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Power Capacitors for AC Power System Application

Central Power Research Institute, Bangalore, is playing an important role in the development of the capacitor industry by providing required facilities for research, testing and evaluation of power capacitors. With the help of these facilities, all types of power capacitors, like all film capacitors, composite dielectric capacitors, metallized film capacitors, etc. are being tested and evaluated. In addition to facilities for routine and type testing of power capacitors according to the IS Standard, sophisticated and expensive equipment for conducting more stringent tests like Endurance test on full-size capacitor units up to unit rating of 1 MVAr and partial discharge test based on advance acoustic emission technique are available in the Capacitors Laboratory of CPRI, Bangalore. Facilities for testing high voltage series capacitors have been developed including discharge current test, disconnecting test on internal fuses and cold duty test. In the field of LV capacitors, special test facilities for charge-discharge and destruction test have been augmented to meet the requirements according to the revised IS:13341-1992. Test facilities are also available according to the UL safety requirements. Capacitor manufacturers in the country and from abroad are availing the facilities of CPRI. Experience of CPRI during testing of different types of LV and HV capacitors of unit rating ranging from 1 kVAr to 1118 kVAr for the last 10 years for will be covered in the paper. Some of the important issues like (a) factors influencing the capacitor losses, (b) influence of dissipation factor on the performance of LV capacitors during 1500 hours aging test, (c) performance of full - size HV capacitors under cyclic over voltage applications at different lower temperature limits, (d) operation of internal fuse, (e) testing of special capacitors for space applications, (f) factors influencing discharge current characteristics for series capacitors, and (g) acoustic emission technique as one of the NDT methods for performance evaluation, etc. will be discussed in the paper.

1.0 INTRODUCTION

In our country, Capacitor industry has seen an amazing growth during the past 2 to 3 decades. With the availability of high dielectric strength, low loss materials and improved processing techniques, high voltage capacitors with very low dielectric losses and good dielectric and thermal performance are being manufactured. Polypropylene film impregnated with suitable synthetic fluid has become the most commonly employed insulation for HV capacitors. The design stress has increased to nearly 75 V/μm. HV capacitors of unit rating up to 1118 kVAr 12 kV AC are being indigenously manufactured.

As far as LV capacitors are considered, Shunt capacitors up to 100 kVAr, Motor/electric fan capacitors and fluorescent/discharge lamp circuit capacitors up to 50 MFD, 415 V AC 3 φ, are being manufactured. MPP film capacitors have replaced conventional mixed dielectric capacitors due to certain distinct advantages like low loss, compactness and low cost. Impregnated all PP-film capacitors are also in use for LV applications [1–3].

Central Power Research Institute (CPRI) is functioning as an Independent Authority for Testing and Certification of electrical equipment, including power capacitors. Capacitor manufacturers, Power Utilities, Bureau of Indian Standards and Customers from abroad are availing the expertise and facilities of CPRI.

All types of HV and LV capacitors like Shunt, Series, Surge Protection, Harmonics Filter, Motor, Fan, Fluorescent, etc are tested at the Capacitors Laboratory of CPRI in accordance with National and International Standards and also for product development as per Customers' requirement. The facilities are being progressively augmented and upgraded to take care of industry's requirements and also amendments and revisions of testing standards. CPRI is thus, playing an important role in the growth and development of the capacitor industry by providing necessary facilities for Research, Testing and Evaluation of Power Capacitors [4].

Thirty-five years of experience of CPRI in testing different types of LV and HV capacitors of unit rating ranging from 1–1118 kVAr will be covered in the paper. Some of the New and Unique tests performed in the recent past have been highlighted.

2.0 EXPERIENCE OF CPRI IN TESTING OF CAPACITORS

A State-of–the-art laboratory has been set up for conducting research, testing and certification of capacitors. A view of the Power Capacitors Laboratory of CPRI is shown in Figure 1.

FIG. 1 A VIEW OF POWER CAPACITORS LABORATORY OF CPRI

The test ranges and types of capacitors covered by Power Capacitors Laboratory of CPRI are summarized in Table 1. With these facilities, capacitors made of different types of insulation

TABLE 1

TYPE AND TEST RANGE OF CAPACITOR TESTING AT CPRI, BANGALORE

Type of Capacitor	Reference Standard	Maximum Rating
HV Shunt capacitors (For Routine and Type tests)	IS:13925-1:1998, IEC:60871-1:2005, IEC:60871-4:1996 IEEE:18:2002	3500 kVAr, 16 kV, 50 μF
HV Shunt capacitors (For Endurance test)	IS:13925-2:2002 IEC:60871-2:1999	1000 kVAr, 20 kV, 8 μF 1000 kVAr, 9 kV, 50 μF
HV Series capacitors (For Routine and Type tests)	IEC:60143-1:2004 IEC:60143-3:1998	3500 kVAr, 20 kV, 50 μF
HV Series capacitors (For Cold duty test)	IEC:60143-1:2004	1000 kVAr, 16 kV, 12 μF
HV Capacitors for surge Protection	IS:11548:1986 (RA March 2006).	0.125 MFD, 40 kV
LV Motor capacitors	IS:2993-1998. IEC:60252-1:2001	100 × 10 MFD, 440 V AC
LV fan motor Capacitors	IS:1709:1984 (RA Mar 2006 Amdt No. 2)	100 x 10 MFD, 440 V AC
LV Capacitors for Lighting	IS 1569 1976 (RA 2001) IEC 61048:2006, IEC 61049: 1991.	100 x 10 MFD, 440 V AC
LV Power capacitors of self-healing type	IS 13340: 1993, IS 13341: 1992 IEC 60831-1:2002 IEC 60831-2:1995	150 kVAr, 600 V AC
LV Shunt capacitors of non self - healing type	IS 13585-1:1994 IEC 60931-1:1996 IEC 60931-2:1995 IEC 60931-3:1996	150 kVAr, 440 V AC

system, like All-film Capacitors, Composite dielectric Capacitors, Metallized film Capacitors, etc., used for varied applications are being tested according to the relevant IS and IEC standards, In addition to facilities for Routine and Type testing, sophisticated equipment for conducting more critical tests like Electrical Endurance test, Discharge current test, Charge–Discharge cycle test, Destruction test and Partial Discharge test are also available in the Laboratory. In addition to Testing and Certification, the laboratory can also facilitate manufacturers to develop new types of capacitors for application beyond power sector. It is expected that with the present facilities, CPRI laboratory will cater to the requirements of capacitor manufacturers within the country and abroad for next 10–15 years.

