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Growth and Contribution of The High Voltage Division

The High Voltage Laboratory at Bangalore was initiated around 1964 in the campus of Indian Institute of Science, also called as Tata Institute. the period between 1978 and 1983 in the history of the High Voltage Laboratory of CPRI could be termed as very productive in building up the expertise in R&D, testing and consultancy that paved way for formulating a road map for ensuring a bright future for the high voltage engineering in CPRI. The activities of the division can we attributed to EHV Test Laboratory (Main Laboratory), Mobile Field Testing Laboratory, Pollution laboratory, Impulse Current Laboratory, Development of measuring equipment like Electro-static field measurement instruments, High Voltage Test and Measurement Instruments and other developments include Grading Ring for EHV/UHV Insulators and Surge Arresters, and Minimum clearance requirement for transmission towers of 765 kV System.

1.0 THE INCEPTION (1964–1979)

The High Voltage Laboratory at Bangalore was initiated around 1964 in the campus of Indian Institute of Science, also called as Tata Institute. The Laboratory, established with assistance from the United Nations Development Program (UNDP), comprised of a Haefely make 1.2 MV, 15 kJ Impulse voltage generator with a suitable voltage divider, a Kirloskar Make 100 kV, 100 mA Power Frequency Transformer and an a high speed dual beam Tektronix make Type 555 oscilloscope along with a Haefely make peak voltmeter to measure the generated lightning impulse voltage. A high speed black and white film based camera was attached to the impulse oscilloscope to photograph the impulse voltage waveform, momentarily displayed by the oscilloscope, as permanent record and use for analysis and for use in the test report after printing on regular photographic paper. This kind of impulse recording system needed precise synchronism between the oscilloscope display and shutter control of the camera. In order to calibrate the impulse and power frequency voltage measurement system, a 1 metre diameter sphere gap system was also established.

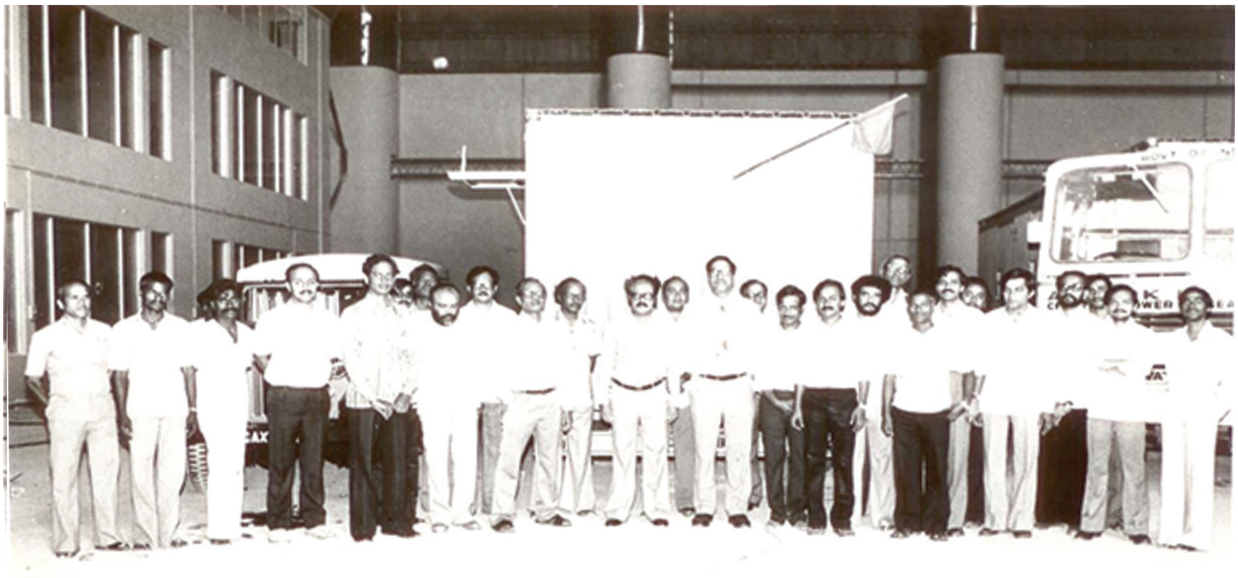
At the inception of the High Voltage laboratory in CPRI, Bangalore, research and testing was possible up to 33 kV system and equipment insulation as against the transmission system voltage of 110/132 kV generally prevalent at that time in the country and possibility of adopting 220 kV transmission system to meet the increasing requirement for bulk power transmission. The research activities at that time were pivoted around lightning stroke as a source of over voltage. Attempts were made to measure natural lightning current using magnetic links, the knowledge of which was essential for providing adequate insulation to power system up to 220 kV level. An important research outcome during this time was a Lightning Arrester Test Kit

THE HIGH VOLTAGE LABORATORY PERSONNEL IN EARLY 80s useful for testing of healthiness of distribution voltage class gap type silicon carbide non-linear resistor type arresters, which was patented. Probably, this was the first patent obtained for a product developed in CPRI.

2.0 MOVING TO THE NEW CAMPUS (1979–1983)

Facilities established in the Indian Institute of Science campus were shifted to the present CPRI campus during the year 1979–1980. The impulse generator was uprated to 2.4 MV, 30 kJ during 1979. A new Kirloskar make power frequency voltage source of 300 kV, 2A was commissioned during 1980 to cater to the testing of insulation up to 220 kV system level and for carrying out Radio Interference tests on line and substation insulator hardware as per CISPR 18-2 Standard. A rain making equipment was added to the facility to undertake Power frequency tests under rain conditions. As processing of the photographs of impulses taken during the use of the impulse generator was time consuming, the division established a dark room for developing the exposed film and make available the negative film for immediate viewing of oscillograms for the test engineer to analyse the test results and declare the outcome of the test to the client without much loss of time. Subsequently, the film based camera was replaced by Polaroid camera which gave instant print of the recorded waveform avoiding the need for processing the film and printing the photographs of the waveforms.

During this phase of the existence of the laboratory, initiation to significant Research and Development activity was made. Aided by a consultant of repute in the form of Dr. Rakosh Das Begamudre, the Division attempted to develop an indigenous Transient Network Analyser to study the switching surge phenomena associated with EHV transmission system. Specifications were framed for procurement of a commercially available professional grade Transient Network Analyser which was subsequently commissioned in the Power Systems Division of CPRI. Attempts were also made to develop digital computer based mathematical models for power system components and development of Basic/Fortran language based computer programs for EHV Line switching transient analysis. Radio Interference measurements and computations were carried out on HV and EHV transmission



MEMBERS OF HIGH VOLTAGE DIVISION AND CIVIL ENGINEERING DIVISION WITH THE THEN DIRECTOR GENERAL DR. M. RAMAMOORTY AND PROF. SREEDHARAN, ADDITIONAL DIRECTOR, ON THE DAY OF COMPLETION OF THE CIVIL WORKS OF EHV TEST LABORATORY. IN THE BACKGROUND ARE THE TWO INSTRUMENTED TRAILERS OF THE MOBILE FIELD TESTING LAB lines. Digital computer programs were developed for computation of lateral profiles of electric and magnetic fields and audio noise produced by EHV Lines. A mobile field testing laboratory to carryout switching surge and staged fault tests on 400 kV systems was established which was successfully and productively used for more than 15 years to carryout insulation design validation and certain equipment performance evaluation on-site tests, equipment insulation failure investigations and defining new operational sequence for safe and efficient transmission system operation. During this period, two useful investigations, namely, study of Ferro-resonance caused over voltage in cable-connected pad mounted distribution transformers undertaken for the erstwhile Delhi Electricity Supply Undertaking (DESU) and a study on the optimization of location of lightning arresters in 11 kV pole mounted substations carried out for Rural Electrification Corporation, were successfully completed. In another investigation, the transient over voltages developed while switching on and off large induction motors was measured for M/s Mysore Paper Mills, Bhadravati, Karnataka, to determine the cause of insulation failure of the large induction motor.

