INVESTIGATION OF EARTHING ARRANGEMENT FOR SINGLE WIRE EARTH RETURN DISTRIBUTION SYSTEM

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

WATER RESOURCES DEVELOPMENT
(ELECTRICAL)

By

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CANDIDATE'S DECLARATION

I hereby state that the dissertation entitled "**INVESTIGATION OF EARTHING ARRANGEMENT FOR SWER DISTRIBUTION SYSTEM**", Which is being submitted in partial fulfillment of the requirements for the award of degree of MASTER OF ENGINEERING IN WATER RESOURCES DEVELOPMENT (ELECTRICAL) University of Roorkee, is an authentic record of my own work carried out during the period from 16th July 1995 to November 30, 1995 under the guidance of **Prof. DEVADUTTA DAS**, WRDTC, and **Prof. P. SULEEBKA** of Electrical Engineering Department, University of Roorkee.

The subject matter presented in the dissertation has not been submitted by me for the award of any other degree or diploma.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

Loss saving & low cost technology is a call for the supply authority either Govt. or Private to renovate old conventional L. V. distribution system of electricity into H.V. distribution system in major areas of Rural electrification and Agricultural pump-sets energization. As per 1991 census data, only about 35% of the total power generated in India is consumed by 70% of the country's rural population. There is a need to extend the facility of electricity for increase of per capita energy consumption in rural sectors having low load densities and small cottage industries. Single Wire Earth Return System (SWER) is one kind of most economical andloss saving HV distribution system suitable for rural scattered loads of both domestic & Agricultural pumps.

Again, the single wire earth return system is using the earth in general as a conductor to complete the return path from distribution transformer (6.35/0.440 KV) to 33/11 KV power transformer.Now since it is a continuous current carrying process the earthing system at distribution transformer poses some problems towards :

- High Ground potential rise
- Increased step & touch potentials
- Power loss on grounding system ($I^2 x R_g$)

- Temperature rise of Ground electrodes
- Telephonic interference due to earth return current in the area.
- voltage drop & voltage regulation as per I.E rules.

Overall the environmental impact of SWER system needs the concerted endeavour of the power engineers to have an in-depth investigation of the above problems, for wide application of this system. Rural Electrification Corporation Ltd, New Delhi and CBIP, New Delhi have published a number of technical reports on SWER system and its economics [1,2,3,4,5,6,11] but there is no specific information available regarding earthing system of SWER and its allied problems and solutions. So an effort has been made in this dissertation to fillup this gap as far as possible.

Design of grounding system mostly depends upon soil resistivity of the area and the electrode depth, shape, size and configuration. Again soil resistivity is a complex variable parameter and its dependancies on soil moisture content, temperature, density, and type of soil, precipitation, and ground water table variation etc, posses a great concern of in-depth study and analysis, both by area field data collection and resistivity survey. Soil resistivity is a depth and time domain function. It varies with time (season) and depth of soil. It is also very difficult to guess, what is inside earth of an area for the purpose of injecting current safely at a certain depth. So, it is felt to have the idea of different layering effect of soil-strata and their respective range of values of resistivity.

Resistivity survey gives an idea for different depths of electrical conducting zones or layers available in the sub-soil. This is a great help in putting the electrode to that depth in order to leave the current in a more stable and safe zone, without facing much fluctuation of resistivity throughouta year.

Secondly different field experimental results help in assessing the best type of geometry and configuration of electrodes to minimize the "ground resistance", the key factor of the system.

The present dissertation work deals with some practical experiments and theorectical analysis to throw some light towards various problems of earthing system in implementation of SWER distribution schemes.

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CHAPTER - 1

INTRODUCTION

1.1 SINGLE WIRE EARTH RETURN SYSTEM (SWER)

Single wire earth return or SWER is nothing but one kind of High voltage (11Kv/6.35 kv) Distribution of Electricity. Where the nature of load is scattered and low load demand especialy in remote tribal hamlet villages and rural areas of sparse-population, the SWER system has been found to be economical. Because, the capital investment in such low load density areas, electrification is never viable with conventional primary distribution at 11 kv and secondary distribution with 440 volt, three phase four wire system in vogue.

This type of Hv distribution system involves in using pole-mounted single phase distribution dry type transformers as shown in Fig. 1.1(a) having ratings 4,6,8,10,16,25 and 50 KVA to suit load demands with HV primary ($11/\sqrt{3}$) 6.35 KV and LV secondary 220 V Table No. (1.1.1). The primary of transformer is connected to HV single phase conductor and the other end is earthed near the pole to serve as earth return circuit, as shown in Fig.1.1(b). Since, the entire major length of supply is on HV up-to the premises of the consumers and there is no 3 phase 4 wire L.T. lines, this system is also sometimes designated as "LT Less Distribution System".

TABLE NO.1.1.1 SWER DISTRIBUTION TRANFORMERS RATINGS WITH GROUND RESISTANCE : [1]

Sl. No.	Rating (KVA)	Normal load Current =KVA/6.35 Amp.	Max. Gr. Resistance R_g Ohm = Potel. Rise/ Current	Ground Potential Rise IR_g V	Fault KVA = Rating KVA/ %age Impendance	Max. Fault Current = fault KVA/6.35KV
1.	4 KVA	0.63 A	50.8 Ohm	32	4/.02 =200	32
2.	6 KVA	0.945	33.9	32	6/.02 =300	48
3.	10 KVA	1.58	20.3	32	10/.025=400	63
4.	16 KVA	2.5	12.7	32	16/.025=640	100
5.	25 KVA	3.94	8.1	32	25/.033=832.5	131
6.	50 KVA	8.0	4.0	32	50/.033=1665	262
7.	100 KVA	15.75	2.0	32	100/.04 = 2500	394
8.	150 KVA	23.63	1.4	32	150/.045= 3334	525

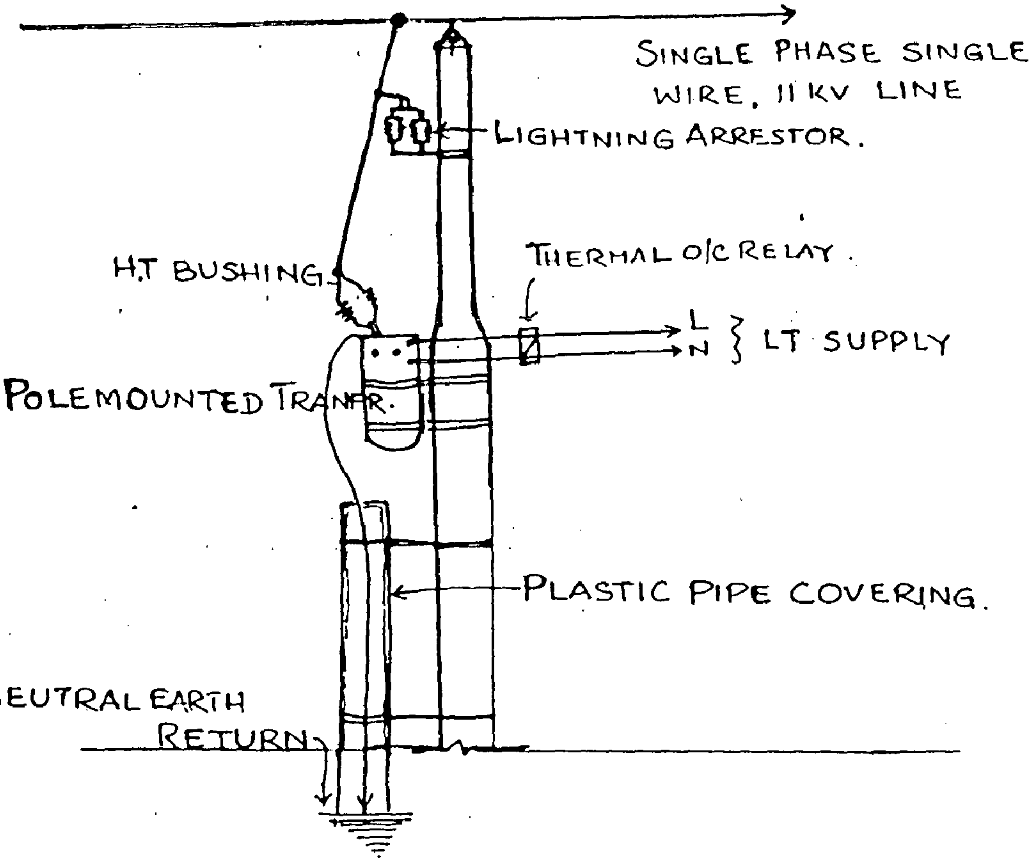


FIG. 1.1.(a) SWER POLEMOUNTED DISTN. TRANSFORMER.

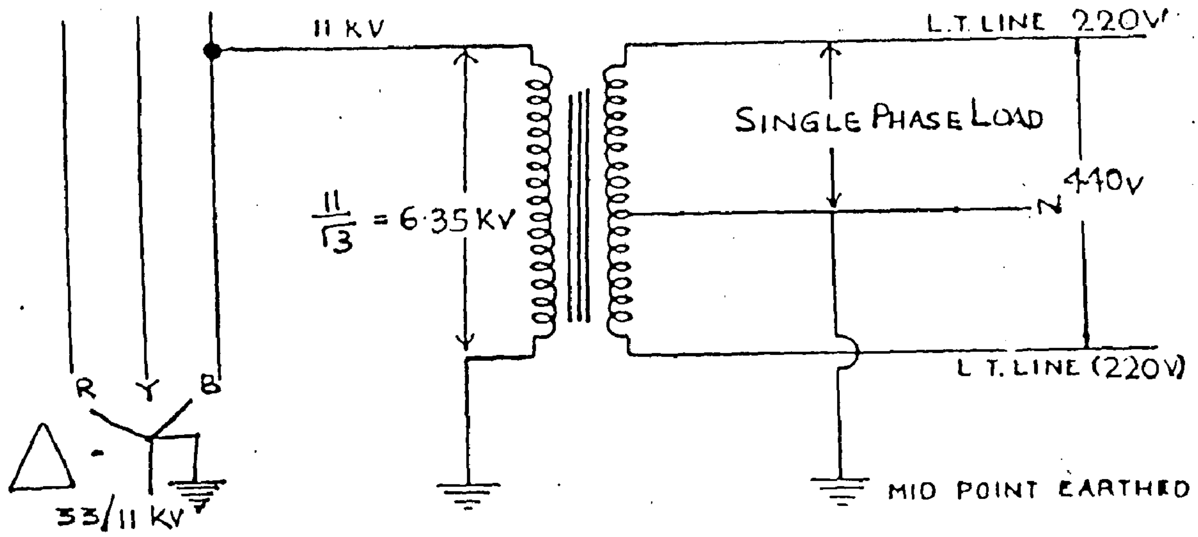


FIG.(1.1.b)- SWER 6.35KV - DISTRIBUTION TRANSFORMER.

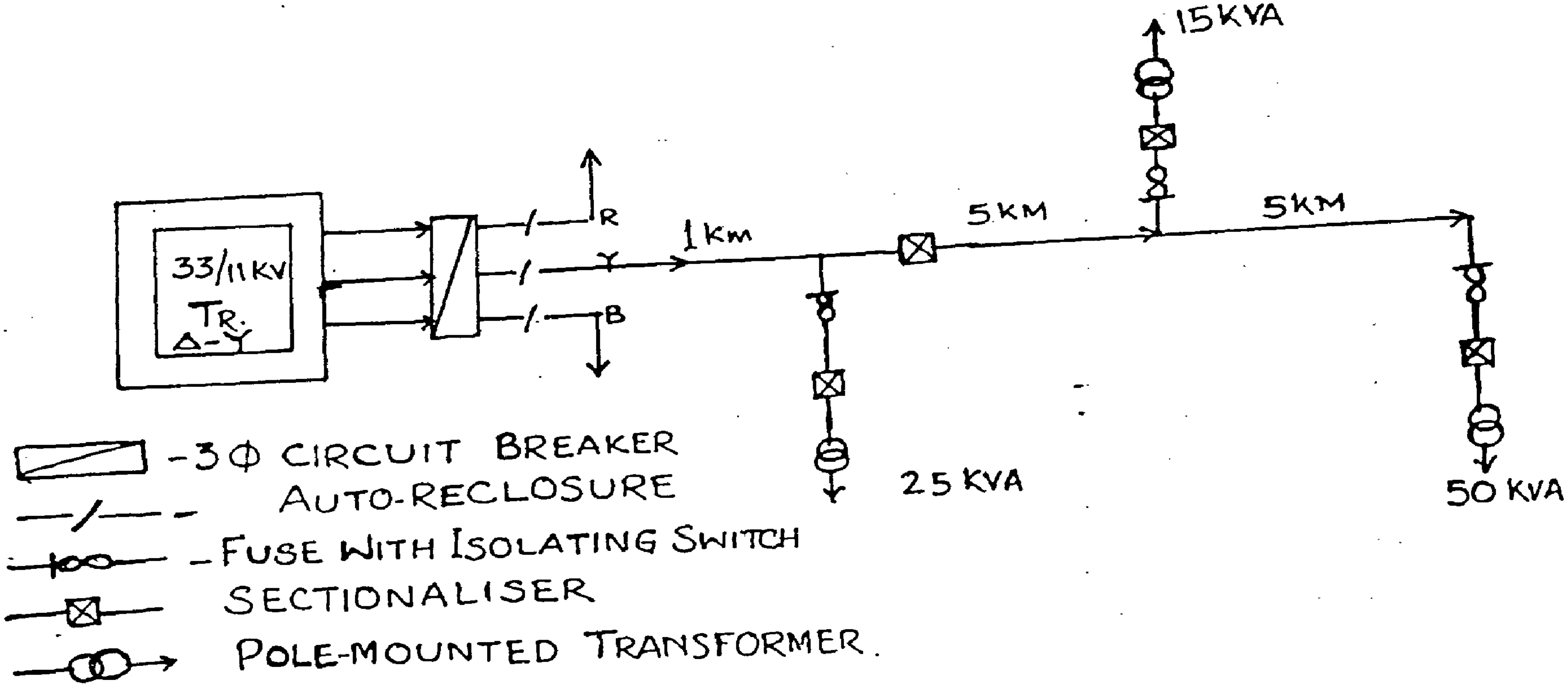


Fig. 1.1.(C) - TYPICAL 11 KV RADIAL FEEDER.

This type of distribution system is widely used in developed Countries like America, Canada, Japan, Australia and European Countries -Philippines also [1]. In India, this system of electrification is found mostly in Himachal Pradesh, Andhra Pradesh, Karnataka, Punjab, & Madya Pradesh on rural scattered bastis both for domestic and agricultural purposes. APSEB is leading on this field for wide application of the system in Agricultural purposes.

1.2 ADVANTAGES OF SWER SYSTEM [1,3]

i) Economical to the extent of 30-40% over conventional 3 phase system under favourable circumstances. The galvanized steel conductor system (in place of Aluminium) affords further economy Fig. 1.2(a) and Table 1.2.1. Use of earth as a conductor, without cost, helps in appreciable metal savings Table 1.2.2.

ii) Better voltage-regulation which is the main problem in long conventional rural feeders, as per I.E. rule 54, -9%, +6% for 11 KV and ± 6% for 220 V.

iii) Improved power factor up to 0.95 - 0.98 as compared to conventional system, having 0.7 to 0.75. The main reason is that in use of single phase motors (agricultural-pumps) capacitor start and run on SWER system, improves power factor.

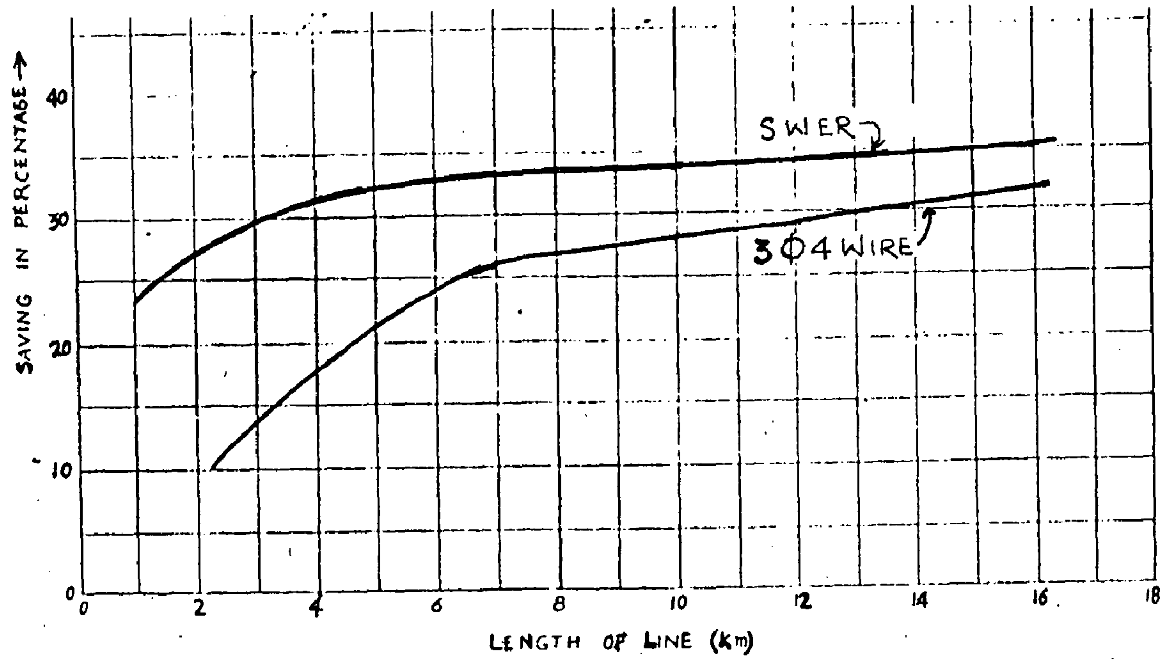


FIG. 1.2 (a) COST COMPARISION OF SWER Vs THREE PHASE FOUR WIRE SYSTEM. [3]

TABLE 1.2.1 KW-KM CAPACITY OF SWER SYSTEM FOR 12.5% VOLT REGULATION AND 0.9 PF, AT 6.35 KV. [6]

KW-KM	Radial Feeder Length (km)	Max. Load (KW) with 8 Amp. (Earth Return)	Type of conductor
2680	132	40.5	For squirrel 4 ACSR conductor
1370	67.6	40.5	For wren ACSR conductor
382	18.85	40.5	For 3/12 Galvanised steel conductor

iv) The reliability of power supply is more and outages are less in SWER than the conventional system due to only single wire run per span. Span loading is also less.

v) No pilferage of electricity by direct hooking from 11 KV line.

vi) And in overall there is less fault in SWER system.

vii) Operational and maintainance charges are very less.

iii) Auto-reclosures and sectionalisers adopted in SWER radial and spur feeders helps in requiring "no-man supervision", with instant proper safety to the supply system.

TABLE NO.1.2.2

COMPARISION OF HV DISTRIBUTION WITH L.V.THREE PHASE SYSTEM [3]

	SWER 6.35 KV	3 phase,440V
Current	10.0	100.0
Losses	0.85	100.0
Voltage drop	0.85	100.0
Power factor	0.9-0.98	0.7-.8
Cost/Km line	8000/-	16,500/-
Motors 3,5,7,5, 10 HP	Less efficient, and High cost	more efficient, and low cost

1.3 MAIN LIMITATIONS IN ADOPTING SWER SYSTEM

The use of Earth as a current carrying conductor is fraught with many technical and environmental problems.

Technical Problems

i) The flow of ground current inevitably has reactions and interferences on the neighbouring current carrying installations. Maximum ground return current permitted by P.T.C. C is 8-10 Amp [1,11]. However, there is hardly any Telecommunication problems in rural areas.

ii) The most important problem, which must be solved in order to make the system a success, are Earth Potential Rise (EPR) in the vicinity of the earth electrode.

iii) Minimisation of energy losses (I^2R_g) in grounding system in earth circuit.

iv) Resistivity survey of the area for SWER and maintenance/check of ground resistance needs thorough and elaborate study. Earth shows very complex behaviour for its resistivity variations with all seasonal effects. High resistivity areas needs costly earthing system and hence sometimes it may not be possible to implement this scheme.

v) Mal-operation of earthfault relay due to unbalance loading both in phase and magnitude, of all the 3 phases on 11 KV lines. When perfectly balanced, $\Sigma(\bar{I}_R + \bar{I}_Y + \bar{I}_B) = 0$. But in practice there is certain mismatch due to individual feeder loading patterns in different spur lines which may cause mal-operation of E/F relays, which are generally set at 20%. Hence, the percentage mismatch or unbalance must be within 20%.

Generally single pole auto-reclosures are adopted individually in all 3 phases to take care of individual phase feeder protection and to see that the power is never completely cutoff.

1.4 ENVIRONMENTAL IMPACT OF CONTINUOUS EARTH CURRENT

i) The power loss in earth conduction causes slow but steady temperature rise of soil [4a].

ii) Electrolysis and electro-chemical changes in soil upto root depth of 1.5 metres may help vegetation and fertilizer effect [4a].

iii) Impact of electric and magnetic field (due to earth current) on biological behaviour of underground creatures [35]

iv) Earth current flow in areas of explosives both on ground surface and underground may create some explosion hazard [35].

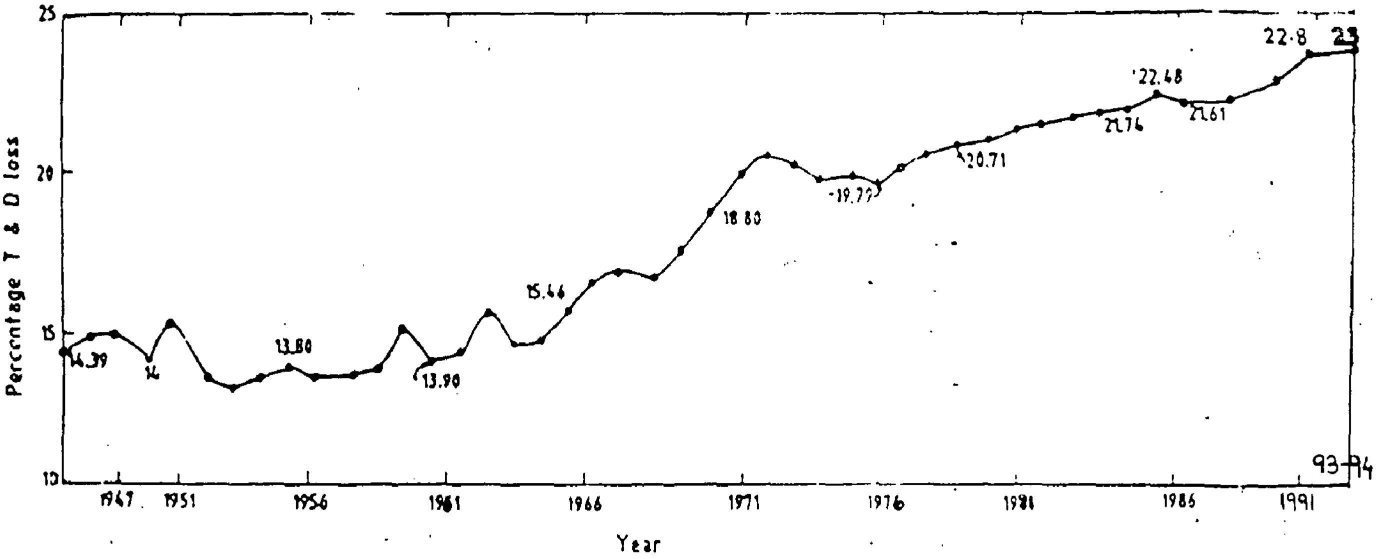


Fig.1.5(a) Trend of T & D Losses in India [2]

GROWTH RATE OF ELECTRICITY :

4.7 % 1977 - 78 - 82-83
5.5 % 1982 - 83 - 87-88
6.0 % 1987 - 88 - 2000 - 2001

REQUIREMENT OF ELECTRICITY

8th. Plan (94-95) = 72,711 MW (peak demand)
9th. Plan (1999-2000) = 1,12,319 MW.

TABLE NO- 1.5.1 Review Of System Losses [2]

System Element	Existing Level %	International Norm %	
		Max. Tolerable limit	Target Level
Transmission	4.0	4.0	2.0
Sub Transmission	5.0	4.5	2.25
High Voltage Distribution	6.0	5.0	3.0
Low Voltage Distribution	8.0	2.0	1.0
Total	23.0	15.5	8.25

1.5 NEED OF SWER SYSTEM

i) Last census (1991) says at present about 35% of the total power generated in India is consumed by over 70% of the country's rural population. The rural electrification including energisation of agricultural pumps are still to be accomplished by low cost design technology of power supply system. And SWER is one of the systems, most suitable for rural electrification, agro-based industries and small scale cottage industries for integrated and balanced socio-economic developments of rural India.

ii) The present electricity tariff on LT Bus has gone up to Rs 1.60 paise per unit. The same can be achieved on H.V. (11 KV SWER system with 10% transformation energy loss) having at, 1.60/1.1 = Rs. 1.45 per unit. More over, the state electricity boards can incur less loss due to agricultural subsidies [2].

iii) The data Table (1.5.1) on T & D energy loss shows, India in the International level at 23 % as on 1993-94 [2]. India has maximum energy loss of 8% on LT secondary distribution in comparision to 2 % International Standard. Hence,our planning of distribution system should be augmented to H.V. distribution system at least to save 2 % energy on an average, while converting from low voltage to H.V. distribution system. If distribution losses can be saved by 1 % in national level which can result in saving of about 550 M.W. power (with equivalent cost of generation about Rs. 2000 crore) [2].As per Fig. 1.5(a), with the growth rate of electricity in our country, the T&D losses is increasing from year to year, which needs to be controlled.

iv) The 'Kutir Jyoti' scheme of present National Government warrants very well its implementation by SWER, most economically.

Hence, SWER system is a timely thought for the country's present power economy, both in planing and implementation in place of conventional L.T. distribution system for low load density areas. In the same way also the limitations and problems of this system needs further study and investigations to throw some light for its success and wide application in furture.

1.6 ARRANGEMENT OF THE REPORT

(i) Chapter 2, deals with literature review and background information required for the SWER earthing system, collected both from text books as well as National and International Journals, as given in Reference and Bibliography

(ii) Chapter 3, deals with detailed analysis of different dependancies of soil-resistivity, resistivity survey & measurements, observation of seasonal effects on resistivity.

(iii) Chapter 4, deals with earth-electrodes, and various experiments on electrode configuration. Potential rise test and Heat-run test are also discussed in this chapter. Artificial treatment of soil both theory and experimental observations are dealt with in this chapter.

(iv) Chapter 5, deals with conclusions of various experimental observations and suggestions for future works.

(v) The last but not the least items of the dessertation are References, Bibliography and Appendixes.

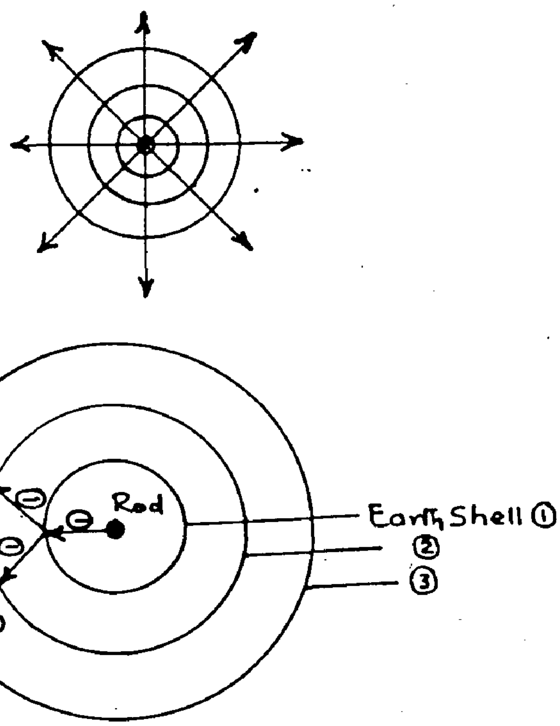


FIG. 2.1(a) SPREADING OF ELECTRONS, INSIDE EARTH SHELLS.

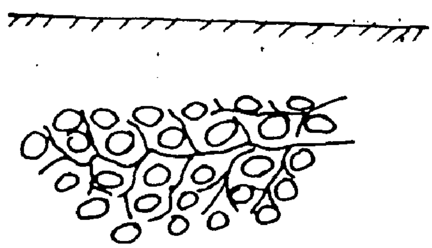


FIG. 2.1.(b) MOISTURE IN SOIL FORMING ELECTROLYTE

CHAPTER 2

LITERATURE REVIEW

2.1 EARTH AS A CONDUCTOR OF ELECTRICITY [24]

Earth is a very Complicated 3 phase type of physico chemical system, with the very different electrical conducting properties of metals, dielectrics, & electrolytes. There are three types of conduction take place inside earth.

(i) Electronic or Ohmic Conduction

Flow of electrons into earth layers by spewing, spraying and discharge of electrons from the conductor in a increased surface area in one plane. Hence the resistance decreases, gradually from layer to layer, as shown on fig. 2.1 (a).

(ii) Electrolytic Conduction : The propogation of current in soil by ionic conduction i.e by molecules having an excess or deficiency of electrons. Hence, the resitivity varies with mobility concentration and degree of dissociation of the ions in presence of water & chemicals Fig. 2.1 (b).

According to Archie (1942), [14] the soil resistivity pertaining to a depth 'Z' & time 't' is a function of soil porosity (Density, ϕ) soil mositure 'S' Temperature (T), salt concentration andwater resistivity $\rho(w)$, Mathematically $\rho_{z,t} = F_n(\phi, S, T, \rho_w \ \ldots)$

(iii) **Dielectric Conduction** in soil is the displacement of current flowing in non-conductors when the external electric field changes with time. The significant parameter in dielectric conduction is dielectric constant(k) or speicfic inductive capacity of the medium.

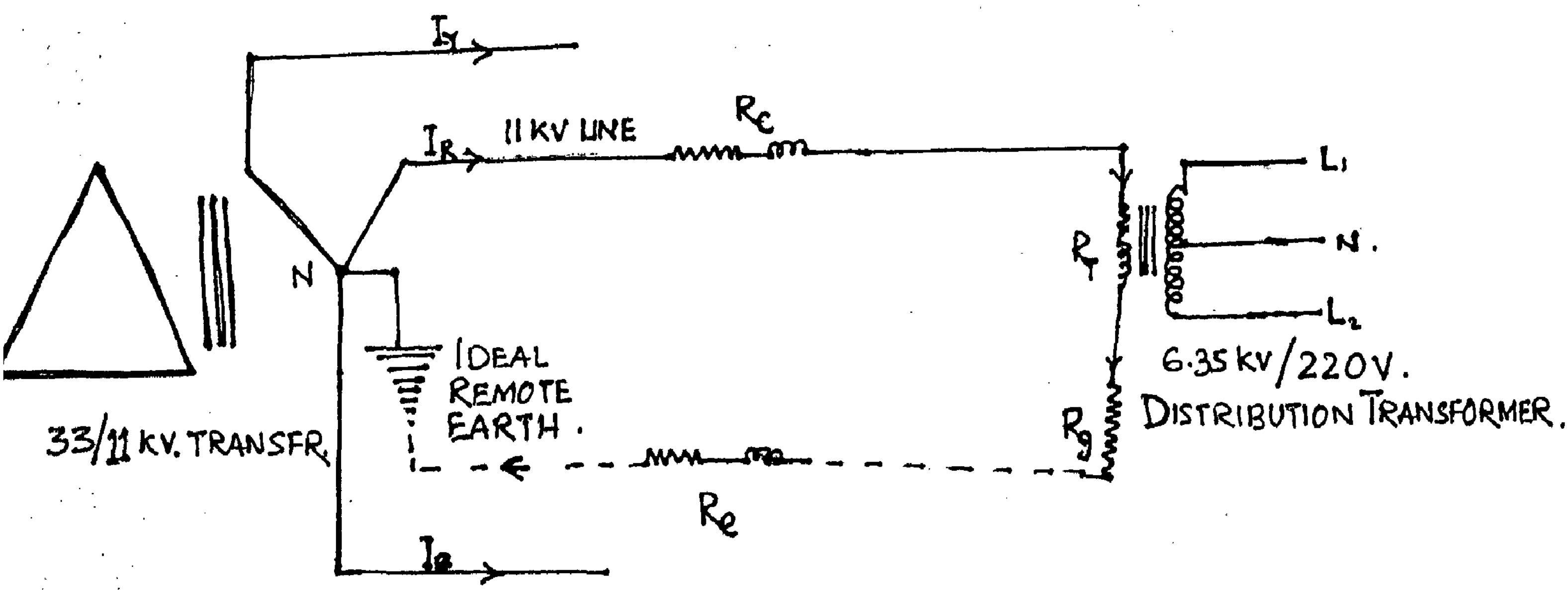


FIG. 2.1.1(a) SWER EQUIVALENT ELECTRICAL CIRCUIT.

