PROJECT REPORT

ON

EFFECT OF HIGH VOLTAGE TRANSMISSION ON COMMUNICATION & BIOLOGICAL SYSTEMS

DEPARTMENT OF ELECTRICAL ENGINEERING
COLLEGE OF ENGINEERING & TECHNOLOGY
O.U.A.T., BHUBANESWAR - 751 003.
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A Note to All Readers

This is not an original electronic copy of the bachelor’s project report, but a reproduced version of its hardcopy. I got hold of this after 10 years or so. Then, thought of making a softcopy. Somehow did not get the bibliography page. As far as I remember some well known books and papers were referred.

Saraju P. Mohanty
07/19/2006

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I convey my sincere thanks to **Prof. B. Sahu, H.O.D., Electrical Engineering** for his guidance and encouragement. I also thank my groupmates who helped me in making the Project successful.

C E R T I F I C A T E

This is to certify that the above feasibility report on " **EFFECT OF HIGH VOLTAGE TRANSMISSION ON COMMUNICATION & BIOLOGICAL SYSTEMS** " submitted by **SARAJU PRASAD MOHANTY** ,in the partial fulfilment of requirements of the Degree of B.Tech in Electrical Engineering of C.E.T.,O.U.A.T. is a record of project work carried out by him under my guidance & supervision in the department of Electrical Engineerig,C.E.T.,O.U.A.T., Bhubaneswar.

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(PROF. B.SAHU)

C O N T E N T S

INTRODUCTION TO HIGH VOLTAGE TRANSMISSION

1. HISTORICAL DEVELOPMENTS IN ELECTRIC POWER TRANSMISSION -

In recent year, particularly after the Second War, a number of developments have taken place in the field of transmission of electrical power leading to adoption of ever increasing high voltages.The present trend is to transmit large amount of power over medium & long lines at voltages which are termed extra high voltages or simply **EHV**. Voltages of 330 kV and above fall in this category. with the increased demand of electric power more and more countries are now going in for EHV lines. Upto 1960, 220 kV was practically the highest voltage in the U.S.A. but by 1964 it had more than 5,000 km of transmission lines working at 345 kV and above. It is estimated that in 1975 the U.S.A. had more than 50,000 km of EHV lines while in thecase of Russia over 16,000 km of transmission lines working at 330 kV and above were in operation. A large number of EHV lines are today in operation and under construction in manycountries all over the world.

In the initial stages d.c. was used for electric power transmission. This was due to two important reasons-first, ease of control and second, d.c. motors were the only satisfactory electromechanical energy convertors. However, with theintroduction of transformers in 1881 and the three phase a.c. systemm in 1881 the situation changed in favour of a.c. The ease with which alternating voltage could be transformed with the help of transformer from one value to another coupled with the better performance of a.c. motors tilted the scales in favour of a.c. for electric power transmission.

The first three phase line of 169 km length at 15 kV and transmitting about 130 kW was commissioned in 1891 in Germany. Later on three phase a.c. systems developed rapidly. The operating voltages also became progressively higher. In 1923 the first 220 kV line of 320 km length and transmitting 100 MW was put into service in California. Considering this to be a very high voltage of transmission, never to be exceeded, more attention was paid in subsequent years to othe problems of consolidation and interconnection of large power systems. However, in 1952 Sweden successfully commissioned a 380 kV, 400 MW, 960 km single circuit line between Harspranget and Hallsberg. This event set the trend of adoption of still higher voltages. In 1956 Russia commissioned the first 400 kV line line over a distance of 800 km between Kuibishev and Moscow folowed in 1959 by the first 500 kV, 1,000 km Volograd-Moscow line. By the year 1962 Russia had about 4,000 km of 500 kV lines. In November, 1965 a 750 kV, 584 km long line between Manicouagan and Montreal in Canada was inaugurated. In 1966 Russia installed a 750 kV experimental and industrial line 90 km long with a transmission capacity of 1,250 MW. In the next few years several lines operating at this voltage are expected to come up in Russia. With recent researches a new level of 1,000 - 1,100 kV a.c. has also been proposed.

Simultaneously there have been important and remarkable developments in d.c. transmission. It has staged a sort of comeback to the field of electric power transmission at high and extra high voltage.

To give an ideal of progress in this direction, a historic event was the commissioning of 100 kV, 20MW, 96 km d.c. sub-marine cable link between the mainland of Sweden and Island of Gotland in 1954. This was followed in 1961 by cross-channel link connecting the 275 kV French and British systems. This d.c. link operates at 200 kV ($\pm$100 kV) and transmits about 160 MW of power over a distance of 56 km. Years 1962 and 1965 saw the completion of first and final stages of 800 kV ($\pm$400 kV), 750 MW, 473 km Volgagrad-Dombass overhead line respectively. Several high voltage d.c. lines employing progressively increasing voltages and longer distances followed in high voltage d.c. lines employing progressively increasing voltages and longer distances followed in subsequent years in various contries the world over. So much so that

United States Federal Power Commission is now making arrangements to transmits to transmit power of the order of 4,000 MW over a distance of 1,000 to 3,000 km and of about 12,000 MW over a distance of 2,500 km employing 1500 kV d.c.

In India, 400 kV a.c. transmission lines have been introduced during 1970's. 3 **HVDC transmission links have been executed** (1991). By the year 2000, about ten HVDC transmission links are expected to be commissioned in India. HVDC transmission systems are selected as an alternative to extra high voltage a.c. transmission systems for any one or more of the following reasons.

(i) For long distance high power transmission lines.

(ii) For interconnection (Tie-lines)between two a.c. system having their onwn load frequency control.

(iii) For back-to-back asynchronous-tie sub-stations.

(iv) For underground or submarine-cable transmission over long distance at high voltage.