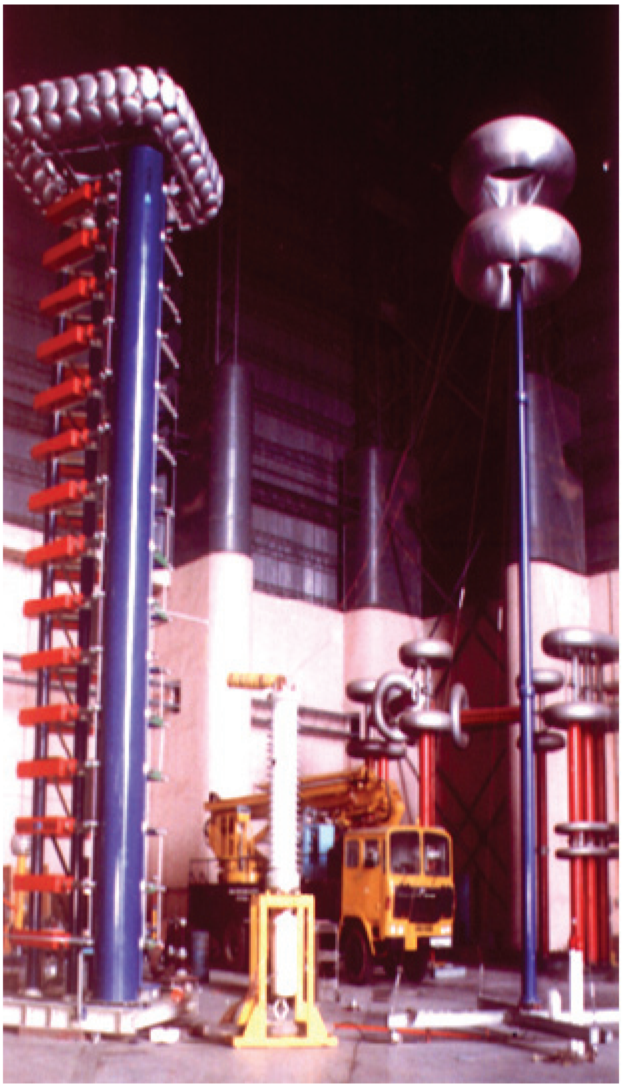
In a nutshell, it can be said that the period between 1978 and 1983 in the history of the High Voltage Laboratory of CPRI could be termed as very productive in building up the expertise in R&D, testing and consultancy that paved way for formulating a road map for ensuring a bright future for the high voltage engineering in CPRI.

3.0 THE NEW ERA – 1983 ONWARDS

During early 80's some of the Indian Power Utilities like Uttar Pradesh State Electricity Board (UPSEB), Madhya Pradesh Electricity Board (MPESB) and Maharashtra State Electricity Board (MSEB) had established long 400 kV transmission lines based on the imported know how and equipment. As the requirement for bulk power transmission over long distances was increasingly becoming inevitable due to establishment of pit-head super thermal power stations and load growth associated with industrial development and rapid urbanization far away from them, other Utilities also started establishing 400 kV transmission lines. A central power transmission utility, Power Grid

THE 1800 kV TUR MAKE POWER FREQUENCY TEST VOLTGE SOURCE (CASCADE TRANSFORMER)

Corporation of India, was formed to establish National power transmission grid at 400 kV system voltage level. This prompted the manufacturing of equipment of 400 kV class in the country. This also indirectly increased the number of equipment of lower voltage class manufactured in the country as growth of sub-transmission and distribution system became inevitable to provide supply the consumers. With this large growth in the manufacturing base, naturally, the high voltage test facility available at that point of time in CPRI was grossly inadequate. In addition, the induction of 400 kV transmission systems brought in challenging problems as far as selection of adequate insulation levels suitable for different environmental conditions in which the lines will be operating. Considering all these, the high voltage laboratory expanded its activity many folds by upgrading/uprating existing facilities to test EHV class insulation (EHV Test Laboratory) and added new specialised laboratories like Mobile Field Testing Laboratory, Pollution Laboratory, Electro Static laboratory and Impulse Current Laboratory. With the expansion of the activities, the High Voltage Laboratory was called “High Voltage Division” during 1983–1984. The facilities and achievements of the Division in the new era are presented.



THE 3 MV, 150 kJ HAEFELY MAKE IMPULSE VOLTAGE GENERATOR

4.0 THE EHV TEST LABORATORY (MAIN LABORATORY)

In order to house the uprated impulse voltage generator suitable to test 400 kV class equipment and line insulation, a laboratory building of size 50 m × 40 m × 35 m was built. An outdoor test bay equipped with a cascade transformer of three units, each rated 600 kV, 2000 kVA, with overall rating of 1800 kV, 2000 kVA making as one of the largest power frequency test sources at that time was commissioned in 1983. The laboratory was fitted with a wall bushing of 800 kV to bring in the Power Frequency test voltage from outdoor bay into the EHV laboratory to facilitate conduction of corona and radio interference tests on insulator strings and equipment. Addition of coupling capacitors of rating 2300 Pf, 500 kV and 2400 pF, 600 kV as well as upgrading of Rain making equipment made the EHV Test laboratory as one of the well-equipped and busiest high voltage test laboratories in this part of the world. The impulse recording system was modernized with fully computerized version and the using photography for impulse voltage measurement was dispensed with.

In the year 1995 the impulse generator was upgraded to 3 MV, 150 kJ to facilitate testing of transformers of rating up to 100 MVA, 220 kV to match the testing capability of High Power laboratory and inductive loads such as line traps with inductance as low as 0.5 mH. Table 1 gives the range of products and the dielectric tests that are conducted on them in the EHV Test laboratory as of today.

TABLE 1			
RANGE OF PRODUCTS AND TESTS CARRIED OUT IN EHV TEST LABORATORY			
Sl. No.	**Products or items tested**	**Types of tests performed**	**Range of testing/ limit of detection**
1	All insulators ranging from 3.6 kV–400 kV (inclusive of polymer and porcelain).	Corona inception/ Extinction and Visible discharge	1200 kV
2	All types of Polymeric insulators from 11 kV–400 kV (Inclusive).	Steep front impulse flash over	500 kV
3	All types of Insulators and Insulating Materials. All types of Switches/Circuit Breaker/Bus Duct/ Cable/Bushing/Panel All types of Reactors All instrument transformers. Ratings from 1 kV–420 kV All types of Power/Distribution Transformers. Up to and inclusive of 5 kVA–100 MVA Rating. 3.6 kV–220 kV	Impulse withstand	2500 kV
4	All types of insulators and similar insulating materials	Impulse flashover	2500 kV
5	All types of Insulators and Insulating Materials. All types of Switches/Circuit Breaker/Bus Duct/ Cable/Bushing/Panel All types of Reactors All instrument transformers. Ratings from 1 kV–420 kV All types of Power/Distribution Transformers. Up to and inclusive of 5 kVA–100 MVA Rating. 3.6 kV–220 kV	Power Frequency Withstand (Dry and Wet)	1200 kV
6	All types of Insulators and Insulating Materials	Power Frequency Flashover (Dry and Wet)	1200 kV
7	All types of Insulators, Circuit Breakers, Lightning Arresters, instrument Transformers. Rating from 5 kV–400 kV	Pollution performance	1200 kV
8	All types of Insulating Materials including Battery Containers, Rubber Mats, Ratings from 1 kV–110 kV	Power Frequency puncture withstand voltage	600 kV
9	All types of Insulators and Insulating Materials. All types of Switches/Circuit Breaker/Bus Duct/ Cable/Bushing/Panel All types of Reactors All instrument transformers. Ratings from 1 kV–420 kV	Radio interference voltage (Dry and Wet).	550 kV
10	All types of insulators and Insulating Materials. Ratings from 1 kV–110 kV.	Temperature cycle (on porcelain Insulators)	–

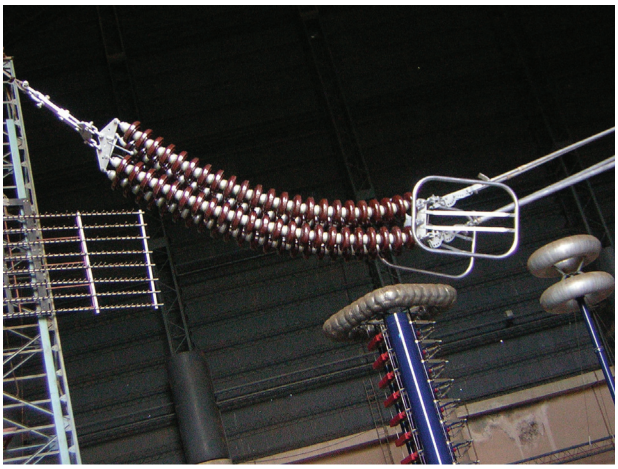
11	All types of insulators and Insulating Materials. Ratings 1 kV–420 kV	Porosity test (on porcelain insulators)	–
12	Insulator, Strings of all types 11 kV–420 kV	Voltage Distribution	550 kV
13	Disc/Pin/Post/Solid Core Ratings from 1 kV–36 kV	Electro Mechanical Failing Load Test	400 kN, 100 kV
14	Disc/Pin/Post/Solid Core/Insulator Ratings of 1 kV–36 kV	Mechanical Failing Load Test	400 kN
15	Disc Insulator (ball and socket, tongue and clevis), long rod	Mechanical performance test	400 kN
16	Polymer insulators from 1 kV–145 kV	Damage limit proof test Assembled core load time test	400 kN 400 kN
17	Instrument Transformers Ratings from 1 kV–400 kV	Discharge Test	2500 kV
18	Voltage Transformers, C.V.T., Coupling Capacitor, Rating above (145 kV–400 kV)	Fast Transient Impulse Voltage Test/Multiple chopped test on CT's	2500 kV
19	CVT (above 3.6 kV–420 kV)	Ferro Resonance Test	500 kV
20	CVT (above 3.6 kV–420 kV)	Short circuit withstand capability test	500 kV


