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# Power Cables Laboratory

*This paper presents bird's eye view of contribution made by Power Cables Laboratory of CPRI during the Golden Jubilee period 1960–2010 towards research, testing and certification. The laboratory started way back in 1960 at the Indian Institute of Science campus, Bangalore with bare minimum test facilities. The laboratory assisted many of the Indian cable industries by providing consultancy and testing services for improvement and produce better quality cables. Over the years the laboratory has been augmented with the state of art test facilities for research and qualification tests on power cables and materials. At present, CPRI has state art of facilities for testing of cables and accessories of voltage rating up to 220 kV rating. CPRI is setting up facilities for Pre-qualification testing of 400 kV EHV XLPE Cables as per IEC-62067. With this facility, CPRI test facilities will get enhanced to type testing and pre-qualification tests of cables up to 400 kV voltage rating. The research activities undertaken in this laboratory during this period is summarized.*

## 1.0 INTRODUCTION

Central Power Research Institute (CPRI), Bangalore a premier Institute of in the power sector, has complete Test facilities for testing and evaluation of Power Cables and Accessories rated up to 400 kV as per various national and international standards. The laboratory is being upgraded, to test cables up to 400 kV and long term tests like pre-qualification test for 8760 hours in accordance IEC 62067. CPRI is extending these services to many of the Indian utilities, manufacturers and many of overseas customers for the last few decades. In this paper the role of CPRI in research and testing services to the Power Cable industry is highlighted.

## 2.0 HISTORY OF CABLE DEVELOPMENT

Power cable technology had its beginning when the gutta-percha cable was made as early as 1846. In 1890 Ferranti developed the first oil impregnated cables operating at 10 kV. Rubber cables were manufactured in 1892 in United States and the commercial cable in the voltage range of 9–20 kV came into existence during 1909. The oil filled paper power cables was first explored by Emanueli in 1917 and by the year 1928 the first oil filled cable rated at 66 kV was manufactured. Due to thermal constraints, manufacturing cost and operational problems the paper insulated and rubber cables were gradually replaced with poly ethylene cables during 1950. Cross linked polyethylene cables with higher operating temperatures came into existence during the years 1964. The low density poly ethylene (LDPE) 225 kV, 800 sq.mm cable with a insulation wall thickness of 22 mm to operate at a maximum voltage gradient of 10 kV/mm were designed in EDF in 1969. The high density poly ethylene (HDPE) cable manufacturing started in Norway, Japan, Sweden and United States. A 138 kV lead sheathed XLPE cable was made in 1976 at Detroit Edison company. In 1980 a 345 kV XLPE cable was manufactured using dry curing process. In 1985, cables of 400 kV designed to operate at stress of 12 to 15 kV/mm were manufactured. During 1990 a 500 kV XLPE cable was manufactured and is in use. In 1995 a 500 kV LDPE cable was made.

## 2.1 Existence of Power Cables laboratory at CPRI

The Power cables laboratory came into existence way back in 1960 and took birth at Indian Institute of Science, Bangalore (IISc). At the time of inception, the laboratory was called as “Discharge Detection Laboratory” with basic testing facilities like AC/DC testing source, discharge detector, equipment’s for cable insulation characterisation. During early sixties manufacture of paper insulated cable of 6.6 kV rating had made a beginning and was in use. However due to technological deficiencies and operation and maintenance problems the failure rate of LT paper cable was high. During this period CPRI had assisted many of the Indian cable industries by providing consultancy and testing services for improvement and produce better quality cables.

Gradually with improved design, 11 kV paper cables was manufactured, however belted cable came into the offing. As there were lot of failures of the belted cables, design and production 11 kV screened cable came into existence. The handling of these paper cables while preparing the termination and joints posed a biggest challenge which necessitated for alternate insulating material Poly Vinyl Chloride.

FIG. 1 M.C.RATRA, LAB HEAD EXPLAINING TO THE VISITORS

When the Govt. of India took a policy decision to switch over from paper insulated, lead covered cables to 11 kV voltage class PVC cables, many difficulties were experienced by the cable manufacturers in the country. The laboratory played a significant role in the development of good quality PVC cables by providing laboratory facilities for product development and evaluation. The test facility was extensively used by manufacturers of PVC cables and contributed to the development of PVC cables in the country.