Facilities at the power capacitors laboratory have been accredited for electrical testing according to the ISO/IEC 17025 by National Accreditation Board for testing and Calibration Laboratories (NABL), Govt. of India and signatory to International Laboratory Accreditation Co-operation (ILAC) Mutual recognition Arrangements, UL and BIS. CPRI has been given the Membership status in the group of Short Circuit Testing Liaison (STL) of Europe.

Capacitor manufacturers within the country and from abroad are availing the facilities of CPRI. Three decades of experience of CPRI during testing of different types of LV and HV capacitors are given below. It is earnestly hoped that the information would help the industry in taking suitable measures to further enhance the reliability of capacitors.

3.0 GROWTH OF CAPACITOR TESTING

Testing activity at the Power Capacitors Laboratory of CPRI has increased in tune with the demand and performance of capacitor industry. The growth in testing activity at CPRI has almost coincided with the rate at which capacitor industry has grown, as most of the manufacturers have approached CPRI for testing of their new development. Manufacturing of capacitors in India started in early 1970s. The first capacitor of rating 1 kVAr, 415 V AC was tested at CPRI in the year 1974. Since then, capacitor industry and hence the Capacitor Laboratory of CPRI has seen a phenomenal expansion. Different types of capacitors like Shunt, Series, Surge protection, fan/motor, lighting, filter, etc. are being indigenously manufactured and CPRI has provided necessary facilities for testing these capacitors. CPRI has tested more than 2500 capacitors till date (September 2009). Some of the important mile stones of testing at CPRI are outlined below separately for LV and HV capacitors.

3.1 LV CAPACITORS' GROWTH

The growth in the LV capacitor manufacturing in India is depicted in Figure 2, in terms of maximum output rating tested in a particular year at CPRI. The rating of LV capacitors tested at CPRI has increased from 1 kVAr, 415 V AC duringthe year 1974 to the highest an rating of 100 kVAr 525 V AC in the year 2007. Increase in LV capacitor testing activity at CPRI is shown in Figure 3, in terms of number of capacitors tested per year for the last 35 years.

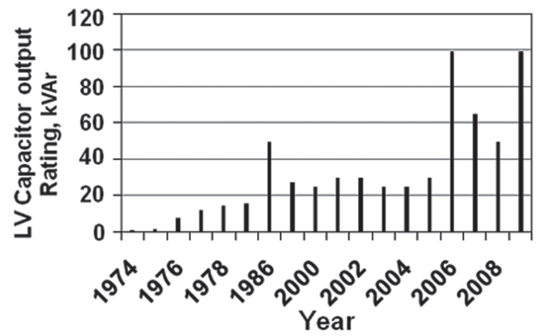


FIG. 2 GROWTH IN RATING (kVAr) OF LV CAPACITORS TESTED

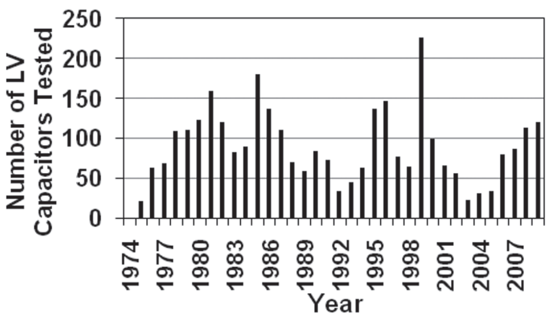
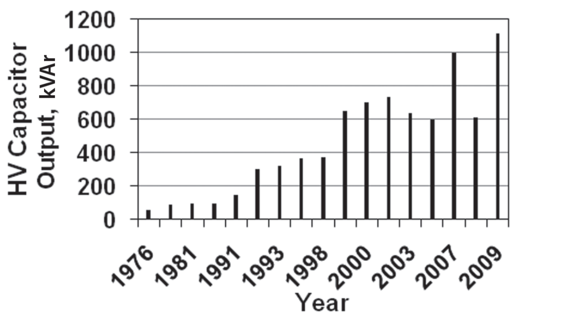


FIG. 3 TREND OF NUMBER OF LV CAPACITORS TESTED AT CPRI

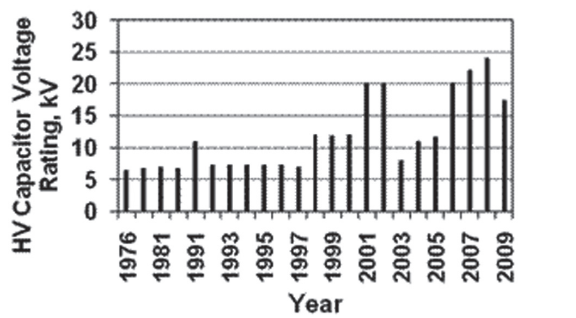
3.2 HV Shunt Capacitors' Growth

There are more than 10 major HV capacitor manufacturers in the country. With the availability of high dielectric strength and low loss materials like polypropylene (PP) film and improved processing techniques, high-voltage capacitors with very low dielectric losses are being manufactured. The lowest tan δ value measured for all PP film oil impregnated internal fuse type capacitor 0.00013. The design stress has reached as high as 75 V/µm and consequently, reducing the size of capacitor.

The first HV shunt capacitor of unit rating 55 kVAr, 6.35 kV was tested in the year 1976 according to the IS 2834:1964. Figures 4(a) and 4(b) show the trend of HV capacitor rating, with reference to the highest kVAr and kV for a particular year, respectively, tested at CPRI. The highest unit rating (kVAr) of HV shunt capacitor tested as on September 2009 is 1118 kVAr, 12 kV for all Routine and Type tests in accordance with IS 13925 -1:1998. The highest voltage rating is 24 kV AC (Figure 4 (b)). A gradual increase in HV capacitor testing activity at CPRI is shown in Figure 5, in terms of number of capacitors tested per year for last 33 years.