COMPUTERIZED HAEFELY MAKE IMPULSE MEASURING SYSTEM

During late 80's NTPC established India's first ±500 kV HVDC Line between Rihad and Dadri. At the same time, to promote development of indigenous HVDC Technology in the country, a National HVDC Project was conceived by Department of Electronics, Govt. of India, with participation of BHEL, CPRI, IITK, IISc, and many other institutions. A collaborative pilot project was taken to convert the existing 220 kV AC line between Barsoor in Madhya Pradesh and Lower Sileru in Andhra Pradesh initially as +100 kV monopole ground return mode 100 MW DC line. Under this scheme, High Voltage Division was provided funds to commission a ±800 kV, 200 mA DC source during 1987–1988. Using this source, the Division carried out the air insulation studies under DC voltage. The data generated in the study was useful in choosing the safe transmission tower clearances and the dimension/configuration of insulator strings required for the pilot DC line. The laboratory also carried out +100 kV thyristor valve testing required for the pilot study during 1989–1990 and subsequently testing of +200 kV thyristor valve around 1995 for up-gradation of pilot DC line to +200 kV. Tests were also carried out for the first time in the

INSULATOR STRING UNDERGOING RADIO INTERFERENCE TEST

country on thyristor valves of 11 kV and 33 kV Static Var Compensators manufactured by BHEL.



INSULATORS STRING UNDERGOING LIGHTNING AND SWITCHING IMPULSE TEST

During 80's many test methods were being advocated for diagnostics of power transformers. A study to compare Frequency Response Analysis (FRA) method, Inductance signature method and Low Voltage Inductance method was undertaken during 1986–1987 to establish relative merits and demerits of these methods. It was concluded that FRA method is superior to the other two methods. Incidentally, FRA is one of the most widely followed diagnostic methods in the world even today.

A study was undertaken during 1988–1989 to establish the relationship between the impulse flashover voltage and ambient humidity as there was disagreement between leading high voltage laboratories on the use of "humidity correction factor" of IEC Standard. It was found that the IEC's correction factor is inaccurate, particularly while applying in laboratories in tropical countries like ours. The data generated in the study was shared with the working group of IEC and subsequently, IEC modified the Humidity Correction Factor.

By 90's many Indian utilities had operated their EHV system for more than 10 years and insulator failure while the line is in service was a common problem faced by them. A study was carried out during 1990–1991 to determine the number of failed (punctured/shattered) insulators that can still be present in a live string in-spite of which the line can continue to be in service till next scheduled maintenance with minimal risk of line flashover. The outcome was published in International Conference for the benefit of transmission Utilities.

Fast transient test on insulator was introduced by the Division during 1991–1992. A good amount of effort went into the generation and measurement fast transient with 2500 kV/μs front time. Today, the Laboratory has the best fast transient test facility for porcelain and polymeric insulators. The maintenance of calibration of such a measuring system is very expensive.

Over a period of time, difficulties were encountered while carrying out Radio Interference Tests with test voltage source as outdoor cascade transformer and bringing the test voltage through the wall bushing. In order to overcome this drawback, one unit (600 kV) of the cascade transformer was moved into the laboratory building. Thus the rating of the outdoor cascade transformer is as on date limited to 1200 kV, 2000 kVA which is sufficient enough to carry out dielectric tests on 400 kV system insulation. Attempt is on to restore the original rating of 1800 kV for the cascade transformer by September 2012 by procuring a similar transformer unit.

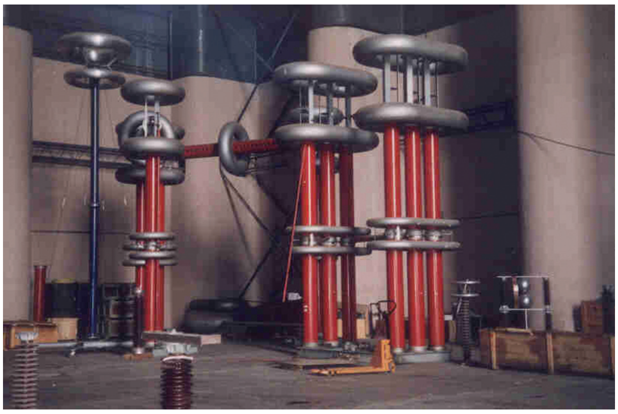
POWER TRANSFORMER UNDERGOING IMPULSE TEST

FAULT THROWING ARRANGEMENT AND FAULT ARC DURING MEASUREMENT OF SECONDARY ARC CURRENT

5.0 THE MOBILE FIELD TESTING LABORATORY

The insulation of 400 kV line and equipment is chosen on the basis of the magnitude of switching surges that occur in the system taking into account the protection offered by strategically placed surge protective devices. Need for characterizing the switching over voltages occurring in Indian 400 kV system and adequacy of insulation provided to the line and substation equipment, chosen on the basis of experience of overseas utility and manufacturer's experience, to withstand the transients that occur in the Indian system was felt. In the absence of such information on Indian transmission system, Transient Network Analyzer or Electro Magnetic Transient Program based simulation studies formed the basis for computation of switching transients and selection of line and equipment insulation. As at that time (early 80's) the mathematical/miniature physical models of power system components were still being standardized, carrying out actual tests on the transmission system, though expensive and time consuming, was considered to be essential to check the adequacy of insulation provided based on simulation studies. This exercise was also necessary for not only to look for improvements in insulation selection, but also to give confidence to the inexperienced system designers and operators of 400 kV transmission systems in the country.

In order to carry out such field tests on transmission systems in the country, High Voltage Division procured a state of the art Mobile Field Testing Laboratory in 1984 from M/s CESI, Italy. This comprised of two trailers housing sophisticated transient voltage and current measuring and recording instruments, control instrumentation for control of system circuit breakers at the sending end and receiving end of the line and recording instruments in both the trailers controlled in synchronism with the operation of the line circuit breaker. They also housed capacitors for setting up of capacitive voltage dividers at measurement site (in sub-stations), corona rings for the voltage



THE 800 kV, 200 MA HIGH-VOLT MAKE DC VOLTAGE SOURCE

dividers, current shunts and interposing CTs for measurement of transient currents occurring during the switching activities. The transmission of signals from the secondary of voltage dividers and current shunts was by Fiber Optic Links and from the interposing CTs, it was by means of tri-axial shielded cables. A point on wave controller for switching on circuit breaker was available to control the switching instant with respect the phase of the bus voltage as the magnitude of switching over voltage and transient currents resulting out of the switching action are directly related to the angle of switching.

ONE OF THE TWO INSTRUMENTATION TRAILERS OF THE MOBILE FIELD TESTING LABORATORY

During those times, in addition to characterizing of switching transients in EHV transmission systems, there was also a necessity to investigate the performance of different types of circuit breakers employed for switching on and off shunt reactors and capacitor/filter banks to provide suitable over voltage protection to them; the over voltage occurring due to breaker arcing activity like, current chopping, re-strike and re-ignition.

VOLTAGE DIVIDERS TEMPORARILY ERECTED IN A UTILITY SUBSTATION FOR FIELD TESTING

In the initial stages of operation of 400 kV lines in the country, the single phase auto re-closing adopted in 400 kV lines was not fully successful. The dead time chosen for auto re-closing mainly depends on the duration of the 'Secondary Arc', whose magnitude and duration not only depends on line length but also on the ambient weather condition prevailing at the time of occurrence of the fault. The mobile field testing laboratory carried out staged fault tests on Koradi – Bhusawal and Bhilai – Sarni 400 kV lines during 1984–1987 to measure the secondary arc currents in these lines after clearing Single Line to Ground fault on single phase mode. This gave good insight into proper selection of dead time for single phase auto re-closing of 400 kV lines in the country.

The type of tests carried out by the Mobile Field Testing Laboratory were:

(a) Switching on and off of transmission lines, transformers, shunt reactors, capacitor/filter banks, large motors, etc.

(b) Staged fault tests to measure fault current magnitudes, secondary arc current magnitude and duration during clearing of single phase-to-ground fault cleared on single phase auto-reclosing mode to optimize single phase auto reclosing dead time.

(c) Measurement of voltage and current harmonics in industrial, domestic and traction power supply systems as a pre-requisite to define limits on them for adoption in Indian Power system.