Initially 1.1 kV PVC cables were developed. The drawback of this material was that the softening temperature was very low and the material was not meeting the electrical parameters as required for power cable application. Research and developmental activities were strengthed to develop LT PVC cable to meet the electrical requirements. Subsequently 3.3 kV PVC cables were developed and further 6.6 kV and 11 kV PVC cables. The 11 kV PVC cables could not be used much in the network because the failure rates of PVC 11 kV cables were very high compared to paper cables.

Cross Linked Poly Ethylene (XLPE) insulation which had better electrical properties was used for higher rating cables. But the compatibility of the various chemical ingredients used in the construction of cable was big technical challenge. Various components of the cables were improved to achieve the compatibility of the cable. Initially 1.1 kV XLPE cables were manufactured and subsequently cables of rating 11 kV. Agin compounding of XLPE was a big task. Detailed studies on XLPE cables were also undertaken in the cables laboratory and improvements were suggested to the manufacturers. Research investigations were also carried to understand the importance of partial discharge tests for high voltage insulation, discharges in artificial cavities in polythene dielectric, detection and location of incipient defects in high voltage plastic insulated cables. The research investigations and testing experience has been shared in several national conferences by way of publications.

During 1977–1978 the laboratory was moved from IISc campus to its own campus adjacent to IISc and the laboratory was renamed as Cables and Capacitors laboratory. The laboratory was involved in testing of low voltage (LV) and medium voltage (MV) cables. Further the laboratory was augmented with several facilities like 100 kV AC, partial discharge free testing transformer (Figure 2), Discharge detector, and associated accessories (Figures 3 and 4), coupling capacitor (Figure 5) high voltage 80 kV DC source, Current transformers, current loading coils.

FIG. 2 100 kV AC, PD FREE TRANSFORMER

FIG. 3 TRANSFORMER REGULATOR


FIG. 4 A VIEW OF CONTROL PANEL

FIG. 5 COUPLING CAPACITOR

Schering bridge, Standard capacitors, dividers, conditioning chambers like ovens (Figure 6), humidity chamber, cold and salt fog chambers, cable termination (Figure 6) etc from UNDP funds of 30 lakhs.

The services of cables laboratory have been extensively utilized by the cable manufacturers in the country. On a specific request from utilities like Delhi


FIG. 6 A VIEW OF AGEING OVENS

FIG. 7 A VIEW OF 66 kV CABLE TERMINATION

Supply undertaking, Andhra Pradesh state electricity Board, Maharashtra Electricity Board, Karnataka Power corporation, HAL, etc. the laboratory undertaken investigations of failure analysis of power cables, joints and terminations during service and rendered services which have been appreciated by the utilities.

Intensive Research and Development activities were initiated during the period early 80's with induction of younger generation scientists and Engineers. Development projects related to the functional evaluation of insulation system of power cables and accessories were taken up. This knowledge enriched the young scientists and Engineers in understanding the behaviour of various high voltage insulation systems under operating stresses. The main contribution from this laboratory included the design and evaluation aspects of Power cables and accessories of cables.

The current carrying capabilities of conductors and screens of cable under different situations and development of new techniques for checking the quality and reliability of cables have been experimentally investigated. The research findings were were published in National and International conferences. During this period the laboratory had published about 30 research technical papers.

## 3.0 INSULATING MATERIAL EVALUATION

The insulating materials used are either oil impregnated paper or extruded polymer which meets the properties like: High dielectric strength, high Insulation resistance, durability and long life, low thermal resistivity, low relative permittivity and low tan-delta when used for a.c. cable application, preferably non-hygroscopic, Immunity to chemical attacks, easy handling and low cost. For many years, the preferred choice of cable dielectric was oil impregnated paper. Gradual replacement of paper insulation with polymeric insulation had several advantages over oil impregnated cables. Polymeric materials like Poly-Vinyl Chloride (PVC), Poly-Ethylene (PE), Cross Linked Poly-Ethylene (XLPE), Ethylene Propylene Rubber (EPR) are commonly used either for insulation, sheathing or jacketing purposes.

The major problem of XLPE insulated cables has been due to premature failure of cables due to phenomenon known as 'Treeing'. Two types of trees generally are observed in this material, electrical and water trees. The presence of contaminants, voids and protrusions of semiconducting shield, in the insulation which causes high electrical stress and electrical trees develop with in the solid dielectrics and these gradually penetrate the insulation wall eventually resulting cable failure. The combination of moisture and electrical stress in the insulation leads to water trees. The presence of water trees decreases the AC breakdown strength of cables.