4(A) CAPACITOR OUTPUT



4(B) VOLTAGE RATING

FIG. 4 TREND OF HV CAPACITOR RATINGS TESTED

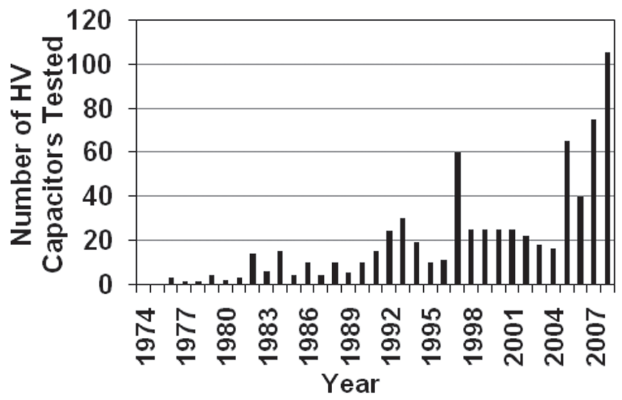


FIG. 5 NUMBER OF HV CAPACITORS TESTED PER YEAR AT CPRI

3.3 HV Series Capacitors' Growth

Application of Series Capacitors for series compensation is gaining importance to transmit sufficiently large amount of power over long distances and also to increase the capability of already existing lines. At present, there are very few manufacturers for series capacitors in the country. The first series capacitor tested was of unit rating 97.8 kVAr, 4.16 kV according to the IEC:143-1:1992 in the year 2001. The highest unit rating (kVAr) tested for each year from 2001 to September 2009 is shown in Table 2. Since 2001, around 70 series capacitors have been tested.

TABLE 2

HIGHEST RATING (kVAr) OF SERIES CAPACITORS TESTED (YEAR-WISE)

Year of testing	Capacitor Unit rating		
	kVAr	kV	C, µF
2001	158.00	5.280	18.066
2003	670.40	6.057	57.56
2004	645.90	10.000	20.68
2005	593.00	5.738	58.238
2006	552.50	7.100	34.852
2007	33.00	7.100	1.951
2008	424.00	6.360	34.361
2009	697.64	10.460	19.975

4.0 PERFORMANCE OF CAPACITORS DURING TESTING AT CPRI

4.1 HV Shunt Capacitors Routine and Type Tests

For the last three decades, more than 300 HV shunt capacitors have been tested for Type and Routine tests. As depicted in Figure 4(a), the maximum unit rating of shunt capacitor tested so far is 1118 kVAr 12 kV during September 2009. Majority of the capacitors have generally passed Routine and Type test sequence. Some of the important aspects which influence the capacitors' performance are discussed as under.

One of the interesting observations is the value of tan δ for impregnated all PP film type HV capacitors. There is a substantial reduction in tan δ value over the last 30 years from 0.00024 to 0.00009. Figure 6 depicts this improvement of capacitor loss in terms of W/kVAr for internal fuse and external fuse type capacitors during the last 20 years.

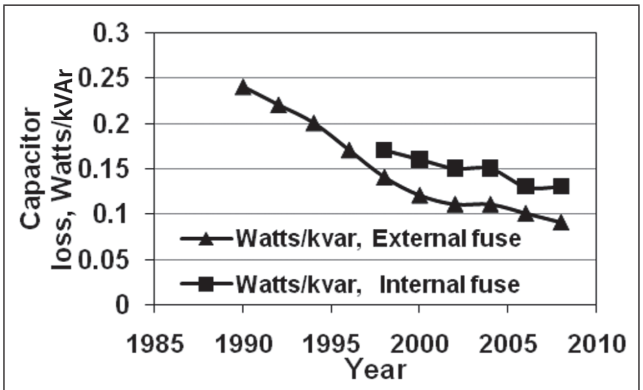


FIG. 6 TREND OF CAPACITOR LOSS FOR INTERNAL FUSE AND EXTERNAL FUSE TYPE CAPACITORS

The least tan δ value achieved by Indian capacitor manufactures is as low as 0.00013 for internal fuse capacitors and 0.00009 for external fuse capacitors. The test data shows that internal fuses in HV capacitors contribute to a loss of the order of 0.03 W/kVAr. Although Indian manufacturers are employing imported raw materials which possess low dielectric loss, the process of manufacturing has improved significantly to maintain the purity and quality of material in the finished product as indicated by the tan δ value.

Similarly, a better performance of capacitors during thermal stability test has been observed. For example, during 1999, increase in case temperature was as high as 9 K, whereas it is around 3 K and change in capacitance and tan δ during 48 hours of thermal stability test is negligible.

Influence of temperature on capacitance and tan δ has been studied over a wide range of temperature from minus 50°C to + 60°C. A typical set of data for a 200 kVAr, 7.3 kV Shunt capacitor is depicted in Figure 7. An almost linear change in capacitance and tan δ with temperature have been observed in the temperature range considered. This information will help the manufacturers to assess the change within the lowest and highest temperature category limits and also to estimate the values of C and tan δ over the temperature range.

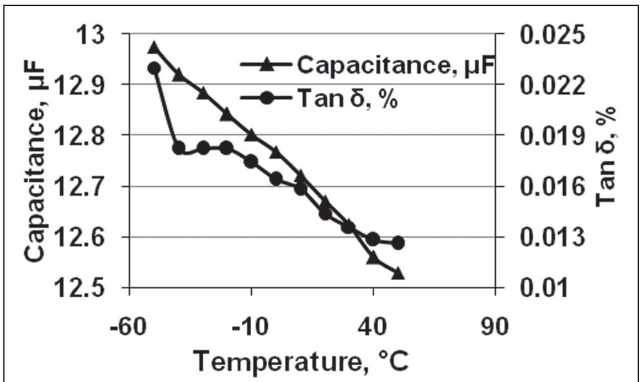


FIG. 7 TYPICAL VALUES OF CAPACITANCE AND TAN Δ AS A FUNCTION OF TEMPERATURE FOR A 200 kVAr, 7.3 kV, SHUNT CAPACITOR

Performance of capacitors during sealing test has considerably improved. During early 1990s, a few cases of leakage of impregnant were observed. However, the change over from solderable type of bushing to weldable type has significantly arrested the leakage.

The overall performance of HV capacitors for Routine and Type tests is satisfactory as per CPRI test data.

4.2 HV Shunt Capacitors : Electrical Endurance Test

Endurance test has been proved to be an important test in checking the reliability of the capacitors, as it checks the performance of the capacitors under transient over-voltage cycles. The capacitors are expected to withstand certain over-voltages due to switching operations. The amplitude of over-voltages that may be tolerated without significant deterioration of the capacitor depends on their duration and total numbers.

