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Commissioning of UHV Indoor Double Shielded Laboratory for Radio Interference Voltage and Partial Discharge Measurement

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Abstract

In recent years, due to advancement of technology, the transmission voltage levels are goes on increasing. Worldwide 800 kV systems is very common and in India experimental 1200 kV AC is successfully commissioned. Testing of vital equipment of such UHV transmission network is paramount importance to provide uninterrupted, reliable and quality power to the customers. Worldwide few testing laboratories having facility to test upto UHV class equipment, the Ultra High Voltage Research Laboratory (UHVRL) of Central Power Research Institute (CPRI), India is one among them. Recently, 2X600 kV, 2 A, 2400 kVA HVAC test system is commissioned in double shielded indoor laboratory at UHVRL, Hyderabad, India. This manuscript elaborates the experiences of commission of AC test system along with radio interference voltage and Partial Discharge (PD) measurement.

Keywords: Double Shielded Indoor Laboratory, Performance Test on AC Test System, PD Measurement, UHVAC Test System

1. Introduction

India's power demand is expected to increase to more than 500,000 MW by 2027, for which installed generation capacity of 700,000 MW is required[1]. To meet these ever increasing demand requirements, Indian power sector necessitates large generation capacity addition and commensurate increase in transmission and distribution network. Majority of the power is generated in the north eastern region of India while the demand requirements are primarily located in the northern, western, southern and central regions. Development of large transmission network for transfer of bulk power over these longer distances poses various technical challenges, Right of Way (ROW) and environmental related issues. The ROW is of more critical particularly in the chicken's neck area power corridor, a narrow stretch of 22 km located in upper part of West Bengal, India. By interconnecting power generation packets, larger power transfer capability transmission line network is to be established to scatter the increase in power demand. However, existing 400 kV and 765 kV lines has loading capacity of 600 MW and 1200 MW, respectively. Bulk power transmission line is achieved with quantum jump in transmission voltage level, i.e., 1200 kV transmission line have the power transfer capacity of 8000 MW to 10000 MW. POWERGRID Corporation of India (PGCIL) is likely to establish 1200 kV AC transmission line between Wardha and Aurangabad in near future[1].

In the operation of such ultra-high voltage transmission system, proper functioning of interconnected equipment of transmission network is of paramount importance to provide uninterrupted, reliable and quality power. Reliable service of the equipment is ensured by performing design test in laboratory as per relevant International and National standards. In India only few high voltage laboratories having UHV class test facility. Ultra-High Voltage Research Laboratory (UHVRL) of Central Power Research Institute (CPRI), Hyderabad is one such laboratory having facility to test various electrical equipment of UHV range.

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UHVRL is equipped with 1600 kV, 6 A and 9600 kVA rated outdoor UHVAC generation facility with 2X800 kV cascaded metal tank testing transformers. +/- 1200 kV, 200 mA, four stage outdoor UHVDC generation facility to perform testing related to UHV DC transmission systems. A 720 m long 10 bundle moose conductor with overall diameter of 1.4m experimental transmission line in three spans of 180 m, 360 m and 180 m to perform experiments related to ionic and electric field studies of UHV transmission line. A 25 stage outdoor 5MV, 500 kJ impulse voltage generator to perform dielectric tests and 24 m (diameter) and 27m (height) artificial pollution laboratory for salt fog test on insulators.

In addition to the existing facilities, recently 1200 kV, 2A, 2400 kVA indoor UHVAC generation facility has been established to perform partial discharge testing of various electrical equipment, particularly, instrument transformer. This UHV AC source is commissioned in 50 m (length) X 35 m (width) X 35 m (height) double shielded indoor laboratory. Background partial discharge of 4.6 pC has been achieved at 850 kV without any test object. Experiences of UHVRL in commissioning UHV AC source in indoor test facility (laboratory) is presented in this manuscript. Details of AC source, testing system and performance test are discussed in section 2 to 4. Radio interference voltage measurement (RIV) and Partial Discharge (PD) test are elaborated in Section 5 and 6.