2. EHV-AC VERSUS HVDC TRANSMISSION -

1] **For Backbone Network** : EHV-AC is superior for forming the mesh. Voltage can be easily stepped up, stepped down. The network has natural tendency to maintain synchronism. Load-frequency control is easy and simple. Network can be tapped at intermediate points to feed underlying submission network.

2] **Bulk power** load **distance** transmission **lines** : HVDC proves economical above breakeven distance. Number of lines are less for HVDC. No need of intermediate sub-stations for compensation.

3] **Stability** of Transmission **System** : HVDC gives asynchronous tie and transient stability does not pose any limit. Line can be loaded upto thermal limit of the line or valves (whichever in lower).

4] **Line Loading** : The permissible loading of an EHV-AC line is limited by transient stability limit and line reactance to almost one-third of thermal rating of conductors. No such limit exists in case of HVDC lines.

5] **Surge Impedance Loading** : Long EHV-AC lines are loaded to less than 0.8 Pu. No such condition is imposed on HVDC Line.

6] **Voltage along the line** : Long EHV lines have varying voltage along the line due to absorption of reactive power. This voltage fluctuates with load. Such a problem does not arise in HVDC line. EHV-AC Line remains loaded below its thermal limit due to the transient stability limit. Conductors are not utilized fully.

7] **Number of lines** : EHV-AC needs at least two three-phase lines and generally more for higher power. HVDC needs only one bipole line for majority of applications.

8] **Intermediate Sub-stations** : EHV-AC transmission needs intermediate sub-station at an interval of 300 km for compensation. HVDC line does not need intermediate compensating sub-station.

9] **Asynchronous Tie** : System having different prevailing frequencies or different rated frequencies can be interconnected HVDC link provides asynchronous tie. Fequency disturbance does not get transferred, large backouts are avoided.

10] **Better Control** : Power flow through HDVC tie line can be controlled more rapidly and accurately than that of EHV-AC Interconnector.

11] Corona Loss & Radio Interference : For the same power transfer and same distance, the corona losses & radio interference of DC systems is less than that of AC systems, as the required DC insulation level is lower than corresponding AC insulation.

12] **Skin Effect** : This is absent in d.c. current. Hence current density is uniformly distributed cross-section of the conductor.

13] **Tower Size** : the phase-to-phase clearances, phase to ground clearances and tower size is smaller for DC transmission as compared to equivalent AC transmission for compared to equivalent AC transmission for same power and distance. Tower is simpler, easy to installed and cheaper.

14] **Charging Current** : Continuous line charging currents are absent in HVDC lines.

15] **Number of Conductors** : Bipolar HVDC trnsmission lines require two-pole conductors(instead of several three-phase conductors as in case of AC) to carry DC power . Hence HVDC transmission becomes economical over AC transmission at long distance when the saving in overall cnductors cost losses, towers etc. compensates the additional cost of theterminal apparatus such as rectifiers and convertors.

16] **Earth Return** : HVDC transmission can utlize earth return and therefore, does not need a double circuit. EHV-AC always needs a double circuit.

17] **Reactive Power compensation** : HVDC line does not need intermediate reactive power compensation like EHV-AC line.

18] **Flexibility of Operation** :Line may be operated in a monopolar made by earth as return path when the other line develops permanent fault.

19] **Superior Control** : HVDC system control can be modified for (1) frequency control of AC network (2) Damping control for improved stability of AC networks.

20] **Short- Circuit Level** : In AC transmission, additional parallel line result in higher fault level at receiving end due to reduced equivalent reactance. When an existing AC system is interconnected with another AC system by AC transmission line, the fault level of both the system increases.

However, when both are interconnected by a DC transmission, the fault level of each system remains unchanged.

21] **Rapid Power Transfer** : The control of converter valves permit rapid changes in magnitude and direction of power flow. This increases the limits of transient stability.

22] **Cables** : DC transmission can be through underground or marine cables since charging currents are taken only while energizing the d.c. link and are not effective later. In a.c.systems there is limit on length of cable depending upon rated voltage.

This limit is about 60 km for 145 kV, 40km for 245 kV and 25 km for 400 kV AC cables.

23] **Voltage Regulation** : In HVDC systems, the line can be operted with constant current regulation or constant voltage regulation by suitable adaptation of grid control of rectifiers and inverters.

24] **Lower Transmission Losses** : line losser are lesser than equivalent AC transmission losses as the reactive power does not flow through D.C.

3. COSTS OF TRANSMISSION LINES & EQUIPMENT -

It is universally accepted that cost of equipment all over the world is escalating every year. Therefore, a designer must ascertain current current prices from manufacturers of equipment and line materials. These include conductors, hardware, towers, trasformers, shunt reactors, capacitor, synchronous condensers, land for switchyards and line corridor, and so on. Generating station costs are not considered here, since we are only dealing with transmission in this book. In this section, some idea of costs of important equipment are given(which may be current in 1995) for comparison purposes only. These are not to be used for decision-making purpose.

(1 US \$ = Rs.32,1 Lakh= 100,000;1 Core=100 Lakhs=10 Million)

(a) **High Voltage DC (±400 kV Bipole)**

Back -to-back terminals : Rs. 45 Lakhs/MVA for 150 MVA
Rs. 35 Lakhs/MVA for 300 MVA

Cost of 2 terminals : Rs. 32 Lakhs/MVA
Transmission line : Rs.22 Lakhs/Circuit (cct)km
Switchyards : Rs. 2500 lakhs/bay

(b) **400 kV AC**

Transformers : 400/220 kV Autotransformers
Rs. 3.3 Lakhs/MVA for 200 MVA 3 phase unit
Rs.2.5 Lakh/MVA for 500 MVA 3-phase unit to
400 kV/13.8 kV Gnenerator Transformers
Rs. 2 Lakh/MVA for 250 MVA 3-phase unit
Rs.1.3 lakh/MVA for 550 MVA 3-phase unit to

Shunt Reactors

Non-switchable Rs.2.3 Lakh/MVA for 50 MVA unit to
Rs.2.0 Lakh/MVA for 80 MVA unit

Switchable Rs.8 Lakhs to Rs.3 Lakhs/MVA for 50 to 80 MVA units.