Electrical endurance test at CPRI was started in year 1991 on model capacitor units. The first capacitor tested was of unit rating 30 kVAr, 7.3 kV according to IEC 60871-2:1987 during 1991. The next highest rating of a full size capacitor tested was 200 kVAr, 7.3 kV in the year 1998. The highest rating of full size capacitor tested for Endurance test at CPRI till date is 2 × 500 kVAr, 8.4 kV shunt capacitor according to the IEC 60871-2:1999 during the year 2006.

CPRI has tested over 90 capacitors for Endurance test, from 1991 to Sept 2009. During the year 1999, the procedure for Endurance test was revised by including temperature of 60°C in addition to test voltage of 1.4 UN. The duration of Aging test was increased from 500 hours to 1000 hours. The number of OVC cycles was reduced from 1700 cycles to 850 Cycles.

During the past 18 years, failure rate has reduced from 25 % (during 2000) to 12 % (as on Sep. 2009). Majority of failures have occurred during early cycles of OVC test (within 200 cycles) and during Aging test at 60 °C as per the latest IEC. The improvement in performance of capacitors is due to continuous advances being adopted by the Capacitor Industry in the country to meet the latest IEC requirements.

In order to assess the performance of capacitors during endurance test, capacitance and tan δ values were periodically monitored during 1000 hours of aging test. No appreciable change in capacitance and tan δ values has been observed for those capacitors which passed OVC and Aging tests. The maximum observed change in capacitance is 0.04 μF and for tan δ, it is 0.006%.Tan δ values measured during aging test for three typical ratings of capacitors are shown in Figure 8.

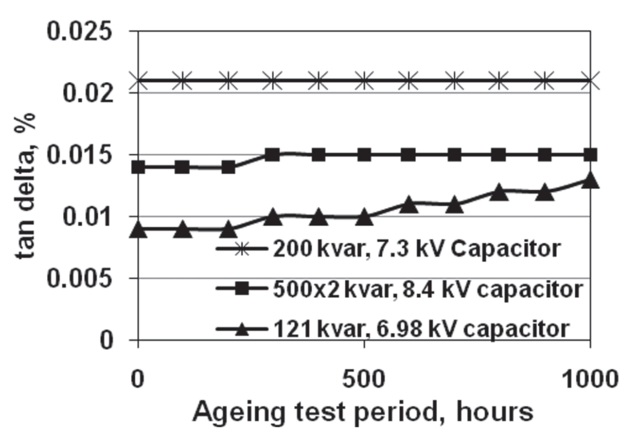


FIG. 8 CHANGE IN TAN Δ WITH TIME DURING AGING TEST AS PER IS:13925-2/IEC:60871-2:1999

4.3 HV Series Capacitors

For the period from 2001 to 2009, around 80 numbers of HV series capacitors have been tested. Among the type tests, Cold duty test, Aging test, Disconnecting test on internal fuses and Discharge Current are the important tests. Performance of series capacitors during these tests are discussed below.

4.3.1 Cold Duty Test

Cold duty test as per IEC 60143-1:1992 specifies 100 power frequency over voltage cycles. Cold duty test has been carried out on 6 numbers of series capacitors out of which 3 capacitors have failed during initial cycles (like 1st cycle to 41st cycle). During the year 2004, IEC standard was revised by reducing number of cycles to 50 and changing the voltage levels. Cold duty test as per the revised IEC has been carried out on 6 numbers of series capacitors out of which 3 capacitors have failed during first few cycles itself (like 1st cycle to 9th cycle). This data indicates the need for improvement in design, material and construction of series capacitors for cold duty test requirements.

4.3.2 Discharge Current Test

Test facilities for Discharge Current test as per IEC:60143-1:2004, have been established in the year 2004. Series capacitor of rating 552.5 kVAr, 7.1 kV was tested for the first time at CPRI for discharge current test. Methodology of testing and test requirements are covered in CAPACIT 2005 paper [6]. So far, 3 numbers of series capacitors have been tested for Discharge current test, details of which are summarized in Table 3.

TABLE 3

SUMMARY OF DISCHARGE CURRENT TEST ON SERIES CAPACITORS TESTED

Capacitor details				Result
kVAr	kV	µF	ΔC, µF	
552.5	7.1	34.77	–0.153	Pass
424	6.36	34.693	–0.02	Pass
697.64	10.46	19.975	0.031	Pass

Performance of series capacitors tested so far is generally satisfactory.

4.4 LV Capacitors: Routine and Type Tests

During the last 35 years period (1974 to 2009), more than 2500 LV capacitors from various manufacturers have been tested in CPRI as per IS:2834-1986, IS:1569, IS:1709, IS:2993, IS:13340:1993, IEC:60831-1-2002, IS 13585-1, IEC:60931-1-1996. Types of capacitors tested include mixed dielectric, impregnated all PP, dry and impregnated MPP used as shunt capacitors, fluorescent lamp capacitors, fan capacitors, AC motor capacitors, self healing and non-self healing type capacitors. Performance of the capacitors during the Routine and Type tests is generally satisfactory. IS:2834-1986 was the most commonly used specification by most of the LV capacitor manufacturers and utilities till late 1990s. IS:2834 covered testing of both self-healing and non-self-healing type capacitors. However, Bureau of Indian Standards published separate standards namely IS:13340-1993, IEC:60831-1-2002 and IS:13341-1992, IEC:60831-2-1995 for testing of self-healing type and IS:13585 Part 1, 1994 for non-self healing type capacitors. IS:13340 and 13341 for LV capacitors and IS:13925 parts 1 and 2 for HV capacitors, have superseded IS:2834.

Summary of the performance of the above capacitors for the period 1974 to 2009 are depicted in Figure 9.

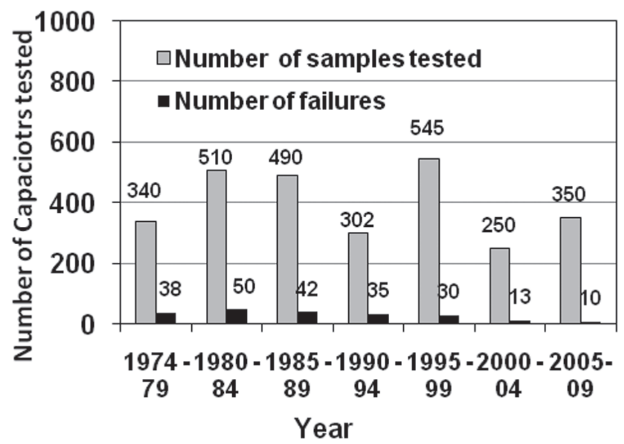


FIG. 9 PERFORMANCE OF LV CAPACITORS TESTED

Over the years, performance of LV capacitors has improved significantly as indicated in Figure 9. Percentage of failure has reduced from 10 % to less than 2% over a period of 35 years of testing at CPRI.