2. UHV AC Test System

The high voltage AC generated by a cascading of two 600 kV metal tank transformers. Photograph of two partial discharge free metal tank transformers connected in cascade in the shielded indoor laboratory along with 1200 kV capacitive voltage divider is shown in Figure 1, as 1200kV AC Test system. Supply to the AC test system and voltage regulation is realized by a switching cubicle and a regulating transformer including adaption transformer. For compensation of capacitive current, it consists of a variable and fixed compensating reactor. For improvement of quality of AC test voltage, it consists of harmonic filters to filter out 3rd to 7th harmonic levels at the input and output of first cascaded metal tank transformer. In particular, it also consists of a low voltage filter to supress the noise signals which may disturb partial discharge measurements. It also seen in Figure 1, AC test system consists of blocking impedance and capacitive voltage divider, which is used as coupling capacitor also for radio interference voltage as well as partial discharge measurement. A computer control and measuring system including capacitive divider and display unit in control panel was used to makes the operation of AC test systems as automatic or semi-automatic. These AC system with partial discharge free metal tank transformers is used for partial discharge measurement, radio interference voltage measurement and to perform withstand test as well as flashover test under dry and wet conditions on various electrical equipment in UHV range.

Figure 1. 2×600 kV, cascaded transformer along with divider.

3. Test Voltage Measuring System

The 1200 kV AC voltage measuring system is consists of 1200 kV capacitor, which is series connection of three 400 kV measuring capacitors, low voltage part, measuring cable and AC/DC peak voltmeter. The schematic representation and photograph of HV AC measuring system is shown in Figures 2 and 3, respectively.

Low voltage arm capacitor output is displayed in control panel after multiplied it by a scale factor. The scale factor is a number by which the value of the measuring instrument reading is multiplied to obtain the value of the input quantity of the complete measuring system. The assigned scale factor for this 1200 kV ACTS is 3715. Generated test voltage fulfilled the requirements of IEC 60060-1[2], for the range of 120 kV to 1200 kVrms, i.e., from 10% to 100% of the rated test voltage. Throughout this range, generated 50 Hz AC voltage had sinusoidal wave shape without any harmonics. Also found that the deviation from positive and negative peak and ratio of peak to Root Mean Square value (RMS) values was less than 1% and √2 respectively.

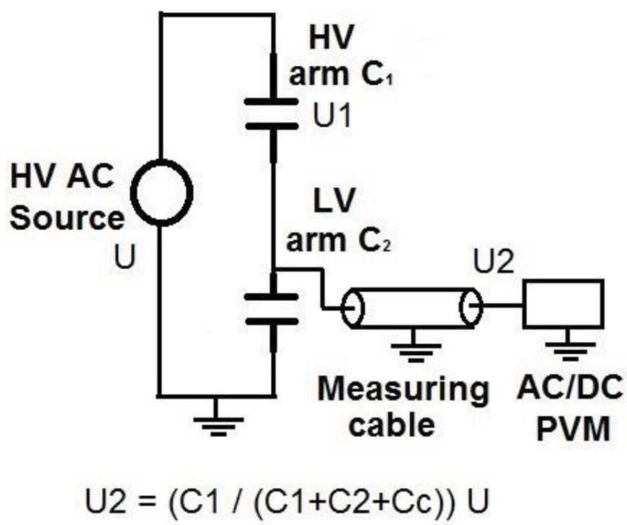

Figure 2. Schematic representation of HV AC measuring system.

Figure 3. Photograph of HV AC measuring system.

4. Performance Test on AC Test Voltage Measuring System

Assigned scale factor of the measuring system is to be revalidated at frequency intervals, preferably once in a year, by conducting tests in compliance with IEC 60060-2[3], which are referred as performance test of measuring system. During these tests the measured scale factor shall not vary by more than ±1% of assigned scale factor. If the deviation is more, then the scale factor shall be reassigned. As per IEC 60060-2, the performance tests of AC test system includes, determination of scale factor, linearity test and dynamic frequency response analysis.

4.1 Determination of Scale Factor

Scale factor of the UHVRL AC measuring system is determined as the product of the scale factors of converting device, which includes, high voltage capacitor divider, cables, secondary capacitors and measuring instrument, i.e., digital AC/DC Peak voltmeter. For converting device, scale factor is determined by calculation based on measured impedances. Capacitance of high voltage arm (C_1) is measured as 2.08 nF using precision capacitance and tan delta measuring bridge at 80 $kV_{rms.}$ Consequently, the low voltage arm capacitance along with measuring cable is measured as 7760 nF at low voltage using precision LCR Q meter. Then the scale factor of the divider F_1 is 3731.769. Scale factor of indicating instrument (F_2), digital AC/DC peak voltmeter, is determined independently by applying a reference low value input voltage to it, and simultaneously the displayed output voltage in the instrument is recorded. The ratio of reference input voltage and displayed output voltage is the scale factor of measuring instrument. (F_2). It was observed as 1.000. Scale factor of the measuring system is the product of F_1 *and* $F_{2,}$ is 3731.769. Since, the calculated scale factor lies within ±1% limit of assigned scale factor, it is considered as valid. All measurements are the mean value of multiple readings.