Shunt Capacitors Rs.0.8 Lakh/MVA

Synchronous Condensers (including transformers) :
Rs.12 Lakhs/MVA for 70 MVA to
Rs.6.5 Lakhs/MVA for 300 MVA

Transmission Line Cost : 400kV Single Circuit:Rs.24 Lakhs/cct km
220kV:S/C:Rs.12 Lakhs/cct km
D/C:Rs.20 Lakhs/cct km

4. DESIGN ASPECTS OF TRANSMISSION LINE -

The lines and sub-stations constituting transmission systems are designed to deliver required amount of power continuously reliably with voltages within specified limits and with environmental factors within specified limits with lowest overall annual cost over the service period. The system should also have provision of expansion, with minimum changes in existing layouts.

The transmission system designs have four important parts :

- Electrical design
- Mechanical design
- Structural and civil design
- Miscellaneous design

Furthermore, the transmission system design includes :

- Sub-station design
- Transmission line design
- Network planning

The electrical design of AC transmission systems is quite different from that of HVDC transmission systems. The electrical design involves the following aspects :

- Choice of transmission voltage.
- Choice of conductor configuration.
- Voltage control and reactive power compensation.
- **Corona losses and Radio Interference**
- Transient stability, autoreclosing.
- Abnormal operating conditions and protection systems.
- Insulation co-ordinating and surge arrester protection.
- Neutral grounding & Sub-station grounding
- Earth electrodes & electrode lines (for HVDC)
- **Harmonics and filters (for HVDC).**
- Overhead shielding wires and lightning protection
- Power line communication (PLC)
- **Radio Interference (RI), Telephone Interference (TI)**
- **Television Interference (TI)**
- **Audible noise (AN)**

INTRODUCTION TO HIGH VOLTAGE HAZARDS

1. NOISE IN COMMUNICATION SYSTEM -

The term **noise** is used customarily to designate unwanted waves that tend to disturb the transmission and processing of signals in communication system, and over which we have incomplete control. The **noise should be at very low level** compared with the wanted signal. So the signal will be distorted and the received information subject to error. Amplification after the point of entry of noise into the system will be of no avail, because the noise will be amplified with the signal, and the signal to noise ratio will be unchanged. These remarks also apply to the amplifiers or radio receivers as well as complete systems.

If all the possible sources of noise are considered, a distinction can be made between **sources external** to the disturbed communication channel and **sources inside** the channel.

Noise from an external source is often referred to as interference. This may be produced by radiation from moving electrical contacts, dynamic electrical machinery, fluorescent lamps, **power transmission** lines and many other causes. Again radiation from electrical discharges in the atmosphere or from the distant galaxies may cause interference. In a multi-channel telephony system **inter-channel interference** is referred to as **cross-talk** and may produce varying amounts of either intelligible or unintelligible speech.

Noise may be produced inside the communication channel itself from intermittent contacts in faulty components. **Electrastatic** or **magnetic** fields produced by alternating current power leads may cause **hum** in signal circuits. When all these sources of noise have been removed, two other type of noise remain, namely **thermal agitation noise** & **shot noise**, collectively called fluctuation noise. This arises from a more fundamental cause than

than other types of noise mentioned and unlike them can never be entirely eliminated.

The output level of noise picked up from an external source usually depends on the location of the equipment. Such noise can generally be reduced if not eliminated by careful screening of the input circuits. Hum can be reduced to a sufficiently low level by a filtering of the supplies and screening of signal leads. This is especially necessary in the early stages of an amplifier where it is essential that noise from whatever cause should be at extremely low level.

2. RIGHT OF WAY (ROW) -

Transmission line requires right-of-way for the line through urban, rural, jungle and other areas en-route. The cost of purchase of land, clearing and keeping right-of-way clean, free from trees considered while selecting the line route.

In some cases, big cities, big cities, industrial localities it is becoming impossible to acquire right-of-way for EHV-AC lines.

3. CORONA -

The design of conductors for EHV-AC transmission lines and HVDC transmission lines should be such that the coronal losses and radio interferences are within specified/permissible limits. Corona is a type of electrical discharge at the surface of conductors at high voltage. The corona discharge occurs in the air surrounding a charged conductor when the voltage stress at the conductor surface reaches the critical value. Corona generally occurs in foul weather.

Corona commences at voltage (V_c) called critical voltage at which the maximum voltage gradient at the surface E_{max} attain critical value(E_c). (E_c = 30kV/cm at n.t.p.,i.e.760mm Hg & 25°C).

The critical value of voltage stress depends upon pressure, temperature, humidity, pollution level in air and condition of conductor surface.

The conductor diameter should be made so large by using bundle conductors or hollow conductors that the coronal losses and radio interference are within limit.

Critical corona viltages are different for positive voltage and negative voltage, the negative voltage being more severe.

Corona cause losses, radio interference and television interference

In DC corona, the charges released from one conductor must be carried to the ground or the other conductor because of the opposite polarity. Therefore the corona performance is characterised by the line voltage rather than the surface gradient.

The corona behaviour of a monopolar HVDC line is different from that of bipolar line due to the difference in release of the charge from the vicinity of the conductor surface.

Corona losses depend upon the roughness, cleanliness of conductor surfaces, and also weather condition. It is difficult to predict the corona loss in exact mathematical form. Corona losses vary through the year depending upon weather condition.

In case of AC voltage, the peak value of voltage wave is 2 times the rms value. In case of DC there is no such great factor.