Out of the type tests conducted, thermal stability test is of prime importance in deciding the test temperature for aging test. Based on the test data, an analysis has been made to assess the influence of tan-δ values on the thermal performance of capacitors. Figure 10 shows tan δ versus increase in capacitor case temperature due to thermal stability test. As can be seen from the Figure 10, tan δ upto

0.0005 has resulted in 4K rise in capacitor case temperature. Beyond this, a steep rise in case temperature has been observed with tan δ value. Effect of tan δ value and rise in case temperature on performance of capacitors during aging test has been discussed in detail as under.

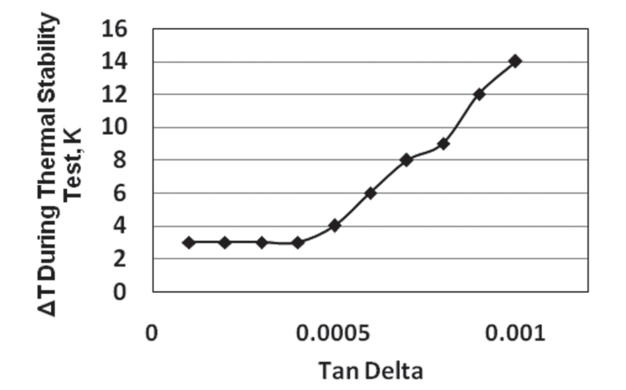


FIG. 10 INFLUENCE OF TAN ΔON CAPACITOR CASE TEMPERATURE DURING THERMAL STABILITY TEST

4.5 LV Capacitors: Aging and Destruction Tests

Aging test and Destruction test at CPRI was started during the year 2000 on a 1 kVAr, 440 V Capacitor at the request of BIS. Since then, more than 60 numbers of capacitors have been tested till Sept. 2009 for Aging test and 56 numbers for Destruction test in accordance with IS:13341/ IEC:60831-2. Performance of capacitors during aging and destruction test for the period from the year 2000 to 2009 is shown in Figures 11 and 12. As seen from these figures, performance is generally satisfactory, with more than 85 % of capacitors successfully withstanding the aging test and destruction test.

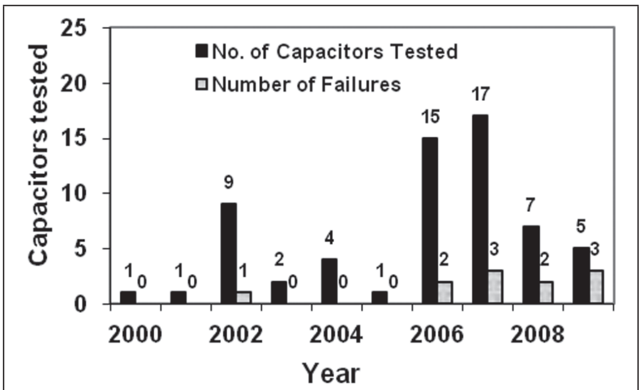


FIG. 11 PERFORMANCE OF LV CAPACITORS DURING AGING TEST

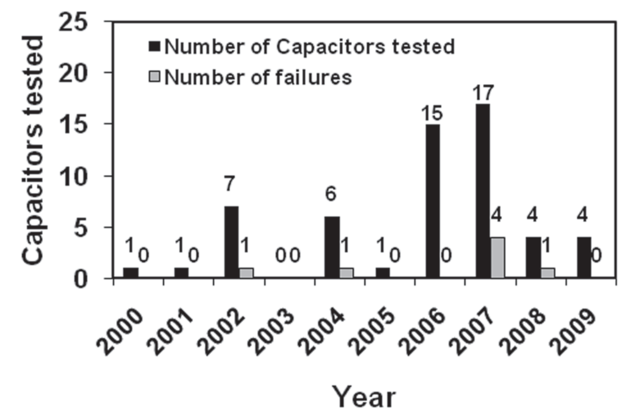


FIG. 12 PERFORMANCE OF LV CAPACITORS DURING DESTRUCTION TEST

During destruction test, maximum failures have been observed due to bursting of the capacitors. Some of the failures have resulted in flames with fiery particles ejecting from the capacitors.

During 1500 hours of aging test, change in capacitance has been monitored and tan δ value has also been recorded. The observed change in tan δ (absolute) value is in the range of 0 to 0.003. The analysis of change in capacitance is summarized in Table 4 for 60 numbers of capacitors tested. This analysis was to find out the number of capacitors tested falling into the different categories of change in capacitance. More than 50% of the capacitors tested have shown less than 1% change in capacitance.

TABLE 4

CHANGE IN CAPACITANCE DUE TO AGING TEST

Observed change in capacitance (ΔC)	Percentage of capacitors showing the change (ΔC)	Result
<1%	53	Pass
1 to 2%	10	Pass
Above 2 to 5%	22	Pass
Above 5%	8	Fail
Open circuit	7	Fail

Laboratory test data on thermal stability test, show that tan δ value beyond 0.0006 results in more than 5 K rise in capacitor case temperature during 48 hours of thermal stability test, as shown in Figure 10. Aging test temperature is decided based on the rise in capacitor case temperature during thermal stability test. Aging test data on more than 60 capacitors indicate that majority of the capacitors with tan δ values beyond 0.0006 have failed during 1500 hours of aging test. Some capacitors with tan δ value beyond 0.0008 have failed within 10 hours of aging test. Such failures are attributed to compounded effect of tan δ, increased capacitor case temperature and consequently higher aging test temperature.

It may also be noted that failures have been experienced due to reasons other than high tan δ value. For example, capacitors with tan δ value lower 0.0005 have failed during aging test due to dielectric failure (reduction in capacitance) or poor internal element connection or poor terminal end connections (open circuit).

5.0 NEW AND UNIQUE TESTS PERFORMED

Some of the New and Unique tests performed with the new facilities at CPRI for the first time in India are listed below.