2.1.1 GROUND RESISTANCE

For transfer of power through earth, it is necessary to have ground electrodes at each end of the line, through which current is conveyed to the earth. The resistance of the grounding (Rg) arrangement constitutes the major part of the total circuit resistance, as shown in Fig. (2.1.1 a)

R_c = Conductor resistance

R_T = Resistance of distribution transformer

R_g = Grounding Resistance of distribution transformer

Re = Earth Resistance

Rc, R_T, Re are very less as compared to Rg. which is in the order of 25 ohm.

According Rudenburg [4] effective resistance of ground return path is given by $R_e = \pi^2 \times f \times L \times 10^{-7}\ \Omega$

L = Length of line in mts.

f = 50 c/s

For L = 1000 mt. = 1 km

$$R_e = 3.14^2 \times 50 \times 1000 \times 10^{-7}$$

$$= 493.48 \times 10^{-3}$$

$$= 0.05\ \Omega \text{ per km}$$

No metal conductor has so much low resistance per km. And it is interesting to note that the arth resistance is independent of its own resistivity. This paradox is explained bythe fact that at high resistivity, the current spreads out over a large area and at low resistivity, it restricts to an area nearer to the condutor.

2.1.2 Self-inductance of Earth Return Path

$$L = 2 \log_e \frac{562.5}{h} \sqrt{\frac{\rho}{f}} \times 10^{-7} \text{H/km}$$

Where,

h = Height of over head conductor above ground in mt.

ρ = soil/earth resistivity in Ω mt.

f = 50 c/s

For h = 10 mt, ρ = 100 Ω mt, f = 50

$$L_e = 2 \log \frac{562.5}{10} \sqrt{\frac{100}{50}} \times 10^{-7} \text{H/km}$$

$= 2 \times 4.376 \times 10^{-7}$

$= 8.753 \times 10^{-7}$ H/km

$X_e = 2\pi fL \quad = 6.28 \times 50 \times 8.753 \times 10^{-7} \ \Omega / \text{km}$

$= .2748 \times 10^{-7} \ \Omega / \text{km}$

$= .000275 \ \Omega / \text{km}$

The inductance of SWER system per km is very less in comparision to resistance, hence, the earth circuit is a resistance dominated circuit. And accordingly,earth resistivity Plays an important role on all grounding designs. Since the resistance and reactance of earth are very small, the earth can be regarded as a very good,cost-free conductor with very little loss and voltage drop.

2.2 EARTH IMPEDANCE AND GRADIENT PROBLEM NEAR GROUND ELECTRODE

In case of AC current flow, the distribution of current is modified and limited due to the inductive effect of magnetic field, except very near the electrode, where local resistance dominates

local resistance in order of 5-25 Ω.

Again the current density decreases in the transverse direction, being highest under the conductor.

Since the electrode resistance, which is many times greater than other reisistances met in the earth return circuit, is responsible for

i) High and hazardous potential-gradient in the immediate vicinity of the electrode

ii) More power loss (I^2Rg)

iii) Temperature rise of soil and electrode.

Total impedance of earths = 0.05+j0.000275+ground resistance ($Rg \approx$ 5-25 ohm), which is approximately equal to ground resistance.

One of the natural effects of current flow through earth electrode is that a voltage gradient is present on the surface of the earth in the immediate neighbourhood of the electrode. The fundamental reason of this gradient is that the resistace of the electrode is not concentrated at one point but is distributed over the soil in the vicinity as shown Fig. 2.2(a & b).

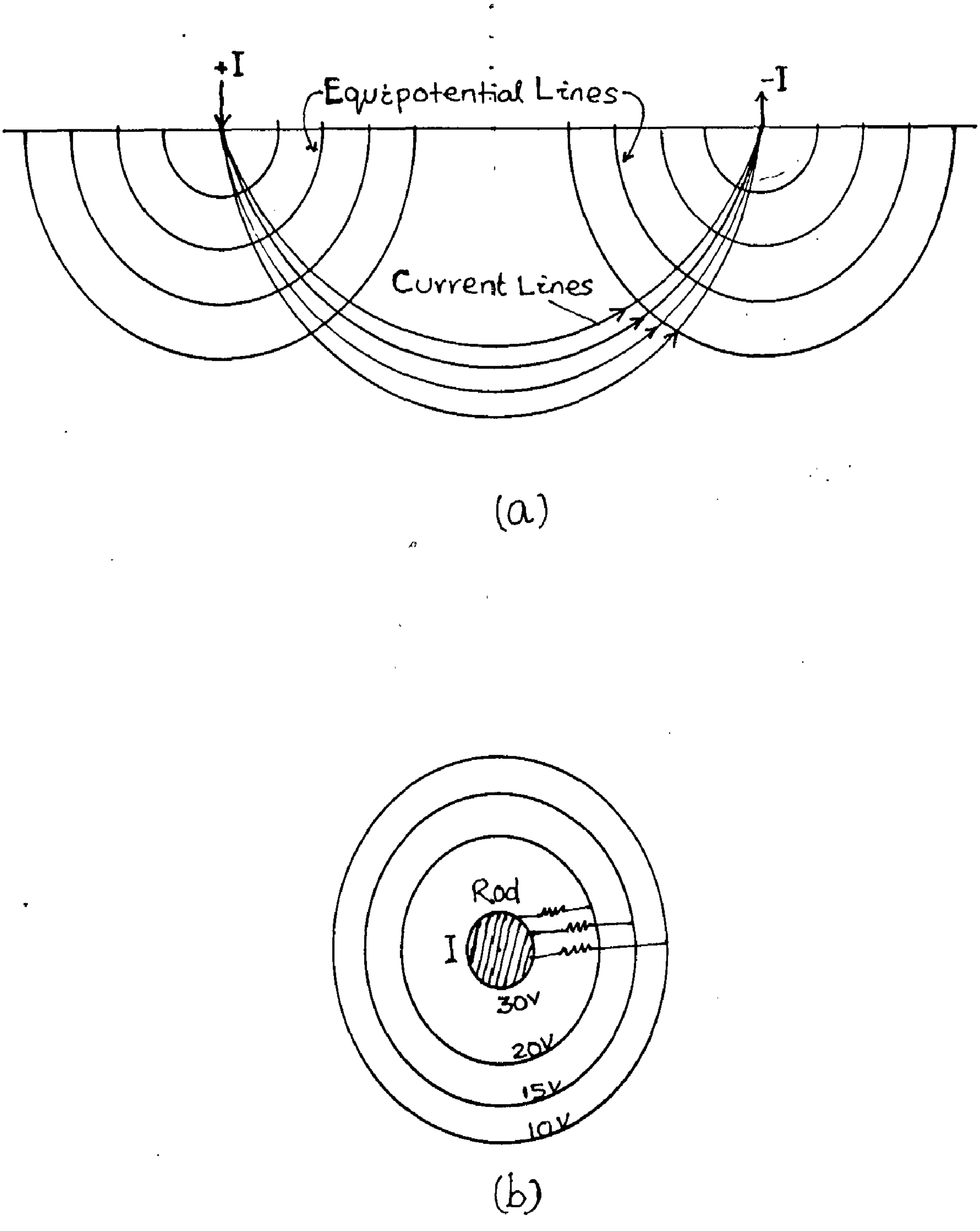


Fig. 2.2(a) & (b) Flow of Current & Potential difference Across an Electrode.

Taking a simplest possible electrode, a sphere in the ground, symmetrical in all directions. If a current "I" flow through the electrode. Then current density at a distance "x" mt from the centre of the electrode is given by

$$J = \frac{I}{2\pi \ x^2} \ \text{Amp/m}^2$$

This produces an electric field strength in the soil equal to $E = \rho \ J$ volt/mt

$$= \rho \ \frac{I}{2\pi \ x^2} \qquad \left[\text{Voltage} = \frac{\rho \ I}{2\pi x}\right]$$

where, ρ = Resistivity of Soil in Ω mt,

This shows that a considerable potential difference can exist over a relatively short distance near an earth-electrode

2.3 EARTHING PRINCIPLES ADOPTED IN SWER SYSTEM

A 33/11 Kv, 3.2 MVA(Delta/Star) Transformer is earthed at secondary neutral, with grounding resistance of 3-5-ohm at the sub-station. Because $\bar{I}_R + \bar{I}_Y + \bar{I}_B = 0$ (in ideal case) but in practice at worst condition of 12% unbalance current can flow through the neutral. Earth fault relay setting usually at 20%

For a power transformer of capacity 3.2 MVA, power per phase.

$$\sqrt{3} \ V_{ph} \ I_{ph} = \frac{3.2 \times 10^3 \ \text{KVA}}{3}$$

If $V_{ph} = 6.35$ Kv, $I_{ph} = \frac{3.2 \times 10^3}{3 \times \sqrt{3} \times 6.35 \text{ KV}} = 97$ A

This amount of per phase current is very very higher than the PTCC limit of 10 Amp. If, we limit each phase current to 10 Amp(Due to PTCC restriction) max KVA /phase = 6.35 x 10 = 63.35 kVA, can be transmitted to different distances depending upon the KW-KM loading capacity of the conductor used as per Table No. 1.2.1. With maximum unbalance current of 20% of 10 Amp = 2.0 Amp willflow through neutral of the power transfomer.For HV/LV plinth mounted distribution sub-stations it is ususal to combine the L.V. neutral & H.V. metal works (Transformer frame & structures) to a common earth of resistance value of 1 Ω or less [28].

But in case of pole mounted transformer in SWER system the H.V. metal work & L.V. neutral earths are kept separate, either by shifting the secondary L.V.earthing atleast one pole distance away or by insulating either one, and running them in opposite directions. A separation of 25 feet (8 mt) is found to be sufficient to avoid the proximity effect of the 2 earthings [6].

As per I.S 3043 [28] there should be one or two distinct earthings separately connecting the metal structures of Transfomer The H. V Primary terminal earthing is made directly connecting a burried under gound electrode insulating itself from upper ground surface contact (about 0.6m) in order to

i. Reduce the ground potential rise near the electrode

ii Secondly due to maximum proximity-effect induction voltage, there may be leakage current in between primary & secondary of transformer through these 2 earthings, raising neurtral potential greater than zero [6].

2.4 NEED FOR LOW ELECTRODE RESISTANCE AND EARTHING DESIGN CONSIDERATIONS FOR SWER

As per IEEE/American National Standards [9] the limting earth resistance of i) major Generating Stations & EHV.S/s <1.ohm

ii for medium grid S/S < 3 Ω

iii) Other distribution s/s 5-10 ohm, but as per NEC recommendations, the max. resistance should not be more than 25 ohm at any case [10].

While designing the grounding system, it should be borne in mind the cost of the system accounts for hardly 1% of the total capital cost of project investment, hence any attempt to economise on this front at the cost of risk, may not result any substational savings but on the contrary may seriously imperil the lives of personel and equipments [7].

The permissible earth resistance $R_p = \frac{\text{Max. potential Rise}}{\text{Max. Gr.fault Current}}$

$$R_P = \frac{V_p}{I_f} \text{ ohm}$$

The approximate resistance of ground can be calculated from Laurent's fomala $Ra = \frac{\text{soil resistivity } (\rho)}{4a}$

Where, a = radius of a circle having equivalent area of the station of interest.

If, Ra>Rp, additional means are necessary for limiting the max. E_{step} , E_{touch} and EPR/ GPR within permissible limits

In SWER system, the normal load current

(i) small in magnitude but flow indefinitely

(ii) and the fault current high in magnitude but flows for a short while.

The first one causes heating of electrode, where as the second type of current causes flash over or fusing of electrode when unable to carryout heavy rush of fault current.

So the earthing system (electrode + soil) should be capable to cater in

(i) Handling the fault current for short time & normal load current for indefinite time.

(ii) Reducing E_{step} & E_{touch} voltage occuring under normal or fault conditions to safe limit.

(iii) Limiting Temperature rise of grounding system by better dissipation of heat generated by powerloss in grounding system. From the Table (1.1.1) it is seen that grounding Resistance forsmall KVA Transfer (4 to 25 KVA) are not problematic in comparison to higher rating 50 KVA Transfermer. Where the required grounding resistance is in the order of 1-2- Ω in order to keep the potential rise ≤ 32 volt (from safety point of view)

2.5 ENERGY LOSS CALCUATION DUE TO GROUND RESISTANCE OF A 25 KVA TRANSFORMER (AGRICULTURAL LOAD)

In a firm house say 7.5 HP pumps 2 nos = 15 H P

5 HP grinder or Thrusher motors 2 nos = 10 H.P

25 H.P

(25 HP) 18.0 KW + 2.0 KW Light load = 20 Kw

20 KW at 0.9 pf = 22.3 KVA plus transformer losses & power loss in grounding, Transformer capacity = 25 KVA

Rated current at 6.35 KV= 3.94 A(as per Table 1.1.1)

(i) For Safety Point of view, required minimum ground resistance for 32 V potentialrise = 8.1 Ω Assuming 75% load factor maximum load current = 3.94 x .75 = 3 Amp, for day time loading 12 Hrs & 10% for night light loads (12 Hrs), approximately.

Energy loss in a day $(3)^2$x 8.1 x 12 Hrs + $(.3)^2$x 8.1 x 12

= 883.5 watt-Hrs ≈ 0.884 KW hrs.

Energy loss in a month = 0.884 x 30 = 26.52 KW hrs.

= Say, 27 Units loss

Engergy loss in a year = 27 x 12 = 324 units

= 324 x 1.60 = Rs 518.40

With minimum required value of earth electrode resitance of 8.1 Ω even, there is a loss of revenue of Rs 518.40 Per annum. If there is an improvement of 50% of electrode resitance by some extra means & cost, the saving is calculated as follows.

(ii) Energy Saving - Now, say with 50% improvement, earth electrode resistance becomes 4.05 Ω

Energy loss/Day = $(3)^2 \times 4.05 \times 12^{Hrs} + (.3)^2 \times 4.05 \times 12$ Hrs

= 442 watt Hrs or .442 KW hrs

Energy loss/year = .442 x 360 = 159 KW-Hrs/units

= Rs 254.40

Cost saving $= \frac{518.4-254.4}{518.4} = 50.93 \approx 51\%$

With improving earth resistance by 50 % Hence, there is a financial justification for the need of reducing or lowering earth electrode resistance. It is an energy saving to the power system along with less financial loss to power supply authority.

2.6 POTENTIAL DUE TO A POINT ELECTRODE AND THEORY OF ARTIFICIAL TREATMENT of soil [16]

Figure 2.6(a) Shows the Section through a point, current electrode (A) on surface of a conducting solid (earth). If, the

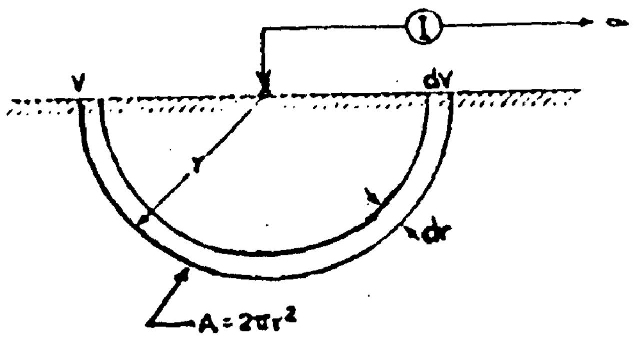


Fig. 2.6(a) Section through point current electrode, showing how potential V is related to resistivity ρ, current I, :

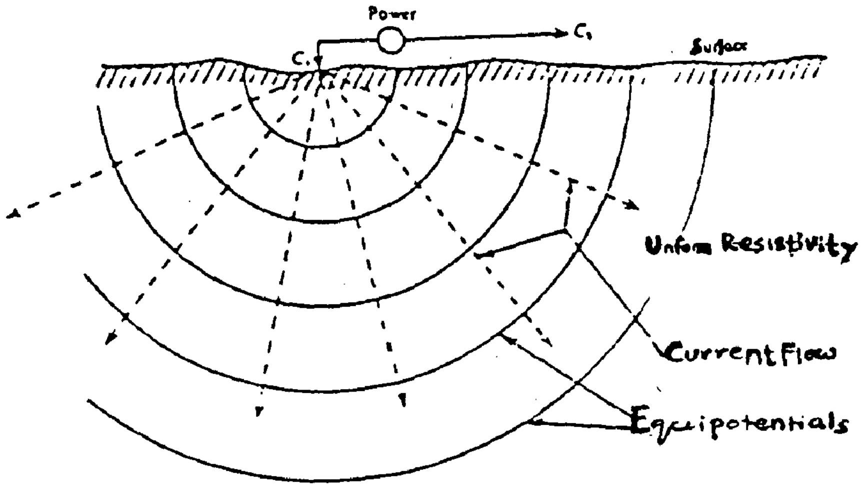


Fig. 2.6(b) Point source of current at the surface of a homogeneous medium.

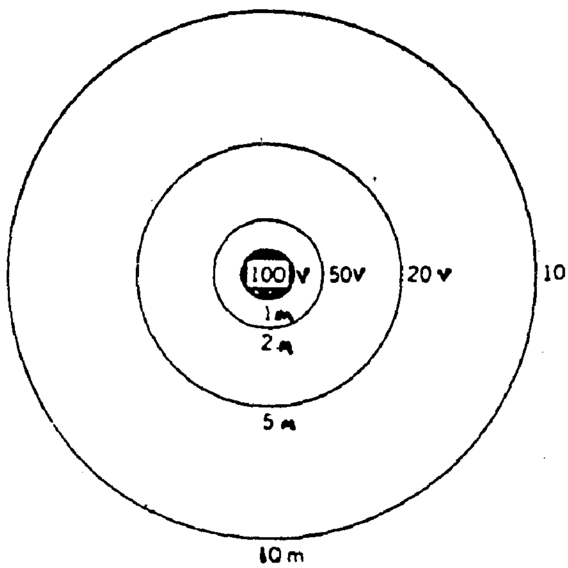


Fig. 2.6(c) Plan view of equipotential circles on surface of the ground near a hemispherical electrode of 1-m radius on which 100 V is impressed.

point electrode delivering I Amps current is located at the surface of the homogenous isotopic medium and if the air above has zero cnductivity, then all currents, flows into earth radiating from the centre of point electrode [2.6(b).

Treating it as a half hemisphere, whose centre lies at point electrode, A. The current density (J) is the total current through the hemisphere devided by the area of the hemisphere.

$$J = \frac{I}{2\pi r^2} \quad Amp/m^2$$

Where, I = current (A) entering ground from electrode

R = Radius (m) of hemisphere

$2\pi r^2$ = Area of hemisphere (m^2).

The electric field intensity or the voltage gradient is

$$\xi = \rho J = \frac{\rho I}{2\pi r^2} \quad Volt/mt$$

Where, ρ = Resistivity of earth in ($\cdot\Omega$ mt)

The electric potential at any point in the earth with respect to a point- at infinite distance called ("Remote earth") is

$$\frac{dV}{dr} = - \rho J = - \xi$$

$$dv = - \xi \; dr.$$

$$\text{or } v = - \int \xi \; dr, = -\int_r^{\infty} \rho I x dr/2\pi r^2$$

(Negatative sign due to opposite current)

$$V = -\frac{\rho I}{2\pi}\left[\frac{1}{\infty} - \frac{1}{r}\right]$$

$$V = \frac{\rho I}{2\pi r} \quad \text{Volt}$$

This value of potential holds good at the surface of the earth as well as along vertical or inclined layers.The resistance of electrode with respect to remote earth is given by

$$R_e = \frac{V}{I} = \frac{\rho}{2\pi r} \quad \Omega$$

And hence is directly proportional to soil resistivity & inverssely proportional to size of electrode (Radius,r). From the above equation it indicates that low ground resistance (R_g) warrants either (i) lowering of resistivity (ρ) or (ii) by increasing size of electrode.

Increasing size of electrode and multiple numbers will be discussed in next chapter of electrodes.

Kimbark [16] has discussed the lowering of soil resistivity which is described below.

Now, let us think for lowering soil resitivity by deviding the soil into two parts ρ_1 & ρ_2 such that $\rho_1 < \rho_2$ Fig. 2.6(d).

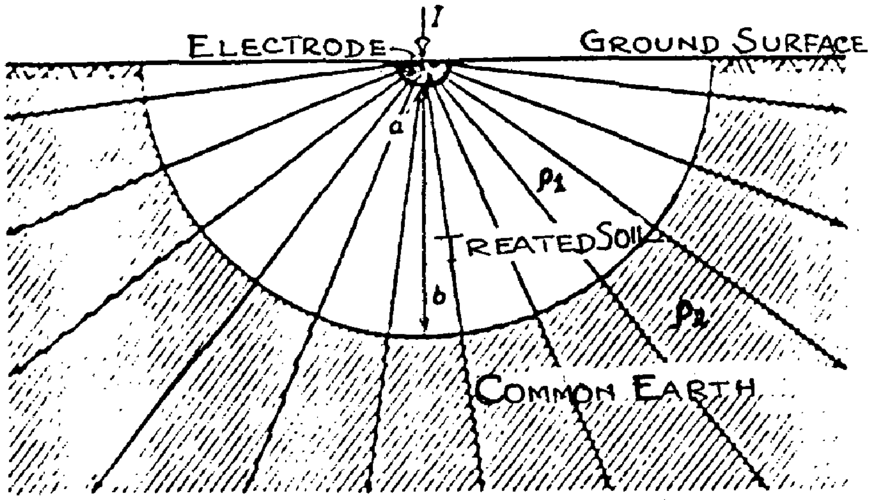


Fig.2.6(d) Hemispherical electrode in hemispherical volume of soil of radius b and of resistivity ρ_1 less than resistivity ρ_2 of the rest of the earth. [16]

This idea tends to creation of artificial/chemical treatments of soil in the vicinity of electrode who serves in increaseing the effective diameter/radius of the electrode located at its centre, without actually increasing the metal- volume of electrodes.

Now we will have the same previous current density on metal electrode surface, $J = \frac{I}{2\pi r^2}$ or $\left(\frac{I}{2\pi a^2}\right)$ Amp/m^2

and voltage gradient $\xi = \rho \, j = \frac{\rho I}{2\pi r^2}$ volt/mt.

Now, the potential at the artificial junction layer (when r=b) is the potential of volume of material with resistivity ρ_1 from a to b plus potential of volume of material with resistivity ρ_2 from b to ∞ (remote earth). Mathematically.

$$\therefore \; dv = -\left[\xi_1 \, . \, dr + \xi_2 . dr\right]$$

$$= -\left[\frac{\rho_1 \, . I . dr}{2\pi \, r^2} + \frac{\rho_2 . I \; dr}{2\pi \, r^2}\right]$$

Now, integrating dv from 'a' to ∞

$$V = -\left[\frac{\rho_1 I}{2\pi} \int_a^b \frac{dr}{r^2} + \frac{\rho_2 I}{2\pi} \int_b^\infty \frac{dr}{r^2}\right]$$

$$= -\left[\frac{\rho_1 I}{2\pi}\left(\frac{1}{b} - \frac{1}{a}\right) + \frac{\rho_2 I}{2\pi}\left(\frac{1}{\infty} - \frac{1}{b}\right)\right]$$

$$= -\left[\frac{I}{2\pi}\left(\frac{\rho_1}{b} - \frac{\rho_1}{a} + \frac{\rho_2}{\infty} - \frac{\rho_2}{b}\right)\right]$$

$$= \frac{I}{2\pi}\left[\frac{\rho_1}{a} + \frac{\rho_2}{b} - \frac{\rho_1}{b}\right]$$

$$= \frac{I}{2\pi}\left[\frac{\rho_1}{a} + \frac{(\rho_2 - \rho_1)}{b}\right]$$

or,

$$R = \frac{V}{I} = \frac{1}{2\pi}\left[\frac{\rho_1}{a} + \frac{(\rho_2 - \rho_1)}{b}\right] \text{ ohm}$$

where,

a = Radius of metal electrode

b = Radius of circle enclosing the electrode with treated soil.

ρ_1 = Soil resistivity of treated soil volume

ρ_2 = Soil resistivity of rest of earth beyond treated soil.

R = Earth resistance of electrode.

Now, with spliting the orginal soil resistivity (ρ) into ρ_1 and ρ_2 (such that $\rho_1 < \rho_2$), the effective soil resistivity reduced to a new amount ($\rho_2 - \rho_1$) and it is again devided by 'b', the radius of volume of artificial is treated soil. The more the value of b the less is the term $(\rho_2 - \rho_1)/b$.

From the above discussions it is inferred that the value of ρ_1 and b of treated soil should be suitably choosen while applying artificial treatment across an electrode, in order to minimise the term $(\rho_2 - \rho_1)/b$ and minimise the net value of R, (earth resistance) in the equation.

—x—

CHAPTER - 3

EARTH RESISTIVITY INVESTIGATIONS

3.1 RESISTIVITY AND CONDUCTIVITY OF SOIL [13]

Resistivity is a property of the media conducting electricity. Even resistivity and conductivity are reciprocal to each other, there is a basic physical difference between resistivity and conductivity of soil. Resistivity is a measure of the opposition to flow of charge in a material, where as, electrical conductivity is a flow mobility of charge carriers.

conductivity $\sigma = ne\,\mu$

where, n = density of charge carrier

e = charge in emu

μ = mobility measured by velocity in mt/sec per unit electric field.

The charge carriers may be ions, electrons, or holes (the absence of a charge)

$$\sigma = \frac{1}{\rho} = \frac{L}{RA} \qquad \left[\text{since } \rho = \frac{RA}{L}\right]$$

$$= \frac{L}{A}\,\frac{1}{V/I} \qquad \left[\because R = \frac{V}{I}\right]$$

$$= \frac{I}{A} \Big/ \frac{V}{L}$$

$= J/E$

or, $J = \sigma E.$ Amp/m^2

J = Current density in Amp/m^2

E = Electric field (Volt/mt

3.2 LOGIC OF UNIFORM SOIL

As per IS Code 3043, 1987 (20.5), [28],[17] soil resistivity in an area can neverbe uniform. Yet a uniform resistivity soil model has been used extensively in earth electrode performance calcuation. Such an assumption is valid if the resistivity varies between relatively narrow limits over different electrode spacings increasing from 1 mt to 50 metre (In steps of1,5,10,15,25 & 50 mt) The limit of variation is from 20-30% i.e.

$$\left[\frac{\rho_1}{\rho_2} = \frac{100}{130} = 0.77\right],$$

The soil in the vicinity of the test location may be then considered uniform [7].

Two layer soil model has also been assumed to represent variation of soil resistivity along the depth below earth surface. Such variation is possible because of stratification of earth structure.

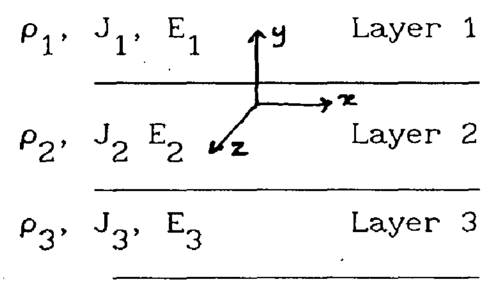
3.3 EFFECT OF INHOMOGENEOUS GROUND [13]

So far, we have considered current flow and potential in and over homogenenous ground, a situation which is extremely, rare in the field and which would be of no practical significance anyway. Since the current flows in ground is 3 dimensional (x,y,z) and the current finds the least resistive path to move, it may face some hudles like different interfaces of vertical or horizontal contact planes of soil layers.

Deriavation for current density (J), Electric field (E) and ressitivity (ρ) in three dimensional stratified earth [13].

Let, J_1, J_2, J_3 ......J_n be the current density of layers 1,2,3 ..... n^{th} layers. E_1, E_2 E_3....... E_n be the electric field intensities of 1,2,3........ n^{th} layer. ρ_1, ρ_2 ,ρ_3..... ρ_n be the resistivities of 1,2,3 .... n^{th} layerth, σ_{11}, σ_{12}, σ_{13} are conductivities of soil layers (1), mutual conductivity between 1 and 2 and 1 and 3.

$$\begin{bmatrix} J_1 \\ J_2 \\ J_3 \end{bmatrix} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$



Where, $J = \sigma E$ Amp/m^2 in a homogenous soil, on discussed earlier

In X direction, $J_x = \frac{E_x}{\rho_1} = \frac{1}{\rho_1} \left(\frac{\partial E_x}{\partial_x}\right)$

In y direction, $J_y = \frac{E_y}{\rho_1} = \frac{1}{\rho_1}\left\{\frac{\partial E_y}{\partial y}\right\}$

In Z direction, $J_z = \frac{E_z}{\rho_n}$ (since, $\rho_z = \rho_n$ for n^{th} layer)

Div. $J = J_x + J_y + J_z = 0$

$$\text{or, } \frac{1}{\rho_1}\left\{\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y}\right\} + \frac{1}{\rho_n}\frac{\partial E_z}{\partial z} = 0$$

The horizontal components (x,y) of the electric field is dominant over the vertical component, (z), but the vertical component is more sensitive to a change in the electrical properties in the stratified earth medium. The vertical (z) component helps in searching the least resistivity path for the current to flow.

3.4 STUDY OF SOIL RESISTIVITY WITH SEASONAL VARIATIONS [14,16]

The soil resistivity an electrical property of soil is a complicated and highly variable characteristic. Its value depends onthe following factors of geographic and seasonal variations of the place and time.

(i) Depth of soil

(ii) Moisture content of soil

(iii) Freezing effect of soil

(iv) pH value-chemical and mineralogical composition of soil.