To ensure reliability and better performance of cables, studies were undertaken in the cables laboratory of CPRI to develop the techniques for growth, detection and analysis of electrical and water trees in samples of LDPE, XLPE and EPR insulation. For observation of water trees, wafers of samples microtomed to 0.5 to 1 mm thickness using special blades, dyed and examined. Staining techniques like (a) Iodine exposure, (b) Methylene blue dye, and (c) Siemens dyeing technique were adopted. Optical projectors with 50X magnification (Figure 8) was used for observing the water trees. Based on the studies techniques for studying the resistance of XLPE materials to electrical and water treeing have been standardised. The findings also revealed that resistance of materials to electrical treeing is inferior in the case of XLPE materials. It was also observed that there is a good correlation between the loss tangent of the insulation and growth of water trees.

FIG. 8 OPTICAL PROJECTOR, 50X

Dissipation factor is an important electrical parameter for judging the behaviour of an insulating materials used in power cables. The experience of tests in the laboratory has revealed that the measured value of dissipation factor of XLPE cables with the three electrode system us less than actual value and sometimes measured value is negative. Understanding of the reasons for such behaviour is of obvious importance for the interpretation of the observed results and for improvement of the measuring system.

To facilitate proper interpretation of measured values and to locate the source of inference, a study was undertaken in the laboratories of CPRI. Experiments were performed on XLPE cables of various rating and electrode configuration. The results of measurements are analysed and compared theoretically. A typical plot showing the variation of tan delta as function of temp and humidity for different guard gaps is shown in Figure 9.

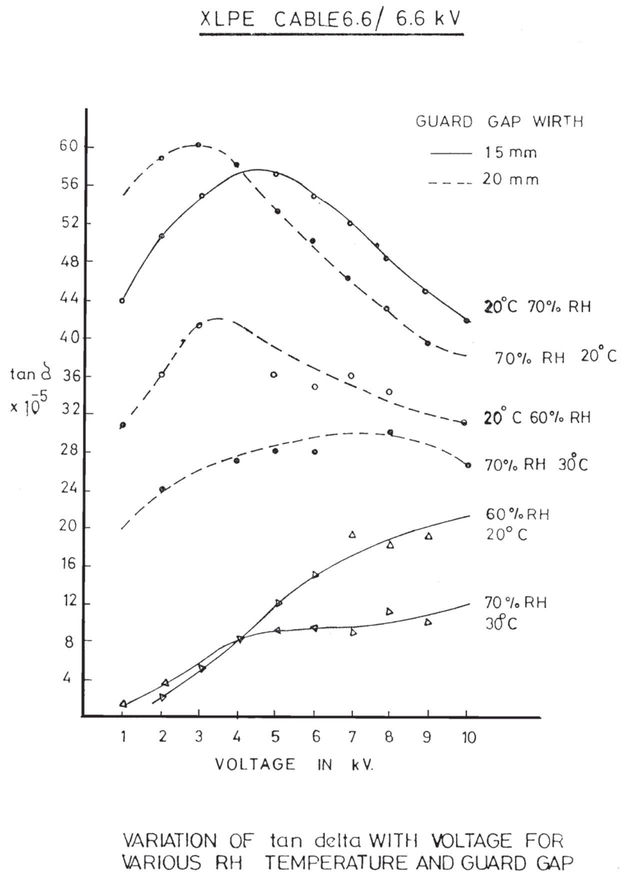


FIG. 9 VARIATION OF TAN δ WITH TEMPERATURE AND HUMIDITY

Based on the studies the anomalous effects in the dielectric loss measurements were identified as due to surface conductance of the guard gap in three electrode system. The optimum guard gap was suggested.

During mid 1980's the laboratory was augmented with infrastructure to test facilities like 300 kV, ac test source (Figure 10), Water termination for testing 220 kV cable, 500 kV, 15 kJ Impulse Generator (Figure 11), automatic measuring bridges and accessories.

FIG. 10 300 kV AC TEST SOURCE WITH DIVIDER

FIG. 11 500 kV, 15 kJ IMPULSE GENERATOR WITH DIVIDER

### 3.1 Advances in Vulcanisation process

EHV XLPE cables are manufactured generally by Continuous Catenary Vulcanization (CCV) process or Vertical Continuous Vulcanizing Line (VCV) process. The key factors that are to ensured during manufacture are highest purity of the insulating compound, minimization in numbers and size of voids within the extruded insulation. Of late a modern technique Mitsubishi Dainichi Continuous vulcanizing (MIDCV) process is adopted in India where cross linking is carried out in a special Long Land Die under strict process control, employing dry curing at elevated temperature and pressure and also ensuring void free homogeneous insulation.