5.1 Highest Rating Shunt Capacitor Tested at CPRI

Recently, CPRI Type tested a 1118 kVAr, 12 kV, 1Φ, 24.71 µF, 93.17 A, BIL 38/95, external fuse type, Shunt capacitor as per IS 13925-1:1998. This is the highest (kVAr) unit rating capacitor tested at CPRI for the first time in India. A view of 1118 kVAr capacitor in comparison with a 100 kVAr capacitor is shown in Figure 13. The physical dimensions of 1118 kVAr, 12 kV capacitor were 348 mm x 200mm x 1833 m(H), weighing about 150 kg. The main challenge was the thermal stability test, which was performed on the test unit along with two dummy capacitors, mounting horizontally. The test was carried out successfully with the help of a test chamber with internal dimensions of 2 m × 2.2 m × 2.5 m(H) to maintain the test temperature of 55°C±1°C and provide necessary clearance for application of test voltage. A Parallel Resonance test system of rating 6800 kVA, 50/40/30/20 kV having a voltage regulation within ±2% was employed for carrying out the test. A view of the arrangement for thermal stability test is shown in Figure 14. At the request of the manufacturer, Lightning impulse voltage test between terminals and container test was also carried out in the horizontal position, as shown in Figure 15.

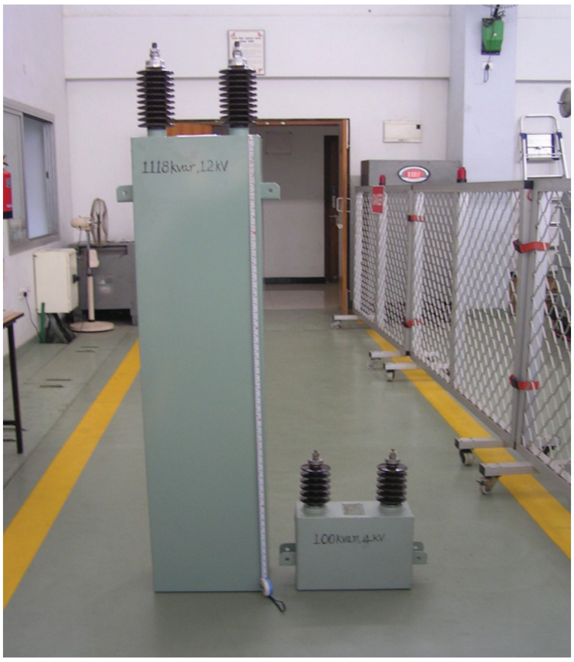


FIG. 13 A VIEW OF 1118 KVAR, 12 KV SHUNT CAPACITOR ALONG WITH A 100 KVAR CAPACITOR

FIG. 14 ARRANGEMENT FOR THERMAL STABILITY TEST ON 1118 kVAr, 12 kV SHUNT CAPACITOR

FIG. 15 A VIEW OF LIGHTNING IMPULSE VOLTAGE TEST BETWEEN CAPACITOR TERMINALS AND CONTAINER

5.2 Fuse Disconnecting Test

Internal fuse is connected in series with each internal capacitor element, which is intended to isolate, if the element becomes faulty. The failure of an element results in discharge current from the parallel elements through the associated internal fuse and blowing of the fuse. This results in increased voltage on the parallel elements within the unit and much smaller increase in the voltage across the associated unit.

The range of currents and voltages for the fuse is, therefore, dependent on the capacitor design. Operation of an internal fuse is in general determined by one or both of the following factors:

(a) The discharge energy from elements, or units connected in parallel with the faulty element or unit

(b) The power frequency fault current.

IEC has specified Fuse Disconnecting test for HV capacitors with internal fuses. IEC:60871-4: 1996 and IEC:60143-3:1998 cover this for Shunt and Series capacitors, respectively.

According to the IEC:60871-4, internal fuses for shunt capacitors are to be designed to operate correctly for voltages that are greater than 0.9 UN and up to and including 2.2 U_N. According to the IEC:60143-3, internal fuses for series capacitors are to be designed to operate correctly at the lower AC test voltage of 0.5 U_N and upper test voltage of 1.1 U_{lim}. Design of capacitors shall take into account the additional current and voltage resulting from blowing of some of the fuses.

Fuse disconnecting test on Series capacitors is more stringent than shunt capacitors, in terms of test voltage levels. In case of series capacitors, the upper test voltage depends on the limiting voltage (U_{lim}), which is to be declared by the manufacturer depending on the capacitor bank design. U_{lim} is normally will be in the range of 2.3–2.5 U_N.

To meet the requirements of IEC, CPRI has established facilities for conducting disconnecting test on internal fuses for both Shunt and Series type capacitors. The first disconnecting test was carried out during the year 2005. Till date, 8 Shunt and 8 Series capacitors have been tested for disconnecting test, the highest rating tested is 1000 kVAr. Summary of disconnecting test performed during 2005–2008 for Shunt and Series capacitors is given separately in Tables 5 and 6, respectively. More test data is required to assess the design and performance of internal fuses during fuse disconnecting test.

TABLE 5

SUMMARY OF FUSE DISCONNECTING TEST ON SHUNT CAPACITORS

Year	Capacitor Rating		Result
	kVAr	kV	
2005	400	11.56	Pass
2006	242	6.98	Pass
2006	238.09	10.14	Pass
2006	600	12	Fail
2006	600	12	Pass
2007	1000	14.4	Pass
2008	428	9.9	Pass
2008	610	7.56	Pass

TABLE 6

SUMMARY FUSE DISCONNECTING TEST ON SERIES CAPACITORS

Year	Capacitor details		Result
	kVAr	kV	
2006	437.5	6.57	Pass
2006	437.5	6.57	Pass
2006	294	6.36	Fail
2006	294	6.36	Pass
2006	294	6.36	Fail
2008	424	6.36	Pass
2008	314	7.46	Pass
2008	314	7.46	Pass

5.3 Discharge Current Test on Series Capacitors

CPRI has necessary test facilities for carrying out discharge current test on series capacitors. The important feature of discharge current test is to achieve the stipulated peak current and discharge energy (I^2t) as mentioned in the IEC 60143-1:2004. For achieving IEC requirements, high-voltage reactors and resistors were critically designed so as to withstand the high inrush currents of the order of kilo amperes. Another critical component required is the device for capturing high-frequency discharge current waveform. The same has been accomplished with the help of a high current shunt and a fast response oscilloscope. With these facilities, Capacitors Laboratory of CPRI has successfully conducted Discharge Current Test on the highest unit rating of 697.45 kVAr, 10.46 kV series capacitor manufactured in the country [6]. A view of test set up is shown in Figure 16. A typical wave-form of discharge current recorded during the test is shown in Figure 17.