4.2 Linearity Test

The linearity of measuring system is verified using sphere gap measurement in compliance with IEC 60052[4]. Sphere gap arrangement is connected in parallel with the measuring system and the test voltage applied simultaneously. UHVRL is equipped with 50 cm diameter vertical sphere gap arrangement for measurement of AC and impulse voltages. At gap spacing of 3.5 cm, 7.5 cm, 12 cm, 17 cm and 24 cm, the displayed high voltage and calculated (by applying suitable correction factor) breakdown values of voltages are compared and it was found well within the limit of ±3%. During this voltage application, the corresponding input voltage applied to the HVAC generator is also noted through MU18. To prove the linearity, without sphere gap arrangement, the input voltage applied to the system and displayed output is recorded upto 1200 kV. It was observed that the output is varying linearly with applied input voltage.

4.3 Dynamic Behaviour of AC Converting System

To characterize the dynamic behaviour of measuring system, it is subjected to a sinusoidal input of known amplitude (V_{in}) of test frequency 50 Hz, and the resultant voltage across the low voltage (V_o) arm is recorded simultaneously. These measurements are repeated for range of frequencies between 1 to 7 times the 50 Hz, i.e., 50 Hz to 350 Hz, in steps of 50 Hz. Normalized amplitude-frequency response of the measuring system intended for single test frequency was found to be in compliance with IEC 60060-2. The dynamic behaviour of converting device, 1200 kV capacitive voltage divider, for fundamental frequency of 50 Hz is shown in Table 1. The deviation in amplitude – frequency gain of other frequencies from fundamental frequency is shown in Figure 4. It is evident that the deviation is in compliance as per IEC 60060-2. Further, the scale factor of indicating instrument is obtained using the universal calibrator is tabulated in Table 2. It was found that the calculated scale factor is 3726 using universal calibrator and 3732 calculated from capacitance values, both are well within ±1% of assigned scale factor 3715 for 1200 kV AC test system. Hence, the assigned scale factor 3715 is valid.

4.4 Measurement Uncertainty

Contribution of measurement uncertainty for a measured parameter that randomly varies is evaluated using Type A uncertainty. Other than the statistical analysis, based on all available information on the possible variability of an input quantity, such as, short term stability, long-term stability, ambient conditions during measurement, drift, proximity effect of nearby objects, limited resolution of measuring instruments, and uncertainty contribution of measuring instruments are considered in Type B evaluation. The evaluated combined uncertainty of UHVRL AC test system is 1.5% and is in compliance with IEC 60060-2.

5. Radio Interference Voltage Attenuation

When the substation equipment and transmission lines are energized with high voltage may cause electromagnetic interference to the neighbouring equipment. The radio noise may cause many unwanted disturbance within the radio frequency band of interest including, audible noise, radio and TV communication interference, affects an electric circuit by electromagnetic induction, electrostatic coupling or conduction. Further, it plays a key role in deciding the height of equipment and transmission line from ground. Hence, Radio interference and corona discharge in transmission lines and equipment is one of the major design concerns in the construction of UHV systems.

International standards and Special International Committee on Radio Interference Voltage Measurement (CISPR) had specified methodology for measurement of radio interference emission from various electrical equipment. To validate the design and for compliance with international standards, the RI noise emission is measured in the laboratory. In laboratory the radio noise is measured as conducted quantities, either voltage or current, using the measuring instrument as per CISPR 16-1-1[5]. In some applications the utilities requires, particularly for instrument transformers, the noise level shall be less than 250 μV at 1 MHz frequency. As per standards, the background noise level is checked before start of every test and it shall be, preferably, at least 10 dB below the level specified for the test object or desirably at least 6 dB below the level. Many a times, it is challenging to meet this requirement in outdoor laboratory. This can be achieved in indoor test laboratory with proper shielding.