The recent developments are the self cure Sioplas compound and Water tree retardant XLPE compounds. Self cure Sioplas are the modern methods where the process of cross linking is done at ambient conditions after extrusion and does not need sauna, CV tube or steam bath.

### 3.2 Heat transfer characteristics of cables

Studies were undertaken in the cables laboratory for determining the current ratings and rating factors. Experimental investigations were carried out to determine the temperature profiles of cables under different conditions like (a) cables laid in air and exposed to the surrounding atmosphere, (b) cables laid in ducts and tunnels, and (c) cables laid underground and measurements were carried out at different ambient conditions.

Heat transfer characteristic studies were also undertaken in the laboratory to determine the current capacity which is limited by heat transfer rate from conductor surface to external ambient. The investigation was to develop new conductor design profiles for EHV conductors based on slotted tubular conductor and squirrel cage models.

As the demand for testing higher rating cables were on the rise, new facilities were added during late 1980 to test cables rated 220 kV. The infrastructure included 600 kV, 600 kVA series resonant transformer (Figure 12), 600 kV standard capacitors, Partial discharge detector, coupling capacitor, 220 kV high voltage cable termination, Capacitance and tan delta bridge for cable and accessories.

## 4.0 JOINTS AND TERMINATIONS

The joints and terminations form integral part of cable system when in service. Based on the stress control techniques different termination methods like tapex, heat shrinkable, premoulded push on and pre stretched cold shrinkable system are used. The conventional approach was tapex terminations which involves wrapping of insulation tape around the screen terminus to from a stress relief cone. During early 1980's CPRI had designed and developed a 11 kV XLPE cable termination using indigenously available self adhesive PVC tape. This technique is almost obsolete now and it has been replaced by factory made pre-moulded cones.

FIG. 12 600 kV, SERIES RESONANT TRANSFORMER JOINTS

Pre fabricated Composite joint design which allows pre testing of all main electrical parts and reduces the installation risks and installation time on site. A typical pre moulded joint is shown in Figure 13. This type of joint consists of an insulation body made of epoxy resin with an integrated field control electrode. The Stress control is achieved by stress cone made from silicone rubber with an integrated stress control using a deflector. The Stress cone is mechanically pre-loaded by means of a metal spring device. This device ensures a very homogeneous pressure distribution on the stress cone. In recent time joints with embedded capacitive sensors for monitoring partial discharge activity are becoming popular.

FIG. 13 A PICTURE OF PRE-MOULDED JOINT

## 5.0 TERMINATION

EHV cable terminations are fitted with porcelain insulator filled with insulating fluid (Oil or $SF_6$ Gas). At present synthetic insulator are getting used in the place of Porcelain insulator. The synthetic insulator has an increased creepage length which helps in higher pollution and salt fog requirements. In addition, it reduces the weight by a factor of 1.5 to 2, depending on the pollution class of the standard porcelain. At present the terminations are also coming up with integrated capacitive PD Sensor and a monitoring system to detect losses of insulation oil.

### 5.1 Fire Safety Evaluation Techniques

The fire and smoke characteristics of cable materials are evaluated by several test techniques and more are being published every year.

Some of the important test facilities to evaluate flammability and smoke characteristics on cables and polymeric materials were Limiting oxygen index (LOI) test as per ASTM 2863 (Figure 14), Evolved combustion gases of wire/cable (Figure 15) Smoke density of wire/cable, ASTM E 662 for Specific optical smoke density (Figure 16), facility for flammability characteristics on sing and bunched cables (Shown in Figures 17 and 18) were set up.

FIG. 14 OXYGEN INDEX TEST APPARATUS

FIG. 15 HCL DETERMINATION TEST APPARATUS


FIG. 16 SMOKE DENSITY CHAMBER

FIG. 17 FLAMMABILITY TEST ON PLASTICS

FIG. 18 FLAMMABILITY TEST ON BUNCHED CABLES

Fire survival test to check the electrical integrity of cables under fire conditions for a duration of 3 hours were also added. The general arrangement is shown in Figure 19.