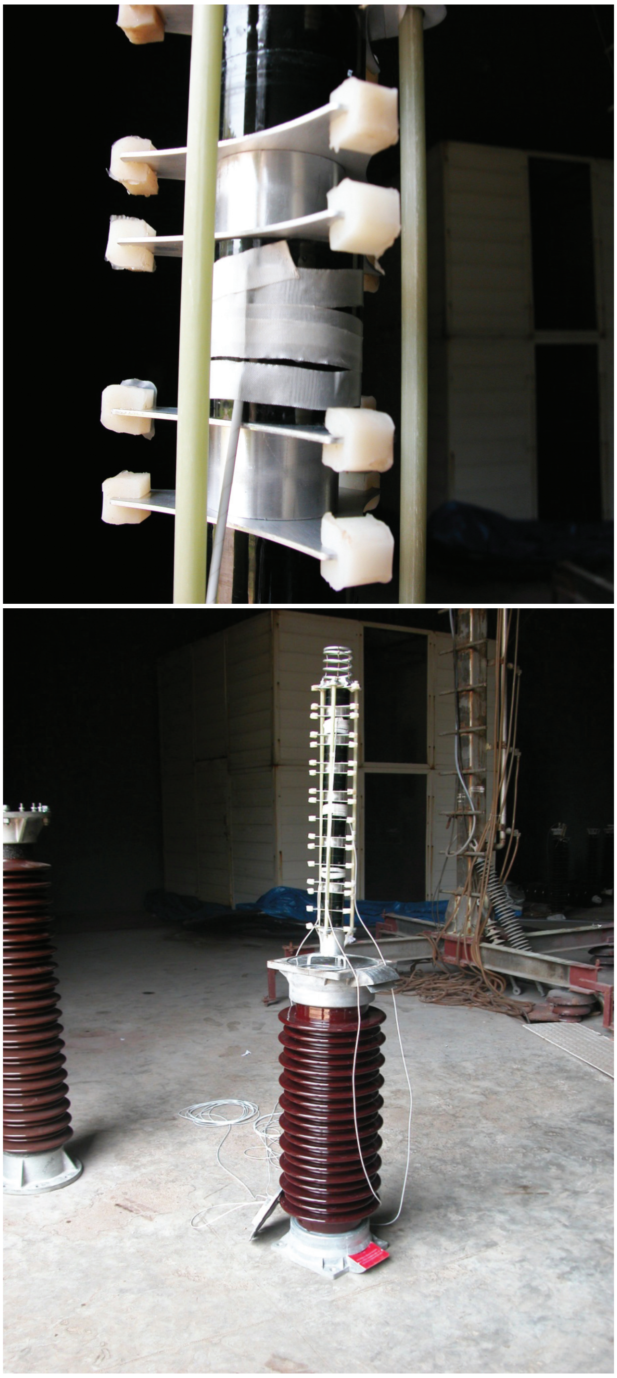
(d) Failure investigation of power system components like, generators, transformers, circuit breakers, lightning/surge arresters, large capacity motors, current transformers, filter/capacitor banks, etc.

Later half of 80's saw the Indian Power system operator's concern for the power quality, as many equipment were reported to have failed due to the presence of harmonics in the power supply network. The Mobile Field Testing Laboratory started carrying out survey type harmonic measurements in industrial networks, railway traction system, etc. This was initiated as part of investigating failure of capacitor banks, transformers and motors. For the first time, a comprehensive harmonic measurement program for Indian railways was initiated through RDSO. Harmonics and sequence voltages and currents present in Chandrapur and Phadge 400 kV buses were measured to obtain background harmonics information for the design of AC filters and controller for the ±500 kV Chandrapur – Phadge DC line. Harmonic measurements were also carried out in Lower Sileru and Barsur AC and

THE OLD POLLUTION LABORATORY

DC switch yards of the experimental +100 kV DC Line as a part of commissioning tests on the NHVDC line. The Laboratory personnel actively participated in the CBIP Working group to formulate limits on voltage and current harmonics to be adopted in the country.

A full-fledged investigation on failure of transformers in electric locomotives was carried out for RDSO in 1988. The work involved measurement of voltage and current transients and harmonics to which the transformer is subjected to during all types of locomotive operation including running at different speeds up to 110 kM per hour and disconnecting the transformer of stationary locomotive from the HT supply.



ZnO ELEMENT STACK BEING INSPECTED AFTER THE POLLUTION TESTS

A number of useful field tests were carryout by the Mobile Field Testing Laboratory during 1984 and 1996 before the laboratory was decommissioned due to difficulty in maintenance and emergence of reliable transient computation software with which the transient studies could be carried out accurately and with little cost. A list of major tests carried out is presented below:

1) Field test on Maharashtra State Electricity Board 400 kV Koradi – Bhushawal Transmission system -1985.
2) Field test on Madhya Pradesh State Electricity Board 400 kV Bhilai – Sarni Transmission System - 1987
3) Lower Sileru – Barsoor +100 kV, 100 MW, National HVDC Experimental line commissioning tests - 1989–1990.
4) Harmonic Analysis, Voltage unbalance measurements and 400 kV shunt reactor switching tests on MSEB Network - 1991.
5) Field test on 33 kV Harmonic filter banks at Madhya Pradesh Iron and Steel Company, Malanpur, Gwalior - 1992.
6) Measurement of Harmonics and negative sequence voltage on traction sub-station of M/s Madhya Pradesh Electricity Board - 1993.
7) Switching Surge and harmonic Measurement in electric Locomotive for M/s. RDSO Lucknow - 1993.
8) Harmonic and RIV measurements in lower sileru – Barsoor National HVDC Experimental line ±100 kV, 100 MW - 1993.
9) Measurement of Harmonics and voltage unbalance in 400 kV substation of M/s PGCIL. M/s PGCIL - 1994.

10) Switching Surge measurements on UPSEB system to investigate lightning arrester failure - 1996.

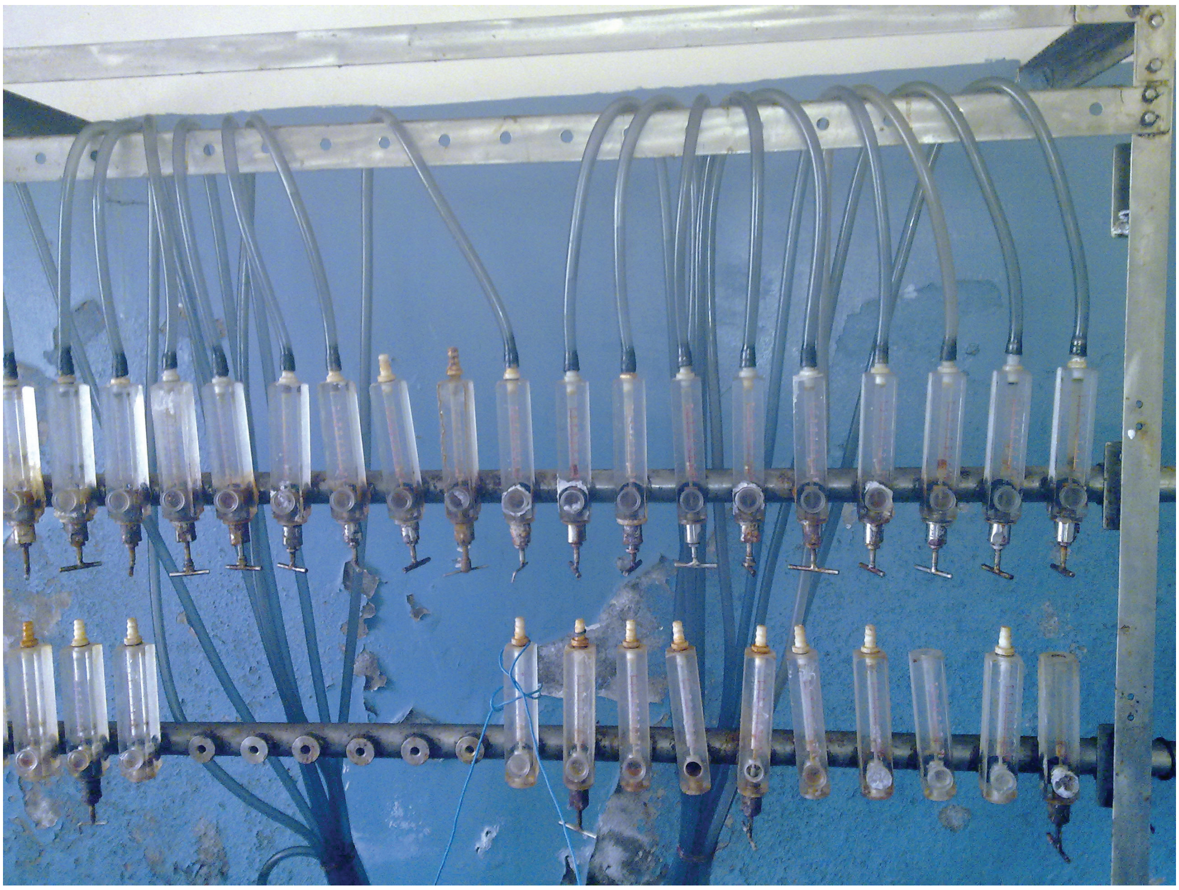
11) Field Tests on PGCIL'S 400 kV Moga – Hishar Line to investigate requirement of Circuit Breaker PIR for short lines - 1997.