(v) Temperature of soil

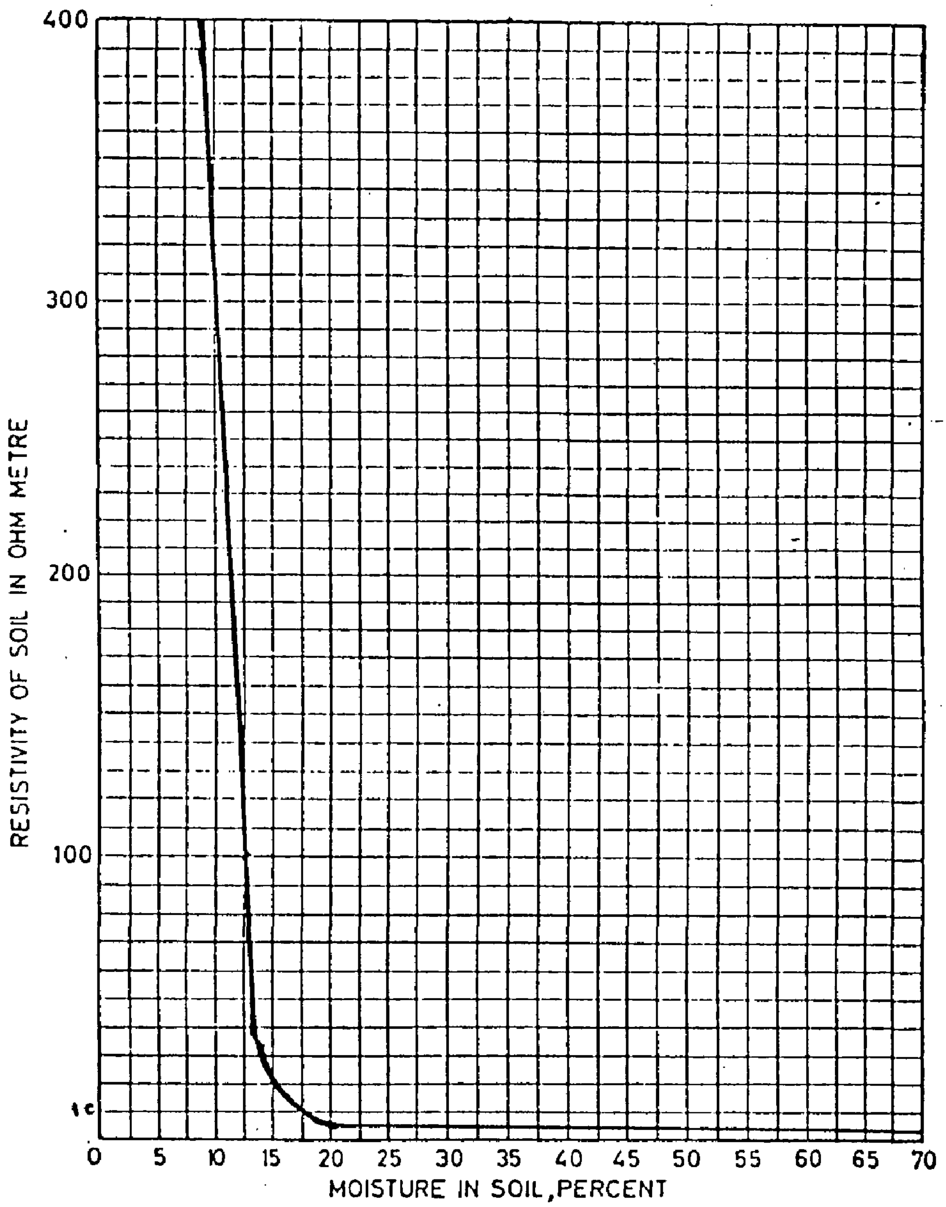


FIG. 3.4(a) VARIATION OF SOIL RESISTIVITY WITH MOISTURE CONTENT

IS : 3043 - 1966

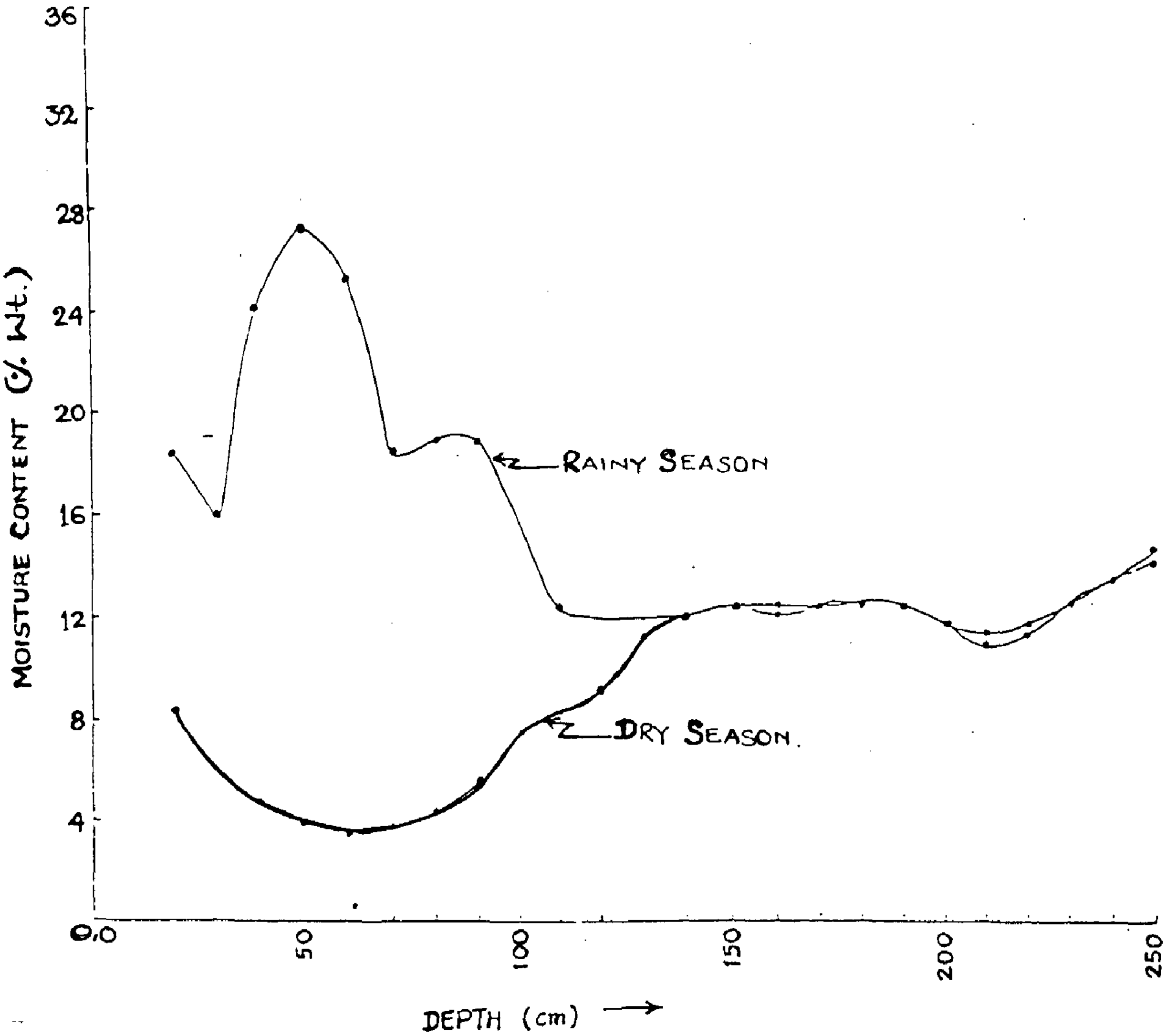


Fig.3.4(b) Moisture Variation with depth in typical alluvial unsaturated soil profiles. [14]

(vi) Chemicals and salts in soil.

(vii)Type of soil, its mechanical composition & soil structure etc.

As these soil parameters vary greately with season i.e mositure in rainy season and temperature in summer, seasonal variations has many effect on the change of soil resistivity, low in rainy seaons high in dry season.

(i) Depth Variation

Depth is a main factor of dependancy because at higher depth the electrode meets more numbers of layers of earth strata may be of different thickness and resistivities but they all considered equivalant to resistors connecged in parallel. Also, it meets the steady value of moisture content in deeper strata and hence the resistivity decreases with the depth.

So, if by any means the thicknesses of different layer can be determined in an area, then it is easier to predict the length of electrodes, to be selected for that area.

(ii) Soil Moisture and resistivity relation

The mositure content (w) of soil has a far greater effect on resistivity than all other parameters of soil. Soil moisture content depends upon soil porosity, infiltration capacity, precipitation, ground water table variation etc. and overall the type of oil and its mechanical composition.

Ananyon [14] developes a linear relation (ρ=f(w) with an empirical relation which represents the combined effect of temperature, moisture content on resistivity

$$\rho = e^{a+bt} \times w^{c}$$

where, a = 10.5 to 14.2

b = -0.025 to -0.031

c = -0.81 to - 1.41

The values of a,b,c depends upon type of soil investigated I.S 3043,1987 says moisture content varies from 10 to 35% in dry & wet season (average 16-18%). A typical curve shows the relation of moisture content Vs depth of an Alluvial soil type. Fig.3.4 (b). [14]

(iii)Freezing Effect

There are 2 kinds of soil moisture available in side soil -

(a) Free moisture highly conducting electric chain.

(b) Oriented water (coming from vicinity due to temperature.difference), causes low conducting thin chain.

When soil freezes due to the freezing of only free water of a particular place, the electrical conductivity is determined only by the rest amount of unfrozen water, hence resistance increases.

Table-3.4.1 *Variation of Resistivity with Temperature of Sandy Loam*

Temperature °C	(°F)	Resistivity (ohm-metre)
20	(68)	75
10	(50)	99
0 (water)	(32)	138
0 (ice)	(32)	300
−5	(23)	790
−15	(14)	3300

Table-3.4.2 *Moisture Content and Resistivity*

Moisture content by weight (per cent)	Resistivity	
	Top soil (ohm-metre)	Sandy loam (ohm-metre)
0.0	1000×10^4	1000×10^4
2.5	2500	1500
5.0	1650	430
10.0	530	185
15.0	190	105
20.0	120	63
30.0	64	42

Table-3.4.3- PH Values of Water & Soil.

Extremely acidic	pH value below 4.5
Very strongly acidic	4.5 to 5.0
Strongly acidic	5.1 to 5.5
Medium acidic	5.6 to 6.0
Slightly acidic	6.1 to 6.5
Neutral*	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	9.1 and higher,

*Neutrality is pH 7.0 but in the field those soils between pH 6.6 to 7.3 are called neutral.

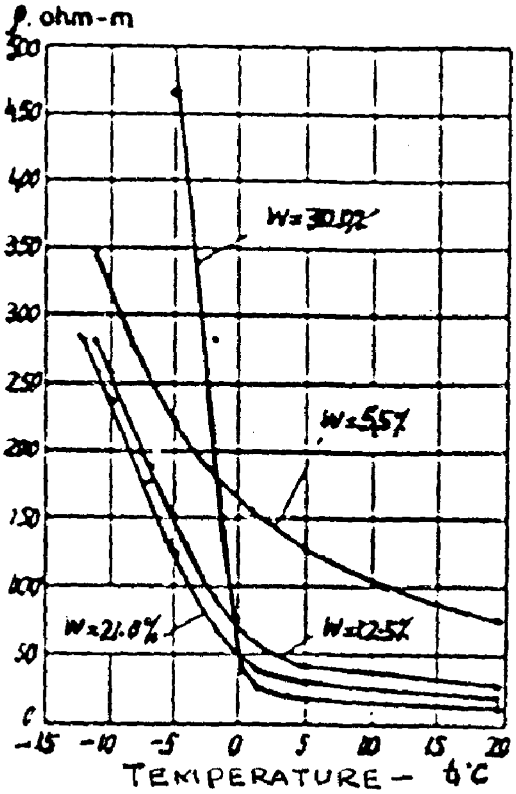


Fig- 3.4.(c) Curves of $\rho = f(t)$ for different W.(MOIST. CONENT)

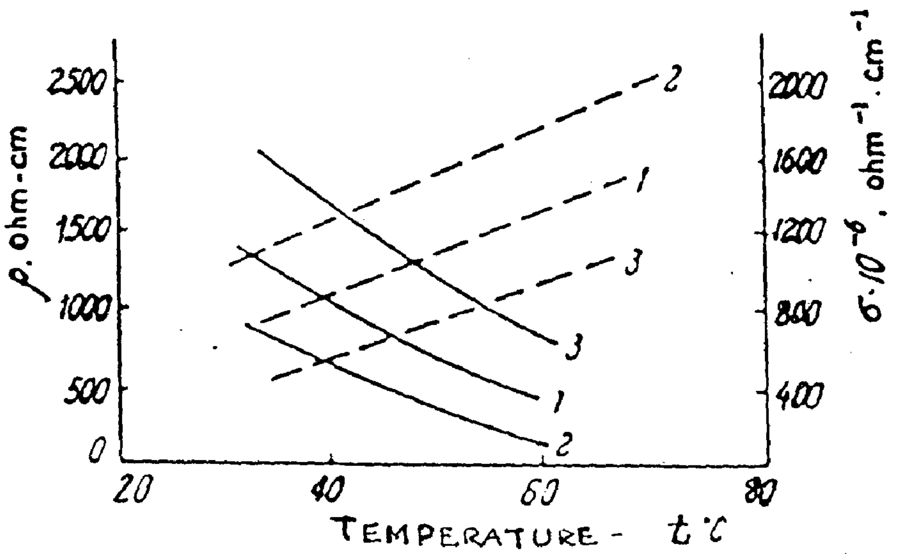


FIGURE 3.4(d) Electrical resistance of soils vs. temperature. The numbers 1, 2, 3 correspond to different soil types:

Solid curves give the resistivity ρ, and dashed curves the electrical conductivity σ.

Ice structures (at o.C to $-15^{0}c$) inside soil hinder the passage of electric current flow as seen in fig. 3.4 (c). The earth electrodes should be placed well below the frost-depth of soil.

IV. Effect of pH value of Water [28]

Simply quantity of water does not improve conductivity becasue pure water (PH value 6.6 -7.3) project high resistivity Unless the soil-water contents sufficient natural elements (salts & chemicals) to form a conducting electrolyte in acidic or alkaline medium. Only water in pure form can not improve conductivity.

(V) Effect of temperature [14,28]

External temperature Variation causes the soil dry up to a depth of 1 or 2 feet (.6 mt) in dry season raising the resistivity to a higher value . Hence, the top soil of about .6 to .9 mt depth vary the resistivity abruptly throughout a year.This depth may be taken as burial depth of grounding grid in order to get rid of the abrupt seasonal variation effect on electrode resistance.The internal temperature rise,helps soil+water solution (electroyte) in ionic conduction.

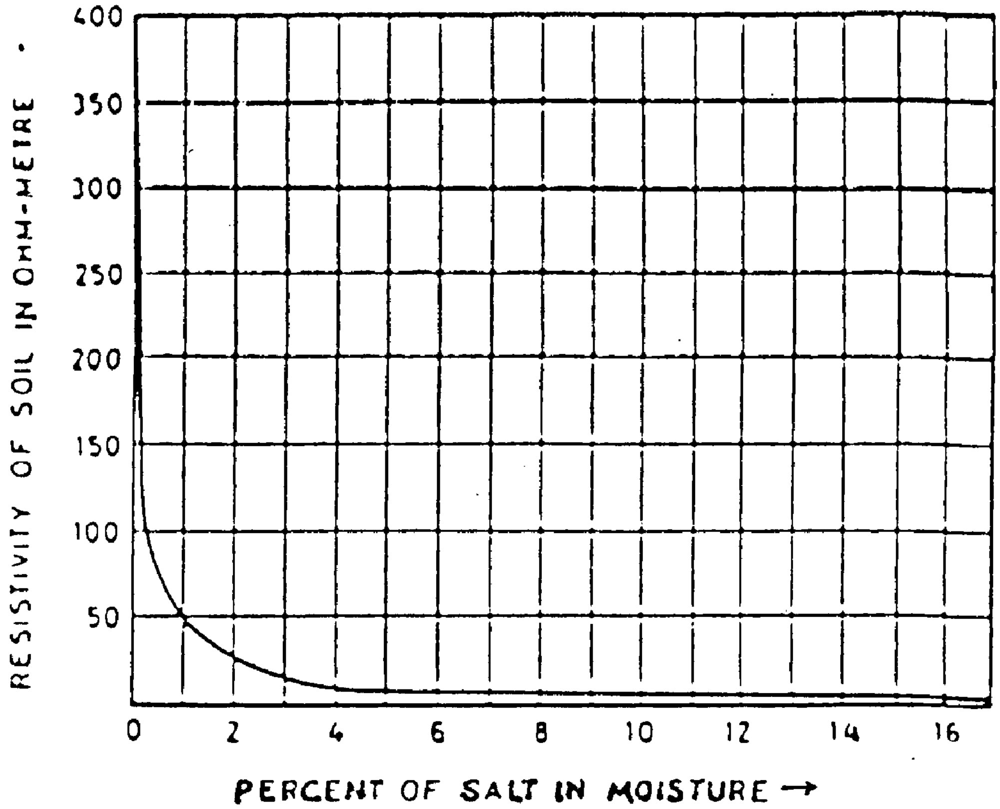


FIG 34(e) VARIATION OF SOIL RESISTIVITY WITH SALT (NaCl) CONTENT. CLAY-SOIL HAVING 3 PERCENT MOISTURE

I.S. 3043 [14]

(vi) Effects of chemcial & salts in soil [14,28]

Fig. 3.4 (e) there is little advantage in increasing salt concentration above 3%. To avoid corrosion, alakline medium is prefered with PH value more than 7. In agricultural areas the presence of nitrous components from fertilizers dissolves inside soil forming NaOH which is very good conductive in nature & maintaining PH of soil more than 7 (alkaline).

3.5 NEED FOR RESISTIVITY SURVEY FOR SWER [7]

As the soil resistivity is influenced by so many geological and seasonal parameters it is necessary that measurement of earth resistivity should be carried out during different seasons, at least over a period of one year. The highest soil resistivity of the time & places (locations of interest) is taken into consideration for design purpose.The question of which kind of earth electrode to be used can only be decided from a knowledge of the sub-soil. In a homogeneous soil where resistivity is uniform,cost of vertical earth & surface earth is about the same.

The second information obtained from resistivity survey is the equivalent depth at which it occurs. It is required to have the idea of high or low resistive zones in sub-soil strata, indication of ground water table position etc. to fix the depth of electrodes and its type of configuration. In this case, the vertical earths are more advisable and fruitfull, because the deeper soil strata are generally of higher conductivity.

Detailed knowledge of resistivity of an area also helps in accessing the costing of earthing system to be provided. High resistivity area requires costly earthing system and low resistivity area saves some cost in earthing system. Again for the same earth resistance a vertical earths needs to be about half the length of a surface earth. Surface earth are usefull when the sub-soil is stony or rocky giving higher resistivity with increase of depth.

Since in SWER system the earth system involves in continuous current carrying process, the earth resistance, potential rise of electrode, all depends upon a suitable range of resistivity values.

3.6 EARTH RESISTIVITY MEASUREMENT & SEPARATION OF ZONES OF DIFFERENT RESISITIVTY [PRESENT WORK]

Two methods adopted for resistivity measurements. [19]

(i) Wenner's Method or potential method, mostly used in USA, Canada and other English speaking countries.

(ii) Schlumberger or Gradient method, mostly used in USSR & some European countries.

But as per I.S-3043-1966 [28] Wenner's method is only recommended. However, it is not suitable for long range more than 50 meters span survey, for long range survey Schlumberger method is

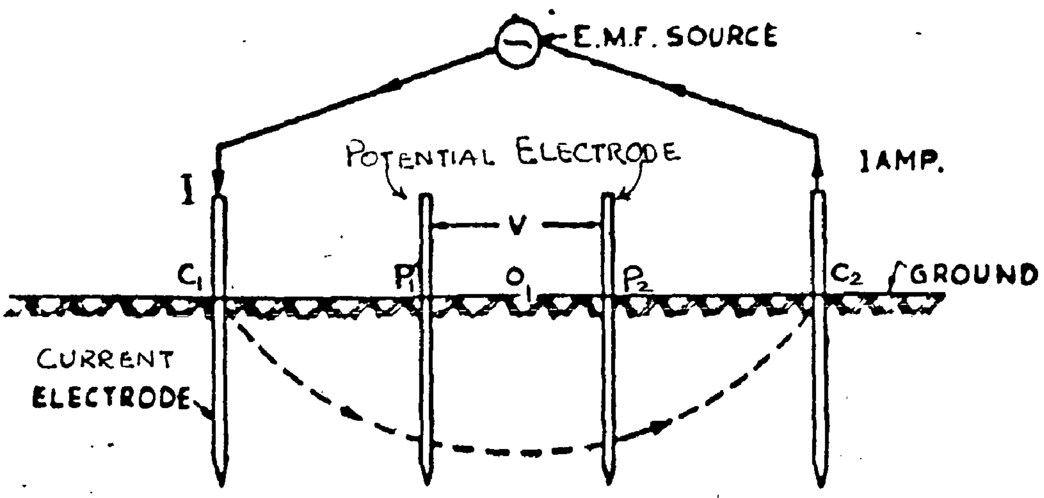


Fig. 3.6.(a)

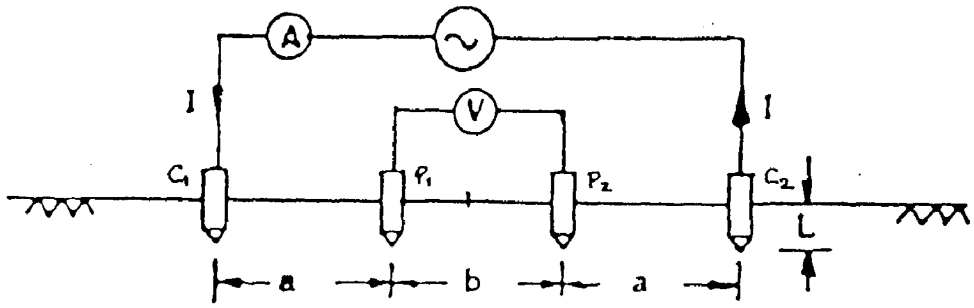


FIG. 3.6(b) Four Pin Method (a) b = a Wenner Arrangement (b) ≠ a Schlumberger - Palmer Arrangement

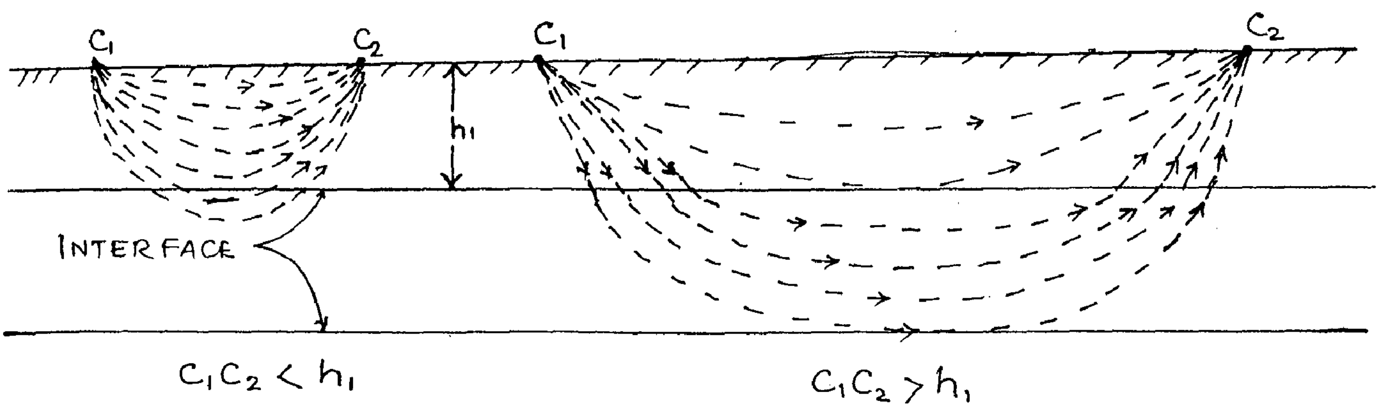


Fig. 3.6.(C) LINES OF CURRENT FLOW BETWEEN ELECTRODES.

suitable. And secondly all software developments for data interpretation to obtain equivalent depth are only possible in Schlumberger method, so far. A computer result of Schlumberger method is shown in Appendix I

Four electrodes are required for both methods, in Wenner it is equally spaced but in Schlumberger it is unequally spaced as shown in Figure 3.6 (a)(b). The resistivity is proportional to spacing between the current electrodes, in both the cases.

The usual practice is to pass current into the the ground bymeans of 2 electrodes called current electrode (C_1 C_2)and the potential drop is measured by a second pair electrodes P_1 P_2 called potential electrode in line with C_1 C_2

By a variable resistnace a null balance is obtained by equal and opposite current in P_1& P_2so that it gives the exact value of resistance ($R= \frac{V}{I}$) for a particular spacing (a).

The apparent resistivity (ρ) = 2π aR ohm-m.

If the different values of resistivity are uniform or within 20-30% variation, the soil or ground is called homogeneous and in this case the apparent ressitivity is equal to true resistivity. But, in practice the earth is not homogeneous, it is a heterogeneous body having many layers of soil stratas, and may be of different resistivities. The combined or net resistivity is a weighted average of the resistivity of the sub-soil stratas, through which the current passes.

In a horizontal two layer soil as per [15]

(i) if C_1 C_2<< h_1, all the currents is virtually confined to the surface of the layer1.

(ii) If, C_1 C_2>> h_1, a greater fraction of current penetrates deeper in the sub-stratum layer2, where h_1 is the depth in metre of upper layer soil.

As we go on increasing the spacing, more area of earth is covered for current circulation and hence the resistance value go on decreasing. But, the resistivity ($\rho=2\pi aR$) may increase or decrease from spacing to spacing depending on the soil strata as shown in figure 3.6 (c).

Equivalent depth calculation-There is no specification for this in I.S. 3043. However, Goyal [18] suggests the equivalent depth of resistivity is equal to the spacing (a), Reeves [21] suggests the depth equal to 3/4th of spacing (a), and John Walles [10] suggests 2/3rd of spacing (a). Since the third suggestion is given by an International conference report by the Power Division of IEE [10] this value is used in this work.

3.6.1 RESISTIVITY MEASUREMENT AND CALCULATIONS -

Soil Resistivity by Wenner methods was measured in North-South and East-West direction and their average values are calculated and tabulated in Table no 3.6.1.

3.6.2. DISSCUSSION OF RESULTS ON RESISTIVITY MEASURREMENT

The resistivity has been measured by both method of Wenner & Schlumerger at test site. But only Wenner results are taken into consideration for all calculation purposes.

The resistivities measured on both North-South and East-West direction from the test site, does not vary much from each other, indicating there is no lateral veriation in resistivity of earth strata.

The average of the two resistivity is taken and where the variation does not exceed 30% they are considered to be within one zone of uniform soil. Thus from Fig 3.6.(b) of depth Vs resistivity, it is seen that resistivities from 0.3 m depth to 1.2 m. depth are within the variation of 30% and hence in one layer /zone. And similarly, resistivity from depth 1.2 m to 3 m lie within 2nd layer of sub-soil. The second layer soil is of higher resistivity (ρ_2) than top layer soil (ρ_1). From the above discussion and table 3.6.1, it is inferred that the test site is having two layers of soil with average resistivity, ρ_1= 52 ohm-mt, ρ_2= 75 ohm-mt depth of upper soil layer h_1 = 1.2 (approximately).

TABLE 3.6.1 : RESTIVITY MEASUREMENT CALCULATION (August '95)

Sl. No.	Spacing (a) mt	Eauivalent Depth De=2/3x(a)	(R)Resistance (Ohm) East-West Direction	North-South Direction	Resistivity $2\pi aR$ (ohm-m) E-W	N-S	Average Resistivity = $\frac{(E-W)+(N-S)}{2}$	Remark
1.	0.45	0.3	17.5	18	51	50	50.5	ρ_1 Average =52 ohm-m Variation is less than 30%.
2.	0.9	0.6	8.0	7.8	45.2	44	44.6	
3.	1.35	0.9	6.3	6.0	51	52	51.5	
4.	1.8	1.2	5.3	5.5	62	60	61.0	
5.	2.25	1.5	4.8	5.0	71	68	69.5	ρ_2 Average =75 Ohm-m Variation is less than 30%.
6.	2.7	1.8	4.2	4.8	82	71	76.5	
7.	3.15	2.1	3.8	4.5	92	75	83.5	
8.	3.6	2.4	3.3	4.0	90	75	82.5	
9.	4.05	2.7	2.8	3.2	81	71	76.0	
10.	4.5	3.0	2.0	2.4	68	57	62.5	

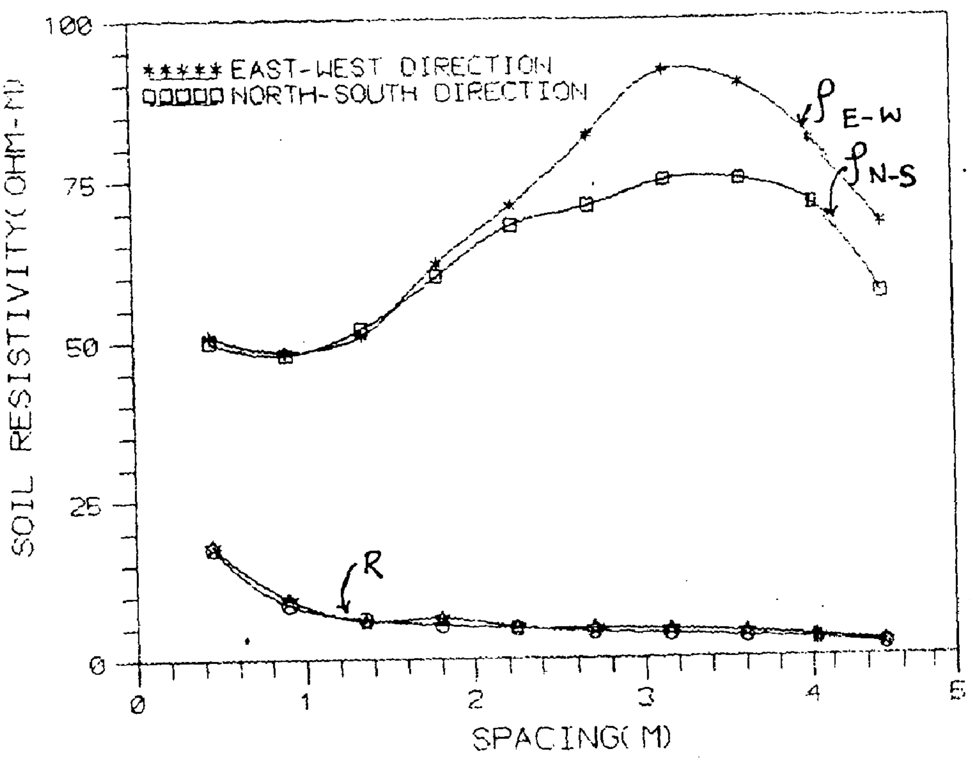


FIG NO-3.6.1(a) RESISTIVITY SURVEY

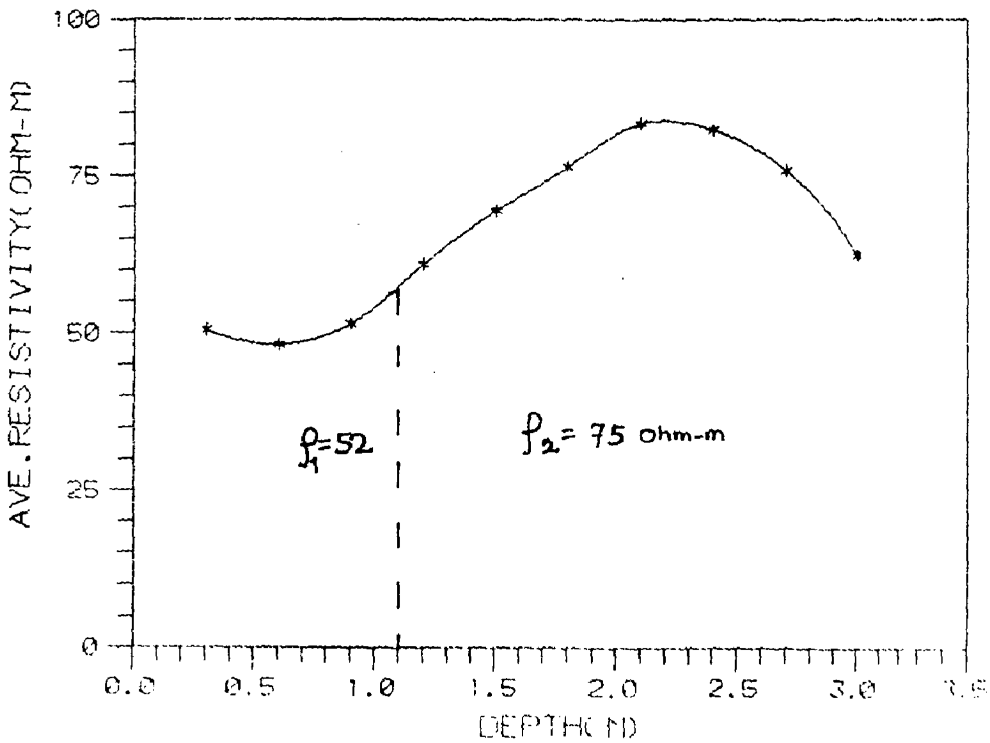


FIG NO-3.6.1(b) AVERAGE RESISTIVITY VS DEPTH

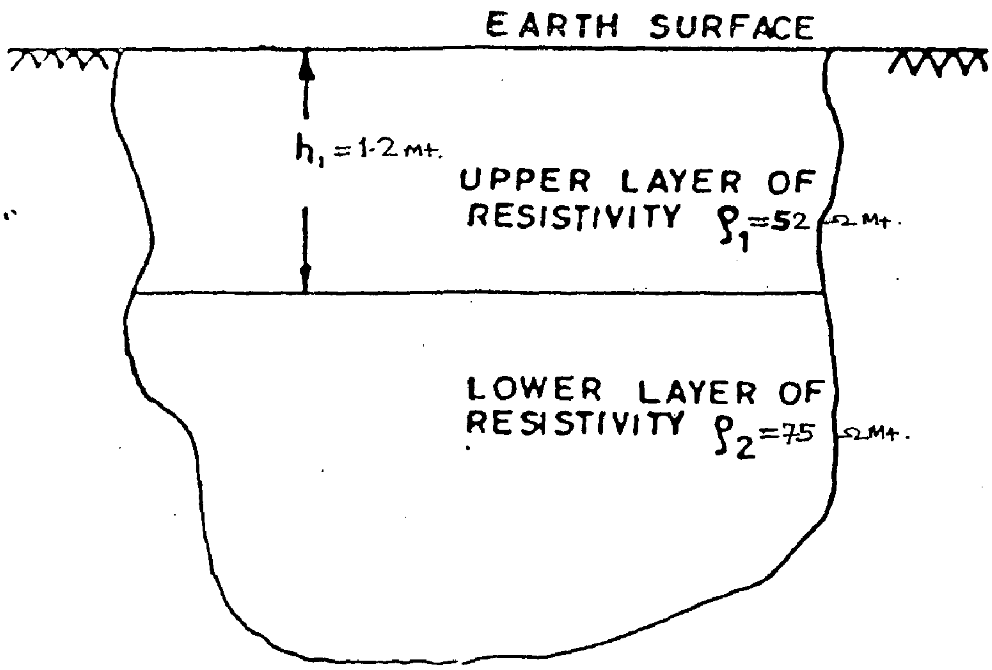


FIG.3.6.1(C) Two Layer Soil Model

3.7 OBSERVATION OF SEASONAL EFFECT ON SOIL RESISTIVITY

The monthly average precipitation, ground water table and soil moisture at a particular depth (0.6m) are tabulated in Table no (3.7.1) from July' to Nov '95 and from graph fig 3.7 (a) and 3.7(c) it is observed that as the precipitation decreases from July to November, the soil moisture content is decreasing gradually and the resistivity is increasing.Ground water table also falls with precipitation.The electrical conductivity and pH values of soil show negligible variation over this period.