Corona losses of AC lines increase more rapidly with increase in rated voltage than the corresponding increase in DC line voltage.

With AC voltage, the ions going away from the conductor surface due to like polarity of charge during a half cycle get attracted towards the conductor during the next half cycle of AC wave.

With DC voltage, the loss with the same polarity as that of the conductor get a time to go away from the conductor. Therefore the corona phenomenon acts differently with AC and DC lines.

Reference values of corona Losses of AC & DC lines

Weather Condition	Corona loss kW/km	
	±400kV DC	500kW AC
Average loss in fair weather	1.35	1.33
Minimum losses in fair weather	0.62	0.12
Maximum loss under worst weather condition	8.00	18.00
Annual mean loss kW/km	2.5	5.5
Line Particulars		
Conductor numbers	2	3
Conductor diameter,mm	46	35
Spacing between conductors,m	10.5	11
Average height	21	18.06

Corona inception voltage gradient is an important parameter for conductor design. For AC lines, stranded bundled conductors are generally used. The corona inception voltage gradient should have about 25% margin above the surface voltage gradient at maximum operating voltage, based on fair weather conditions. If this margin is 0%, under foul weather severe radio interference is likely to occur along the line route and the width of the corridor should be increased.

Corona losses under foul weather conditions should be limited to about 5 kW/km. If more , the power available at receiving end would be reduced due to high corona losses.

4. AUDIBLE NOISE (AN)-

Audible noise is generated by EHV-AC and HVDC transmission lines and sub-stations due to the following causes :

-Corona

-Humming of transformers

-Cooling systems and mechanical and electrical auxiliaries.

The design of transmission lines and sub-stations is governed by the limits of AN. The limits of audible noise are specified by some national standard specifications and the specifications of major unilities in terms of dB at a particular distance from the line sub-station, transformer.

EHV-AC and HVDC lines generate audible noise, generally when the corona is present on the conductor during bad weather. The audble noise is in the frequency range from very low frequency tp 15 kHz.

The design of lines and sub-stations is the basis of limit of audible noise. Thereference values of the limits of audible noise are used on complaints from people working in the vicinity. These limits are as given below :

Nocomplaints :Below 52.5 dB

A few complaints :52.5 59 dB

Many complaints :Above 59 dB.

The width of right-of -way(ROW) for the linecorridor has a reference to the decision about audble noise. Line geometry is based upon 50 dB at the edge of ROW.

The AN caused by a transmission line is a function of the following :

(a) Voltage gradient on surface of conductor
(b) Number of sub-conductors in a bundle
(c) Diameter of condustor
(d) Atmospheic condition
(e) Lateral distance between the line and the point of measurement of noise.

The audible noise is caused by vibrations produced in the air due to change in the air pressure.

5. AC HARMONICS(120 to 200 Ms)

The 3-phase bridge convertor used in HDVC transmission should convert pure sinusoidal AC waveform to pure DC form. But in practice the operation of convertor generates harmonic currents and harmonic voltages on AC side and DC side. These harmonics do not interefere with convertor operation but they flow through AC lines and DC lines and thereby produce the following harmful effects :

-Excessive harmonic currents is synchronous machines, power factor capacitors and other equipment.
-Overvoltages at points in the networks.
-Interference with protective gear.
-Interference in adjusting telecommunication lines, radio interference (RI); Television Interference (TI).
These disturbances spread over the AC network and DC line and surrounding residential areas.

In HVDC convertors, following predominant Harmonics are encountered :

AC harmonics :
DC Harmonics :
n=Pulse number of convertor.x=Integers 1,2...

6. RADIO INTERFERENCE AND TELEVISION INTERFERENCE

Operation of EHV-AC and HVDC transmission lines and transmission sub-stations can cause Radio Interference (RI). The lines and sub-stations should be so designed that the RI and TI small be less than 40 dB and I m V/m at I MHz at the edge of ROW.

Radio interference and television interference is caused by electrromagnetic waves in thefrequecy range of broad cast frequencies.

RI: 0.5MHz-1.6MHz

TI: 54MHz-216MHz

The line is designed such that the radio noise within the width of the line corridor should be below permissible limits (say 40 dB at 1 MHz).

Radio interference is more important factor in line design and in deciding right of way (ROW).

THE MAIN CAUSES OF RI

	EHV-AC	HVDC
1. Corona	*	
2. Partial discharges on insulators	*	
3. Sparks across gaps	*	
4. Pulses due to triggering of thyristors		*

The RI can be eliminated and/or minimised by appropriate design of line conductor and hardware.

The main source of RI in case of AC lines is corona discharge on the surface of conductors of lines and substations. For AC lines bundling of conductors reduces surface voltage stress corona and radio interference.

RI lIMITS IN VARIOUS COUNTRIES

Countries	Distance from outermost phase	RI limit	Frequency
Russia	100 m	40 dB	500 kHz
Switzerland	20 m	200 u V/m	500 kHz
Poland	20 m	760 u V/m	500 kHz

In case of DC line the space charge surrounds the conductor eliminating the advantage of bundling of conductors. Radio interference is normally not a decisive factor to choose a bundle conductor.

In case of HVDC transmission systems, the triggering of thyristors give high fequency oscilations in the range of 0.1 MHz to 10 MHz. The radio interference is reduced by

- Selection of a valley as the site for a sub-station
- Screening of valve hall for electromagnetic radiation
- Installing ground wires on switchyard
- Limiting the height and the length of the conductors in the switchyard.
- Proper selection of insulators and hardware to prevent partial discharges.

7. BIOLOGICAL EFFECT OF ELECTRIC FIELD AND LIMITING VALUE OF ELECTRIC FIELD STRENGTH -

The biological effect of electric field of EHV lines and EHV sub-stations has been studied extensively during 1970s.