5.4 Testing of 66 kV Capacitor Voltage Transformer (CVT)

Capacitors laboratory of CPRI has facilities for testing of capacitor modules of CVT of rating up

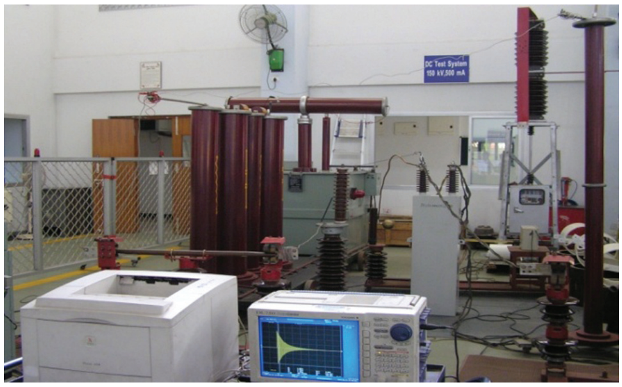
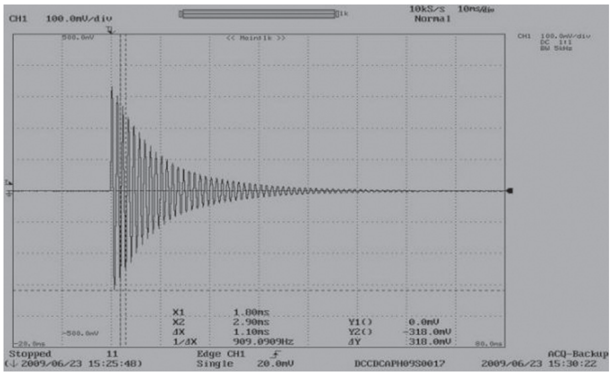


FIG. 16 A VIEW OF TEST SET UP FOR DISCHARGE CURRENT TEST ON 697.45 kVAr,10.46 kV SERIES CAPACITOR



Waveform characteristics,
I^2t:47.9×10^3 A^2 sec, I_{peak}:4.24 kA

FIG. 17 A TYPICAL WAVE-FORM OF DISCHARGE CURRENT RECORDED DURING THE TEST

to 110 kV. Recently, measurement of temperature coefficient of capacitance for a wide range of temperature from −70ºC to +100ºC, for a 66 kV CVT was performed. A climatic test chamber with internal physical dimensions 2.0 m (W) × 2.2 m (D) × 2.5 m (H) and fitted with a 66 kV bushing is employed to conduct the test. Some of the typical results for 66 kV CVT with reference to temperature coefficient of Capacitance is given below.

Capacitor module of a CVT of 66/√3 kV, 8800 pF was tested for determining the temperature coefficient of capacitance according to IEC- 60358-1990. The capacitance and tan δ measurements were carried out by applying a voltage of 19 kV at different temperatures from −25ºC to +80ºC in steps of 15ºC. Temperature coefficient was calculated according to CI. 3.28

of IEC-60358-1990. A view of the test arrangement is as shown in Figure 18.

FIG. 18 A VIEW OF ARRANGEMENT FOR CVT TESTING

The measured values of capacitance, tan δ and calculated values of temperature coefficient of capacitance in percent per Kelvin are shown in Figure 19(a), (b) and (c), respectively.

5.5 Tantalum Capacitors Tested for Space Application

Tantalum capacitor samples for space application were tested for Surge Current test according to MIL-PRF-39003 standard requirements. A batch of 30 polarized tantalum capacitors of different ratings from 47 μF, 20 V DC to 2.7 μF, 100 V DC. View of a 10 μF, 50 V DC Tantalum capacitor is shown in Figure 20.

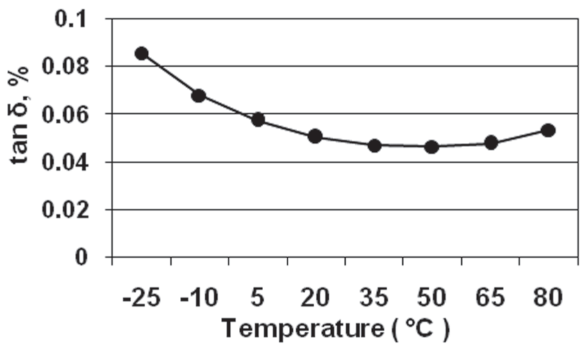


FIG. 19(A) TAN δ VSTEMPERATURE FOR A 66 kV CVT

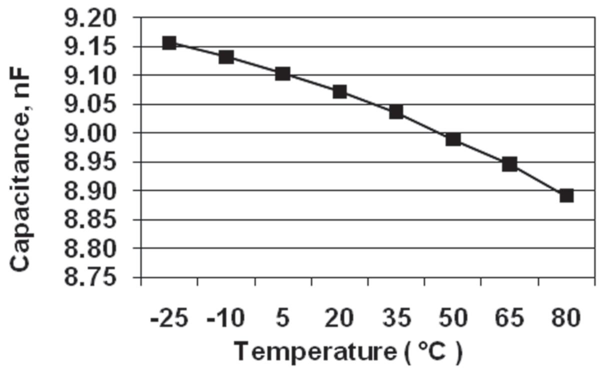


FIG. 19(B) CAPACITANCE VS TEMPERATURE FOR A 66 kV CVT

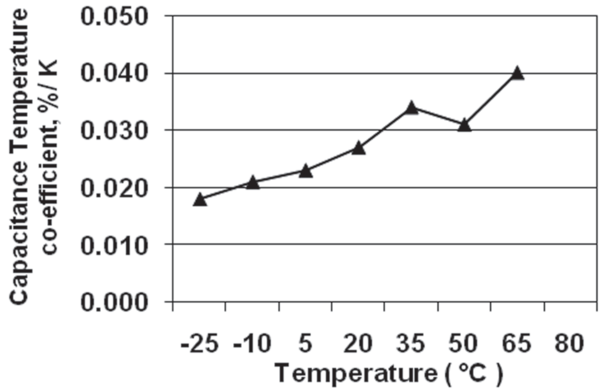


FIG. 19(C) TEMPERATURE COEFFICIENT OF CAPACITANCE FOR A 66 kV CVT

FIG. 20 A VIEW OF A10 μF, 50 V TANTALUM CAPACITOR

The surge current test sequence to meet MIL-PRF-39003 standard requirements was as follows:

(a) Charging the capacitor within 1 sec to rated voltage within 4 sec with a voltage dip less than 2%. The charging source shall have an energy storage bank of 50000 μF (minimum) across the output terminals. The total dc resistance including the wiring, fixtures and the output impedance of the regulated power supply during the charging cycle shall be 1±0.2 Ω.