Table 1. Dynamic behaviour of converting device for fundamental frequency of 50 Hz

Input Voltage V_{in} (V_{rms})	Frequency (Hz)	Output Voltage V_{out} (V_{rms})	Gain = $20\log(V_{out}/V_{in})$ (dB)	Deviation in gain from f_{norm} gain (% dB)	Scale Factor of Divider (F_{CD})
1000	50	0.26832	-71.4271	0.00000	3726.893
1000	100	0.26858	-71.4185	0.85743	3723.285
1000	150	0.26840	-71.4242	0.28806	3725.782
1000	200	0.26844	-71.4232	0.39485	3725.227
1000	250	0.26834	-71.4263	0.07866	3726.615
1000	300	0.26843	-71.4233	0.37867	3725.366
1000	350	0.26841	-71.424	0.30748	3725.644
1000	400	0.26839	-71.4245	0.25570	3725.921

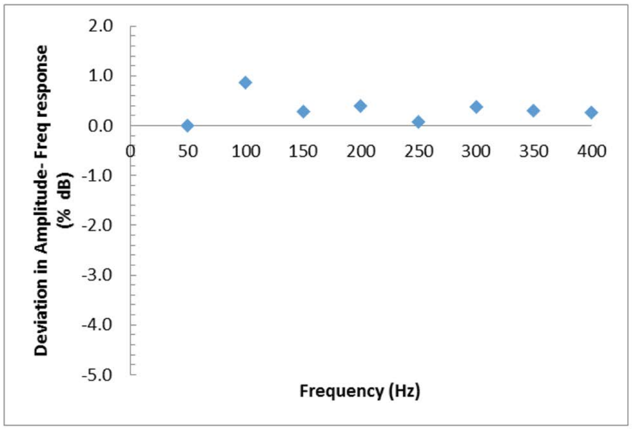

Figure 4. Amplitude- frequency response of 1200 kV measuring system.

The UHVRL indoor laboratory is a double shielded laboratory for its entire size with this background noise of 30-40 µV at 1 MHz frequency using quasi peak detector is achieved at all times.

To prove the effectiveness of the shielding radiated noise emitted both inside and outside the laboratory is measured using loop antenna and M/s. R&S make EMI test receiver with peak, average and quasi peak detectors. Radio noise spectrum of both inside and outside the laboratory is shown in Figures. 5 and 6, respectively. As majority of the measurement are requested with quasi-peak detector, comparison of RI spectrum of quasi peak detector of indoor and outdoor laboratory is shown in Figure 7. The photograph of ambient radio noise measurement inside the shielded indoor laboratory is shown in Figure 8.

The effectiveness of attenuation is measured at frequency, where highest radio noise is recorded. The Akasvani Hyderabad Station is having the frequency of 730 kHz and the UHVRL Hyderabad laboratory is geographically well in broadcast range. The ambient radio noise at 730 kHz with loop antenna and quasi peak detector of EMI test receiver is recorded as 106.4 dBµV/m. The same measurement is repeated inside the indoor laboratory by closing the laboratory and it is recorded as 37.5 dBµV/m. This proves that the shielded laboratory is having an effective attenuation of ambient radio noise of 68.9 dBµV/m. As stated earlier, because of this radio noise attenuation an ambient noise of 20-40 µV was achieved. The system is compliance with IEC/IS to measure conducted radio noise limit of 100 µV also with this background noise level. As shown in Figure 8, the capacitive divider is used as the coupling capacitor to receive 1MHz signal from the test object. Further, the blocking impedance ensures that the radio noise generated from the source, if any, will not contribute to the measured value.

6. Partial Discharge Measurement

One of the non-destructive tests to assess the quality of insulation of test equipment is partial discharge (PD) test. PD pulses are measured in the frequency range of 0.5 to

Table 2. Scale factor of indicating instrument of 1200 kV AC TS

Frequency (Hz)	Reference Voltage (V)	Displayed Voltage in MU 18 (V)	Relative deviation (%)	Scale Factor of Meter (F_{MI})
50	10	10	0.0000	1.00000
	20	20	0.0000	1.00000
	50	50	0.0000	1.00000
	70	70.01	0.0143	1.00014
	100	100	0.0000	1.00000
	150	150.02	0.0133	1.00013
	200	199.98	-0.0100	0.99990
	250	250.08	0.0320	1.00032
	300	300.2	0.0667	1.00067
	350	349.98	-0.0057	0.99994
	400	399.92	-0.0200	0.99980
	450	450.3	0.0667	1.00067
	500	500.03	0.0060	1.00006