From Fig. 3.7(b) it is seen that, the moisture content of soil at a particular depth (0.6 m) at two sites (about 30 m. apart) gradually decreases and the soil resistivity is appreciably rising from August to November. Table 3.7.2 gives the result of Seive analysis done in Soil lab of WRDTC, and the type of soil at site is found to be clayey soil (soil granules mostly less than 300 microns), soil granules greater than 300 microns is sand [14].

The ground water table measured at farm site of IWM,WRDTC but the test site is located at a higher level of about two metres from the farm-site level. Hence, the ground water table result is modified and shown in Table no 3.7.(iii).

TABLE-3.7.(i): OBSERVATION OF SEASONAL EFECT ON SOIL RESISTIVITY PERIOD JULY'95 TO NOV.95

	June	July	Aug.	Sep.	Oct.	Nov.
Rainfall in mm	127	357	436	116	3	0
Ground water level from surface(mm)	560	480	350	270	370	400
Moisture content in soil at .6m depth						
Site 1 WRDTC front	-	30.3%	34%	27%	21.6%	14%
Site 2 EED Front	-	37%	39.5%	34.8%	25.5%	16%
Monthly average soil Resistivity(ohm-mt)		47.5	45.6	67.6	96.8	110.120
Soil PH (.6m depth) Site-1	-	-	7.81	7.8	7.75	7.7
Site-2	-	-	7.28	7.42	7.35	7.3
Electrical conductivity of soil(.6m depth) (m.mho/cm) Site-1			0.20	0.19	0.17	0.18
Site-2			0.19	0.18	0.18	0.16

TABLE-3.7(ii) SIEVE ANALYSIS OF SOIL AT TEST SITE(.6m depth).

4.7 mm size	- 200 gm	= 20%	
2 mm size	- 130 gm	= 13%	
1 mm size	- 25 gm	= 2.5%	
600 micron	- 20 gm	= 2%	
425 micron	- 130 gm	= 13%	
150 micron	- 390 gm	= 39%	→Major constituents 150 microns (Clay Soil)
75 micron	- 55 gm	= 5.5%	
Pan size	- 50 gm	= 5.0%	
	1000 gm	= 100%	

* Tests made in IWM & Soil Lab, WRDTC, University of Roorkee, Roorkee.

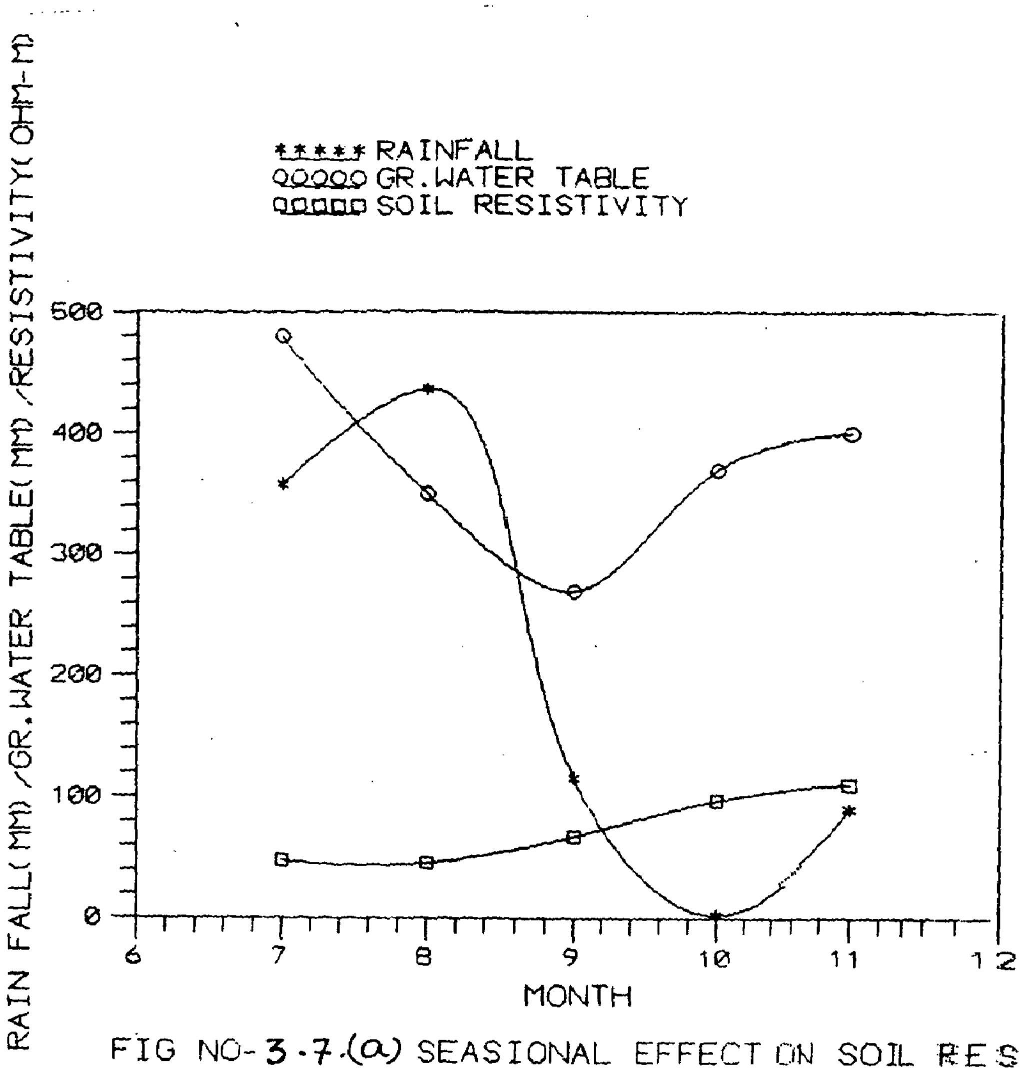


FIG NO-3.7.(a) SEASIONAL EFFECT ON SOIL RESISTIVITY

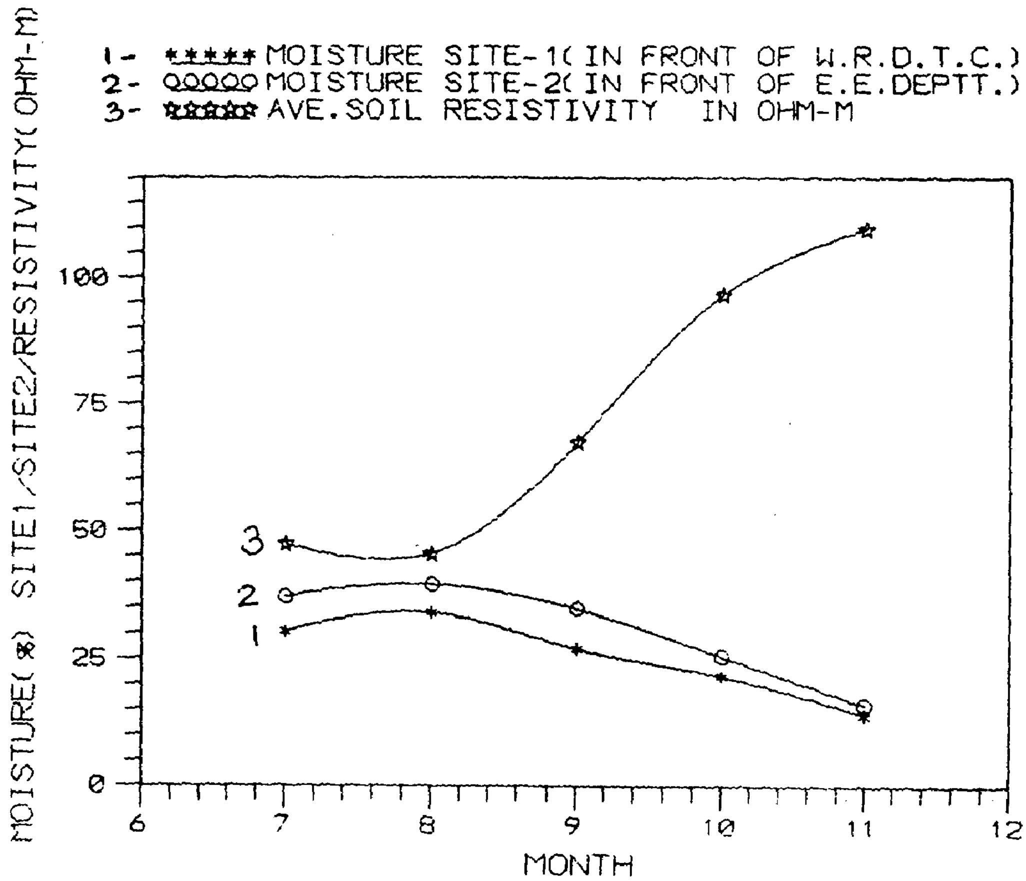


FIG NO-3.7.(b) MOISTURE EFFECT ON RESISTIVITY

TABLE : 3.7(iii)

OBSERVATION OF RAIN FALL EFFECT ON RESISTIVITY

SL. NO.	MONTH	RAIN FALL (mm)	GR. WATER TABLE AT WRD FARM (c.m)	GWT AT TEST SITE (c.m)	AVE. SOIL RESISTIVITY (OHM-MT)
1.	JULY'95	357	430	630	47.5
2.	AUG.'95	437	350	550	45.6
3.	SEP.'95	116	270	470	67.6
4.	OCT.'95	3	370	570	96.8
5.	NOV.'95	0	400	600	110.0

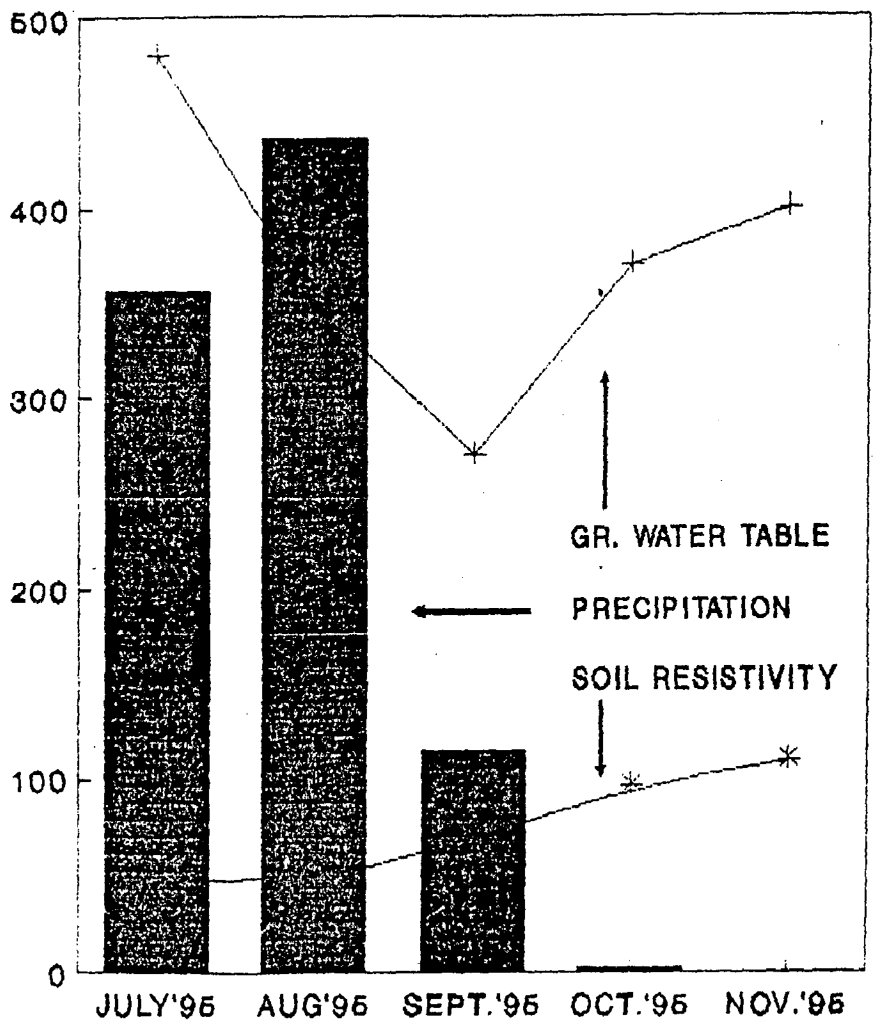


FIG.-3.7 (C)-VARIATION EFFECT ON RESISTIVITY PRECIPITATION & GROUND WATER TABLE

CHAPTER 4

THE EARTHING ARRANGEMENT

4.1 GROUND ELECTRODE

Ground is defined as a conducting connection, by which an electric circuit or equipment becomes grounded. The term 'Electrode' means a way in or way out for electricity.

Electric power systems including SWER systems are grounded i.e. connected to earth by means of earth embeded electrodes for a number of reasons -

i) To assure a safe carriage and dissipation of electric currents into ground under all normal and fault conditions without exceeding any operationallimits that adversly affect the continuity of service.

ii) To assure a high degree of human safety so that a person working or walking in the vicinity of the grounded facilities is not subjected to any danger of electrical shock.

iii) To stabilise the voltage during transient conditions and to minimise the probability of flash over during transients.

iv) To dissipate lightning strokes. Sometimes special consideration is made in grounding design, where the places are prone to higher " Isoceraunic levels".

Ground Potential Rise (GPR), also referred to as earth potential size (EPR) of an earthing system is a function of

(i) Current magnitude and (ii) Earthing system Resistance.

The current through the earthing system multiplied by its resistance measured from a point remote from the sub-station, determines the ground potential rise with respect to that remote ground.

4.1.1 Ground Resistance Components

The grounding resistance of a burried electrode is a function of

(i) The resistance of the electrode itself along with connecting conductor to it.

(ii) Contact resistance between electrode and the surrounding soil.

(iii) Resistance of the body of surrounding soil from electrode surface outwords, in the geometry setup for the flow of current to infinite earth.

The electrodes should be adequate in shape and size so that their metal resistance is negligible. The second contact resistance between electrode and earth is also much less, as per U.S. National Bureau of standards No. 108 [9].

The third component, viz. resistance of the body of earth is the main subject of investigation. The main features are discussed below :

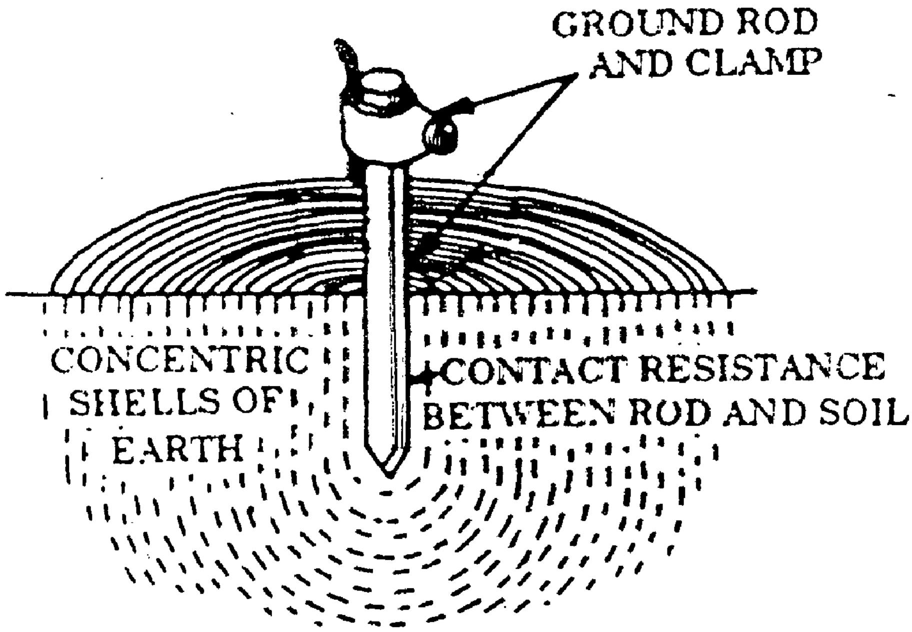


Fig. 4.1.1 Resistance Components of Earth Electrode

A ground rod which has been driven into uniform soil resistivity, earth conducts currents in all directions. As shown in Fig. 4.1.1. Let us consider the electrode is being surrounded by shells of earth, all of equal thickness. The earth shell closest to the ground rod has the smallest surface area and consequently offers the greatest resistance. The next earth shell is some what larger in area and offers less resistance and so on.

Finally, a distance from the ground rod will be reached where inclusion of additional earth shells does not add significantly to the earth resistence.

Earth is a conductor of electricity (if not best like metals). The conductivity of earth surrounding a ground-electrode vary with both season (temperature and moisture) and its own type of composition and nature.

4.2 GROUNDING SYSTEM

The earth-embeded metalic structure either single or in multiple combination of electrodes connected in parallel is called grounding system.

Types of grounding systems in practice and their ohmic values.

(i) Generating station Grounding systems (0.50 ohm) consists of groundmat, ground rods, and other earth embeded metalic structure.

(ii) Transmission tower Grounding system (2-5 ohm) consists rings, crow-footing counter Poises, ground rods etc.

(iii) Small sub-stations (11 kv- 6.35Kv) grounding system consists of Ring, mat, and rods. (2-5 Ω).

(iv) LT domestic consumers graunding system consists of one or more ground rods, pipes as simplest types of grounding systems (5-25 Ω).

As per national electric code (NEC), ANSI/NFPA 70-1981- [9] the maximum resistance of single electrode is less than 25-Ω.

4.3 MEASUREMENT OF EARTH ELECTRODE RESISTANCE BY 3 POINT METHOD OR POTENTIAL GRADIENT METHOD

Earth resistance measurement is done using the earth tester based on the principle of fall of potential. Let us consider steel rod (R), as an earth-electrode driven into the ground, at a distance D from the mother earth electrode (E).

A potential is applied between E and R as shown in Fig. 4.3(a) and the current flow is measured in the ammeter (A). If, a second rod (P) called potential electrode having a volt meter (v) is now driven into the ground at various points on the straight line of E and R, the voltmeter will measure the potential difference between mother electrode E and the respective points in the surrounding soil.

By Ohms law, this potential difference will be directly proportional to the resistance of the earth upto the point measured and hence the relationship between the resistance and

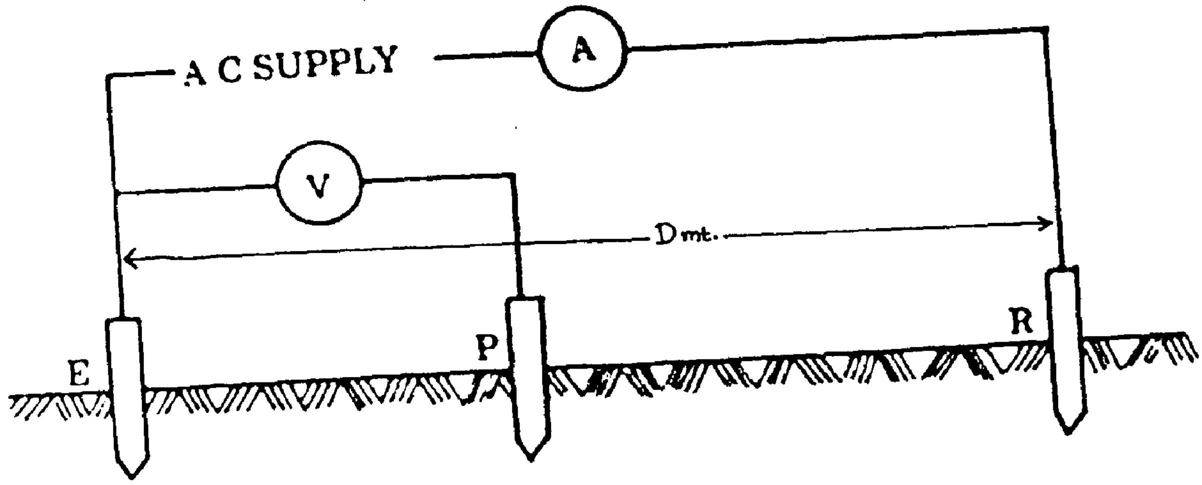


Fig. 4.2(a) Fall of potential method

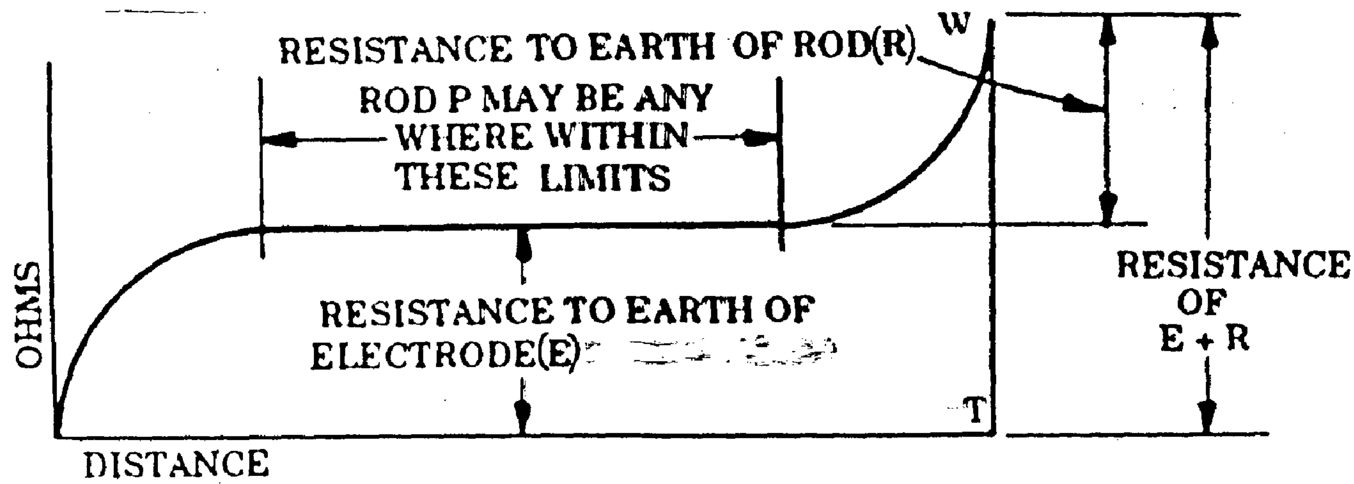


Fig. 4.2(b) Effect of the resistance area of the distance rod "R" on the fall of potential curve

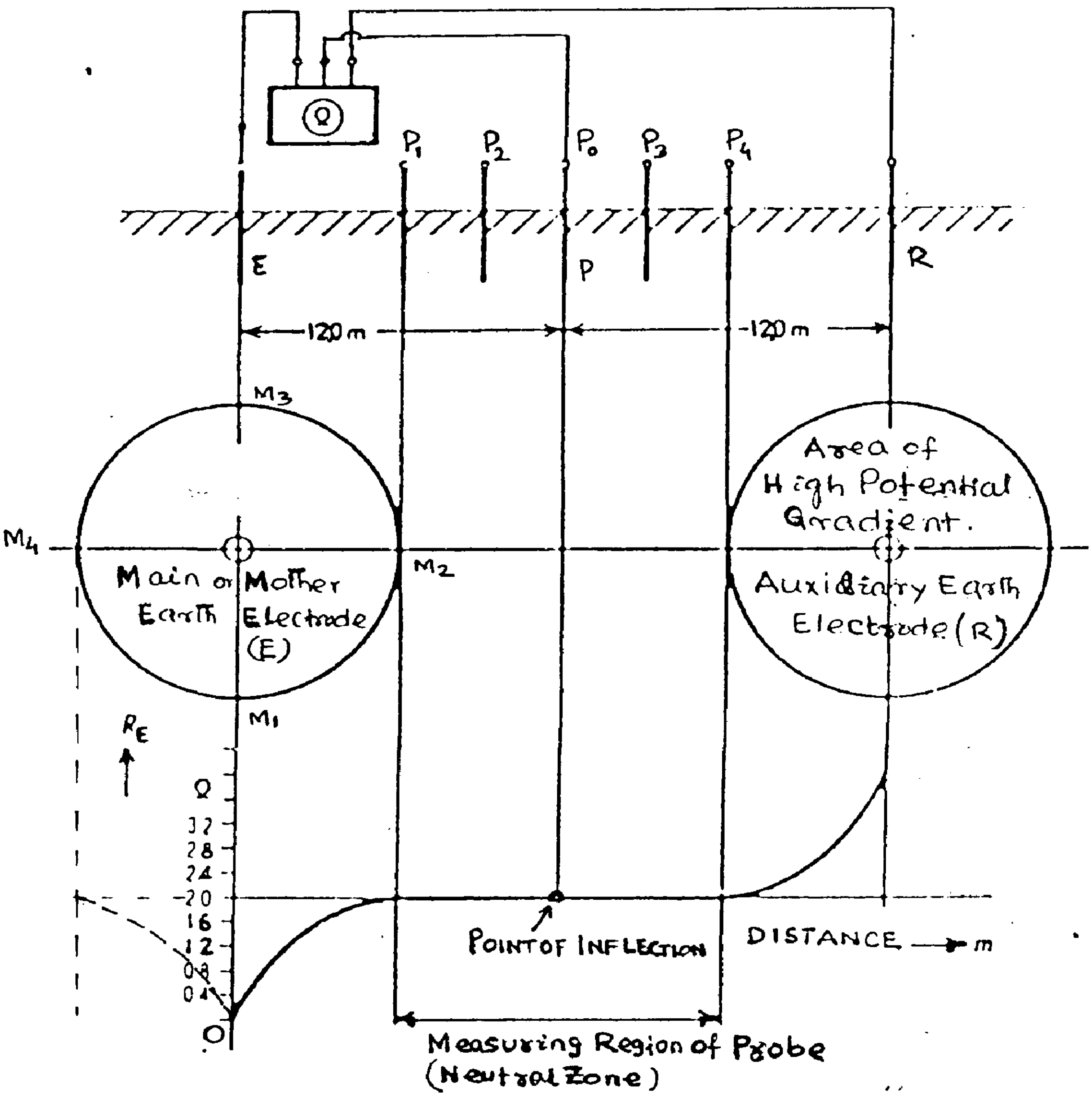
distance from E can be plotted as shown in Fig 4.3 (b). It is found that the resistance increased as the rod P is placed further away from E towards R.

The rate of increase rapidly diminishes so that at a certain distance from E, it becomes negligible. Infact, the amount of resistance, represented by this distance is about 99% of the total resistance to an infinite distance. Similarly, an equal curve can be plotted in opposite direction radiating from the electrode and a sereis of points say m_1, m_2, m_3 and m_4 obtained encircling an area m_1, m_2, m_3 and m_4 which for all practical purposes may be to contain the whole of the resistance of the electrode (E) to earth Fig. 4.3(c).

This is called " Resistance Area" of the earth-electrode. The shape and size of resistance area solely depends on the dimension of the electrode. The resistance area of a rod or pipe driven into earth will have a comparatively small resistance area and that of a multiple electrodes connected in parallel will have a correspondingly large-area. The resistance measured depends on the dimension of the resistance area and the resistivity of the soil within it.

The conditions for this type of measurement are -

(i) The current electrodes E and R must be sufficiently far away from each other. So that resistance areas do not over-lap.



E - Earth electrode

P - Probe

R - Auxiliary earth electrode

R_E - Earth resistance at particular location

P_1 to P_4 Locations of probe in measurement sequence

Fig. 4·2(C) Variation of resistance obtained from earth resistance measurements

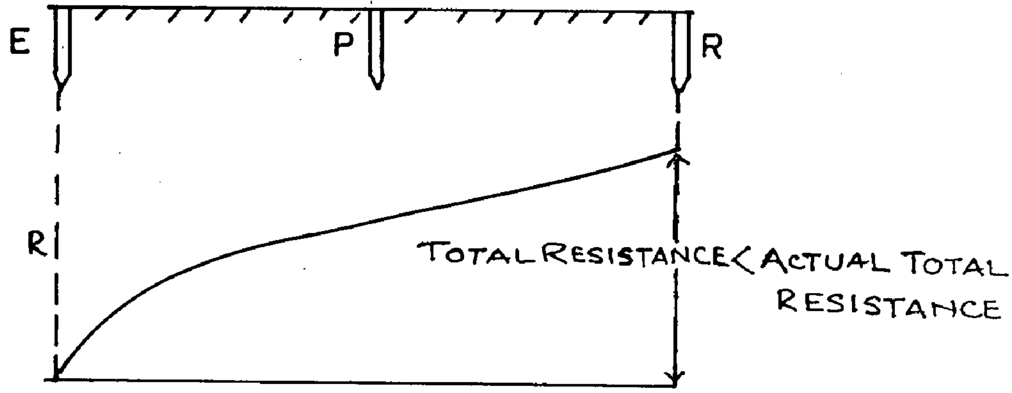


Fig. 4·2(d)

(ii) The potential electrode (P) must be between electrodes E and R in a straight line, joining them.

It is noted that, this resistance curve at first rises rapidly, then becomes nearly horizontal and eventually rises again as the rod (P) enters the resistence area of rod (R). The mid point between E and R, where the value of resistance tends to change the direction, as we go towards R is called "Point of inflection" Fig. 4.3 (c).

When, the rod (R) is too close to E, and the 2 resistance areas overlap, the behaviour of the curve is as follows Fig. 4.3 (d). There is no horizontal portion of curve.