12) Measurement of Harmonics and power profile on M/s Usha Martin Industries Ltd., System - 1997.

6.0 THE POLLUTION LABORATORY

The increased AC transmission system voltage and increased adaptation of DC Transmission lines world over due to obvious reasons brought in a new problem to the power system insulation by way of seasonal tripping of lines operating close to polluting industries and close to sea coast. Pollution related flashover, occurring during favorable ambient weather conditions around the polluted insulators and bushings, posed serious threat to the reliability of the system as auto re-closing is ineffective resulting in prolonged outage of the line. The phenomena being weather dependent and information on its systematic study in tropical weather condition was scarce, High Voltage Laboratory in the year 1986–1987 embarked on the ambitious plan of establishing a pollution laboratory to undertake Research and Development activity primarily and subsequently offer quality assurance testing on insulators (both AC and DC), cable terminations and lightning/surge arresters.

First and foremost requirement of a pollution laboratory is the compliance of the voltage source used for the tests as stipulated in Standard IEC:60507 with respect to the short circuit current at test voltage, R/X and IC/ISC ratios. The 600 kV, 2000 kVA power frequency transformer available in the EHV test laboratory



SALINE WATER CONTROL TO THE SALT SPRAY ARRANGEMENT has all these necessary characteristics and hence designated as test voltage source for the Pollution Laboratory.

Initially, the pollution chamber of dimensions 8×8×9 meters made of mild steel frame covered with fiber glass sheets and fitted with an in house made bushing to take about 100 kV AC voltage to carry out pollution tests up to 132 kV system was established.

To start with the activities, experimental work to understand the mechanism of pollution flashover was carried out on two dimension flat plate model and the outcome was used to develop pollution flashover static model. Further the model was extended to represent dynamics of pollution arc.

A salt fog generation arrangement as per the requirements of the IEC Standard was fabricated and its working was consolidated. This period was basically used to understand the concepts of pollution testing and prepare for establishing a 220 kV class pollution laboratory and further research work. Salt fog tests were carried out on 132 kV system voltage insulators of standard, semi-fog and anti-fog type disc insulators and the maximum withstand salinities of these insulators were evaluated for the first time in the country.

The steam input rate required for solid layer pollution tests, a deviation from the value specified in the IEC Standard due to tropical weather prevalent in the country, was determined and published in learned forums for its acceptability as a deviation from the Standards. Using the modified steam input rate solid layer pollution tests up to 132 kV insulator string was conducted again for the first time in the country.

Subsequently, in the year 1992 the in-house made bushing was replaced by a regular 275 kV porcelain wall bushing to upgrade the pollution laboratory testing capability to 400 kV class insulators. The salt fog generating set up was up-graded to suit carrying out pollution tests and R&D up to 400 kV system insulators and surge arresters. This was necessary as the pollution flashover voltages are reported to be non-linear with respect to the string length and pollution flashover voltage has a tendency to saturate at higher string lengths, consequently more number of insulators are required than the number obtained from the extrapolation of results of the tests on insulators used in lower voltage systems. Hence, experimental investigation is very much necessary for the design of insulation system at EHV and UHV levels.

An important research activity undertaken during this time was to investigate the suitability of the pollution test method stipulated in ANSI/IEEE C:62.11 Standard to gapless Metal Oxide surge arresters, a contemporary research carried out world over to define a new IEC test method. A digital computer based Electro-thermal model of porcelain housed metal oxide surge arrester was developed and used to compare the outcome of different test methods and different pollution

INSULATOR UNDERGOING SALT FOG TEST IN OLD POLLUTION LABORATORY severity conditions on the highest temperature rise of the Zinc Oxide elements, the building blocks of the surge arrester. Fiber optic based temperature measuring probe and a personal computer based arrester housing surface charge measuring circuit was designed and fabricated to measure the temperature of the elements and correlate it with the surface charge representing pollution accumulation severity, when the single unit and multi-unit arresters are energized to test voltage of the order of 75 kV to 150 kV. The outcome of the research was made available to the CIGRE/IEC Working group on pollution testing of Metal oxide surge arresters as input to the standardization of test method. The experience gained and the facilities created were further upgraded to carryout pollution tests up to 400 kV class metal oxide surge arresters.

Around 1989, a ±400 kV, 7.5 mA DC source was commissioned to undertake dielectric tests as per IEC:601325 and the facility was offered as quality assurance test laboratory for Indian porcelain industry for insulators used in DC systems. During the same time, studies to understand ageing mechanism of glass and porcelain insulators used in DC lines was taken up, a contemporary research at that time, as transmission utilities abroad already owning DC transmission lines had reported some insulator failures. It is the same time India was also establishing its DC lines in northern and central part of India. The Long duration ageing study involving ion migration and thermal run-away tests and measurement of electrical body resistance at different temperature on single disk insulators with different contamination severities was helpful in understanding the mechanism of failure and criteria for selection of insulators for DC lines operating close to pollution source.

During 1992–1993 a sophisticated dust chamber experiment was carried out to study the effect of electro-static force on the accumulation of pollutant on the insulator surface under DC voltage. This research was to understand the mechanism of the pollution accumulation in DC line insulator and its effect on the dielectric strength which is an important factor in the selection of insulator for DC Lines.

ARRANGEMENTS UNDER WAY FOR POLLUTION TEST ON ZINC OXIDE SURGE ARRESTER

In the early 90's the Indian power transmission utilities started employing polymeric insulators to overcome pollution flashover problem posed by the porcelain insulator. High Voltage division also started focusing on this area for research and in the year 1992 a 150 kV, 1A DC source with thyristorised feedback system was commissioned. Using this source, salt fog pollution ageing studies were carried out on polymeric insulators under DC voltage. The results of the study showed that low conductivity fog is severe for insulators under +ve polarity DC voltage application.

During the year 1996, a new pollution chamber of dimensions 12×12×12 meter was commissioned to replace the old chamber with fiber glass sheet. Additionally, a 100 kV, 6 A AC voltage source was also inducted to pollution laboratory to carry out pollution tests on less than 132 kV system voltages.

THE NEW POLLUTION LABORATORY

In the new pollution laboratory the evaluation of profile for DC insulators for higher pollution withstand capability for use in ±500 kV HV DC line was undertaken for M/s BHEL. On completion if the work, it became a commercial product of BHEL and they have supplied to Power grid for use in Talcher – Kolar DC Line.

Evaluation of different types of profiles for AC insulators was also carried out up to 400 kV system levels for estimation of risk of flashover, an important factor considered in the insulation coordination of AC transmission systems.

One way of overcoming the pollution flashover of insulators is to apply Room Temperature Vulcanized (RTV) coatings on insulators. Two commercially available RTV coatings, namely, Silicon Rubber and Poly Urathin were evaluated for long-term ageing performance. It was found that the RTV Silicon coating performs better. This investigation was carried out for NTPC.

As the composite insulators are made from different polymeric materials like, Silicon Rubber (SR), Ethylene Vinyl Acetate (EVA) and Ethylene Propylene Diene Monomar (EPDM), a research project was undertaken to rank these material in terms of long term ageing performance by carrying out multi-stress ageing tests as per CIGRE ageing cycle comprising of salt fog – UV radiation – heating – humidity – rain. It was shown from the study that Silicone rubber's performance is much superior compared to the other two. This was publicized though conference publications.