EHV & UHV lines are designed such that maximum electrostatic field gradient is below 9 kV/m at mid-span under the line near ground level.

Safe line to ground clearance of 20m at mid-span is recommended for 400 kV lines and 24 m for 1100 kV lines. This permits movement of vehicles safely.

8. INTERPERENCE IN RELAY & CIRCUIT-BREAKER -

Any disturbing signal which interferes or disturbs the electronic measurement/signal/parameters is electrical noise. All electronic circuits and their installations should be with the noise below acceptable level. This is very important for accurate functioning and reliability of static relay functioning. Conventional electromagnetic relays do not have such a problem.

Relaying and control installations for static devices should be designed with particular attention to noise and transient over voltages. The effect of noise and transient over-voltages is two-fold.

(i) Maloperation (ii) Error in measurements.

The noise tends to spread throughout an electronic system because of electrical relationships between circuit conductors, enclosures, chassis and ground connections through conductive, capacitive and inductive couplings. Electromagnetic radiation causes voltages gradient between two conductors although not connected physically.

Adjacent conductors are coupled electrostatically. An inherent capacitance exists between, ground, conductors and chassis, shields, enclosures. Thus the voltage change occuring in one conductor causes a change in other conductor, proportional to the capacitance between them and length of conductors in paralled.

ELECTROSTATIC & ELECTROMAGNETIC EFFECT OF HIGH VOLTAGE LINE

1. INTRODUCTION -

Electrostatic effects from overhead e.h.v. lines are caused by the extremely high voltage while electromagnetic effects are due to line loading current and short-circuit currents. Hazards exist due to both causes of various degree.These are, for example, potential drop in earth's surface due to high fault currents, direct flashover from line conducters to human beings or animals. Electrostatic fields cause damage to human life,plants,animals, & metallic objects such as fences & buried pipe lines. Under certain adverse circumstances these give rise to shock currents of various intensities.

Shock currents can be classified as follows :

(a) **Primary Shock Currents** - These cause direct physiological harm when the current exceeds about 6-10 mA. The normal resistance of the human body is about 2-3 Kilohms so that about 25 volts may be necessary to produce primary shock currents. The danger here arises due to ventricular fibrillation which affects the main pumping chambers of the heart. This results in immediate arrest of blood circulation. Loss of life may be due to :

(i) arrest of blood circulation when current flows through the heart,

(ii) permanent respiratory arrest when current flows in the brain, and

(iii) asphyxia due to flow of current across the chest preventing muscle contraction.

The 'electrocution equation' is $i^2t = K^2$, where K = 165 for a body weight of 50 kg, i is in mA and t is in seconds. On a probability basis death due to fibrillation condition occurs in 0.5% of cases. The primary shock current required varies directly as the body weight. For i = 10 mA, the current must flow for a time interval of 272 seconds before death occurs in a 50 kg human being.

(b) **Secondary Shock Currents** - These cannot cause direct physilolgical harm but may produce adverse reactions. They can be steady state 50 Hz or its harmonics or transient in nature. The latter occur when a human being comes into contact with a capacitively charged body such as a parked vehicle under a line. Steady state currents up to 1 mA cause a slight tingle on the fingers. Currents from 1 to 6 mA are classed as 'let go' currents. At this level, a human being has control of muscles to let the conductor go as soon as a tingling sensation occurs. For a 50% probability that the let-go current may increase to primary shock current, the limit for men is 16 mA and for women 10 mA. At 0.5% probability, the currents are 9 mA for men, 6 mA for women, and 4.5 mA for children.

A human body has an average capacitance oif 250 pF when standing on an insulated platform of 0.3m above ground (1 ft.). In order to reach the let-go current value, this will require 1000 to 2000 volts. Human beings touching parked vehicles under the line may experience these transient currents, the larger the vehicle the more charge it will acquire and greater is the danger.

Construction crews are subject to hazards of electrostatic induction when erecting new adjacent to energized lines. An ungrounded conductor of about 100 metres in length can produce shock currents when a man touches it. But grounding both ends of the conductor brings the hazard of large current flow. A movable ground mat is generally necessary to protect men and machines. When stringing one circuit on a double circuit tower which already has an energized circuit is another hazard and the men must use a proper ground. Accidents occur when placing or removing grounds and gloves must be worn.

It is very common for a telephone line to be run along the same route as a power line, possibly for a few miles only or, in a few cases, for many miles. In the case of a communication line which is the property of a power company this line may be run on the same towers as the power line. Interference with such communication circuits may be due to both electromagnetic and electrostatic action, the former producing currents which are superposed on the true speech currents, thereby setting up distortion, and the latter raising the potential of the communication circuit as a whole. In exteme cases this raising of potential above that of the ground may be sufficiently high to render the handling of the telephone receiver extremely dangerous, and in such cases elaborate precautions have to be taken to avoid this danger.

2. ELECTROSTATIC FIELD -

Suppose an open wire HVDC transmission line is located at height above earth surface and we want to find field due to this line at any point P.

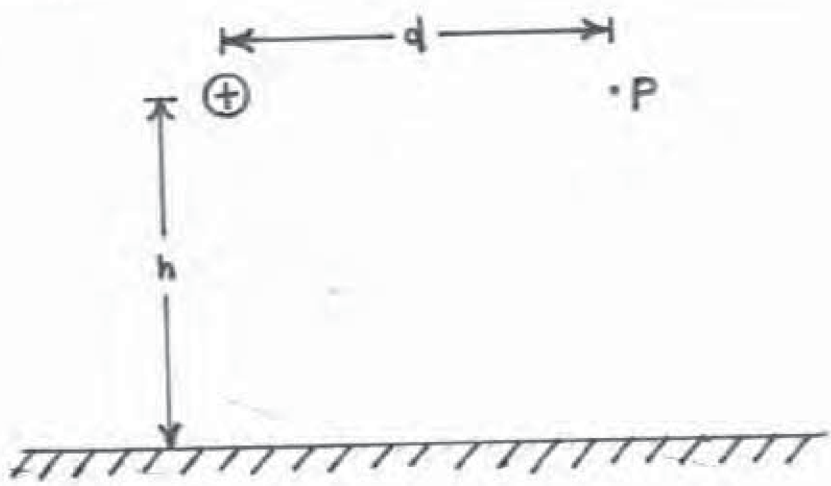

FIG.1 SINGLE WIRE HVDC TRANSMISSION LINE

In this case the actual charge distribution is not known. So to determine the behaviour of the electric field in the dilectric we have to use image method. By this method the distribution of charge density upon the plane can be determined easily.