4.4 EFFECT OF ROD DIMENSIONS ON RESISTANCE

As per [25] increase in length is more effective in reducing the electrode-resistance than that of diameter. As per mathematical formula resistance to earth, for a single ground rod developed by professor H.B. Dwight

$$R = \frac{\rho}{2\pi L} \cdot \left[\log_e \frac{4L}{a} - 1 \right] \text{ ohm.}$$

or in a more simplified manner, as given in [10].

$$R = 0.3666 \frac{\rho}{L} \log_{10} \frac{3L}{d} \text{ ohm.}$$

where,

ρ = Average soil resistivity in ohm-mt, uniformly distributed over entire soil volume.

L = Ground Rod length in mt.

a = Ground Rod radius in mt.

d = Diameter of rod in mt.

Taking the example of a rod of length 1 m x 20 mm diameter

ρ = Average resistivity = 50 mt.

$$R = \frac{0.366 \times 50}{1} * \log_{10} \frac{3 * 1}{0.02}$$

= 40 ohm.

Case (i) If, diameter is doubled i.e 40 mm; keeping length constant at 1 m.

$$R = 0.3666 \frac{50}{1} * \log_{10} \frac{3 * 1}{0.04}$$

= 34.32 ohm.

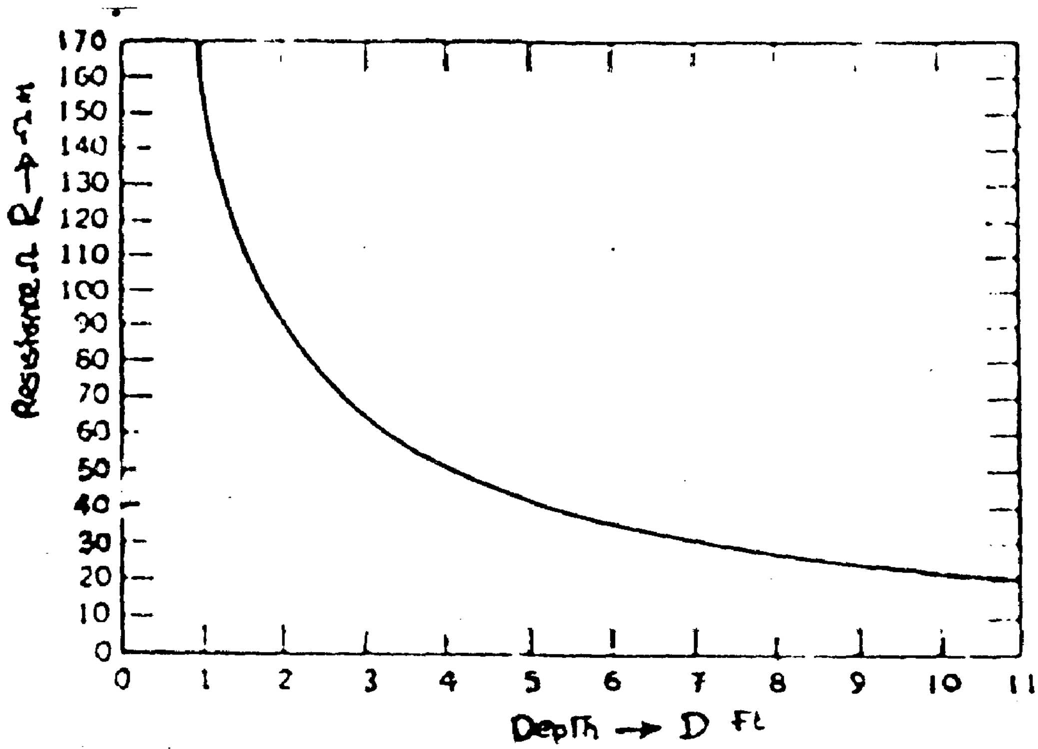
$$\% \text{ Decrease in resistance} = \frac{40 - 34.32}{40} \times 100 = 14.2\%$$

Case (ii) If, the length of rod is doubled, keeping the diameter constant at 20 mm. and ρ = 50 ohm mt. L=2m.

$$R = \frac{0.366 \times 50}{2} * \log_{10} \frac{3 \times 2}{0.02}$$

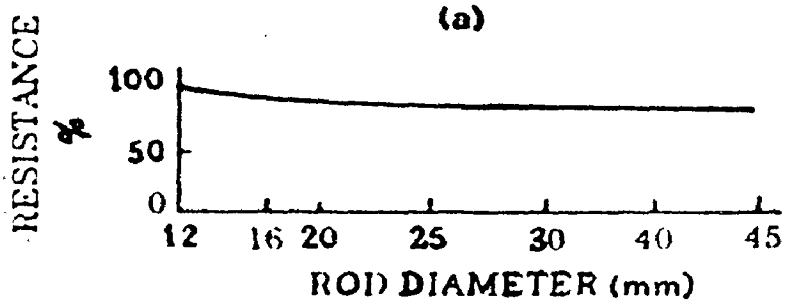
= 22.66 ohm.

$$\therefore \% \text{ Decrease in resistance} = \frac{40 - 22.66}{40} \times 100 = 44\%$$

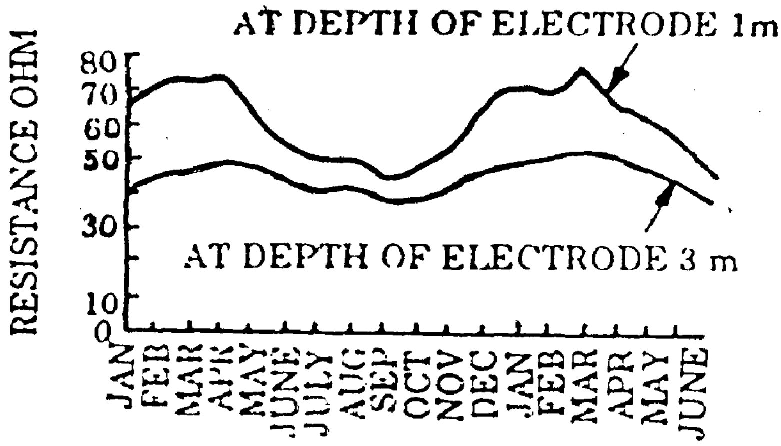


Variation of soil resistivity with depth for soil having uniform moisture content at all depths (From National Bureau of Standards Technical Report 108.)

(a)



(b)



SOIL RESISTANCE SEASONAL

(c)

Fig.4.4 Variation in earth resistance: [Ref.25]
(a) with depth;
(b) with diameter;
(c) seasonal

Hence, as seen from Fig. (4.4a and b) doubling the rod length reduces the resistance by more than 40% . Doubling the diameter of the rod, however, does not appreciably reduce its resistance, more than 15% .

The effect of change in length of rod has been confirmed by our depth experiment also, at 4.6.

4.5 EFFECT OF SOIL RESISTIVITY ON RESISTANCE

Dwight formula shows that the resistance to earth of grounding electrode depends not only on the depth and to some extent on the surface area of the electrode, but also on soil resistivity.

As discussed in chapters -3, soil resestivity is the key factor that determines the resistance of a grounding electrode and the depth to which it must be driven to obtain low ground resistance. The resistivity of soil varies widely throughout the world and changes seasonally also. Hence, the resistence of any grounding system varies accordingly during different seasons as seen in Fig. (4.4c). The seasonal variation is less significant at large depths.

Hence, it follows that ideally the grounding system, should have ground rods driven down to a considerable depth to have least and steady resistance at all times. Best results are obtained, if the ground rods reaches the permanent moisture level (sub-soil water level).

4.6 EXPERIMENTAL RESULTS OF DIFFERENT ROD CONFIGURATIONS AND DISCUSSIONS

4.6.1 Single Rod Experiment at Different Depths (Table 4.6.1(i)

i) At .3 m depth - 83.0 Ω
ii) At .6 m depth - 50
iii) At .9 m depth - 37
iv) At 1.2 m depth - 30 Ω

Resistance curves shown in Fig. 4.6.1 (a) (b) (c) (d)

4.6.2 Two Rods in Parallel Combination

i) Two Rods with 1 m spacing in straight line along the mother electrode = 29 Ω

ii) Two Rods with 1 m spacing in in perpendicular to the mother electrode = 25 Ω

iii) Two rods with 2 m spacing perpendicular to the mother electrode = 18.5 Ω

iv) Two rods with 3 m spacing perpendicular to the mother electrode = 16 Ω

v) Two rods with 6 m spacing perpendicualerto the mother electrode = 5 Ω

vi) Two rods with 8 m spacing perpendicualer to the mother electrode = 4 Ω

TABLE NO4.6.1(i) ROD DEPTH Vs. RESISTANCE MEASUREMENT BY GRADIENT METHOD (SEPT'95)

Distance (Mt)	.3mt depth (i)	.6mt (ii)	.9 mt (iii)	1.2mt (iv)
0.5	.5	.5	.5	.5
1.0	.7	.7	.8	.8
2.0	.9	1.0	1.0	1.2
3.0	1.0	1.2	1.2	1.4
4.0	1.5	1.6	1.5	1.6
5.0	2.0	2.2	2.4	2.6
6.0	2.5	2.8	2.8	3.0
7.0	3.5	3.6	3.5	3.6
8.0	4.5	4.8	4.5	4.6
9.0	5.0	5.0	5.0	5.0
10.0	5.0	5.0	5.0	5.0
11.0	5.0	5.0	5.0	5.0
12.0	5.0	5.0	5.0	5.0
13.0	5.0	5.0	5.0	5.0
14.0	5.0	5.0	5.0	5.0
15.0	5.0	5.0	5.0	5.0
16.0	5.0	5.0	5.0	5.0
17.0	5.0	5.0	5.0	5.0
18.0	5.0	5.0	6.0	6.2
19.0	6.5	6.5	7.0	7.2
20.0	7.2	7.0	8.0	8.4
21.0	8.0	9.0	11.0	11.5
22.0	10.0	12.0	14.0	14.5
22.5	15.0	16.0	16.0	16.5
23.0	20.0	23.0	17.5	19.0
23.5	35.0	30.2	20.0	22.0
24.0	88.0	55.0	42.0	35.0

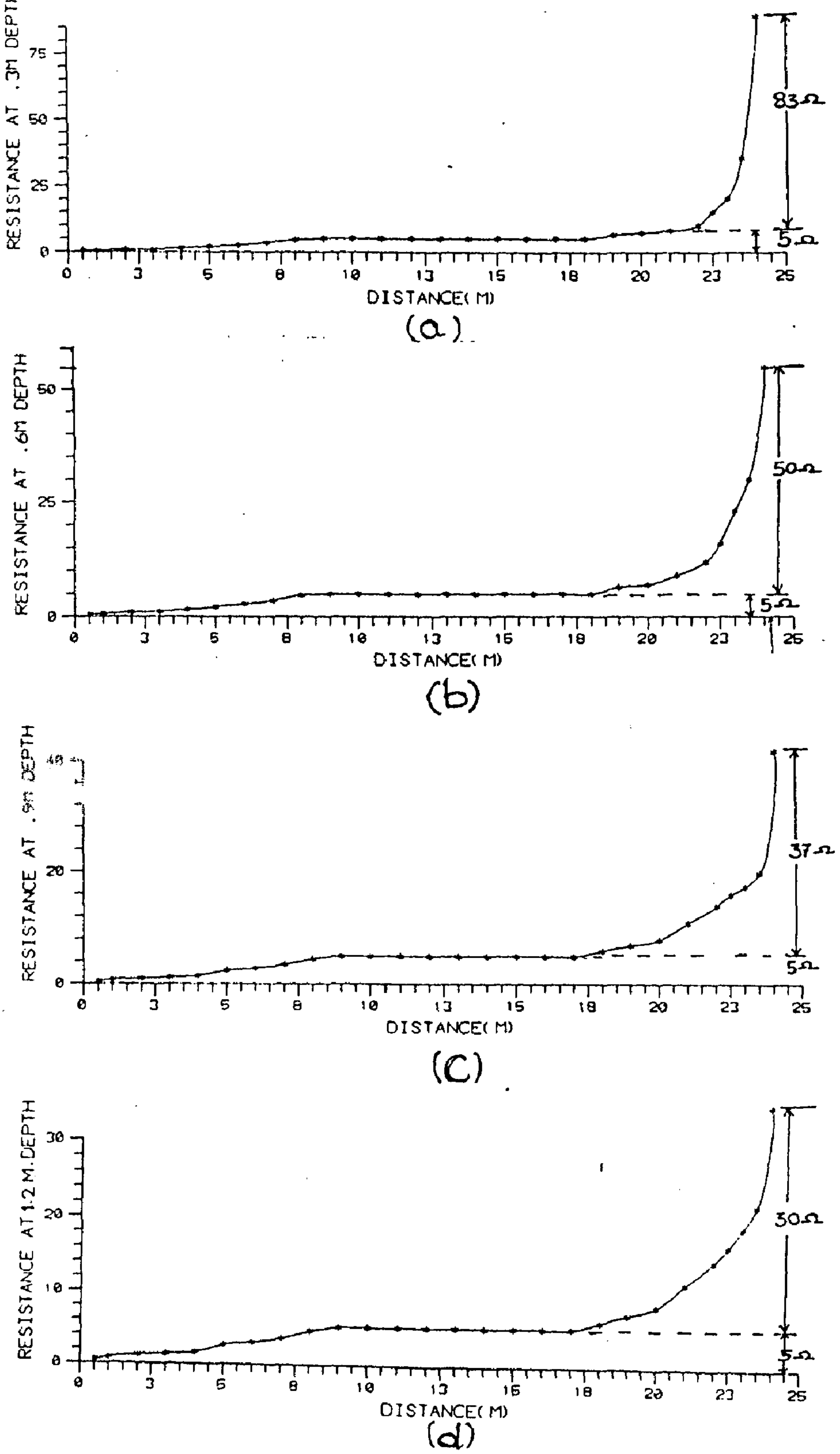


FIG. 4.6.1 - SINGLE-ROD AT DIFFERENT DEPTHS.

4.6.3 Three Rods in Parallel (Triangle)

i) 3 Rods, 1 m spacing in straight line along the motter electrode = 25 ohm

ii) 3 Rods, 1 m spacing in perpendicular to motter electrode = 18 ohm

(iii) 3 rods, 1 m spacing in triangle, with one rod facing the mother electrode = 22 ohm.

iv) 3 Rods, 1 m spacing in triangle, tow rod facing the mother electrode = 19 ohm

v) 3 Rods, 2 m spacing in triangle, tow rod facing the mother electrode = 16 ohm

vi) 3 Rod 3 m spacing in triangle, two rod facing the mother electrode = 12 ohm

vii) 3 Rod 4 m spacing in triangle, tow rod facing the mother electrode = 9.5 ohm

viii)3 Rod 6 m spacing in triangle one rod facing the motter electrode = 7.5 ohm

4.6.4 Four Rods in Parallel (Square)

4 Rods with 1 m spacing, 2 Rods facing towards mother electrode = 15 Ω

4 Rods with 2 m spacing, 2 Rods facing towards mother electrode = 11.5 ohm

4 Rods with 3 m spacing, 2 Rods facing towards mother electrode = 8.5 ohm

TABLE NO. 4 . 6 . 1 (ii)

ROD - DEPTH Vs EARTH - RESISTANCE

Depth L (mt)	Resistance Calculated (Ohm) *	Resistance Observed (Ohm)	% Decrease in R-Calculated	% Decrease in R-Observed
0.3	107	83.0		
0.6	64	50.0	40.8	39.4
0.9	45	37.0	57.0	55.2
1.2	39	30.0	65.9	63.7

*. August '95 - Average soil Resistivity (ρ) = 52 Ohm - m

$$R_{calculated} = \frac{0.366\,\rho}{L} \log_{10} \frac{3L}{d}$$

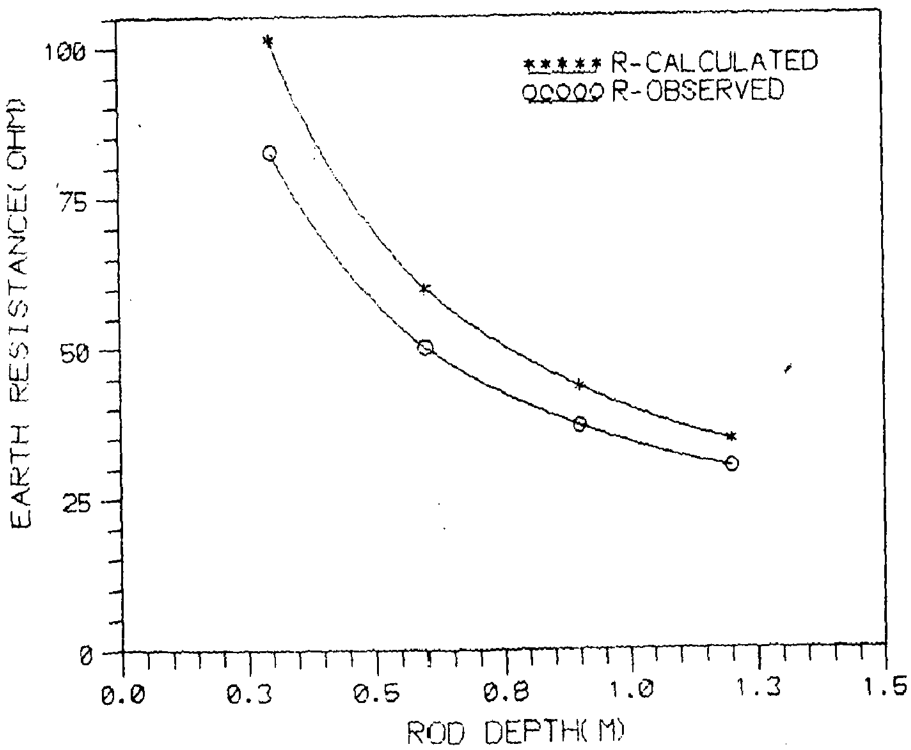


FIG NO-4.6.1 (e) ELECTRODE RESISTANCE VS DEPTH

4 Rods with 4 m spacing, 2 Rods facing towards mother electrode = 6.5

4 Rods with 6 m spacing, 2 Rods facing towards mother electrode = 4.00

4.6.5 Multiple Electrodes

The results of different multiple Electrodes with different spacings are tabulated in Table No. 4.6.5 & the result curves are shown in Fig. 4.6 (a) & (b).

4.6.6 Discussion

Single Rod Experimental Results

From mathematical formula and known-value of resistivity (ρ = 52 ohm). The resistance of rod at different depth and the percentage in increase of electrode length vs. percentage decrease in earth resistance are tabulated in table No. 4.6.1 (ii) (iii).

It is observed from the graph Fig. 4.6.1 (e) that the earth electrode resistance decreases with length and tends to saturate beyond 1.5m. The calculated values remains at higher side than the observed values because, the measured resistivity is not so much closure to accuracy both in soil and instruments. Similarly, the percentage degree in resistance is less than that of calculated value.

Two Rods Results Fig. 4.6.2

TABLE NO. 4 . 6 . 1 (iii)

PERCENTAGE INCREASE IN LENGH Vs PERCENTAGE DECREASE IN RESISTANCE

% Increase in electrode length	% Decrease in $R_{calculated}$	% Decrease in $R_{experimentaly\ Observed}$
100	40.8	39.4
200	57.0	55.2
300	65.9	63.7

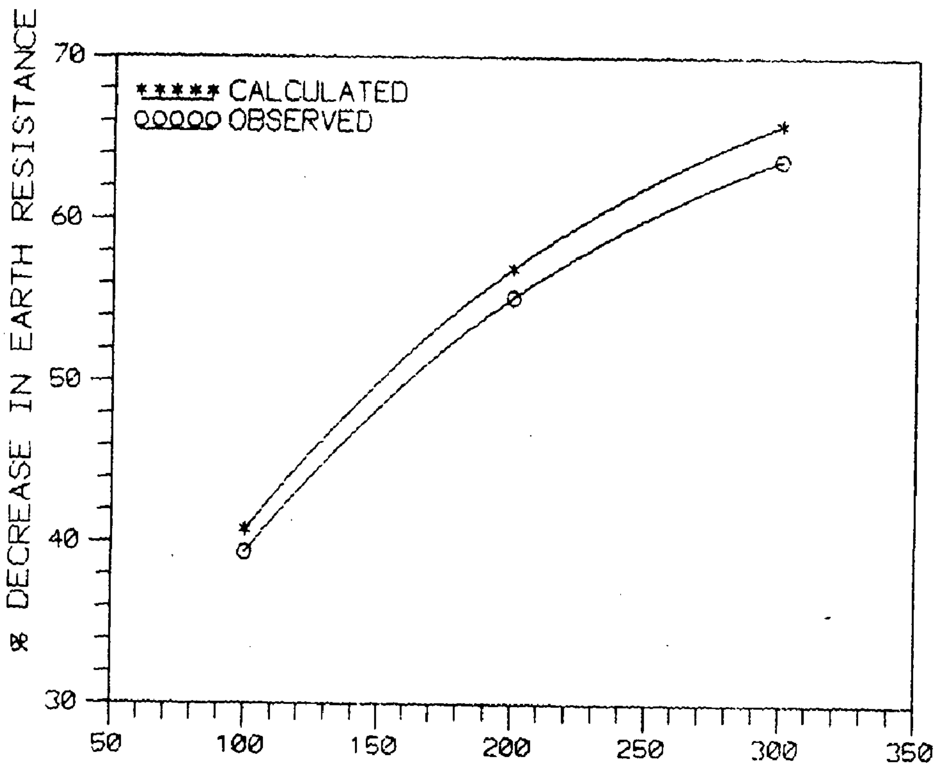
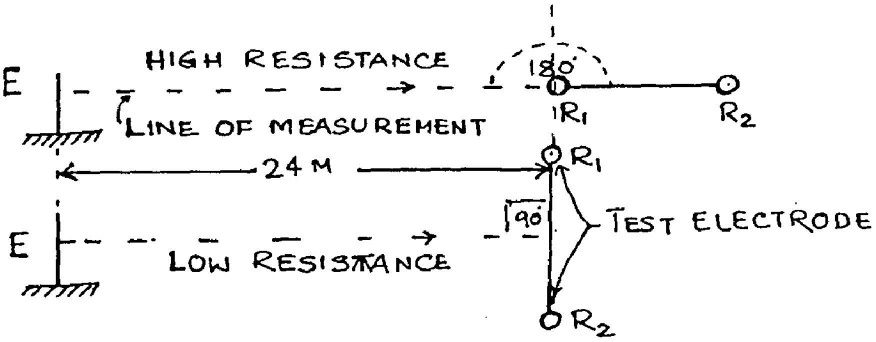
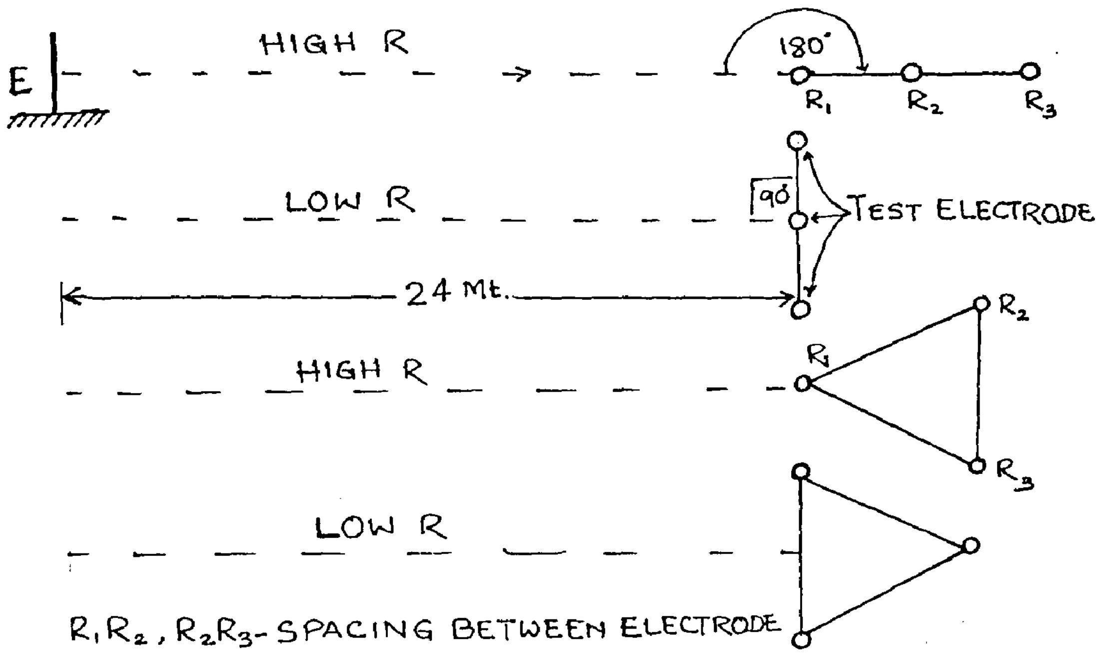


FIG NO-4.6.1(f)-% INCREASE IN ELECTRODE LENGTH VS % DECREASE IN EARTH RESISTANCE



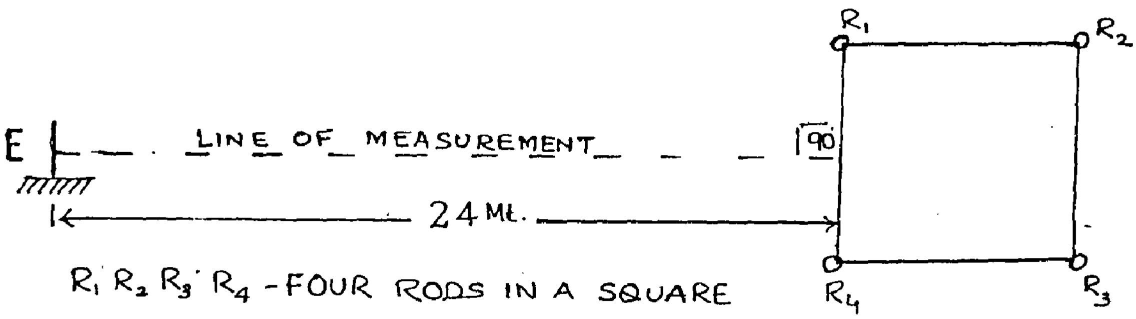
R1 R2 = SPACING BETWEEN 2 ELECTRODES.
E = MOTHER ELECTRODE (REMOTE EARTH)

Fig.4.62 TWO-ROD EXPERIMENT



R1R2, R2R3- SPACING BETWEEN ELECTRODE
E - REMOTE EARTH

Fig.4.63 THREE ROD EXPERIMENT.



R1 R2 R3 R4 - FOUR RODS IN A SQUARE
E - REMOTE EARTH

Fig. 4.64 FOUR ROD EXPERIMENT.

Two rods when driven to .9 m length and the 1 m apart, along the direction of measurement shows higher resistance (29 ohm) than that when placed in perpendicular direction (25 ohm). Along the direction - the front rod only contributes to the maximum extent of current flow than the back one. In the perpendicular direction a both electrodes face the mother electrode and contribute almost equally to the current flow, being equidistant from the source.

From spacing curve in Fig. 4.6.5(a) for two rods, the percentage reduction in resistance is more prominent from 3 m to 6 m than that from 6 m to 8 m. So, for two rods 6 m spacing is most suitable.

Three Rods Results Fig. 4.6.3

The triangle with one rod (corner) facing the mother electrode (source) offers more resistance than that of two rods facing as shown in Figure.With increase of spacing among the electrodes, the resistance gradually decreases and at 6 m spacing the incremental benefit seems to be maximum as seen from Fig. 4.6.5 (a).

Four Rods Results : Fig. (4.6.4)

The four electrodes in square geometry, with 2 rods facing the reference line/mother electrode projects minimum resistance among all the configurations. Fig.4.5.5(a). With increase of

TABLE NO. 4.6.5

RESISTANCE OF MULTIPLE ELECTRODES AT VARIOUS SPACINGS VS % RESISTANCE OF SINGLE DRIVEN ROD

NO. OF RODS	% RESISTANCE OF SINGLE ROD AT DIFFERENCE SPACINGS 1 m	2 m	3 m	4 m	5 m
2	88.3	62	42	30	17
3	64	48	33	25	15
4	50	38	28	22	13

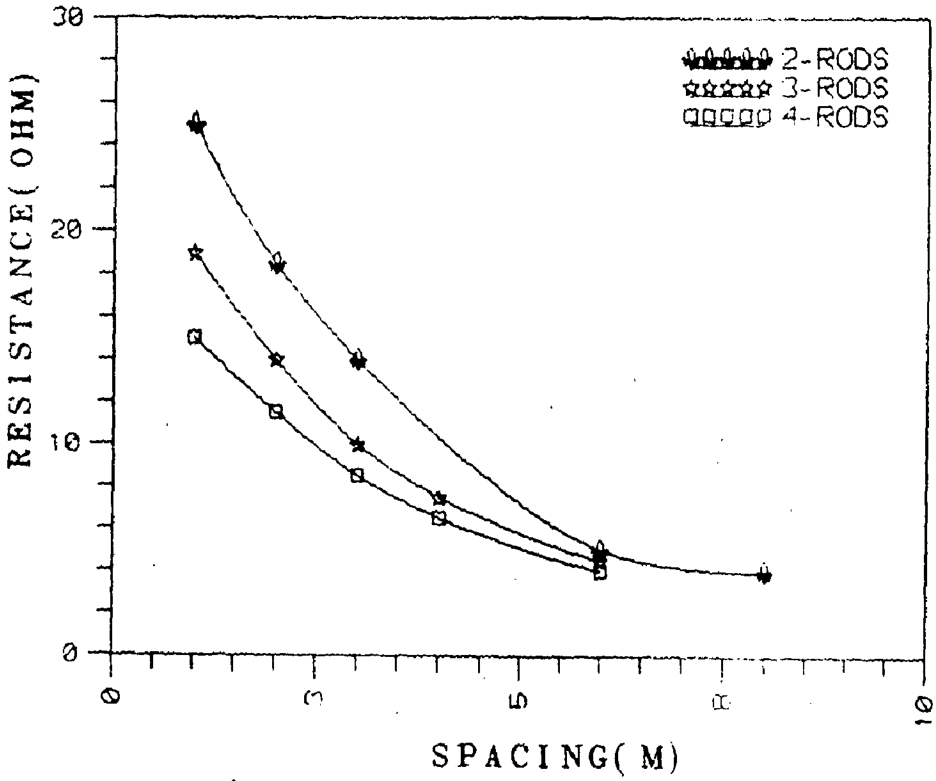


FIG NO 4.6.5(a) RESISTANCE VS SPACING OF RODS

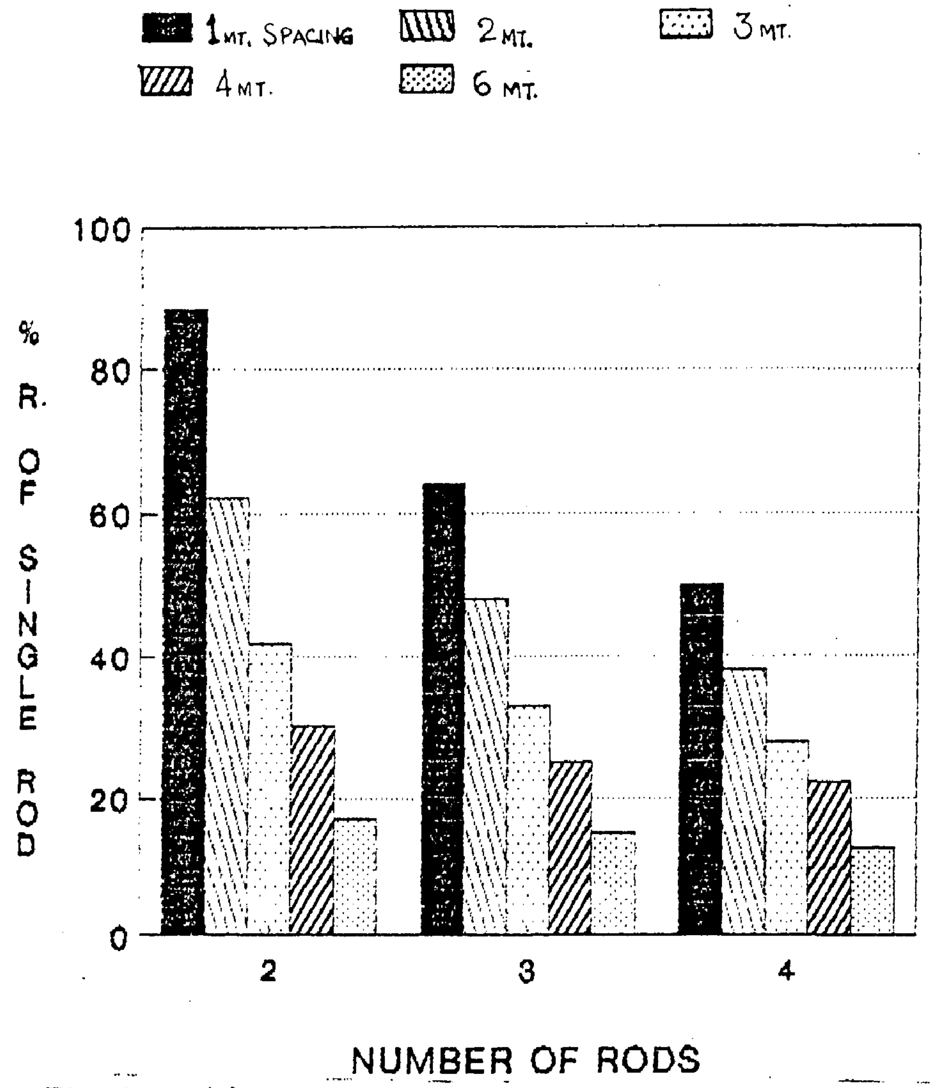


FIG.4.6.5(b) RES. OF MULTIPLE ELECTRODES AT VARIOUS SPACINGS VS % R. OF SINGLE ROD.

spacing, the earth resistances decreases and saturates after 6 m spacing.