CABLE TERMINATION UNDER 1000 HOUR AGEING TEST

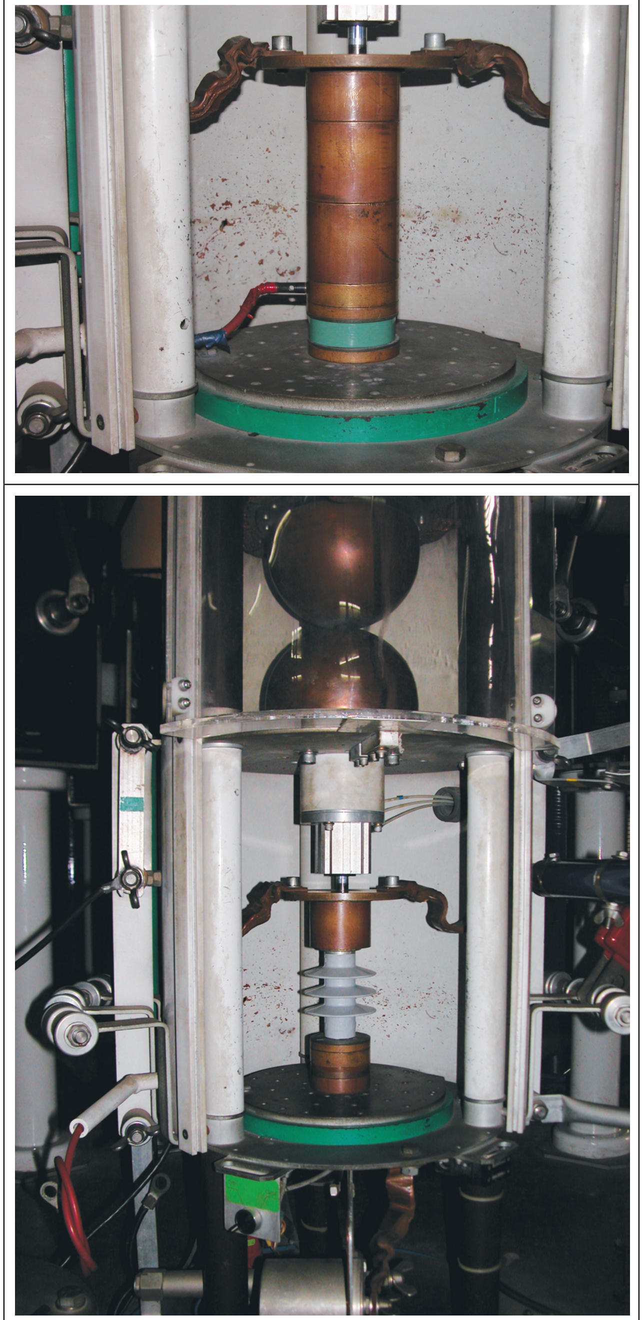
It is reported by overseas utilities that the composite insulators support growth of algae, a bio-contaminant, on its surface, which is of concern to them that there may be possibility of degradation of insulation performance. A long-term ageing under salt-fog test condition was undertaken from 2008–2010 to evaluate bio contaminated composite insulator. It was proved that the algae do not influence the insulation performance of the composite insulator.

As recently as 2011, due to the requirement for adopting an efficient test method to study ageing of polymeric insulators, the Division developed indigenously and commissioned a 'tracking wheel test facility' to check the tracking and erosion property of the polymeric material, that is, the material's withstand capability to natural weathering under polluted condition.

Over the years, the pollution laboratory has undertaken many consultancies to utilities and industries in the areas related to pollution flashover and immensely contributed to the improvement of system availability. Some important consultancies undertaken are:

1. Pollution mapping along the proposed ±500 kV Chandrapur – phadge HVDC line and simulating the same in Dust chamber experiments to arrive at suitable design and profile of insulator to be used in the line.
2. Investigation of tripping of 400 kV AC Faridabad - Ballabhgarh line to check the adequacy of existed insulators to withstand the pollution level prevailing all along the line – Recommended to use anti-fog insulators in place of standard disk insulators. The source of pollution was found to be the brick kilns operating close to the line.
3. Investigation on tripping of 33 kV to 400 kV lines close to sea cost for APSEB.
4. Investigation on Tripping of 400 kV line close to cement factory near Madurai.
5. Investigation on Pollution flashovers of insulators wetted by cooling chimney at Dadri Substation of NTPC.
6. Pollution mapping of geographical area coming under Northern Region Power Committee (States of Uttarpradesh, Himachal Pradesh, Punjab, Haryana, Jammu and Kashmir, Uttaranchal) for POWERGRID, a major work to identify the pollution zones to facilitate respective State and central Utilities to select proper insulator type and dimensions for different pollution zones to avoid transmission line tripping due to pollution flashover.

100 kA, 150 kJ IMPULSE CURRENT GENERATOR



ZnO ELEMENT AND LIGHTNING ARRESTER UNDER IMPULSE CURRENT TEST

7. Investigation on failure of Section insulator assembly in Delhi Metro traction system for DMRCL, Delhi.

8. Electrical and mechanical performance evaluation of aged composite insulators removed from ± 500 kV Richand – Dadri Line for POWERGRID.

The present facility in the Pollution Lab is:

1. Pollution Chamber with AC and DC sources
2. Salt fog and clean for generation facility
3. Leakage current measuring system
4. Fiber optic based temperature measuring system required to carry out pollution tests on gapless metal oxide surge arresters according to the IEC:60066-4 standard
5. Tracking and erosion test facility
6. Ion migration test facility
7. Thermal runway test facility
8. Electrical Body resistance measurement test facility
9. SF_6 puncture withstand test facility
10. Thermo Mechanical test facility
11. Mechanical load time test facility
12. Die – penetration test facility
13. Water diffusion test facility
14. Insulation resistance test facility

7.0 THE IMPULSE CURRENT LABORATORY

Gapless Metal Oxide Surge Arresters found usage in Indian Power Systems along with the establishment of 400 kV lines. To start with the surge arrester activity in high voltage division, a 20 kA, 20 kV impulse current generator was developed in house and commissioned in 1988. An investigation on impulse current ageing of oil immersed Zinc Oxide elements at 105ºC was undertaken for M/S General Electric Co. and the deficiency found was reported to them. In 1991, an investigation on 3 kV, 10 kA, energy class 3

ACCELERATED AGEING TEST FACILITY

ZnO elements for ageing under power frequency – impulse current ageing cycle was performed to detect the occurrence of localized ageing due to impulse current.

By mid 90's demand for quality assurance testing of surge arrester blocks grew as many Indian manufacturers ventured into this area. As a result, in 1996–1997 as a comprehensive test facility was established for testing of Zinc Oxide elements and ZnO arrester pro-rated sections up to 11 kV rating as per IEC:60099-4. It's superiority lies in the fact that, it has a unique Computer-controlled Impulse Current Generator of rating 100 kA, 150 kJ incorporating all conceivable features in a single consolidated design and is perhaps the only one of its kind in this part of the world at the time of its commissioning. The generator has the capacity to generate 8/20 µS lightning impulse current of 40 kA magnitude, 4/10 µS high current impulse of 120 kA magnitude, 1/20 µS steep impulse current of 40 kA magnitude, 36/80 µS switching impulse current of 2 kA magnitude with a 36/90 µS and long duration rectangular impulse current with a maximum duration of 4000 µS and a maximum magnitude of 1 kA. The generator has accessories like separate current shunts for measuring each of the current types mentioned above, wave shaping resistors and inductors. It has a total of 12 stages with a 2.5 µF capacitor in each stage. An advanced Dr. Strauss make impulse recording system (TRAS:100-12, 4 channel, 100 MS/s, 12 bit) with advanced software for recording and analyzing impulse current and voltage and impulse current superimposed with AC voltage at varying time base, which is a unique feature required for recording voltages and currents in Operating Duty tests on arrester nonlinear elements is a part of the Impulse Current laboratory. With this generator set up all type tests on ZnO arrester blocks up to 11 kV voltage rating as per National (IS:3070) and International Standards (IEC:60099-4) can be carried out. The figure below shows the impulse current generator.

IMPULSE CURRENT MEASURING SYSTEM AND CONTROL PANEL

ACCELERATED AGEING TEST OLD OSCILLOSCOPE

With this basic set up, the generator is used extensively to conduct different type tests for various lightning arrester manufacturers in the country. Some of the important type tests conducted is listed below:

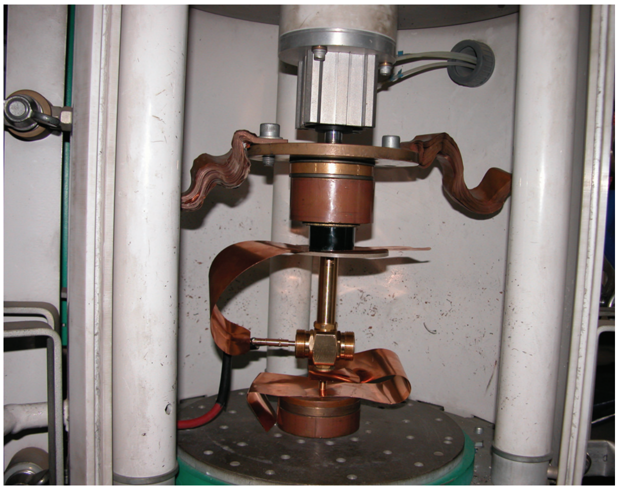
1. Residual Voltage Tests
   - Steep Current Impulse 1/<20 µS.
   - Lightning Current Impulse µS
   - Switching Current Impulse 36/90 µS
   - High Current Impulse 4/10 µS
2. Long duration rectangular Current Impulse test
3. Operating Duty Tests
4. Power frequency voltage V/S Time curve
5. Temporary Over Voltage test as per IEC:60099-4.

Coinciding with the establishment of the professional grade impulse current generator, in 1996–1997, ageing of ZnO elements under SF_6

IONIC CURRENT METER MEASUREMENT SET UP

gas with power frequency and long duration impulse current applications for a planned duration of 1000 hours was carried out. This research work was carried out to investigate the suitability of the ZnO element for use in SF_6 gas media. The tested elements failed at 300 hours indicating the unsuitability of the elements tested for use under SF_6 gas and pointed to the need for developing protective coating for the exposed surface of the ZnO element.