(b) Discharging within 4 sec to less than 1% of rated voltage. Steps (a) and (b) constitute one cycle.

(c) Steps (a) and (b) constitute one cycle.

(d) Number of surge current cycles: 3

(e) Ambient temperature during the test shall be within 25±5°C

The main challenge for undertaking this activity was to arrange the high-energy capacitor and DC power source of high energy. For meeting this challenge, a suitable test circuit was fabricated in-house. Capacitor charging circuit constituted a DC source of rating 200 V, 500 A and a high-energy capacitor bank with capacitance value of 73,000 μF. The discharge circuit was as stipulated in the requirements of the MIL standard with a resistance of less than 1 Ω when measured across the output terminals. A programmable timer with necessary accessories was employed to simulate the surge current. A typical surge current waveform captured with the help of an oscilloscope is shown in Figure 21, which demonstrates the stringent charging and discharging parameters satisfying the MIL standard requirements.

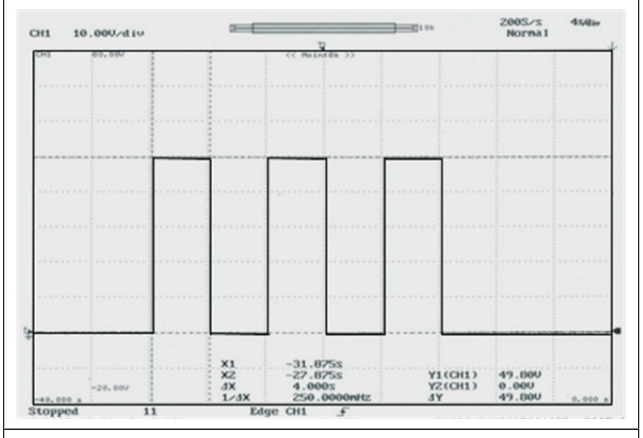


FIG. 21 SURGE CURRENT WAVEFORM

6.0 CHALLENGES OF CAPACITOR INDUSTRY

Some of the technical challenges being faced by Capacitor Industry are discussed below.

(a) Indigenization of raw materials required for manufacturing capacitors:

The raw materials required by the Capacitor industry are presently being imported, as the indigenous materials are not up to the expected quality. Efforts shall be made to indigenize the raw materials to save foreign exchange.

(b) Development of Oil-less capacitors:

As an alternate to oil-impregnated capacitors, gas-or air-filled dry capacitors to be developed to avoid fire hazards and related problems at site.

(c) Quality check:

At present, no strict quality check is practiced by some of the capacitor manufacturers. This may be one of the reasons for poor quality of the capacitors and consequent premature failures. This situation can be overcome by enforcing stringent quality check on the raw materials and finished product.

Another aspect to be seriously considered is the active involvement of utilities in the process of procurement of capacitors right from the stage of study on power supply condition, formulation of capacitor bank specification, physical inspection of manufacturing, process to verify material, design, workmanship etc. CPRI has carried out several root–cause analysis of failure of capacitor banks in joint association of manufacturer and utility. This has helped in identifying the defects and to suggest remedial measures.

The Capacitors Laboratory of CPRI is creating suitable facilities to check the quality of materials employed in capacitors. Necessary equipment to test the PP film and MPP film, mainly for weak spot measurement, have been augmented.

(d) Check for Power Quality:

Another significant contribution for the failure of capacitors is the presence of harmonics and other disturbances like inrush current and over voltages in the power supply. Before the installation of capacitors, a detailed system study is essential.

The Capacitors Laboratory of CPRI has necessary expertise and facilities to measure the power supply disturbances like harmonics, over voltage, etc. Efforts are also being made to suggest remedial measures in case of presence of harmonics, by way of providing filter design.

(e) Testing and Evaluation:

CPRI has established a New Capacitors Laboratory with state-of-the-art facilities for research, testing and evaluation of all capacitors manufactured within the country and received from abroad. The laboratory is first of its kind in this part of the world and will cater to the needs of Capacitor Industry for the next 15–20 years.

7.0 SUMMARY

The Capacitors Laboratory of CPRI has facilities, experience and expertise of more than three decades in Testing and Certification of power capacitors according to National and International Standards. The facilities have been progressively augmented and upgraded to take care of industry's requirements and also amendments and revisions of testing standards. Capacitor manufacturers, Power Utilities, Bureau of Indian Standards and Customers from abroad are availing the services of CPRI.

Some of the important mile stones in the journey of testing are highlighted below:

1. Setting up of a state-of-the-art laboratory for testing of capacitors of rating up to 3500 kVAr, 16 kV, 50 μF.
2. Establishment of a unique test system of rating 6800 KVA, 50/40/30/20 kV parallel Resonance transformer, with output voltage stability of ±.2%, with programmable cyclic over voltage facility.
3. Establishment of a programmable climatic test chamber with internal dimensions of 2.0 m(W) × 2.2 m(D) × 2.5 m(H) and temperature range from −70°C to +100 °C and fitted with a 66 kV bushing.
4. Type testing of 1118 kVAr, 12 kV shunt capacitors for the first time in the country, the highest unit rating shunt capacitor manufactured indigenously as on date.
5. Testing of series capacitors of unit rating 697.64 kVAr, 10.46 kV for Discharge current test for the first in the country, the highest unit rating series capacitor manufactured indigenously as on date.
6. Electrical endurance test on 2x500 kVAr, 8.4 kV, shunt capacitors according to the IEC:60871-2:1999, for the first time in the country.
7. Type testing of 100 kVAr, 525 V AC power factor correction capacitor for a foreign customer from Malaysia for the first time.
8. Tested a 8800 pF, 66 kV CVT capacitor module for the determination of temperature coefficient of capacitance in the range of −25°C to +80°C for the first time.

CPRI testing experience of more than 2500 numbers of capacitors over a period of 35 years has shown a progressive improvement in overall performance of capacitors.

ACKNOWLEDGMENT

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