So, 6 m spacing seems to be next to the optimum value of spacing among the electrodes for minimisation of earth resistance. **Multiple Electrodes-Fig. 4.6.5.(b) shows** multiple rods with different spacing gives resistence as percentage of single resistence. Where single rod is not feasible in field this graph gives an idea about the alternative solutions of multiple-rod combination without sacrificing the result. Multiple rods utilises the horizontal spacings instead of vertical depth.

4.7 VERIFICATION OF TWO-LAYERS SOIL FORMULA WITH EXPRIMENTAL RESULTS

J.Nahman, University of Belgrade, Yugosiovia, 1988 [30]has suggested the following simple semi-empirical expressions for the ground resistance of a single rod, driven in two layer soil, with notations -

ρ_1, ρ_2 = Earth resistivity of the upper and layer soil layers

L, d = Rod length and diameter

h = Depth of upper soil layer

L_1, L_2 = Rod length in upper and lower soil layer.

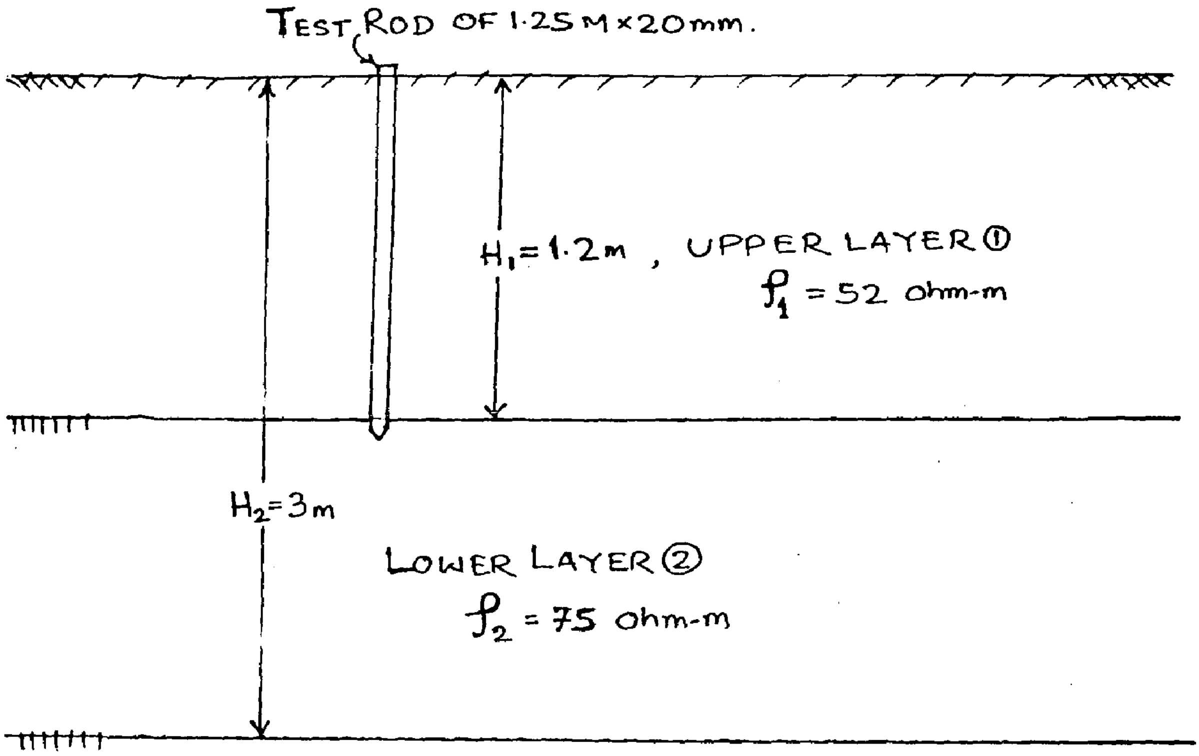


Fig.4.7.1(a) DRIVEN ROD IN TWO LAYER SOIL.

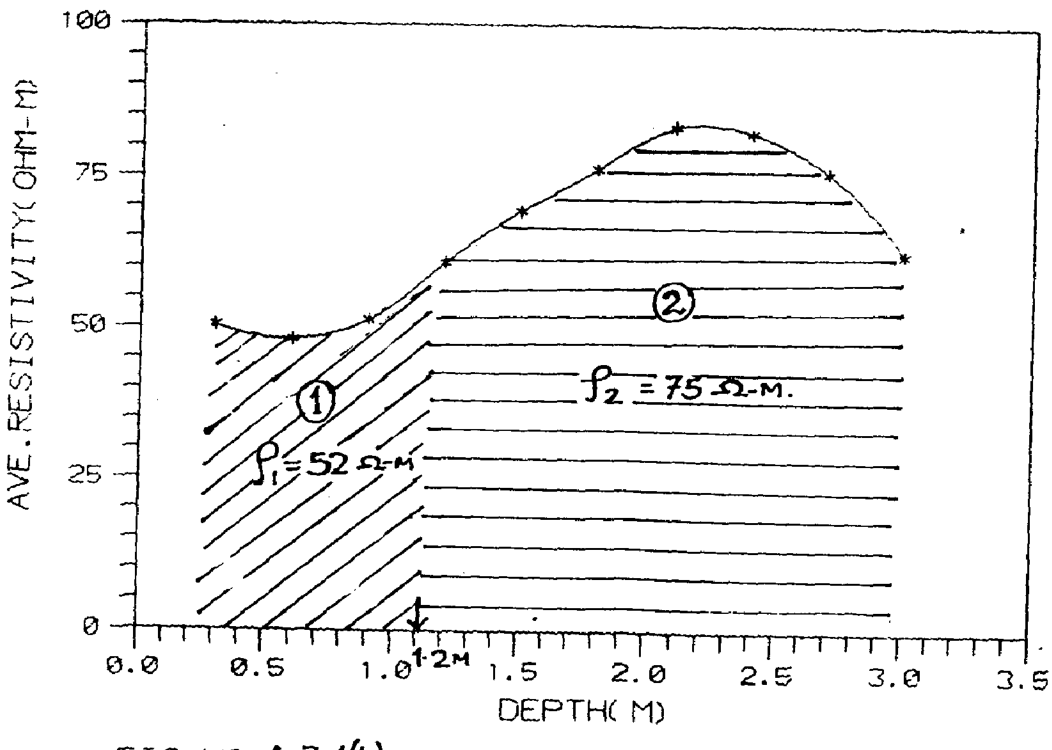


FIG NO-4.7.1(b)AVERAGE RESISTIVITY VS DEPTH

Case(a) Rod entirely lies in the upper soil layer with $\rho_1 > \rho_2$

The general rod formula $R = \frac{\rho_1}{2\pi L} \ln \frac{4L}{d}$

Case (b) Rod entirely lies in upper soil layer but $\rho_1 < \rho_2$

The empirimal formula for this

$$R = \frac{\rho_1}{2\pi L} \ln \frac{4L}{d} + \frac{\rho_1}{2\pi h} \ln \frac{\rho_2}{\rho_1}$$

Case (c) The rod lies in both soil layers

$$R = \frac{\rho_2}{2\pi Le} \ln \frac{4Le}{d}$$

where , $Le = 12 + L1 \cdot \frac{\rho_2}{\rho_1}$

Range of ratio of ρ_1 and ρ_2 = $0.1 \le \frac{\rho_1}{\rho_2} \le 10$

and $0.1 \le l/h \le 5$

The errors of these approximate formula is upto 10% except in case (a) which may yield upto 20% higher resistance

Calculated Result of Rod Resistance in 2 layered soil- The above statements are tried for a check in our 2 layer soil resistivity obtained in Table (3.6.1) and Fig. 4.7.1 (a).

(i) At .3mt depth (Rod in Upper Layer)

$$R = \frac{\rho_1}{2\pi L} \text{Ln} \frac{4L}{d} + \frac{\rho_1}{2\pi h} \ln \frac{\rho_2}{\rho_1}$$

ρ_1 = 52.00 ohm mt, ρ_2 = 75.0 ohm mt

L = .3 mt, d = dia of rod = 0.2 mt, h = 1.2 mt

$$R = \frac{52.00}{2\pi x.3} \log_e \frac{4 \times .3}{0.2} + \frac{52.00}{2\pi\ 1.2} \quad \text{Log} \frac{75}{52}$$

= 104.5 + 2.5 = 107 ohm.

(ii) At .6 mt depth (Rod in Upper Layer)

ρ_1 = 52.00 ohm mt ρ_2 = 75.00 ohm mt

$$R = \frac{\rho_1}{2\pi L} \text{Ln} \frac{4L}{d} + \frac{\rho_1}{2\pi h} \ln \frac{\rho_2}{\rho_1}$$

$$R = \frac{52.00}{2\pi\ 0.6} \log \frac{4 \times .6}{0.2} + 2.5 \quad = 64.0 \text{ ohm}$$

(iii) At .9 mt depth (Rod in Upper Layer)

$$R = \frac{52.00}{2\pi x.9} \log \frac{4 \times .9}{0.2} + .25 \quad = 45.0 \text{ ohm}$$

(iv) Rod Resistance at 1.25 mt depth, touching the lower layers

The rod length was 1.25 mt. and the entire rod was driven into the ground.

$$R = \frac{\rho_2}{2\pi Le} \text{Ln} \frac{4le}{d},$$

$$\text{Where } Le = L2 + L1.\ \frac{\rho_2}{\rho_1}\ ,L_2 = 0.05\ L_1 = 1.2\ \text{m}$$

$$= 0.05 + 1.2 \times \frac{75.00}{52.00} = 1.8\ \text{mt}$$

$$R = \frac{75.00}{2\pi\ 1.8} \ln \frac{4\ \text{x}1.8}{.02} = 39\ \text{ohm}$$

4.7.1 Discussion on Two Layer Results

Table 4.7.1 : Comparison of Experimental Results with 2 Layer Formula

Depth in (mt)		Calculated value of R from 2 Layer Formula	Experimental Value of R (ohm)
1.	.3	107	83.0
2.	.6	64	50.0
3.	.9	45	37.0
4.	1.25	39	30.0

The 2 layer formula of earth resistance has taken an approximate value from the original formula

$$R = \frac{\rho}{2\pi\ L}\left[\log \frac{4L}{a} - 1\right] \text{ as } R = \frac{\rho}{2\pi\ L}\left[\log \frac{4L}{d}\right]$$

where, 'a' is radius and 'd' is diameter of rod.

The used second formula gives the value at higher side about 10%. Otherwise both results of two layer resistance is a good approximation to the journal values. Hence it is confirmed here that the experimental results are correct.

4.8 SELECTION OF BEST EARTHING ARRANGEMENT :

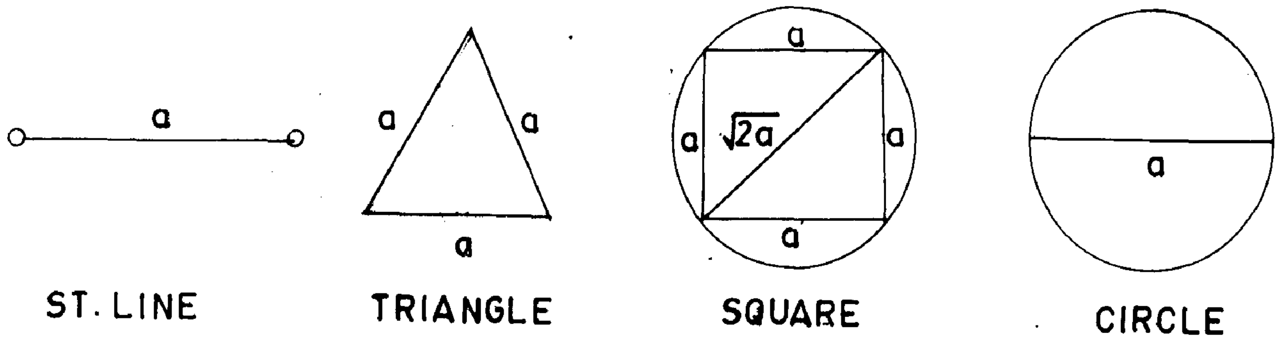


Fig 4.8.1(a) - DIFFERENT GEOMETRICAL CONFIGURATION OF ELECTRODE

4.8.1 Selection From Geometrical Configuration Fig. 4.8.1(a)

	Area	Perimeter
(i) Triangle of side (a)	$0.433\ a^2$	3a
(ii) Square of side (a)	a^2	4a
(iii) Circle of diameter (a)	$0.785\ a^2$	3.14 a
(iv) Circle of diameter ($\sqrt{2}a$)	$1.57\ a^2$	4.443a

Square is preferred so far area and perimeter is concerned but at the corner of a squasre grid, the potential will be higher being $\sqrt{2}a$ times away from the centre. So, if a circle of diameter $\sqrt{2}a$ is chosen, it offers more area (1.57 times) of coverage and of perimeter is also longer than that of a square (1.11 times).

The circular grid ring takes care of ground potential rise, E_{step} and E_{touch} potential and rods take care of depth of lesser conductivity of soil layers.

4.8.2 Selection From Test Results

From Fig. 4.6.5(a) it is seen that all values of resistances are converging towards one point at 8m spacing and from 6m to 8m spacing, all configuration have almost closure value of resistances. Two rods combinatin with 6 m sapcing seem to be economical without sacrificing much and hence can be choosen for a trial, and priliminary model earthing system. Higher spacings can be taken, subject to availability of space and so also the number of rods. With minimum materials optimisation is aimed. Results of 6 metre spacings for triangle & square configurations are also available [6] as shown on appendix IV by Karnatak Electricity Board, Banglore. 6 m finally choosen for comparision purposes also.

The inter connecting wire may be a straight wire or circular or elliptical shape covering more ground area. Again this may be on ground surface or under ground burial. The under ground burial

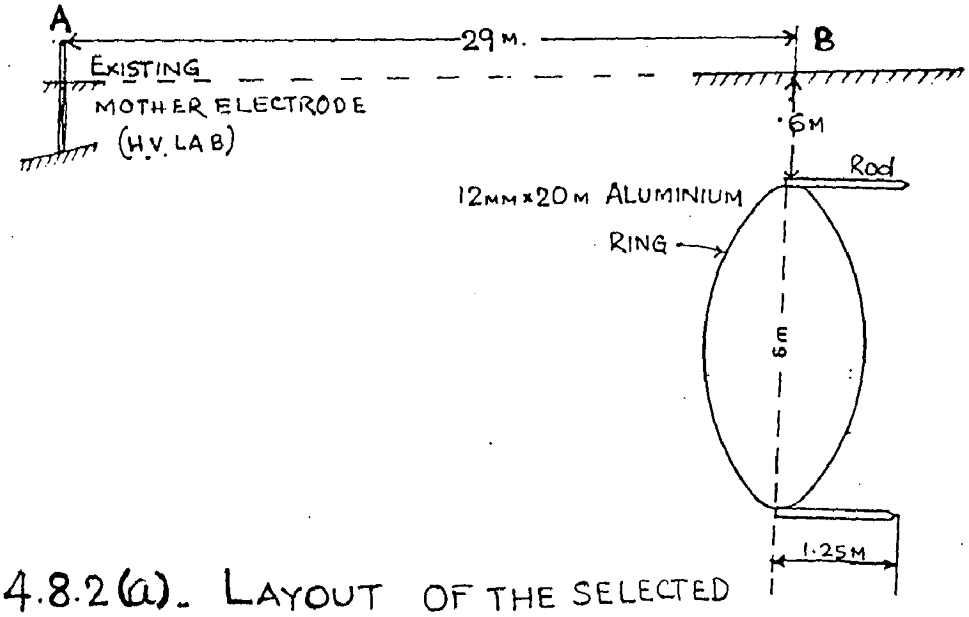


FIG. 4.8.2 (a). LAYOUT OF THE SELECTED EARTHING MODEL PERPENDICULAR TO MOTHER ELECTRODE (A)

is more advantageous in reducing the earth-potential rise and toueh potential [31].

Second decision is to be taken on how much burial of the connecting ring. From the view point of seasonal effects on resistivity, it has been observed that the resistivity and earth resistance of top soil varies more quickly and prominently in dry and winter season. And, it affects the soil moisture upto a depth of .5 to 1m from surface [14, 20]. Hence, it is preferable to bury the earth conductor ring below .5m deep and then the two electrodes are driven full length into the ground and connected to the ring Fig. 4.8.2 (a).

Electrode configuration chosen 6m. circular ring having two electrodes in diametrically opposite direction and to be inter connected by a 12 mm aluminum wire. About 2′ (0.6 m) soil was excavated and then the 2 electrodes are driven into ground by hammering. The aluminum wire with length about 20 mt (πD=18.8) was stretched and inter connected with 2 rods by binding aluminum wire tightly to rod. The RTD was placed just below the inter connection along the length of one electrode Fig. 4.10 (a).

The test earthing connection lead and RTD leads are enclosed on plastic pipes separately and brought to surface after back filling all the dry soil, excavated earlier. The moisture content of this backfill soil was tested to be about 4%.

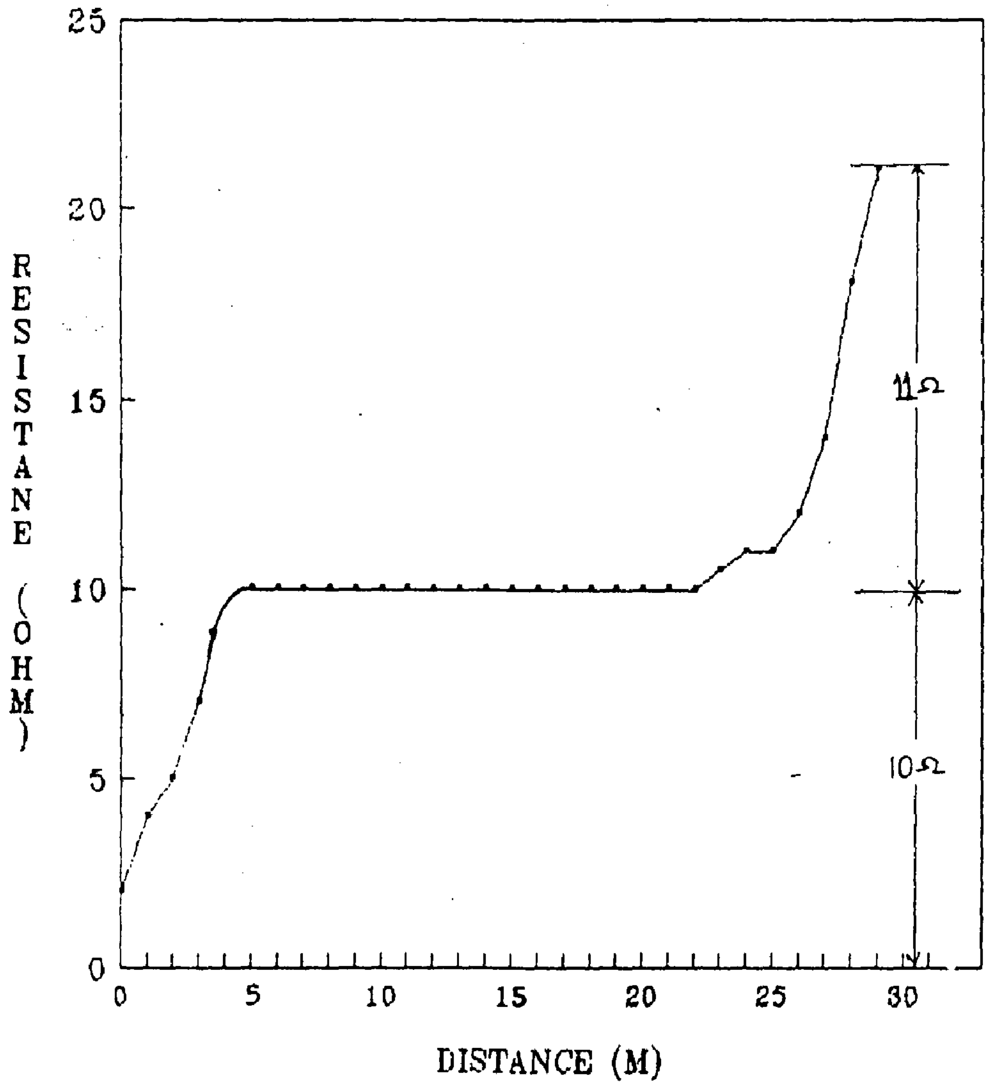


FIG.4.8.2(b) RESISTANCE MESUREMENT
PERPENDICULAR TO ELECTRODE AXIS

TABLE:4.8.2 FINAL RESISTANCE MEASUREMENT FROM H.V. LAB
MOTHER ELECTRODE (A) DTAED-30-11-95
DISTANCE 29 M

Distance (m)	Resistance (ohm)
0	2
1	4
2	5
3	7
4	10
5	10
6	10
7	10
8	10
9	10
10	10
11	10
12	10
13	10
14	10
15	10
16	10
17	10
18	10
19	10
20	10
21	10
22	10
23	10.5
24	11
25	11
26	12
27	14
28	18
29	21
30	11
.31	2
32	0

The soil consolidation (compaction) is done by manual hammering, without treating any water, to observe the value in the worst condition of dry soil.

The resistance of ring model earth system offered

11 Ω table 4.8.2 and graph Fig. 4.8.2 (b) perpendicular direction to a remote earth (Mother-electrode A) as shown in Fig. 4.8.2 (a).

4.9 SOME EXPERIMENTAL RESULTS ON ARTIFICIAL TREATMENT OF SOIL

Since there was no mother earth electrode available near High - Current Laboratory to pass current to earth for the heat run test, it was proposed to prepare one mother earth with artificial treated soil. The same earth was used for the experiment of the model earthing system.

4.9.1. Mathematical Review of Dimensions of Artificial treated Soil volume

From previous chapter (2.6) and Fig. 2.6 (d) it is known that by splitting up the high soil resitivity around the electrode into 2 parts, one treated soil (ρ_1) close to electrode and other one the common soil of earth mass (ρ_2), we have the net resistance of earth electrode of treated soil, -.

$$R_2 = \frac{1}{2\pi} \left[\frac{\rho_1 * b + (\rho_2 - \rho_1) a}{a * b} \right]$$

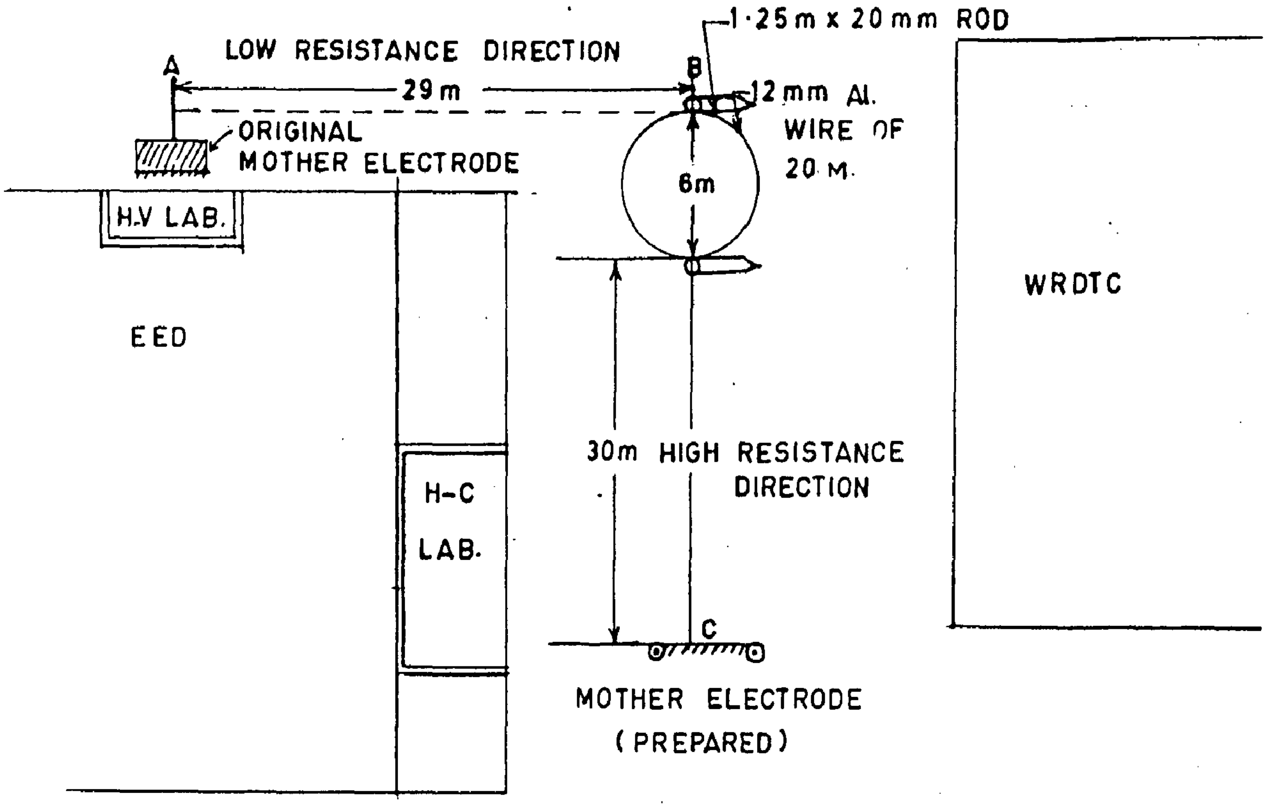


FIG - 4.9.2 (a) - LOCATIONS OF TEST SITES WITH EARTHINGS.

where, a = radius of metal electrode

b = radius of volume of treated soil (Asuming hemispherical volume) around the electrode.

If, R_1 = Original resistance of earth electrode prior to any treatment with common mass earth resistivity ($\rho = \rho_2$)

$$R_1 = \frac{\rho_2}{2\pi a} \text{ ohm}$$

Deviding R_1 with R_2 we get

$$\frac{R_2}{R_1} = \frac{1}{2\pi}\left[\frac{\rho_1 b + (\rho_2 - \rho_1) a}{ab}\right] * \frac{2\pi a}{\rho_2}$$

$$= \frac{\rho_1 b + (\rho_2 - \rho_1) a}{\rho_2 b}$$

$$= \frac{\rho_1}{\rho_2} + \frac{a}{b} - \frac{\rho_1}{\rho_2} * \frac{a}{b}$$

$$= \frac{\rho_1}{\rho_2}\left\{1 - \frac{a}{b}\right\} + \frac{a}{b}$$

If, ρ_2 ia much greater than ρ_1, in Rocky area such that $\frac{\rho_1}{\rho_2} \longrightarrow 0$, then

$$\frac{R_2}{R_1} \sim \frac{a}{b} \text{ or } R_2 = R_1 \frac{a}{b} \text{ ohm}$$

In otherwords, the treated soil merely increases the effective dimension of the electrode materials, in reducing ground resistance, since 'b' always made greater than 'a'.

4.9.2 Preparation of mother electrode with artificial treatment Using Betonite and coal-ash.

At High current laboratory site C as shown in Fig. 4.9.2 (a) a mother electrode was prepared by two rods (of 1.25 meterx 20 mm) having artificial treatment with Betonite and Coal Ash plus salt solution separately. Fig. 4.9.2 (b)

Single rod hammered in dry soil upto 1.2 meter offered 150 Ohm resistance

One 8" dia x 1.2 m deep hole filled with Betonitc 75% + 25 % clay soil with water Compaction the rod offered a resistance of 50 Ohm. Another 8" dia hole filled with Coal-Ash only with water compaction, the rod offered a resistance of 80 Ohm. After allowing 24 hours soaking with crystal salt (sodium chloride 25% solution) next day the resistance measured to be

Rod with betonite = 32 Ohm and after 24 hrs 30 Ohm

Rod with coal ash = 68 Ohm after 24 hrs 65 Ohm

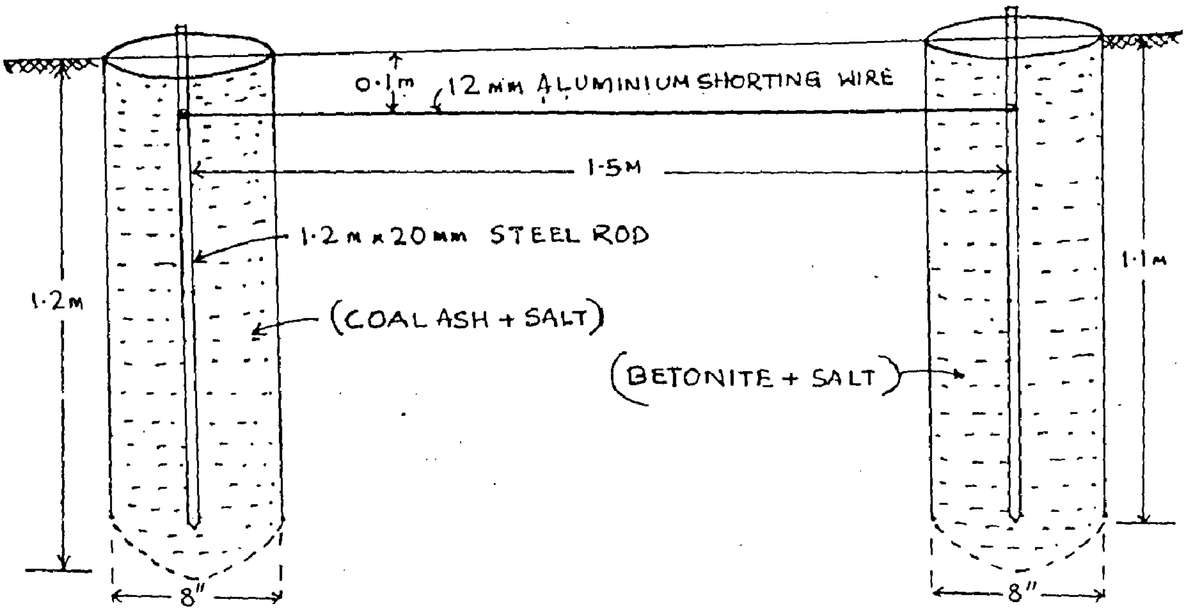


Fig. 4.9.2 (b) PREPARATION OF MOTHER ELECTRODE BY ARTIFICIAL TREATMENT.