In the year 2002–2003, a new test facility was created for conducting accelerated ageing test on ZnO blocks up to 6 kV rated voltage as per IEC:60099-4 standard requirement. The photograph below shows the test set up created. An automatic data acquisition and analyzing system to be used along with the ageing test setup was also developed in-house along with the necessary software for the separation of resistive and capacitive components from the total current of the arrester element and accurate

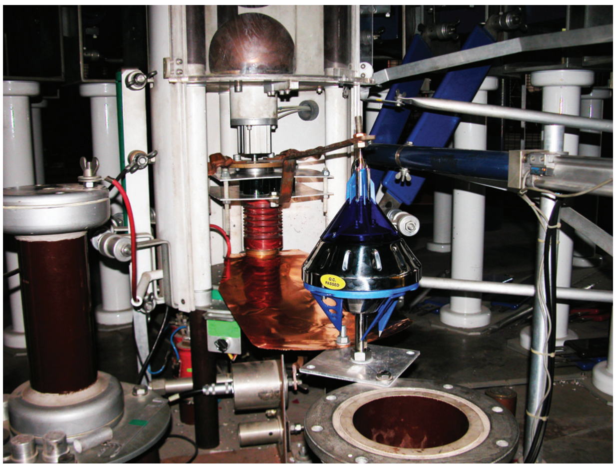


TEST ARRANGEMENT FOR RF CONNECTOR

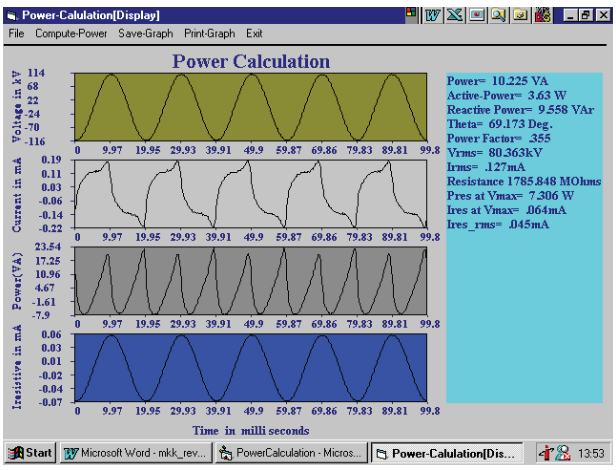
measurement of active power loss, resistive leakage current and Reference Voltage.

The year 2007 saw a sudden spurt in the requirement for testing low voltage protective devices, normal air terminals used for protection of high raise buildings, and ESE (Early Streamer Emission) terminals used for the protection of the high raise structures in place of the conventional lightning rods. Certain accessories required for testing arrangement of these objects were fabricated in house to facilitate establishment of this facility.

Special requirements like testing of Radio Frequency (RF) connectors used for protection of radio frequency communication circuits have also been tested in recent times.



TEST ARRANGEMENT FOR EARLY STREAMER EMISSION LIGHTNING TERMINAL



AN OSCILLOGRAM RECORDED DURING POWER LOSS MEASUREMENT

8.0 DEVELOPMENT OF MEASURING EQUIPMENT

The High Voltage Division has been actively engaged in the design and development of special measuring equipment to meet the needs of the growing power transmission utilities and of its own testing needs.

DC FIELD METER

AC ELECTRIC FIELD METER

9.0 DEVELOPMENT OF ELECTRO-STATIC FIELD MEASUREMENT INSTRUMENTS

Apprehensions off 50 Hz electric and magnetic fields produced by EHV transmission lines having adverse effect prompted Indian utilities to measure these fields in the vicinity of their lines and ensure that the magnitudes are below their maximum permissible limits. High Voltage Division designed and fabricated Spherical Electrode Electric field meter to survey type measurements in the vicinity of lines and in substations. An Indian Patent was obtained for the same.

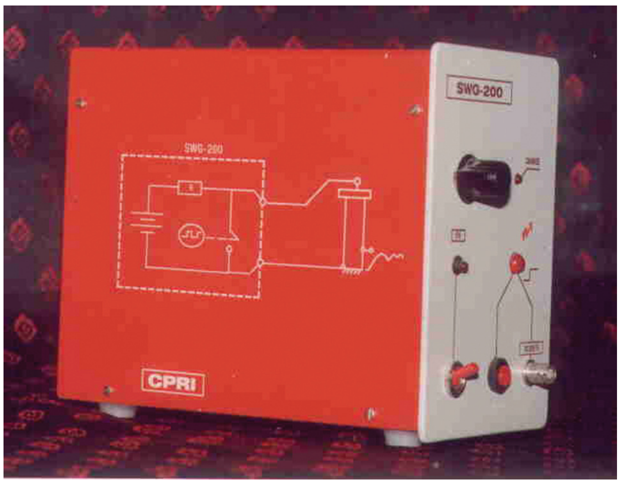
Similarly, Ionic Current measurement in the vicinity of DC transmission lines became necessity with establishment of DC transmission lines and Back-to-back stations. Rotating wane type DC electric field meter and a highly sensitive DC ionic current meter were developed for this purpose.

In order to detect spurious power factor improvement capacitors supplied to agricultural pump sets, a simple to use hand held 'Capacitor Detector' was developed and demonstrated. An Indian patent was obtained for the same.

10.0 DEVELOPMENT OF HIGH VOLTAGE TEST AND MEASUREMENT INSTRUMENTS

Some of the development works in the area of high voltage test and measurement were towards import substitution and providing inexpensive equipment to the other laboratories of CPRI and Government owned institutions. The details are as follows:

- Computerized impulse measuring systems for High Voltage Division, Bangalore, RTL Muradnagar, STDS Bhopal, M/S BHEL (EPD) Bangalore, M/s Kirloskar, Bangalore.



UNIT STEP GENERATOR

- A fully automated combination wave generator for STDS Bhopal.
- AC peak/peak/√2 measuring system as per IEC:6060-2 for Short Circuit Laboratory, CPRI, Bangalore.
- A measuring system for analyzing an assorted waveforms like combination wave, ring wave, Lightning impulse voltage and lightning impulse current for Short circuit laboratory, CPRI, Bangalore for use in testing of the MCCB, Relay contacts, etc.

Most of the products developed are in continuous use without any problem.

IMPULSE MEASURING SYSTEM DEVELOPED FOR STDS BHOPAL (2007)