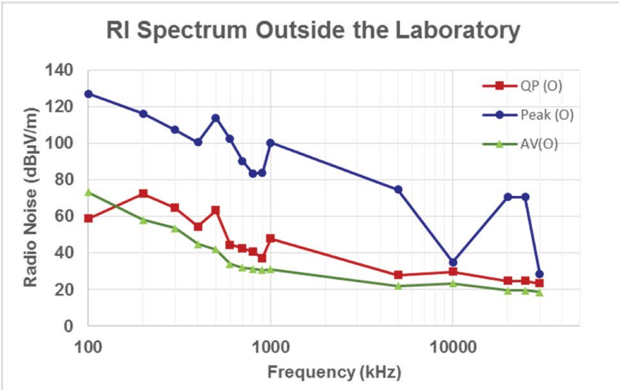

Figure 5. Radio noise spectrum outside the laboratory in UHVRL premises.

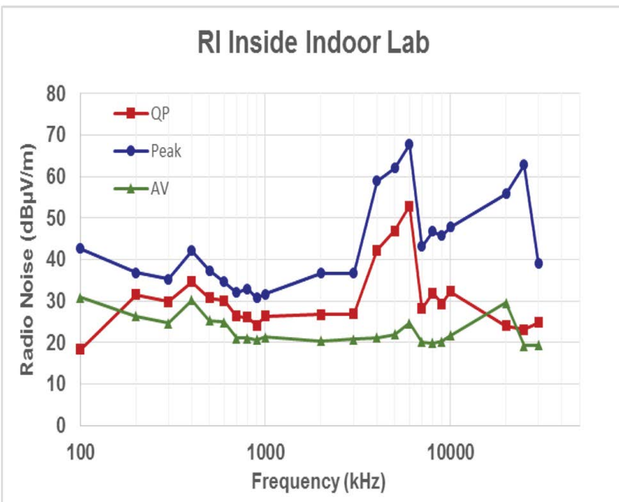

Figure 6. Radio noise spectrum inside the shielded indoor laboratory.

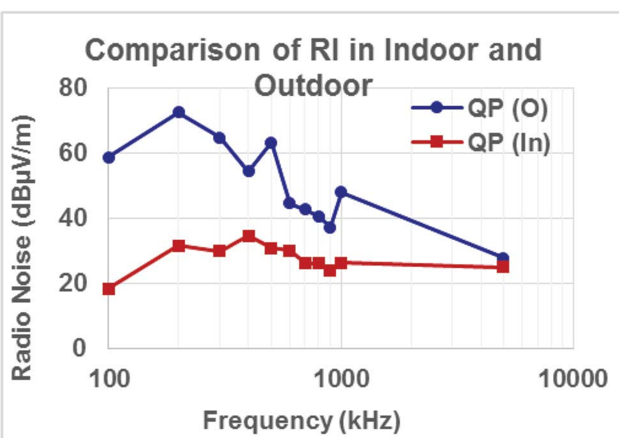

Figure 7. Effect of shielding on RI with quasi peak detector.

Figure 8. Photograph of capacitive voltage divider with blocking impedance.

2 MHz. in compliance with IEC 60270[6]. The lower and upper cut off frequency at 6 dB bandwidth for UHVRL measuring system is 93 kHz and 416 kHz, respectively. Partial discharge test on instrument transformer is very crucial and the acceptable limit is 5pC at test voltage. Hence, it is necessary to have the background noise less than that. Moreover, the sensitivity of the measuring equipment shall be of such that it shall allow detection of PD level as low as 5 pC.

To attenuate the atmospheric ambient PD (background PD), the entire 50 m X 35m X 35m laboratory is made as Faraday cage to perform PD test upto UHV class equipment. The inner and outer sides of laboratory are shielded with 2 mm thick galvanized iron sheet and 0.6 mm thick pre-painted galvanized iron sheets, respectively. The photograph of external view of double shielded indoor laboratory is shown in Figure 9.