This shows that the variation of resistivity with different treatment of soil. Lastly, both electrodes were connected by a 12 mm aluminium wire, 1.5 m long below 0.1 m ground level as shown in Fig. 4.9.2 (b).

The net resistance offered by two rods = 21 Ohm and next day (after 24 hours) 18 Ohms as shown in Table 4.9.2 and graph Fig. 4.9.2 (c). The differences of resistances are due to soaking effect and mositure absorption (salt solution) to dry soil in vicinity, increasing the effective diameter of the volume of treated soil.

4.9.3 CALCULATION OF RESISTIVITY OF BETONITE AND COAL-ASH FROM THEIR RESISTANCES

R_1 = Resistance of Untreated soil = 150 Ohm

R_2 = Resistance of treated soil $\begin{bmatrix} \text{Bet onite + Salt} = 30\ \Omega \\ \text{Coal-Ash + Salt} = 65\ \Omega \end{bmatrix}$

From 4.9.1 Theory of artifical treatment

$$\frac{R_2}{R_1} = \frac{\rho_1}{\rho_2}\left[1 - \frac{a}{b}\right] + \frac{a}{b}$$

where,

ρ_1 = Treated soil resistivity

ρ_2 = Common mass earth resistivity, in present case it is about 110 Ω mt. from table 3.7.1

TABLE:4.9.2 FINAL RESISTANCE MEASUREMENT FROM H.C. LAB MOTHER ELECTRODE (C) DATED-3-12-95

Distance (m)	Resistance (ohm)
0.5	2
1	3
1.5	6
2	11
3	15
4	17
5	18
6	18
7	18
8	18
9	18
10	18
11	18
12	18
13	18
14	18
15	18
16	18
17	18
18	18
19	18
20	18
21	18
22	18
23	18
24	18
25	18
26	18
27	18
28	18
29	18
30	18
31	18
32	19
33	22
33.5	24
34	27
34.5	30
35	32
35.5	34
36	37

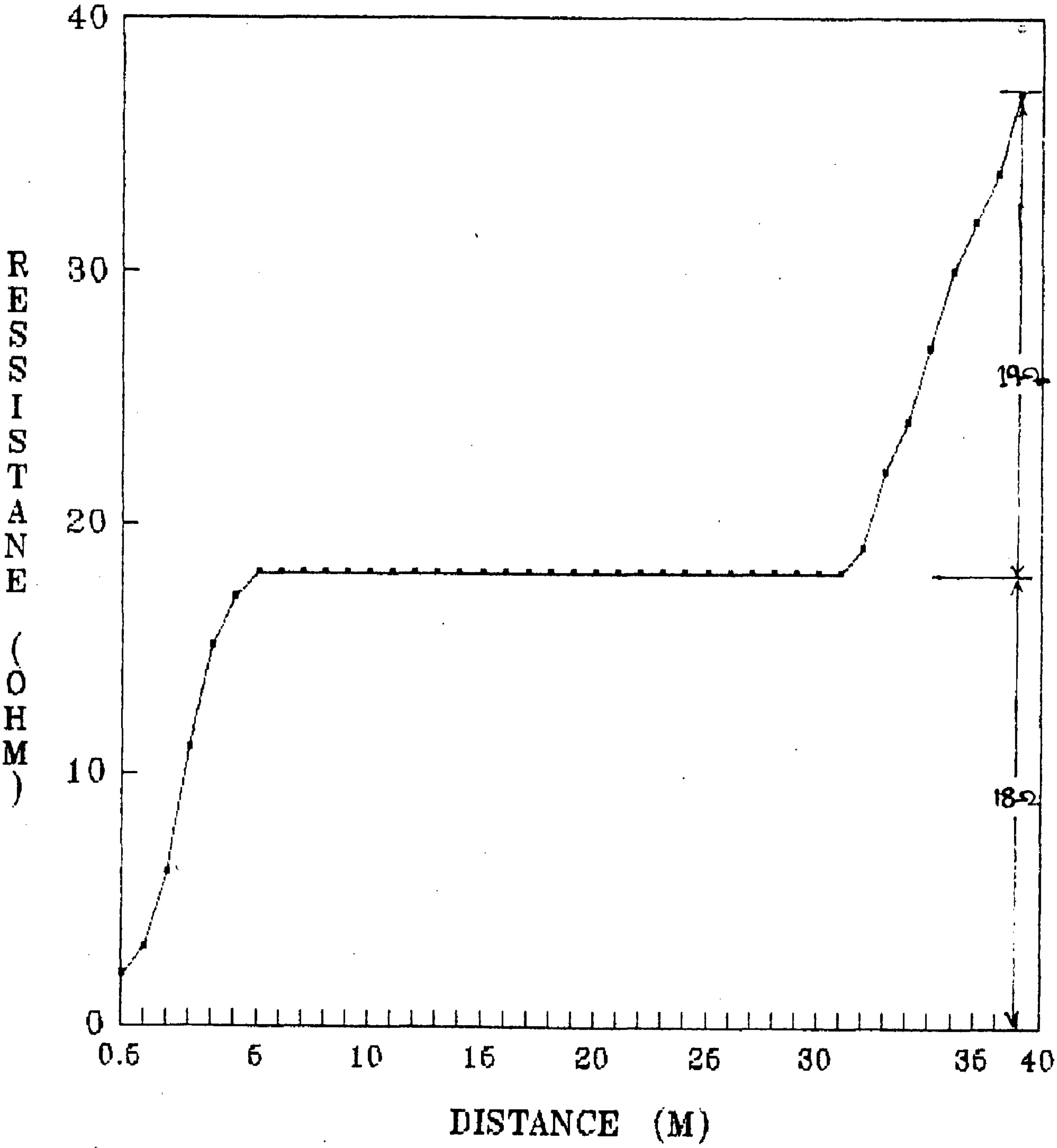


FIG.4.9.2(C) RESISTANE MEASURMENT ALONG THE ELECTRODE AXIS

a = Radious of electrode Rod = 10 mm = 0.01 mt.

b = Radious of treated soil hemisphere = 4" = 10cm = .1 mt

For Betonite,

$$\frac{30}{150} = \frac{\rho_{(Betonite)}}{110}\left[1 - \frac{.01}{.1}\right] + \frac{.01}{.1}$$

$$\frac{1}{5} = \frac{\rho_{(Betonite)}}{110}\left[1 - \frac{1}{10}\right] + \frac{1}{10}$$

$$= \frac{\rho_{(Betonite)}}{110} \times 0.9 + .1$$

or $$\rho_{(Betonite)} = \frac{.1}{.9} \times 110 = 11.11\ \Omega\text{-mt.}$$

For Coal Ash,

$$\frac{65}{150} \quad \frac{\rho_{(Coal-Ash)}}{110}\left[1 - \frac{1}{10}\right] + \frac{1}{10}$$

or, $$\frac{13}{30} = \frac{\rho_{(Coal-Ash)}}{110}\ 0.9 + 0.1$$

or, $$\rho_{(Coal-Ash)} = \frac{0.33}{0.9} \times 110 = 41\ \Omega\text{-mt.}$$

4.9.4 Discussion on Artificial Treatment

Only betonite offered 30 Ω and only coal-ash offered 65 Ω and combindly offer 18 Ω as seen from resitance curve at Fig. 4.9.2 (c).

It is observed that the coal ash has shown some improvement than ordinary soil of the site but less effective than Betonite. This is also confirmed from the following laboratory tests (WRDTC).

	pH Value	Electrical Conductivity mm/cm
i)Soil at test site	7.3 (Alkaline)	0.16
ii)Coal ash(Brick Kiln)	6.3 (Acidic)	0.22
iii)Betonite clay	8.6 (Alkaline)	0.37

From the Calculations of registivity, value of Betonite agrees with the result of K.S.E.B. Research Directorate, Bangalore (1993) [34]. But there is no previous reference values available so far for the registivity of Coal-Ash of brick kiln. However, its registivity is less than common soil. Betonite + Salt offers better result than coal ash + Salt, but Benonite is costlier. Coal ash is chiefly available. Betonite is alkaline and coal + ash is acidic in nature, as seen from their pH values.

4.10 GROUND ELECTRODE HEATING AND TEMPERATURE RISE

Electrode may be subject to the following 3 types of loading.

a) Small current for long duration

b) large current for short duration (impulse)

c) large current for long duration (S.C. current).

Case (a) is only considered at present for the work. With long duration loading the predominating factors are the heating of the comman mass of soil and the conduction of heat away from the electrode. If the thermal resistance is high and heat conduction does not take place, it forms a crust of high resistivity layer of dry soil adjacent to the electrode.

As per Sunde [26] and Taylore [33], if the thermal resistance increases, the electrical resistance also increases, and as such.

$$\frac{\text{electrical conductivity}}{\text{Thermal co ductivity}} \text{ is a constant for any soil}$$

4.10.1 Temprature Distribution around a spherical ground electrode [26, 33]

Heat (H) genrated within the electrode 1^2R, KCal.

I = Current

R = Resistance between rod and soil. sphere

having a redius $x = \frac{\rho}{4\pi x}$.

Heat at any point x, $H = -\ 4\pi x^2\lambda.\ \frac{d\theta}{dx}$

θ = Temperature of ground at radius X

λ = Thermal conductivity of soil

$$\therefore H = -\ 4\pi x^2\lambda\ \frac{d\theta}{dx} = I^2.\ R$$

$$= I^2.\ \frac{\rho}{4\pi x}$$

or $$d\theta = \frac{I^2 \rho \, dx}{4\pi x^2 \lambda \; 4\pi x}$$

Intigrating both sides, $$\int d\theta = \int_r^x - \frac{I^2 \rho \, dx}{16\pi^2 \lambda \, x}$$

$$\text{or} \quad \theta = \frac{\rho I^2}{32\pi^2 \lambda \, x} \left[-\frac{1}{r} - \frac{1}{2x} \right]$$

Temperature is maximum at rod surface, where x=r

$$\therefore \theta_{max} = \frac{\rho \, I^2}{32 \, \pi^2 \lambda \, r^2}$$

$$\text{or } I^2 = 2 \, \frac{\theta_{max} \, . \lambda}{\rho} \times 16\pi^2 r^2$$

$$= 2 \, \theta_{max} . \lambda . \rho \times \frac{16\pi^2 r^2}{\rho^2}$$

$$= 2 . \theta_{max} . \lambda . \rho \, \frac{1}{R^2} \quad \left[\because \; R = \frac{\rho}{4\pi r} . \right]$$

$$\text{or} \quad I = \sqrt{2 . \, \theta_{max} \lambda \, \rho} \; . \; \frac{1}{R}$$

$$\text{or } IR = \sqrt{2 . \theta_{max} \lambda \rho}$$

or potential, $V = \sqrt{2\theta_{max} \lambda \rho}$ volt

If, θ_{max} is assumed constant , the potential (v) depends on square root of thermal conductivity and resistivity (or, electrcal conductivity) of soil. From the above equation, it is evident that potential is independent of the size of the electrode and dependent only on the characteristics of the soil i.e. (θ, λ and ρ). The above equation can be written as

$$\theta_{max} = \frac{1}{2} \frac{1}{\lambda \rho} V^2$$

$$= \frac{1}{2} \cdot \frac{\sigma}{\lambda} V^2 = \frac{1}{2} CV^2$$

Where, c = constant = $\dfrac{\text{electrical conductivity of soil}}{\text{Thermal conductivity}}$

$= 1x10^{-2}$ to $3x10^{-3}$ C/volt^2 for clay soil

4.10.2 HIGH CURRENT EXPERIMENT ON THE SELECTED EARTHING ARRANGEMENT

The experimental setup was made ready as shown in Figure 4.10.2 (a)The test electrode was buried at 0.6 mt. under ground along with the RTD and the leads connections of electrode and RTD were separately brought to surface with proper insulation from each others. At about 36 mt away from the test electrode, the mother earth was also prepared as discussed in previous topic 4.9, near High Current Laboratory to feed 230 V A.C. suply to earth the phase line connected to the test electrode terminal and neutral to the mother earth electrode.

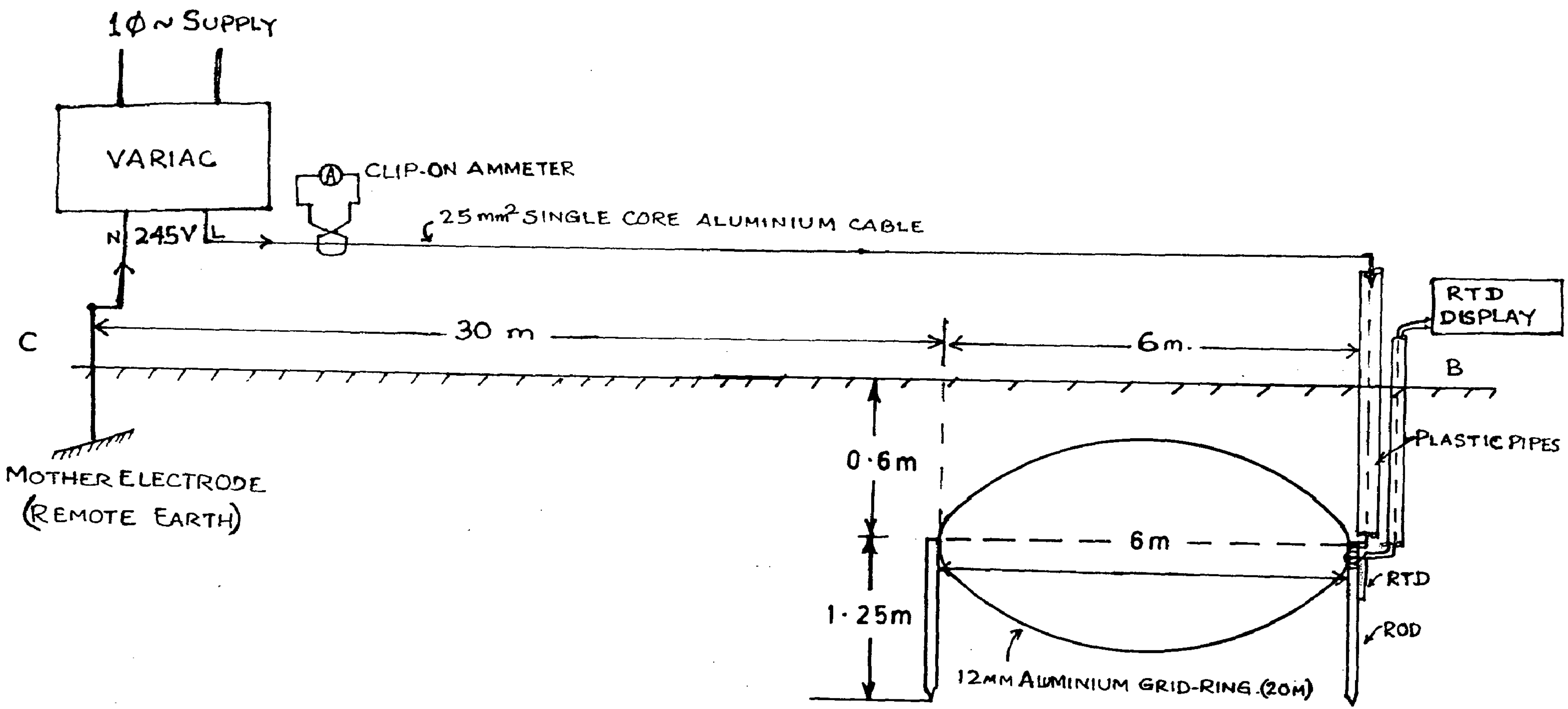


FIG. 4.10.2(a)-EXPERIMENTAL SETUP OF THE SELECTED EARTHING ARRANGEMENT.

TABLE NO- 4.10.2(i)

TIME Vs CURRENT & TEMPRATURE RISE TEST

TIME	CURRENT (A)	RESISTANCE V/I	RTD READING °C	ACTUAL TEMPRATURE °C
18.00	5.5	45.4	32	22
19.00	4.5	55.4	32	22
20.00	3.5	70	32	22
21.00	3.5	70	32	22
22.00	3.4	72	33	22.5
23.00	3.3	72	33	22.5
24.00	3	74.2	35	24
1.00	2.5	81.7	–	–
2.00	2.3	98	–	–
3.00	2	106.5	–	–
4.00	1.8	122.5	–	–
5.00	1.6	136.1	–	–
6.00	1.6	153.1	65	37
7.00	1.6	153.1	70	39
8.00	1.6	153.1	75	40
9.00	1.6	153.1	80	41
10.00	1.5	163.3	85	42
11.00	1.4	175	90	43
12.00	1.3	188.5	95	44
13.00	1.2	204.2	100	46
14.00	1.2	204.2	105	47
15.00	1.2	204.2	109	48
16.00	1.2	204.2	112	49
17.00	1.2	204.2	112	49
18.00	1.2	204.2	112	49
19.00	1.2	204.2	112	49

Table 4.10.2(ii)

Potential Measurement with Digital Voltmeter from mother Electrode

Distance of Electrode	Voltage	Distance	Voltage
.5 mt	1.1V	30 mt	24.7 V
1.0 m	2.36 V	31 mt	13.0 V
1.5 m	3.2 V	32 mt	0.0 V
2.0 m	3.6 V	33 mt	9.0 V
2.5 m	3.9 V	34 mt	10.0 V
3.0 m	3.7 V	35 mt	12.0 V
4.0 m	4.2 V	36 mt	18.0 V
4.5 m	4.8 V	37 mt	11.3 V
5.0 m	4.8 V	38 mt	7.8 V
6.0 m	5.0 V		
7.0 m	5.1 V		
8.0 m	5.1 V		
Volt. Constant from 9m-22m.			
23.0 m	5.1 V		
24.0 m	5.2 V		
26.0 m	6.9 V		
28.0 m	7.9 V		
29.0 m	9.0 V		
30.0 m	24.7 V		

4.10.2(iii)

TABLE NO: RESIDUAL VOLTAGE READINGS AFTER SUPPLY OFF. FROM MOTHER ELECTRODE TO RING ELECTRODE

Distance (m)	Voltage (v)
0	0.001
0.5	0.04
1	0.08
2	0.09
3	0.15
4	0.19
5	0.21
6	0.23
7	0.24
8	0.24
9	0.24
10	0.24
11	0.24
12	0.24
13	0.24
14	0.24
15	0.24
16	0.24
17	0.24
18	0.24
19	0.24
20	0.24
21	0.24
22	0.24
23	0.24
24	0.24
25	0.24
26	0.24
27	0.25
28	0.26
29	0.31
30	0.31
31	0.31
32	0.32
33	0.34
34	0.37
35	0.43
36	0.64
37	0.45
38	0.23

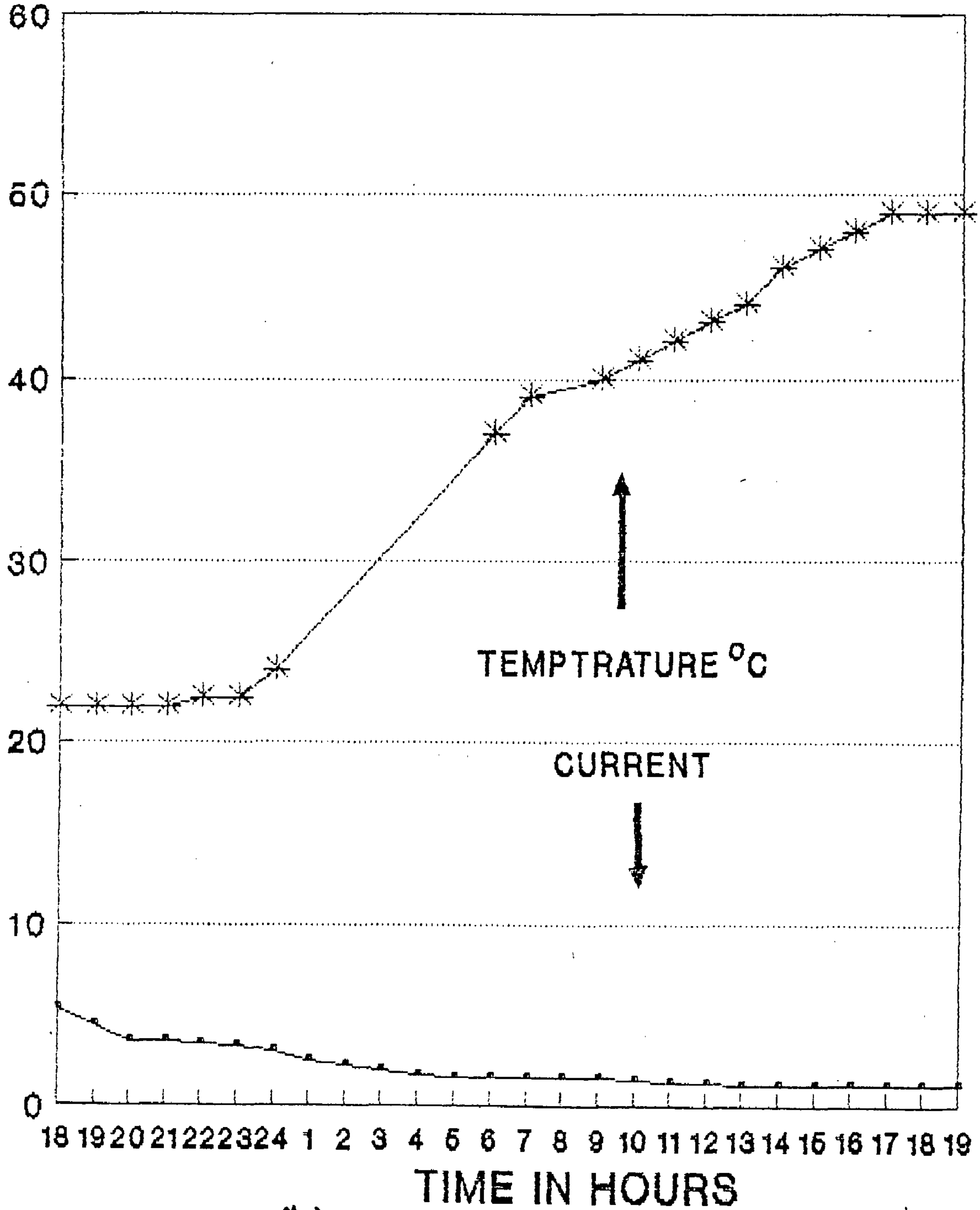


FIG.4.10.2(b)-TIME VS CURRENT & TEMP.

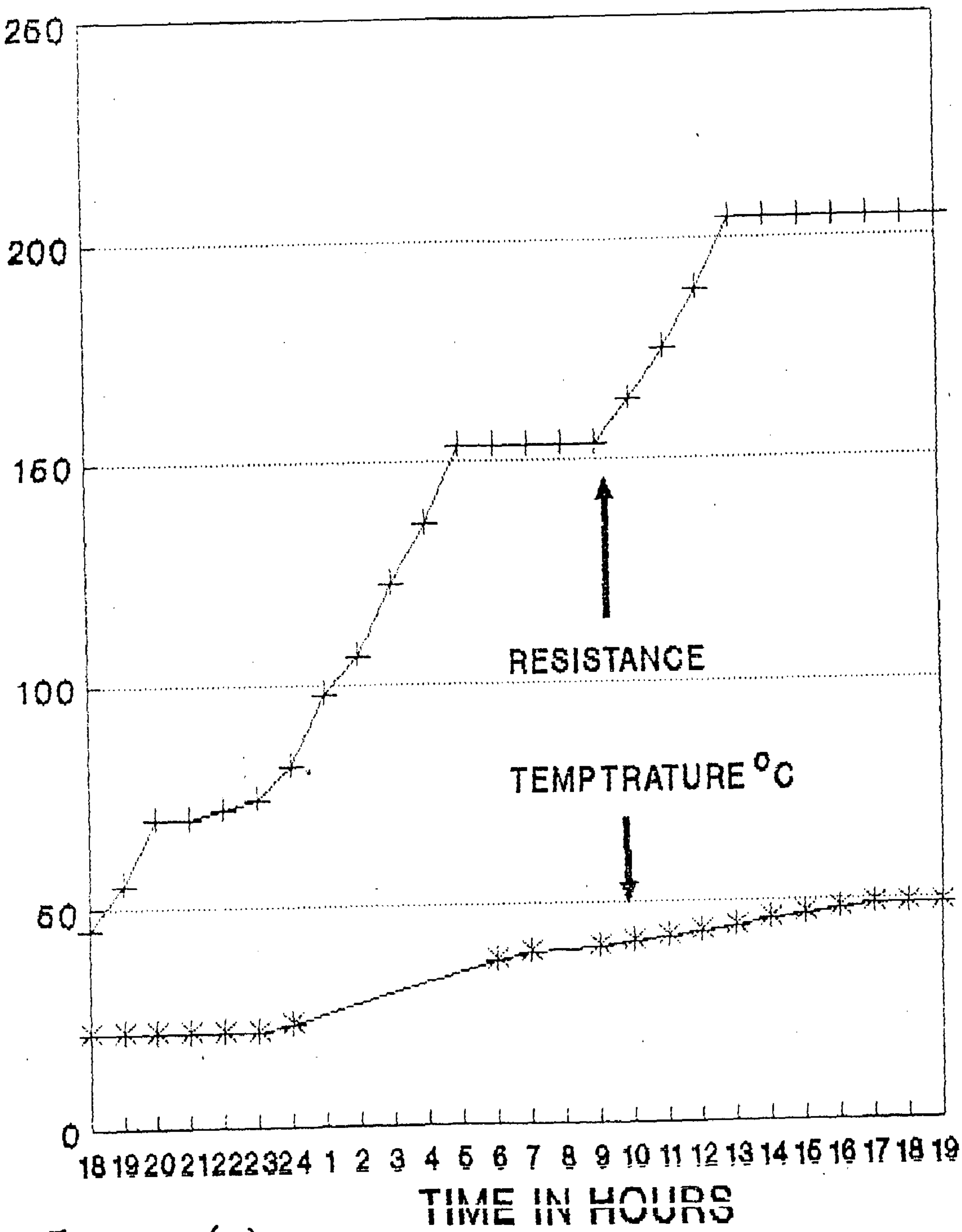


Fig.4.10.2(c) - TIME VS RESISTANCE AND TEMP.

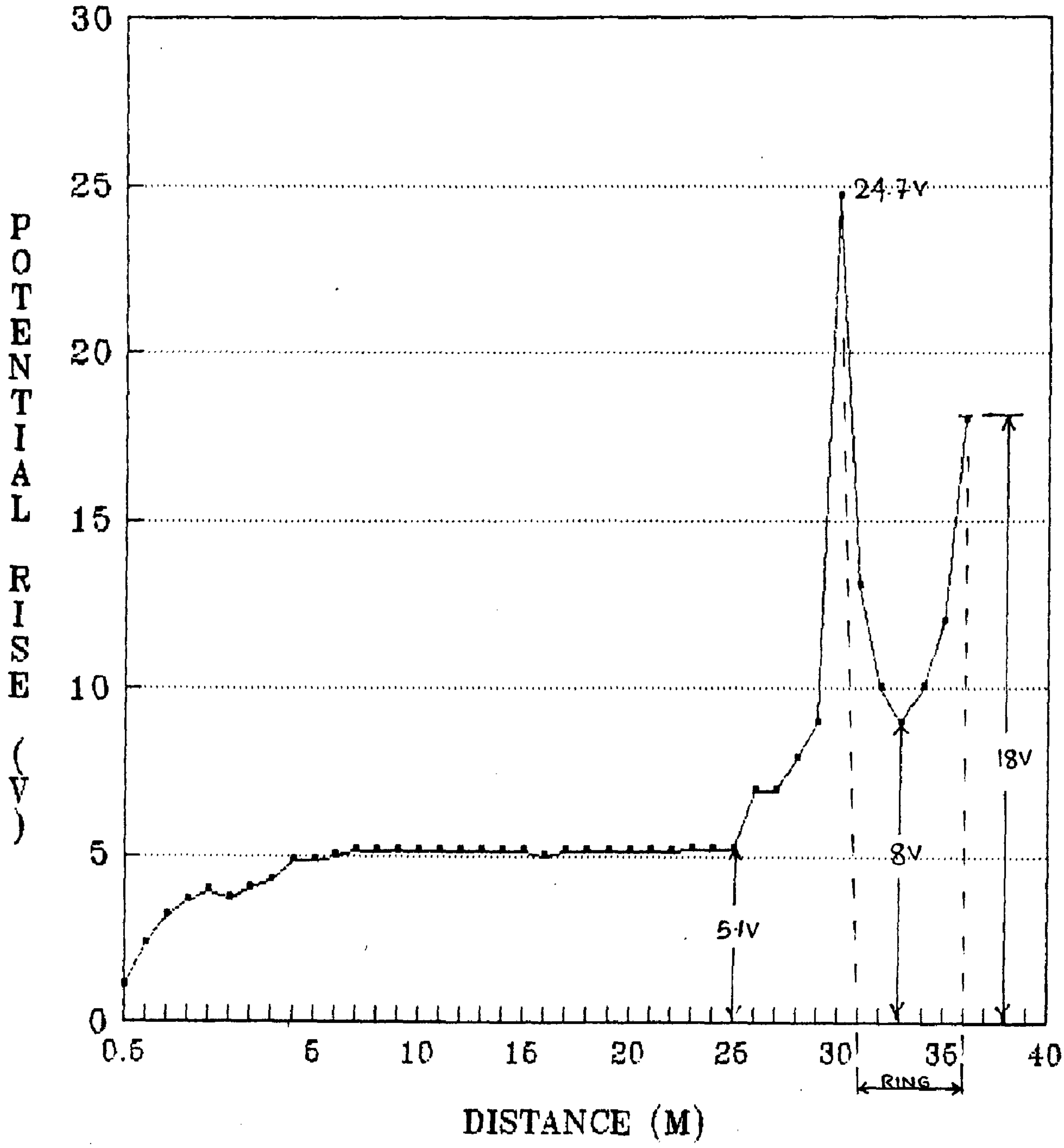


FIG.4.10.1(d) POTENTIAL MEASUREMENT FROM MOTHER ELECTRODE-C

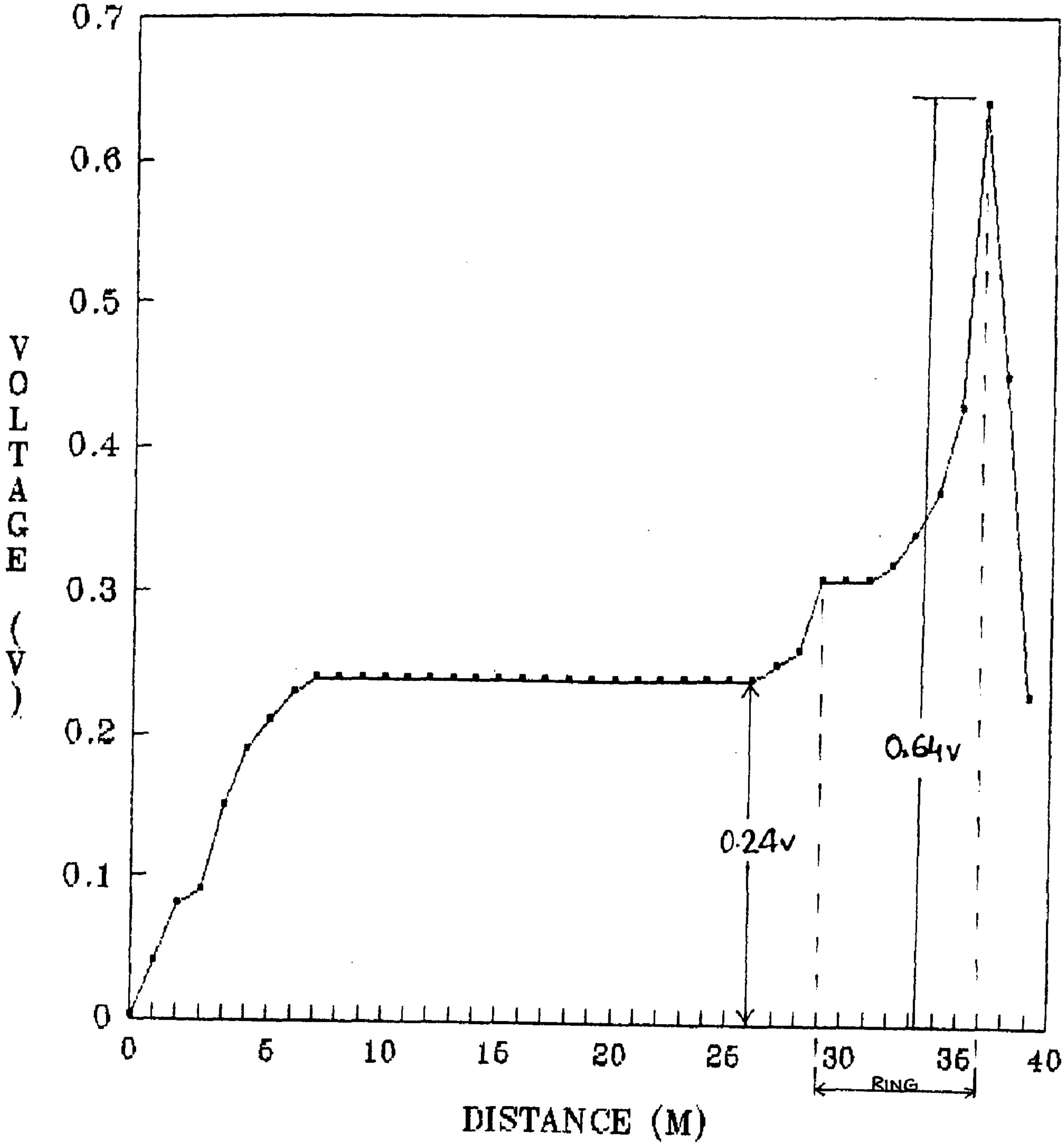


FIG4.10.2(e)RESIDUAL VOLTAGE CURVE

TABLE NO. 4.10.2 (iv)