The Method consists of replacing the actual field by an equivalent field in which an additional charge or charges are placed and the electrodes are altered to permit the equivalent field to satisfy the requirement at the boundry of the actual field. The conducting volume ground is removed and is replaced by an insulating volume of the same dielectric as that of the upper half. Thus we get the following arrangement :

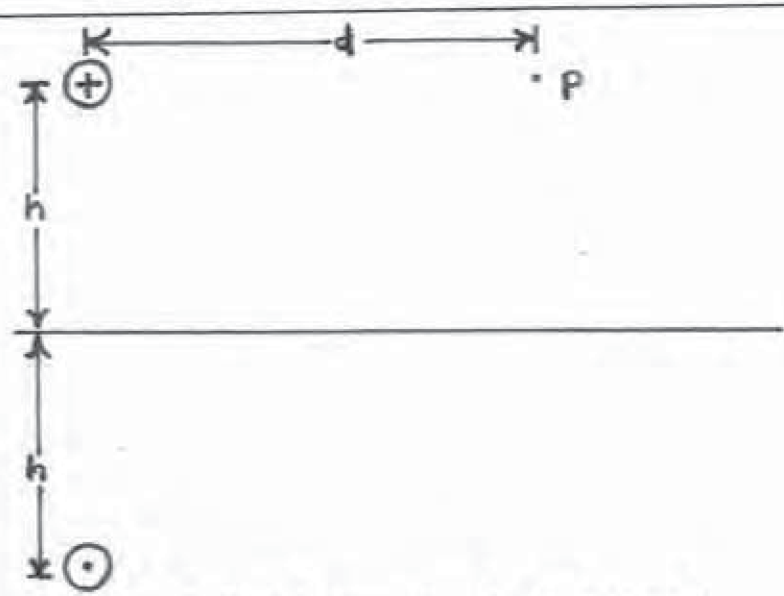

FIG.2. FIELD CALCULATION AT POINT P

Let & be the charge per unit length for the possitive and negative line respectively.

Field strength at P due to the positive line

$$E_+ = \left(\frac{\sigma_+}{2\pi \epsilon d}\right) \qquad \text{............(1)}$$

Field due to negative line

$$E_- = \left(\frac{\sigma_-}{2\pi \epsilon r}\right) \qquad \text{............(2)}$$

Resultant field in x-direction,

$$E_x = E_+ - E_- \cos 0$$

$$= \frac{\sigma_+}{2\pi\epsilon d} - \frac{\sigma_-}{2\pi\epsilon r}\cos\theta$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\left(\frac{1}{d} - \frac{1}{r}\cos\theta\right) \qquad \text{............(3)}$$

where $\sigma_+ = \sigma_- = \sigma$ ....(4)

Resultant field in y direction

$$E_y = -\left(\frac{\sigma}{2\pi\epsilon}\right)\sin\theta \qquad \text{............(5)}$$

Resultant field at P

$$E_{dc} = E_x^{\,2} + E_y^{\,2}$$

$$= \left(\frac{\sigma\sin\theta}{2\pi\epsilon d}\right) \qquad \text{............(6)}$$

where $\sin\theta = \left(\frac{2h}{r}\right) = \sqrt{1-\left(\frac{d}{r}\right)^2}$ ....(7)

To find E_{dc} in term of V_{dc}, let us find V_{dc} in terms of .

Let's consider a point A in between the two lines.

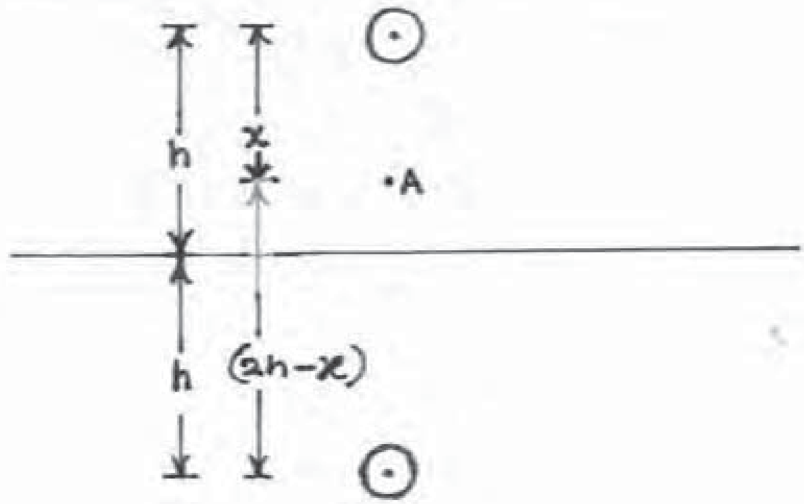

FIG.3. TO FIND V_{dc} IN TERMS OF σ

where field at A

$$E = \frac{\sigma_+}{2\pi\epsilon x} + \frac{\sigma_-}{2\pi\epsilon(2h-x)}$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\left(\frac{1}{x} + \frac{1}{2h-x}\right) \qquad \ldots\ldots\ldots\ldots(8)$$