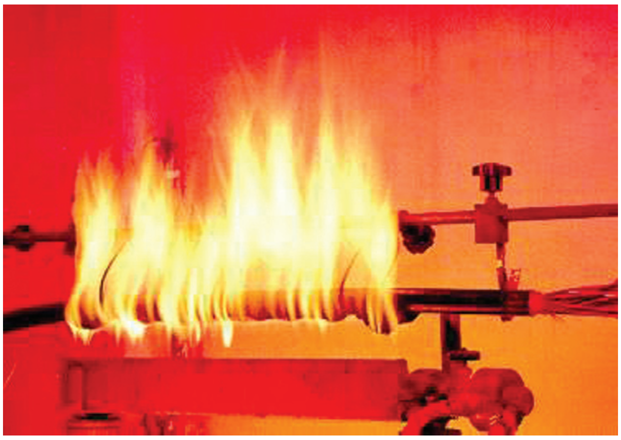

FIG. 19 FIRE SURVIVAL TEST APPARATUS

Heat release (HRR) measurements using cone calorimeter are used to predict the real-scale burning behaviour of materials and assemblies at it quantifies fire size, rate of fire growth and consequently the release of associated smoke and toxic gases. HRR is considered to be a key indicator of fire performance and is defined as the amount of energy that a material produces while burning.

The Cables laboratory was augmented with test facility for conducting heat release measurements and evaluation of toxic gases during the years 2004–2005. Figure 20 shows the photograph of the cone calorimeter and Figure 21 shows the photograph of Toxicity index apparatus.

FIG. 20 A VIEW OF CONE CALORIMETER TEST SET UP

FIG. 21 A VIEW OF TOXICITY INDEX APPARATUS

The heat release measurements on typical cables and sheath materials were made using the Cone calorimeter shown in Figure 22 and heat release measurement data is shown in Figure 23.

FIG. 22 TYPICAL CABLES TESTED

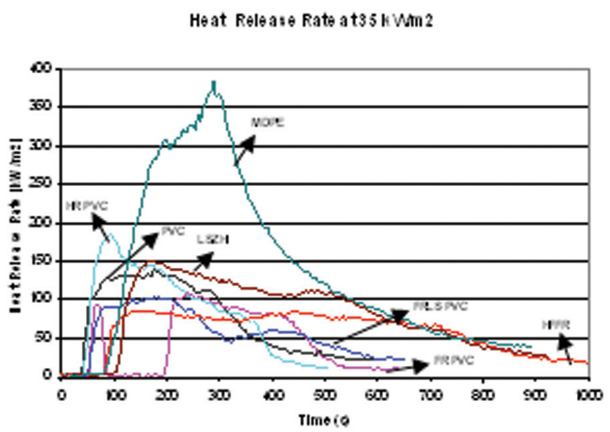


FIG. 23 VARIATION OF HRR WITH TIME, CABLE SHEATH AT 35 kW/M2

### 5.3 Infrastructure at CPRI for Qualification tests on cables

CPRI has facilities to carry out all type test on XLPE/PVC/EPR PAPER Cables and their accessories of voltage rating from 1.1 kV up to 220 kV as per various national and international standards. The test set up for a 220 kV XLPE Cable system is shown in Figure 24.

The range of products tested in CPRI include LT PVC Cables, LT XLPE Cables and their accessories, HT XLPE cables and their accessories, LT AB Cables, EHV Cables and their accessories and Special cables like FR/FRLS and Fire survival Cables.

### 5.4 Pre-Qualification test infrastructure at CPRI

In order to assess the long term reliability of cable system, CIGRE committee 21, working group 21.03 has recommended that a long term ageing "Pre-qualification" test be carried out on a complete cable system comprising 100 m length cable, the joints and terminations. This evaluation technique qualifies the cable system for compatibility and reliability. This test is conducted in accordance with IEC:62067 guidelines.

When a pre-qualification test has been successfully performed on a cable system, it qualifies the manufacturer as a supplier of cable systems with the same or lower voltage rating as long as the calculated electrical stresses at the insulation screen are equal to lower than for the cable system tested.

At present, PQ test facility is not available in our country and most of the Asian manufacturers are dependent on International laboratories like CESI, Italy, KERI, Korea and KEMA, Netherlands. Central Power Research Institute (CPRI), Bangalore a premier Institute in the power sector is setting up pre-qualification test facility under Eleventh plan capital project and the laboratory will be ready in a couple of months. The laboratory is also being upgraded with facilities like 2400 kV, 240 kJ Impulse Generator, 600 kV, 4200 kVA AC test system, 600 kV dividers, Current loading coils, Data loggers, Measuring instruments like Partial discharge detectors, dissipation factor bridges, 600 kV Standard capacitors, etc. to test cables up to 400 kV rating.