COMBINATION WAVE GENERATOR FOR SURGE IMMUNITY TEST DEVELOPED FOR STDS BHOPAL

IMPULSE MEASURING SYSTEM DEVELOPED FOR KIRLOSKAR

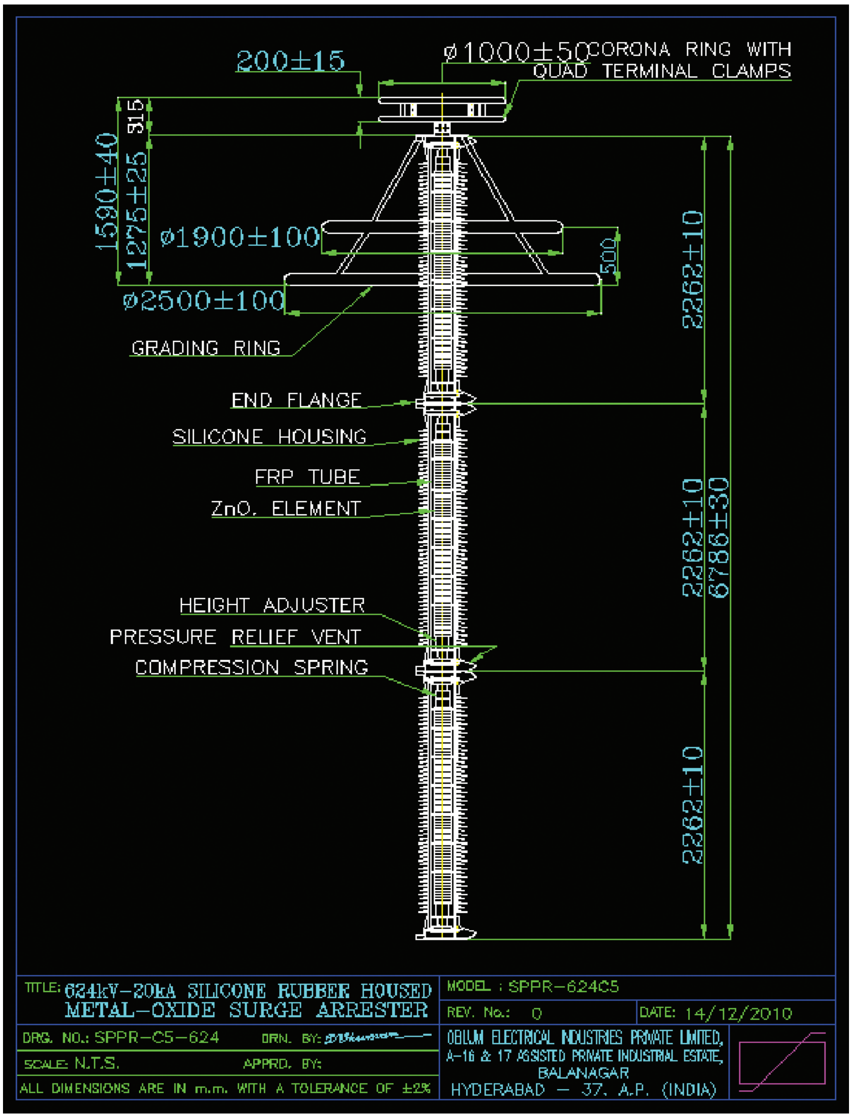
STEEP IMPULSE MEASURING SYSTEM DEVELOPED FOR BHEL

10.1 R&D cooperation in the area of High Voltage Engineering with CESI, Italy

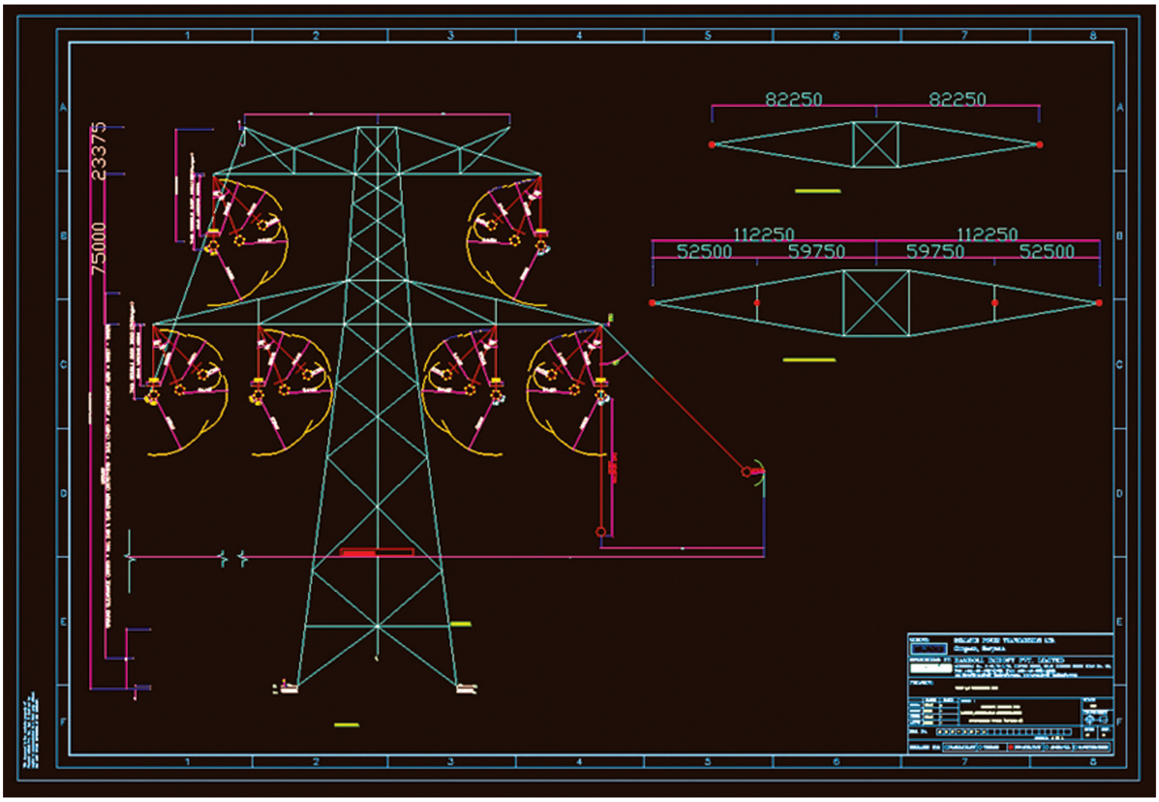
An important phase of the Technological skill development that propelled the High Voltage Division to worldwide reckoning in testing and

R&D was collaborative research and exchange of technical personnel between CPRI and CESI. A large number of collaborative research projects were undertaken between 1985–1994. The following is three list of technical works carried out:

1. EHVDC transmission systems-state of the art - Design of external insulation from the point of view of DC permanent voltage under polluted conditions
2. Establishment of an experimental line facility to undertake research on UHV AC transmission
3. Pollution test in the framework of cooperation between CESI and CPRI (R&D programme)
4. Study of ageing of zinc oxide surge arresters for ac applications
5. Guide for the design of electric system from the point of view of corona phenomena - audible noise
6. Guide for the design of electric system from the point of view of corona phenomena- power loss
7. EHVDC Transmission system - corona phenomena and radio noise



765 kV SYSTEM LA WITH OPTIMIZED GRADING RING



765 kV TRANSMISSION TOWER CONSIDERED FOR OPTIMIZATION OF MINIMUM CLEARANCE ABOVE GROUND

8. Guide for the design of external insulation under overvoltage
9. EHVDC transmission systems - state of the art design of external insulation from the point of view of DC permanent voltage under polluted conditions
10. EHVDC Transmission System - Audible noise
11. EHVDC Transmission System - Corona losses
12. Guide for the design of external insulation from the point of view of permanent AC voltage
13. Study of the methods and procedures adopted at CESI for pollution tests
14. Pollution tests on EHVDC Configurations: line insulators
15. Set up of a pollution method aiming at reproducing as far as possible contamination conditions typical of DC voltage
16. Tests to evaluate the dependence of insulators performance on their geometry (diameter, profile) under pollution and DC voltage
17. Pollution tests on EHVDC configurations - station insulators

Ageing performance of composite insulators under AC and DC voltages

The R&D cooperation between two laboratories resulted in knowledge sharing between the engineers in concerned specialized areas of research. It also helped in setting up of UHV research laboratory test facilities including the pollution laboratory at Hyderabad.

11.0 DEVELOPMENT OF GRADING RING FOR EHV/UHV INSULATORS AND SURGE ARRESTERS

The division started working in the area of Finite Element simulation during the year

2009 and as of now provided the following consultancy services to the reputed electrical industries.

- M/s Aditya Birla Insulators
- M/s Oblum Electical Industries Pvt. Ltd.
- M/s Lamco Industries Pvt. Ltd.
- G.K. Xianghe Electricals Pvt. Ltd.
- M/s Reliance Infrastructure Ltd.
- M/s Elektrolites (Power) Pvt. Ltd.

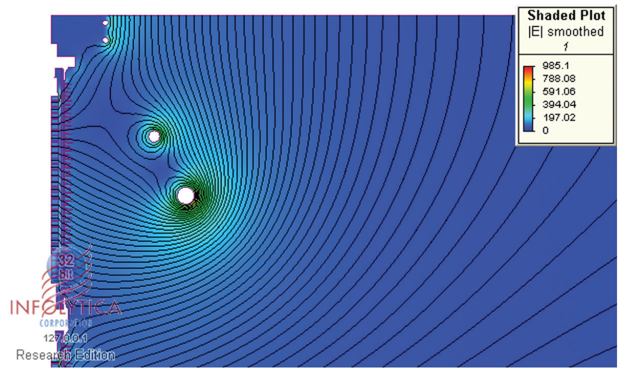


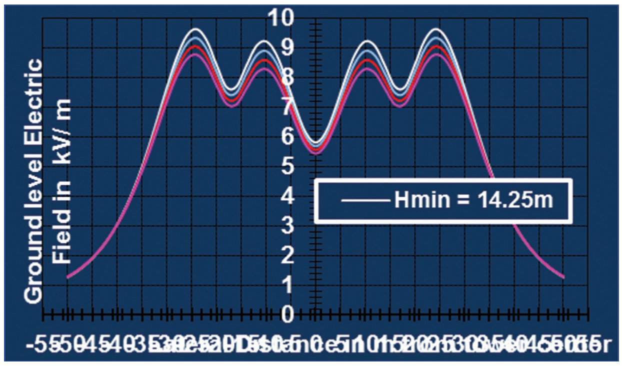
FIGURE SHOWING EQUIPOTENTIAL LINES FOR THE SURGE ARRESTER WITH OPTIMISED GARDING RING

11.1 Optimization of Minimum clearance requirement for transmission towers of 765 kV System

The division started working in the area of optimization of transmission tower clearance above ground based on computed Corona, Radio Noise and Audible Noise performance of the line using the software developed in house. The division has provided the consultancy for the following EPC Contract vendors.

- M/s Sterlite Grid Limited., New Delhi
- M/s Reliance Power Transmission Ltd. Gurgoan, Haryana
- M/s Jyoti structures, Mumbai

Figures below show some of the results of the consultancy works undertaken by the division.



COMPUTED LATERAL PROFILE OF ELECTROSTATIC FIELD UNDER THE 765 kV TRANSMISSION LINE

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