So potential of positive conducter w.r.t. ground is given by

$$V_{dc} = \left(\frac{\sigma}{2\pi\epsilon}\right)\int_a^h\left(\frac{1}{x} + \frac{1}{2h-x}\right)dx$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\left[\ln x\Big|_a^h - \ln(2h-x)\Big|_a^h\right]$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\left[\ln\left(\frac{h}{a}\right) - \ln\left(\frac{h}{2h-a}\right)\right]$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\ln\left(\frac{h}{a}\cdot\frac{2h-a}{h}\right)$$

$$= \left(\frac{\sigma}{2\pi\epsilon}\right)\ln\left(\frac{2h-a}{a}\right) \qquad \ldots\ldots\ldots\ldots(9)$$

From Equation (6) & (9)

$$\frac{E_d}{V_{dc}} = \frac{\sigma \sin\theta}{2\pi\epsilon d}\cdot\left(\frac{2\pi\epsilon}{d}\right)\cdot\frac{1}{\ln\left(\frac{2h-a}{a}\right)}$$

$$= \left[\frac{V_{dc}\sin\theta}{d\ln\left(\frac{2h-a}{a}\right)}\right] \qquad \ldots\ldots\ldots\ldots(10)$$

This is the expression for electric field at any point P due to the transmission line at potential V_{dc}.

For 3-ϕ AC line, for lines R, Y & B we can calculate E_R, E_Y & E_B using equation (10). Then the resultant field can be calculated.

3. EFFECT OF HIGH E.S. FIELD ON HUMANS, ANIMALS & PLANTS -

The use of e.h.v. lines is increasing danger of the high e.h.v. lines is increasing danger of the high e.s. field to (a) human beings, (b) animals, (c) plant life, (d) vehicles, (e) fences, and (f) buried pipe lines under and near these lines.

It is clear that when an object is located under or near a line, the field is disturbed, the degree of distortion depending upon the size of the object. It is a matter of some difficulty to calculate the characteristics of the distorted field, but measurement and experience indicate that the effect of the distorted field can be related to the magnitude of the undistorted field. A case-by-case study must be made if great accuracy is needed to observe the effect of the distorted field. The limits for the undistorted field will be discussed here in relation to the danger it poses.

(a) **Human Beings**

The effect of high e.s. field on human beings has been studied to a much greater extent than on any other animals or objects because of its grave and shocking effects which has resulted in loss of life. A farmer ploughing his field by a tractor and having an umbrella overhis head for shade will be charged by corona resulting from pointedspikes. The vehicle is also charged when it is stopped under a transmission line traversing his field. When he gets off the vehicle and touches a grounded object, he will discharge himself through his body which is a pure resistance of about 2000 ohms. The discharge current when more than the let-go current can cause a shock and damage to brain.

It has been ascertained experimentally that the limit for the undisturbed field is 15 kV/m, r.m.s., for human beings to experience possible shock. An e.h.v. or u.h.v. line must be designed such that this limit is not exceeded. The minimum clearance of a line is the most importantgoverning factor. As an example, the B.P.A. of the U.S.A. have selected the maximum e.s. field gradient to be 9 kV/m at 1200 kV for their1150 kV line and inorder to do so used a minimum clearance at midspan of 23.2 m whereas they could have selected 17.2 m based on clearance required for switching-surge insulation recommended by the National Electrical Safety Council.

(b) **Animals**

Experiments carried out in cages under e.h.v. lines have shown that pigeons and hens are affected by high e.s. field at about 30 k V/m. They are unable to pick up grain because of chattering of their beaks which will effect their growth. Other animals get a charge on their bodies and when they proceed to a water trough to drink water, a spark usually jumps from their nose to the grounded pipe or trough.

(c) **Plant Life**

Plant such as wheat, rice, sugarcane, etc., suffer the following types of damage. At a field strength of 20 k V/m (r.m.s.), the sharp edges of the stalk give corona discharges so that damage occurs to the upper portion of the grain-bearing parts. However, the entire plant does not suffer damage. At 30 k V/m, the by-products of corona, namely ozone and N_2O become intense. The resistance heating due to increased current prevents full growth of the plant and grain. Thus, 20 k V/m can be considered as the limit and again the safe value for a human being governs line design.

(d) **Vehicles**

Vehicles parked under a line or driving through acquire electrostatic charge if their tyres are made of inlsulating material. If parking lots are located under a line, the minimum recommended safe clearance is 17 m for 345 kV and 20 m for 400 kV lines. Trucks and lorries will require an extra 3 m clearance. The danger lies in a human being attempting to open the door and getting a shock thereby.

(e) **Others**

Fences, buried cables, and pipe lines are important pieces of equipment to require careful layout. Metallic fences parallel to a line must be grounded preferably every 75 m. Pipelines longer than 3 Km and longer than 15 cm in diameter are recommended to be buried at least 30 m laterally from the line centre to avoid dangerous eddy currents that could cause corrosion. Sail boats, rain gutters and insulated walls of nearby houses are also subjects of potential danger. The danger of ozone emanation and harm done to sensitive tissues of a human being at high electric fields can also be included in the category of damage to human beings living near e.h.v. lines.

4. ELECTROMAGNETIC FIELD -

If E_{dc} is the electric field strength and H_{dc} is magnetic field strength then

$$\frac{H_{dc}}{E_{dc}} = \sqrt{\frac{\epsilon_0}{\mu_0}} \qquad \text{............(11)}$$

taking air as the medium.

From equation (10) & (11)

$$H_{dc} = \sqrt{\frac{\epsilon_0}{\mu_0}} \left[\frac{V_{dc} \sin\theta}{d \ln\left(\frac{2h-a}{a}\right)} \right] \qquad \text{............(12)}$$

This expression gives the magnetic field at any point P due to transmission lines at potential V_{dc}.