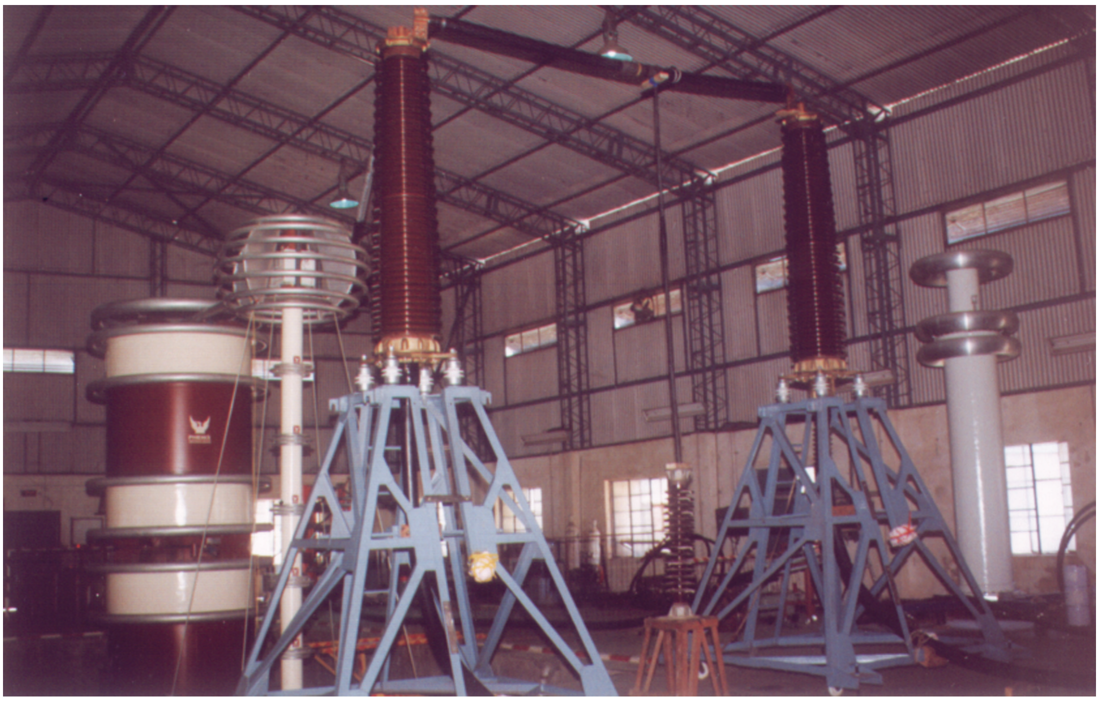

FIG. 24 TEST SET UP FOR 220 kV CABLE SYSTEM


FIG. 25 A VIEW OF 2400 kV, 240 kJ, IMPULSE GENERATOR

## CONCLUSION

This paper presents bird's eye view over the developments in Power cable industry and CPRI, Cables laboratory's role in research and testing during the Golden jubilee period 1960–2010. Cables Laboratory of CPRI has contributed significantly to the growth of Power cable industry and has geared up to take any technical challenges in the near future.

## ACKNOWLEDGMENT

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FIG. 26 A VIEW OF 600 kV, 4200 kVA AC TEST SYSTEM

## PAST MEMORIES

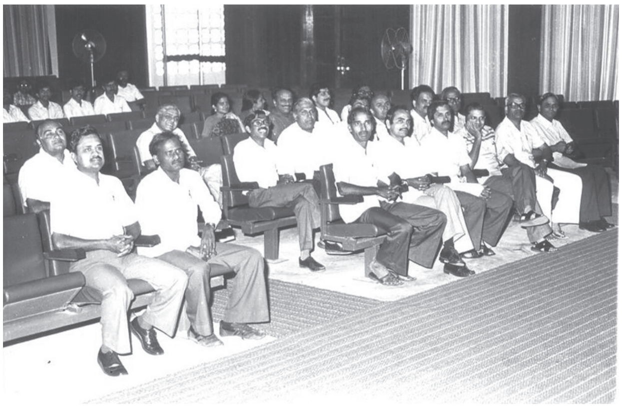

PHOTO. 1 SR. OFFICERS ATTENDING THE CONFERENCE

PHOTO. 2 SR. OFFICERS RELAXING DURING COFFEE BREAK