times its rated output calculated by measuring the capacitance at the rated voltage and frequency. The capacitances are to be measured at an ambient of 25 ± 5 °C between two-line terminals for all three configurations and values thus arrived are denoted as *Ca*, *Cb*, and *Cc*. The output *Q* of the capacitor can be computed. Since all the three units chosen for the study were Delta-connected units, as is normally the case in LV shunt compensated capacitors, the measured capacitance is symmetrical wherein the change in capacitance between the maximum and minimum value will be within 8% and the output of the capacitance is calculated using the formulae[1]

$$Q = (2/3)\ (Ca+Cb+Cc)\ \omega\ U_N^2\ 10^{-9} \text{ ---- Equation (1)}$$

Where

Ca, *Cb*, and *Cc* are expressed in microfarads (μF);
U_N is expressed in volts (V);
ω Omega- expressed as 2*pi*f;
f- frequency of measurement;
Q is expressed in kilovars (kvar).

The test samples are to be exposed to the above test conditions for a period of 48 hours.

Thermal behavior is a function of the relation between a heated body and the environment as per Newton's laws. This fact can be written as the differential relationship:[2]

$$dQ/dt = \alpha A(TS-T)\text{- Equation (2)}$$

where Q is defined as the heat, A is the surface area of the heat-transferring body/surface area available for heat transfer on the body, T is the temperature of the body, surrounding environmental temperature is TS, α is the temperature transfer coefficient based on the material, surface, heat transfer capability and other factors of the material. But since different materials are used in the capacitor construction with PP film, filler in the form of gas or resin, aluminium/steel container for housing the elements, steel or brass studded terminals, etc. it is difficult to compute α. Hence to ascertain thermal equilibrium, the procedure adopted in IEC 60831 was generally used wherein the case temperature of the test sample container was measured at 2/3 of the height from the bottom and the increase between two hourly readings was less than 1°C during the last six hours of the 48 hours.

Since the dissipation factor plays an important role, the measurement of the dissipation factor (tan delta) will also be measured to understand the watt losses of the capacitor.

7. Experimental Setup

The capacitor unit subjected to the study was placed in an oven in the most unfavorable thermal position between two other units of the same rating to simulate the effects of thermal radiation from each other which is the worst-case scenario.

The other units were energized at the same voltage as the capacitor under study. The separation between the units was kept at about 50 mm from each other. in a heated enclosure in the most unfavorable thermal position. A view of the test arrangements is shown in Figure 1.

Figure 1. A view of sample 1 undergoing test.

At the end of the 48-hour capacitance measurements were carried out and the output values were computed using the formulae at Equation (1).

8. Test Results of the Study

Measurements were carried out before the commencement of the test at an ambient temperature of 25 ± 5 °C. These values were kept as the base value for further comparison. The test results of the initial measurement are presented in Table 2.

Table 2. Measured test results- Initial Values at 25°C

Parameter	Sample 1	Sample 2	Sample 3
Measured (Initial) capacitance (μF) at rated voltage and frequency and at an ambient temperature of 25°C	233.84	235.07	638.18
	234.4	234.88	637.47
	233.25	235.29	638.33
Initial calculated output (kvar)	**28.44**	**28.60**	**77.61**
Measured tan delta at rated voltage and frequency and at an ambient temperature of 25°C	0.00061	0.00057	0.00039
	0.00062	0.00056	0.00038
	0.00059	0.00056	0.00039
Initial calculated power loss (in Watts)	17.26	16.11	30.01
Calculated Watt losses/ kvar	0.61 W/ kvar	0.57 W/ kvar	0.39 W/ kvar

Measurements were carried out at the end of the 48th hour at the design max ambient temperature. These values were used to understand the behavior of the capacitor and the variation in output of the SH-type capacitors. The test results of the study after 48 hours are presented in the Table 3.

Measurements were carried out after completion of the test after the capacitors cooled down to an ambient temperature of 25 ± 5 °C. These values were taken as the final values for further comparison. The test results of the final measurement are presented in Table 4.

Table 3. Measured test results- Elevated ambient

Parameter	Sample 1	Sample 2	Sample 3
Measured capacitance (μF) at rated voltage and frequency and at an elevated temperature at the end of the 48 hours	230.14	231.62	629.49
	230.73	231.62	629.35
	229.52	231.94	629.94
Calculated output (kvar) at ambient equal to maximum design ambient temperature.	27.99	28.19	76.59
Percentage change in output kvar from the initial value in the table	-1.58%	-1.43%	-1.32%
Increase in case temperature over and above the maximum design ambient temperature.	13°C	11°C	14°C
Measured tan-delta at rated voltage and frequency and at an elevated temperature at the end of the 48 hours	0.00054	0.00045	0.00037
	0.00052	0.00046	0.00036
	0.00049	0.00046	0.00037
Calculated loss at elevated temperature (in Watts)	14.46	12.87	28.08
Calculated Watt losses/ kvar	0.52 W/ kvar	0.46 W/ kvar	0.37 W/ kvar

Table 4. Measured test results- After tests at 25°C

Parameter	Sample 1	Sample 2	Sample 3
Measured (Initial) capacitance (μF) at rated voltage and frequency and at an ambient temperature of 25°C	233.71	234.99	638.84
	234.32	234.83	638.03
	233.18	235.22	638.94
Calculated output (kvar) at the end of the test	28.43	28.59	77.68
Percentage change from the initial value in the table	-0.04	-0.03	0.10
Measured tan delta at rated voltage and frequency and at an ambient temperature of 25°C	0.00058	0.00059	0.00044
	0.00060	0.00059	0.00041
	0.00059	0.00059	0.00042
Initial calculated power loss (in Watts)	16.78	16.87	32.89

9. Data Analysis of the Study

From the study, it was found that there are changes in the output of the MPP-type capacitors at elevated temperatures. As is known the internal core of the capacitor winding gets heated up due to the watt losses[3]. From the study and the test results in Table 3, it is found that the higher the watt losses, the higher the recorded case temperature. All three samples displayed a similar reduction in output kvar at elevated temperatures. All three samples exhibited a reduction of kvar output from 1.32% to 1.52% on account of a reduction in capacitance at elevated temperatures even though there is a reduction of watt losses/ kvar. This indicates the homogeneity of all three test samples thereby indicating that MPP-type capacitors may have a reduction in output with an increase in capacitor case temperature. From Table 4 it is seen that as the capacitor comes back to its normal temperature the change in output is insignificant at -0.04% to 0.10%. This indicates that the reduction in capacitance is not because of any SH breakdown and the phenomenon is only temporary and there is no permanent damage to the capacitor. So utilities have to factor in this phenomenon of reduction in output when they install capacitors, particularly in cramped locations with poor ventilation.

10. Acknowledgements

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11. References

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