R T D CALIBRATION

R T D Reading °c		Actual Temperature °c
28	--------	18
32	--------	22
42	--------	28.5
82	--------	42
124	--------	53
135	--------	58
158	--------	66
172	--------	72
183	--------	82
194	--------	92
196	--------	96

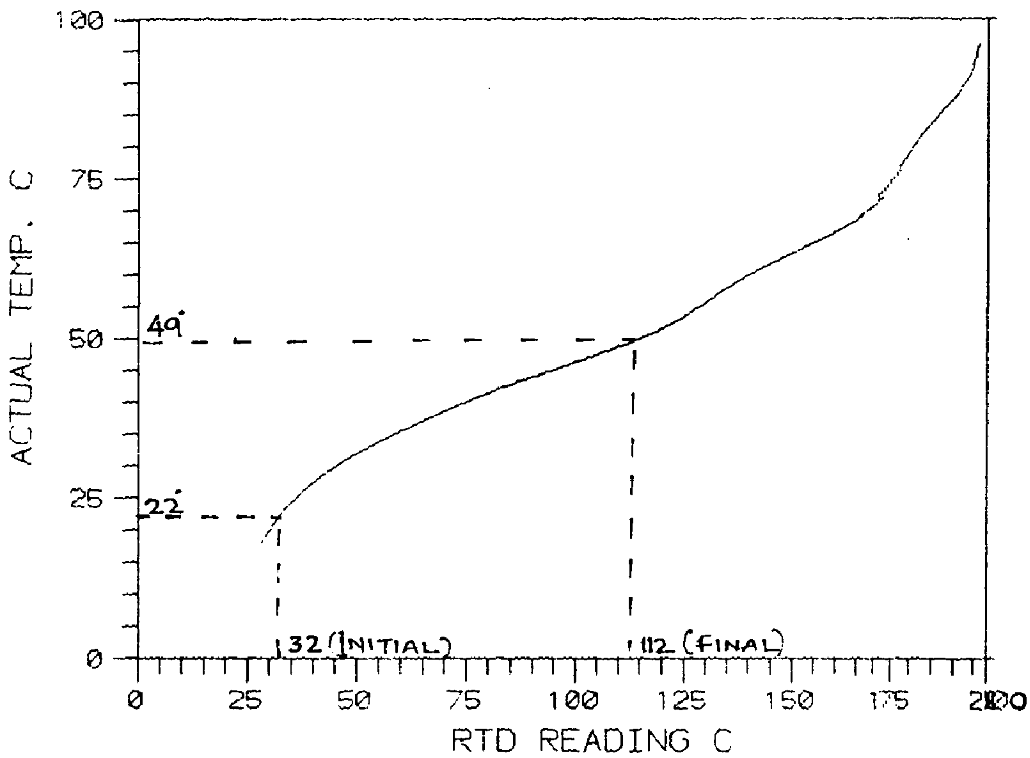


FIG NO 4.10.2(f) R.T.D. CALIBRATION GRAPH

With high current about 5-10 Amp, was planned to pass continuously for observation of temperature rise, potential rise at electrode. But due to lack of capacity of transformer/variac, only 5.5 Amp. was made available. The initial and final readings are noted as follows Applied voltage (Single phase) = 245 V

Initial current = 5.5 Amp.(AC)

Initial resistance = 45.5 ohm

Initial soil temperature at 0.6 meter sub-soil near electrode (RTD) = 22^0C

Atmospheric Temperatore during day time = 18^0C, during night 14^0C

Initial mositure content of back filled soil = 4.2%

After 19 hrs continuous supply current reduces to = 1.2 Amp. & remains steady

After 19 hrs. resistance = 204.2 ohm remain steady

After 22 Hrs. Temperature = 49^0 c and remains steady

After 48 hrs. with supply off moisture content of soil at .6 mt depth near RTD = 2%

4.10.3 Calculation of potential rise (v) & Temperature Rise

Result Tabulation-Resistence and temperature rise Table 4.10.1 (i), Potential Rise Table 4.10.2 (ii). Residual Voltage

Measurement 4.10.2 (iii), RTD calibration Table 4.10.2 (iv).

Grpahs - Fig. 4.10.2 (b) Time Vs Temperature and Current

- Fig 4.10.2 (c) Time Vs temperature and resistance
- Fig. 4.10.2 (d) Distance Vs potential Rise in volt
- Fig 4.10.2 (e) Residual Voltage Curve
- Fig. 4.10.2 (f) - RTD Vs Actual Temperature

The analytical temperature rise from theory, at 4.10.1.

$T_{max} = 1/2\ CV^2$

where, C = Electrical conductivity/thermal conductivity

$= 3 \times 10^{-2}$ (for clay soil)

V = Potential at the ring periphery

= 24.7-5.1 = 19.6 V

$T_{max} = 1/2 \times 3x\ 10^{-2}\ 19.6^2 = 6^0c$

The actual temperature rise observed from RTD display and its calibration graphs

$= 49-22 = 27^0C.$

4.10.4 History and Discussion of Results of past scientists on Heat-Run test

As per [33] some of the results of past scientists are given below

(i) **O.B.BOTEN (1924)** observed in his experiment on a pipe electrode whose resistance increased to several hundred of ohms with 1-2 Amperes of continuous current(AC). When resistance increased to a high value, steam was also observed rising from around the pipe & the temperature inside the pipe measured to be 100^0 C. Cooling the pipe by pouring water inside pipe, caused the resistance to drop back to normal.

(ii) **G.VIEL (1930)** In order to observe the consistency (steady value) of earth electrode resistance in an earth return of H.V. single phase A.C. for Rural Electrification, Viel had chosen a plate electrode of one square meter size, buried vertically in a bed of crushed coke to a depth of 2.5 Mts. Applied voltage 84 v & current 1.4 Amp (A.C) continuously for 4 years to observe the seasonal effect on resistance variation.

He observed no appreciable temperature rise, because the resitance of coke is largely un affected by moisture.The Thermal & electrical conductivity of coke are also very good.

(iii) **T.C GILBERT (1932)** Observed in his experiment on a pipe electrode of 11 feet and 1" diameter carrying current of 1 amp (AC) with applied voltage 90v, into the ground of sandy/gravel soil of resistivity about300 ohm-m, caused the electrode earth resistance to increase in few hours from 90 ohm to 420 ohms. High resistivity sandy/gravel soils have poor thermal conductivity and is the cause of temperature rise.

4.10.5 DISSCUSSION OF HEAT RUN TEST

The theoretical temperature rise(6^0C) and the actual temperature rise (27^0C) differs appreciably because this test is not so sensitive having controlled parameters, like model tests conducted in the laboratory. This is a coarse-method of testing which may not match perfectly with theoretical calculated value.

Secondly, there are so many uncontrolled parameters of soil moisture content, imperfect soil consolidation leading to creation of contact resistance.

i) During back filling of the ring and rod electrodes it was made with completely dry soil and compacted manually, without any water.

ii) Secondly, any slight-looseness might have created some voids along the surface of contact, there by increasing the contact resistance. iii) This increased contact resistance generates heat (I^2R loss) and temperature rise. iv) With continuous temperature rise and under certain condictions it warm up the earth electrode environment and try to evaporate whatever remnant moisture is in the vicinity. Again this, evaporation of moisture cumulatively effects in increasing the resistance and temperature rise progressively.

High Current Test of about 10 Amp. or more was in plan for test. But the high current transformer available could not give more than 5.5 Amp. due to lack of capacity.

After heat run test, with supply made off, the potential measurement with digital voltmeter was done from mother electrode which shows a negligible residual voltage rise from 0.001 to 0.64V upto the connecting lead of electrode ring. This indicates that our results are not ofset by any background earth current.

From the graph of potential rise Fig. 4.10.2 (c), it is seen that the ground surface potential rise is maximum (24.7V) at the front side of ring periphery (30 m) from the remote earth. At the centre of the ring (33 m) 8 V and at the opposite and (36 m) 18 V and decreases beyond 36 m. These potential rise is with respect to the mother earth (remote earth) which is not at zero potential but its potential is at 5.1 V, as seen in Graph. The maximum potential rise 19.6 V is well below the limit of 32 volt.

CHAPTER - 5

CONCLUSIONS AND SUGGESTIONS

All the experiments have been performed in normal ground with general purpose instruments available in the Electrical Engineering Department Laboratory. No special or sophisticated instruments or techniques were used in this work because only a comparative study was contemplated.

5.1 Resistivity survey and measurement gives an indication of the different subsoil layerings and its conductivities, so that while designing, it helps to fix the electrode length atleast upto that level, for preliminary calculations. The measurements show a two layer structure of the test sites.

5.2 From Table 3.7 [iii] and Graph Fig. 3.7(c), it is concluded that regular soil moisture measurement shows that there is a rise and fall of moisture content in soil (at a particular depth of 0.6 meter observed) from month to month. This rate of variation is ofcourse less with deeper soil strata. Hence, the top 0.5 to 1 m depth of soil from surface seems to have been prone to more seasonal changes of moisture and temperature also.

If the electrodes are put beyond this depth, the electrode encounters less effect of change of seasonal resistivity. Hence, the ground resistance offered by a particular system remains almost at steady value which does not go beyond certain limit, fixed as per design value.

Secondly, the ground potential rise minimises when the electrode is put at certain depth below the ground.

5.3 From 3 point measurement of resistance, the rods when put in straight line along the line of mother electrode, offers more resistance, than when put in perpendicular direction to the line of measurement as shown in Fig. 4.6.2 and 4.6.3.

In SWER System, if the 33/11 kV substation neutral earthing is treated as remote mother earth, the electrode configuration axis should be perpendicular to the line joining the remote earth to the distribution transformer using such grounding arrangements. During our experimental observations for a two rod and a ring conductor ground electrode behaves as follows, in two different directions perpendicular to each other.

Resistance offered by Ring electrode with reference to mother electrode at A = 11 Ohm

Resistance offered by Ring electrode with reference to mother electrode at C = 19 Ohm Fig. 4.9.2(a)

5.4 The selected Ring Electrode burried below 0.6 m of depth and backfilled with dry soil and packed manually, without any treatment of water or chemicals, gives a potential rise of 19.6 V with an A.C. current flow of 1.2 Amp during experiment. This is actually high resistance direction choosen for test. In perpendicular direction, with respect to mother electrode (A), the same grounding will give rise to (11 Ohm x 1.2 Amp.) =13 Volt potential rise which is still less.

Further, if a chemical or artificial treatment is applied to this grounding system with proper care of consolidation and compaction, the 11 Ohm earth resistance may reduce to one third of its values (as seen in the case of Botonite + Salt or Coal Ash + Salt). Hence, an ultimate lower value (11/3 = 3.6 Ohm), can be expected, from this test electrode (Ring Model). With less than four Ohm earth resistance, it is now capable of taking about 8 Amp. normal rating current of a 50 KVA distribution transformer, with safe potential rise of (8A x3·6 Ohm) =28·8 Volt, as seen from Table 1.1.1.

If, by chance, this grounding-resistance increases due to ageing in future, this can be controlled easily, by putting one/two more rod-electrodes inside ground, along the periphery of ring conductor. To achieve further lower value of earth resistance, the diameter of ring is to be increased more than 6 m.

5.5 COMPARISON OF EARTH RESISTANCE OF THE MODEL ELECTRODE

With results of Research Directorate, K.E. Board, Bangalore [6] as shown in Appendix IV.

Research Directorate KEB Result	**Test Result of Selected Earthing**
(a) At 50 Ω-mt resistivity-3 electrodes in triangular configuration 3m long 4cm dia. electrode with spacing 6 mts. offers 5.2 Ω.	1.25 mtrs. x 20 mm dia. rods triangular configuration 6mt. spacing offers 7.5 Ω (Aug.'95) with soil resistivity 52Ω-mt.
(b) At 100 Ω-mt, resistivity 2 electrodes of 3 mt long in a square grounding grid 6mx6m with a depth of burial 0.9 mt and m.s. galvanised 7 mm conductor offers 7.1 Ω ground-resistance.	(b) 2 electrodes 1.25mx20 mm connected to a circular-grid ring of 6mt. diameter with a depth of burial 0.6mt and Aluminium conductor of 12 mm dia offers 11 Ω in axial direction, with soil resistivity 110 Ω-m (Dec.'95)

The variation between the above two results may be due to variation in length of electrodes, otherwise, both results are in close approximation at both the values of soil resistivites.

Besides, there is difference in type of soil, site conditions, instruments used and type of shorting (clamping or binding) for making the rods connected parallel.

5.6 SUGGESTION FOR FUTURE WORKS

5.6.1 TECHNICAL WORKS:

(i) Further study needs on impulses current test and longterm observation with currents more than 10 Amp. to be investigated on SWER earth electrode.

ii) This test also can be carried out in different types of soils like sandy/gravel soil and snow fall areas.

(iii) As per CBIP Annual Review 1965 [4a], 4% cement + 4% NaOH (by weight of soil) gives vary good result of low earth resistance. As per CBIP 58th Research Session April'1993 [34], Thermal Power Plant fly-ash also gives some satisfactory result next to Betonite. Since, cement is costlier and may not have good binding with soil mixture, cement plus fly-ash combinations with NaOH treatment may be investigated in different proportions, for artificial treatment to electrodes. It is expected to give good result and long life due to the presence of NaOH (Alkaline).

5.6.2 Environmental Impact Assessment

i) As per [4a], the possible warming-up of soil and movement of moisture (Electrolysis) in soil may be studied in Agricultural fields upto the root-depth of 1.5 mt. Its electro-chemical changes in soil and possibility of fertilizer-effect on vegetation also need to be investigated.

(ii) As per [35], impact of electric and magnetic field due to continuous earth current, on the biological behaviours of under ground creatures, micro-biological behaviours of under ground creatures, micro-biology-changes on soil microbia-population, soil fertility etc. may need to be investigated.

iii) Possibility of explosion hazards due to earth-current flow in areas having explosive gases and materials inside and outside the earth surface also to be studied.

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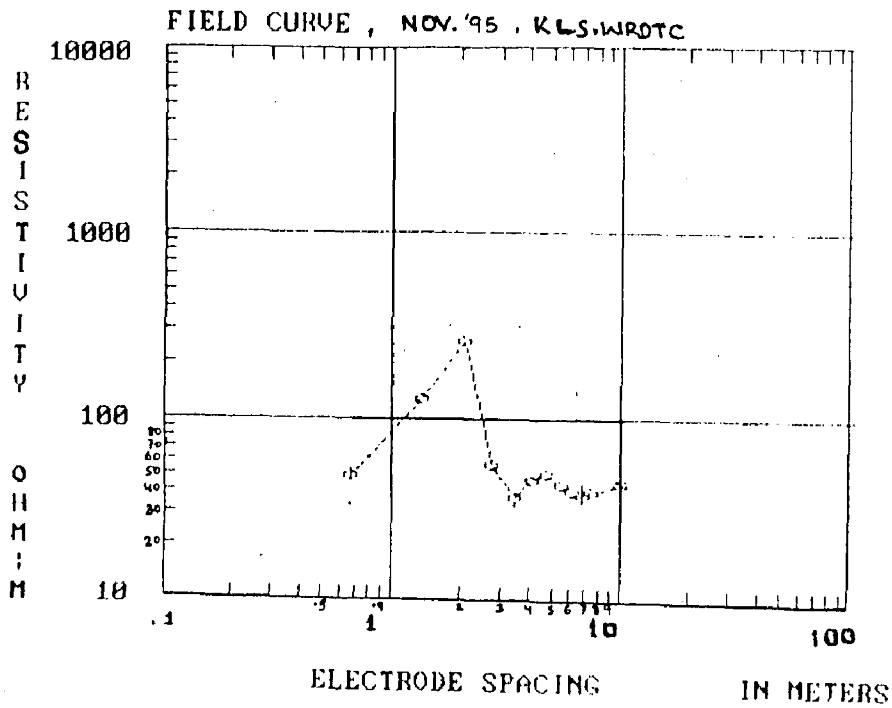
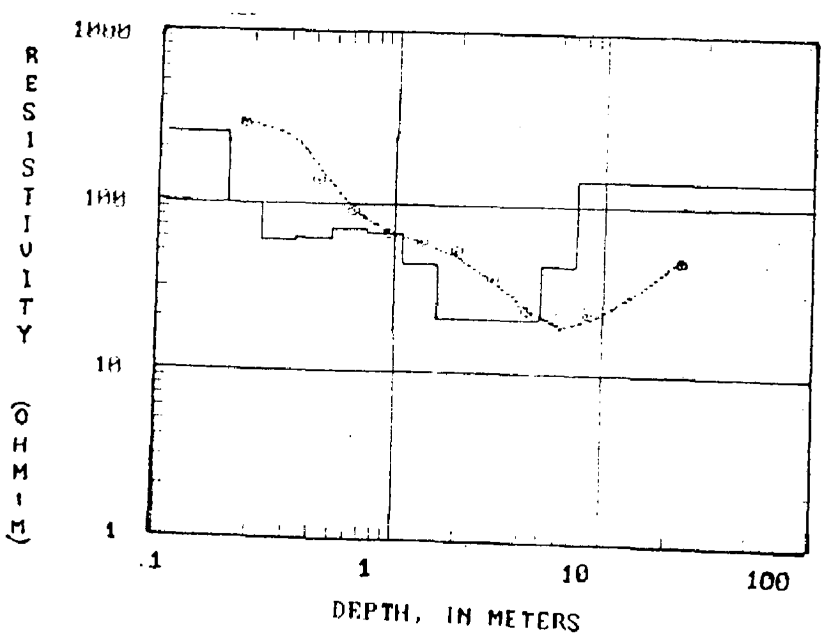
APPENDIX I

MEASUREMENT OF RESISTIVITY BY SCHLUMBERGER METHOD AT TEST SITE BETWEEN WRDTC AND EED, UOR DATED 16.11.95.





Effective ground connection is the key to the successful operation of earth return for continuous flow of the current. And selection of the proper grounding electrodes is of prime importance to provide the effective ground connection.

The Class I earth-electrodes which are generally used for grounding are :

1. Driven rods or pipes
2. Plate Electrodes
3. Strips
4. Buried Straight horizontal wires.

Driven Rods or Pipes

From the practical view point, where conditions are satisfactory, the most suitable form of electrode is the driven rod or pipe. Resistance for rods of different length and diameters and for a specific resitance of 100 ohm-meters as shown in Fig.... These curves show that an increase in length has a much greater effect. The best length of rod to use is determined by the nature of the soil and layering effect of resistivity. If for instance, specific resistance tests indicate that there is an underlying structure or lower resistivity, a rod, long enough to reach this should be used, so that benefits of lower resistivity can be achieved.

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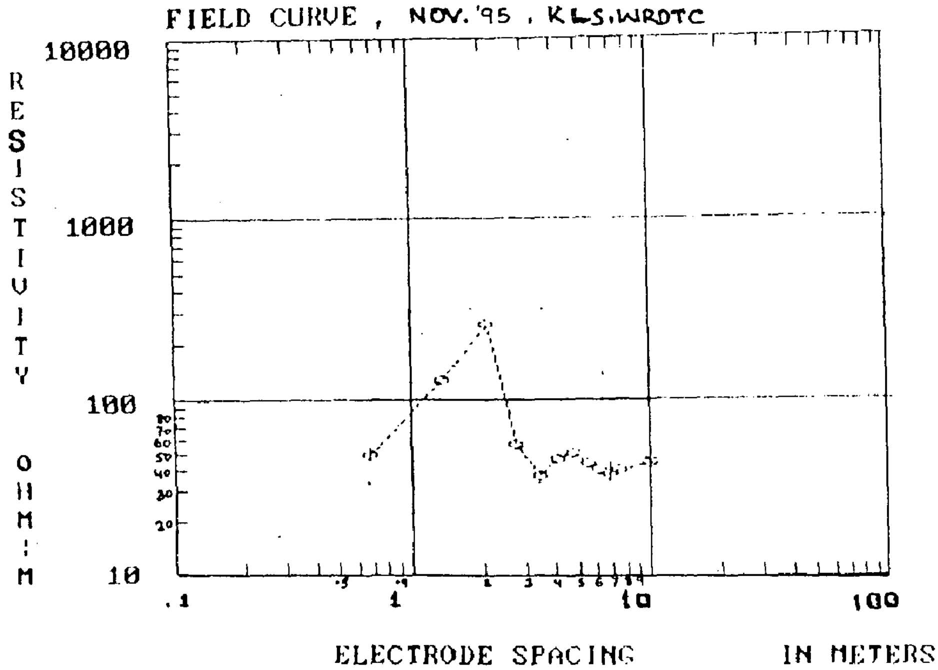

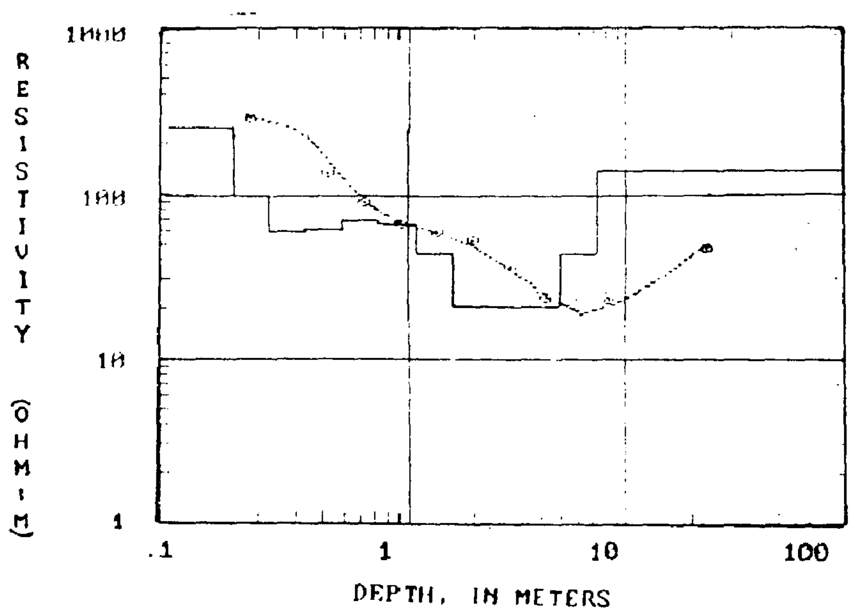

APPENDIX II

REVIEW OF THE DIFFERENT EARTH ELECTRODES AND STANDARD SPECIFICATION

The earth electrodes may be divided into 2 classes.

Class I : Used as primary earth electrodes only - plates, strips, conductors, pipes, rods etc.

Class II: Water pipes, building foundation frame works, well-linings, and cable sheatts and armouring.

Water pipes are in common use for LT domestic earthing and in that case also minimum length of pipe should not be more than 10 feet. In america the use of driven rods/pipes, buried strips/conductors are the commonest earth electrode and buried pipes or plates are very rarely used.

As per IEEE - Standard 142 - 1982 : Usual size of ground rod diameters are upto 1 inch (25.4 mm) and lengths upto 16 ft (4.88m). The metallurgy of the above electrodes are cast-iron, steel, copper and steenless steel. The most favoured metal is copper having best conductivity and corrossion resistant to the salts and oxides present in soil. But it does not have sufficient strength or hardness to enable a copper rod to be driven to a great depth. Copper clad steel rods are more suitable in this case and can penetrate most type of soils to a depth upto 30 m.

Effective ground connection is the key to the successful operation of earth return for continuous flow of the current. And selection of the proper grounding electrodes is of prime importance to provide the effective ground connection.

The Class I earth-electrodes which are generally used for grounding are :

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Driven Rods or Pipes

From the practical view point, where conditions are satisfactory, the most suitable form of electrode is the driven rod or pipe. Resistance for rods of different length and diameters and for a specific resitance of 100 ohm-meters as shown in Fig.... These curves show that an increase in length has a much greater effect. The best length of rod to use is determined by the nature of the soil and layering effect of resistivity. If for instance, specific resistance tests indicate that there is an underlying structure or lower resistivity, a rod, long enough to reach this should be used, so that benefits of lower resistivity can be achieved.

The practical advantages of driven rods over other forms of electode may be summarised as follows :

1) Low cost of driven rods when compared with other electrodes.

2) Where the surface soil is sandy, or where the permanent mositures is at a considerable depth, rods can be driven to such a depth as it results in too much reduction in resistance.

3) Seasonal variations are very much less with the deep rods than with buried electrodes. As such rods will be unaffected by drying-out the soil in summer or freezing in winter.

4) If, artificial treatment with a salt solution is considered necessary, the process is simpler with earth rods than with any other electrode.

5) Quite a number of electrodes can be driven for the cost of single earth plate, giving much lower earth-resistance.

6) The connection between the earth-rod and the conductor to which it is coupled can be quite simple and can be easily inspected and where necessary can be replaced or rejointed.

7) There is flexibility of putting more number of additional rods in case there is any rise of ground resistance due to aeging, in future.

8) In case of steep front surges, pipe electrodes behave better than other form of electrodes.

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Plate Electrode

The second type of earth electrode is the buried plate. This was the earliest form of earth electrode to be used. In the past considerable use has been made of buired platers of 3′ x 3′. The earth plates, due to the following draw-backs, are being possibly replaced by driven rode.

1. Cost of burying the plate is high.
2. The connection between the earth plate and the conductor to which it is connected cannot be quite easily inspected, and is also susceptible to corrosion.
3. Seasional variations are more prominant as compared to the driven rods.
4. After certain depth, the plate can not be driven by hammering.

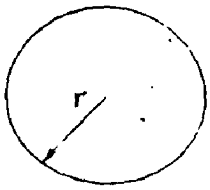
Strip Electrode

These electrode if in the form of strips are ususally made from copper having section not less than 1" x $\frac{1}{16}$ which is preferably untined.These are mainly used for spreading grounding mat and inter connection of electrodes and equipment.

Buried Straight Horizontal Wire

In many situations, where it is desirables to obtan a ground of low resistance, it may be convenient to install a buried wire under ground by digging. Especially where, hard soil rock is present under the surface having a superficial layer of lower resistivity at the top, the only solution is to use horizontal wire buried at the required depth. The depth of burial has little effect on resistance. It is necessary to bury only deep enough to prevent theft.

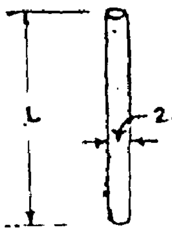
APPENDIX - III



SPHERE

$$R = \frac{\rho}{4\pi r} \text{ ohms}$$

ρ = RESISTIVITY OF THE EARTH IN ohms
r = RADIUS OF THE SPHERE IN meters

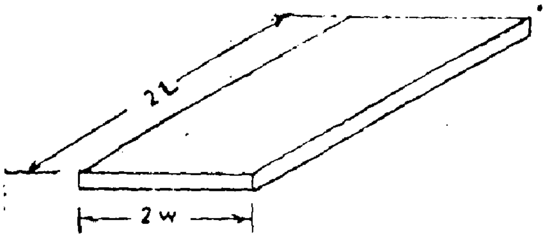


ROD

$$R = \frac{\rho}{2\pi L}\left[\log_e \frac{4L}{a} - 1\right] \text{ohms}$$

OR. $R = 0.366 \frac{\rho}{L} \log_{10} \frac{3L}{2a}$ ohms.

ALL DIMENSIONS ARE IN Meters



STRIP

$$R = \frac{\rho}{4\pi L} \log_e\left(\frac{4L}{w}\right)$$

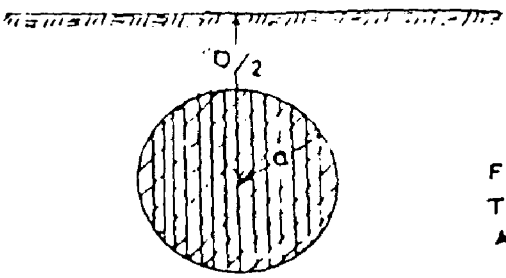
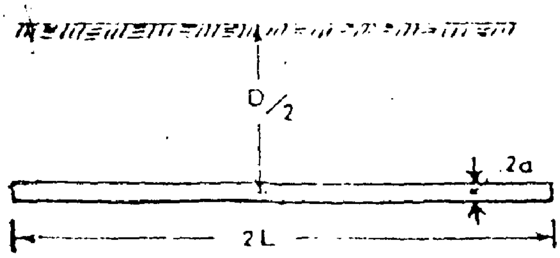


PLATE ELECTRODE

$$R = \frac{\rho}{8a} + \frac{\rho}{4\pi D}$$

FOR SQUARE VERTICAL PLATE THE RESISTANCE IS THE SAME AS FOR ROUND PLATE OF THE SAME AREA

BURIED STRAIGHT HORIZONTAL WIRE



$$R = \frac{\rho}{4\pi L}\left[\log_e \frac{4L}{a} + \log_e \frac{4L}{D} + 2 + \frac{D}{2L} - \frac{D^3}{16L^3}\right]$$

EARTH RESISTANCE OF GROUND ELECTRODES

APPENDIX - IV.

Resistance of Various Types of Earthing Systems for Different Values of Soil Resistivity and configuration of electrodes, Observed by Research Directorate of Karnataka Electricity Board, Bangalore, asper CBIP- Technical Report No.11, June 1977 [6]

Configuration of the grid (Earthing)	Resistivity (Ohm-mt) 25	50	100	200	300	400	500	1000
1. 3 electrodes in delta earthing system similar to Australian pattern (3mt.long & 4cm dia. electrode) with a spacing of 6 mt.between electrodes.	2.6	5.2	10.4	20.8	31.2	41.6	52.0	104
2. 2 electrodes in the opposite diagonals of a square grounding grid buried to a depth of 0.9mt. below the earth surface withm.s. galvanised 7 mm conductor size 5mx5m.	2.2	4.35	8.7	17.4	26.1	34.8	43.5	87
3. -do- size 6m x 6m.(square grid).	1.7	3.55	7.1	14.2	21.3	28.4	35.5	71
4. -do- size 10m x 10m.	1.1	2.24	4.48	8.96	13.4	17.9	22.4	44.8