Before erecting equipment in the laboratory, the background PD was measured with suitable coupling capacitor without applying any voltage. Lemke LDC -5/S3 calibrator along with Lemke LDIC LDS -6 PD measuring

Figure 9. External view of double shielded Indoor laboratory.

system was used for measurement of partial discharge. It was measured that the background PD is 2 pC. The HV arm of capacitive voltage divider is used as the coupling capacitor along with impedance box, where the PD is measured across 300 Ω impedance. After erecting 2X600 kV cascaded testing transformer along with measuring instrument in the laboratory, the background PD measured at 850 kV test voltage is 4.6 pC.

As the background PD is < 5pC, the indoor laboratory shall be used for PD measurement of UHV class equipment in compliance with IEC 60270. Further, PD test on other equipment, viz. breaker, bushings, etc. shall also be performed in the shielded laboratory, however, as stated earlier, the PD test on instrument transformer is crucial, experience on PD testing of 145 kV current transformers is shared herewith.

PD test on instrument transformers shall be performed either with procedure A and procedure B of IEC 61869-1. In procedure A, PD test voltages are reached while decreasing the voltage after the power frequency withstand test. Otherwise, PD test performed after the power frequency voltage withstand test. Test voltage is raised to 80% of power frequency withstand voltage, maintained for 60s, then reduced without any interruption to PD measurement values. This is referred as procedure B. PD measurement values and its limits are given in Table 3.

During PD test the suitable outdoor shielding may be used to avoid any disturbance. Wider shielding may be preferred as the discharge is from internal insulation not from any terminals or connections. Photograph of

Table 3. PD Test voltage and permissible limits[7]

Instrument transformer type	PD test voltage (kVrms)	Max. permissible PD level (pC)	
		Immersed in liquid or gas	Solid
CT and earthed CVT	Um	10	50
	$1.2 \text{ X } U_m/\sqrt{3}$	5	20
Unearthed VT	$1.2XU_m/\sqrt{3}$	5	20

PD measurement of 145 kV CT is shown in Figure 10. The value of PD measured are 6 pC, 4.7 pC and 3.6 pC at pre-stress, Um and $1.2XU_m/\sqrt{3}$ test voltage respectively. During the PD measurement a background PD of 2.8 to 3.0 pC was measured. From Table 3, it is evident that the PD level of this test object is well within the limit and is in compliance with requirement of IEC 61869-1[7] for PD measurement.

Figure 10. PD measurement of 145 kV CT at shielded indoor laboratory.

7. Earth Resistance Measurement

In and around the shielded indoor laboratory eighteen earth pits are made and all are interconnected. 40 mm (1.5 inch) diameter and 9.75 feet (2.75m) length pipe is buried in each earth pit. To increase the contact resistance charcoal and NaCl salt is mixed and filled around the pipe. In addition to that Bentonite slurry formed and filled around the pipe for proper earthing. The value of earth resistance is measured using Megger DET 2/2, Auto Earth Tester by fall of potential method. Value of earth resistance with distance is shown in Figure 11. The value of flat portion is 0.97Ω. It is in compliance with requirements of IEC 60060-1 and IEC 60060-2 for testing laboratories.

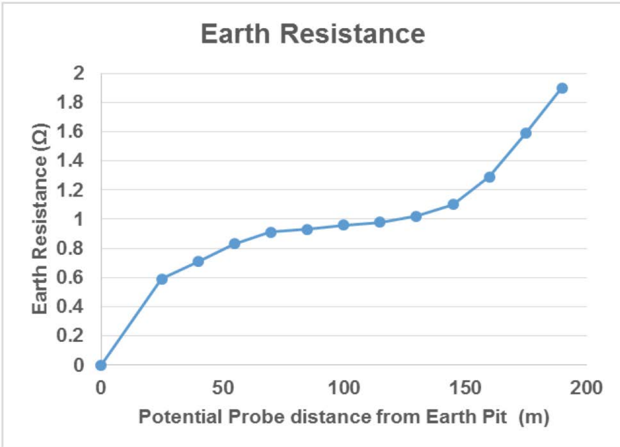

Figure 11. Measured earth resistance of indoor laboratory by fall of potential method.

8. Conclusions

Experiences on commission of 1200 kV ac test system along with performance test of measuring system is elaborated. In addition to that background ambient noise measurement for radio interference voltage and partial discharge measurement is also demonstrated.

9. Acknowledgements

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