5. ELECTROMAGNETIC EFFECT -

Electromagnetic currents are induced by e.h.v. transmission lines in grounded objects near the line. These are harmful to low-voltage circuits which must be suitably protected against damage by fuses, circuit breakers, etc. The induction is also important to line-repair crew who may accidentally come into contact with objects when body currents causing harm can flow. This usually occurs when there is a return path for current through ground so that suitable insulation must be used such as gloves or insulated platforms. Therefore, the method of grounding is all important.

When low-voltage lines run parallel to existing e.h.v. lines, and a lcop exists in the l.v. line, voltages up to 2000 volts/kilometre can exist under normal operating load currents and twice this value under short-circuit currents. The computation of current induced in the l.v. circuit involves mutual inductance between the e.h.v. and l.v. lines, and Carsons' equations for ground-return resistance and inductance have to be used. The usual hazards to workmen when they work on or near lines are of the following types and they may experience shccks by e.m. induction :

(a) High potential developed between an open-ended l.v. line and ground ;

(b) High potential between a grounded line and a remote ground on which they stand ;

(c) Step potential due to current flowing in ground.

6. **TRANSPOSITION OF LINES** -

In some cases the electromagnetically induced current in the communication circuit may be so great as to render speech impossible. The disturbance can be kept down by means of a through transposition of the conductors of both the power line and the telephone line. This transposition has the effect of splitting the induced E.M.F. into a series of mutually opposing E.M.F.s, the principle being identical with that underlying the transposition of heavy laminated conductors in large alternators and transformers. In the case of a telphone line running parallel to a single-circuit power line, if the power line has no branch lines, i.e. the current is constant throughout its length, and the spacings and distances between the two cirucits remain constant, then a single transposition of the conductors of the telephone line is theoretically sufficient, but with both circuits run on the same towers it may be necessary to transpose the power conductors every three or four miles, and the telephone conductors about every 500 feet. The number of transposition necessary is governed largely by the sensitiveness of the receiving apparatus. In the case of a telephone line running parallel to a double-circuit power line the problem is much more difficult, and it is necessary to transpose the conductors of both power lines in addition to those of the telephone line. A possible scheme is shown below, from which it will be seen that the scheme of transposition is a regular one for each individual circuit, and that it is arranged that not more than one transposition will take place at any one point in the line.

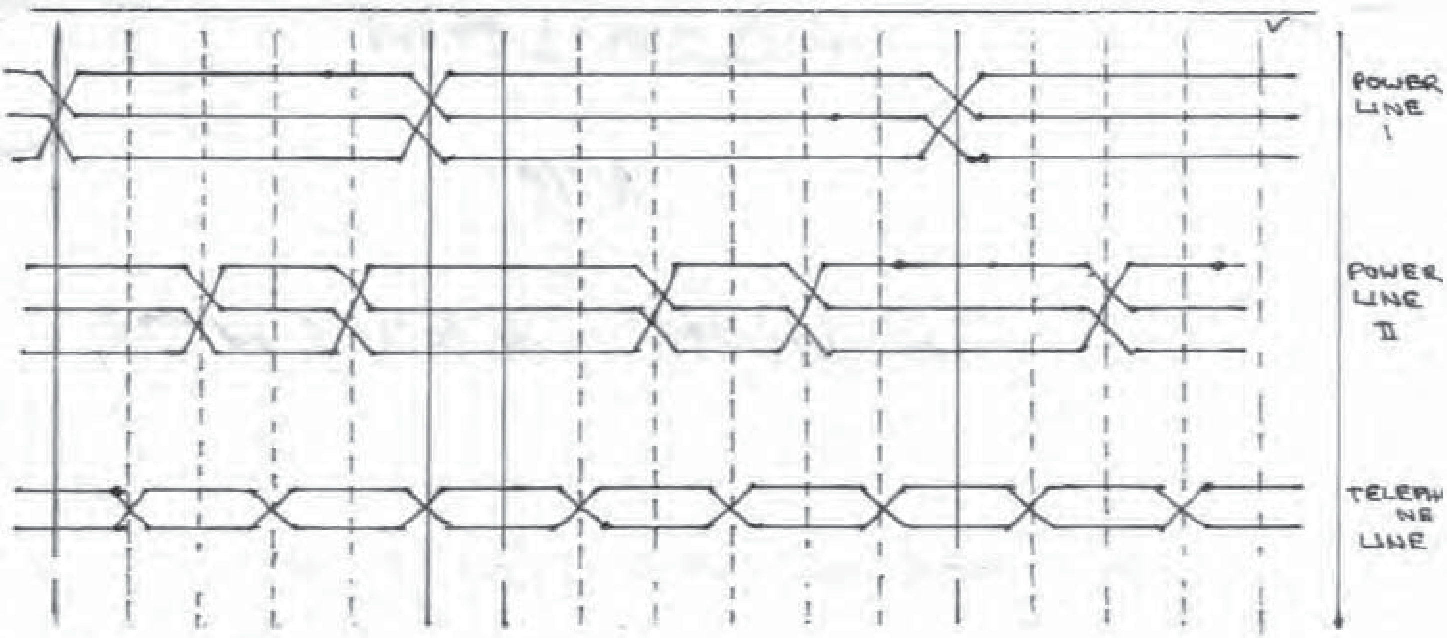

FIG.4 TRANSPOSITION SCHEME FOR TWO POWER LINES & A TELEPHONE LINE

Each transposition of a telephone line consists of a complete cross-over of the two conductors, while each transposition of a three-phase line consists of a twist, in a plane at right angles to the run of the line, of one-third of a revolution. Thus three transpositions are then necessary to bring the phases back to their original positions. Various methods of carrying out the transpositions on both telephone and power lines are shown in the next page.

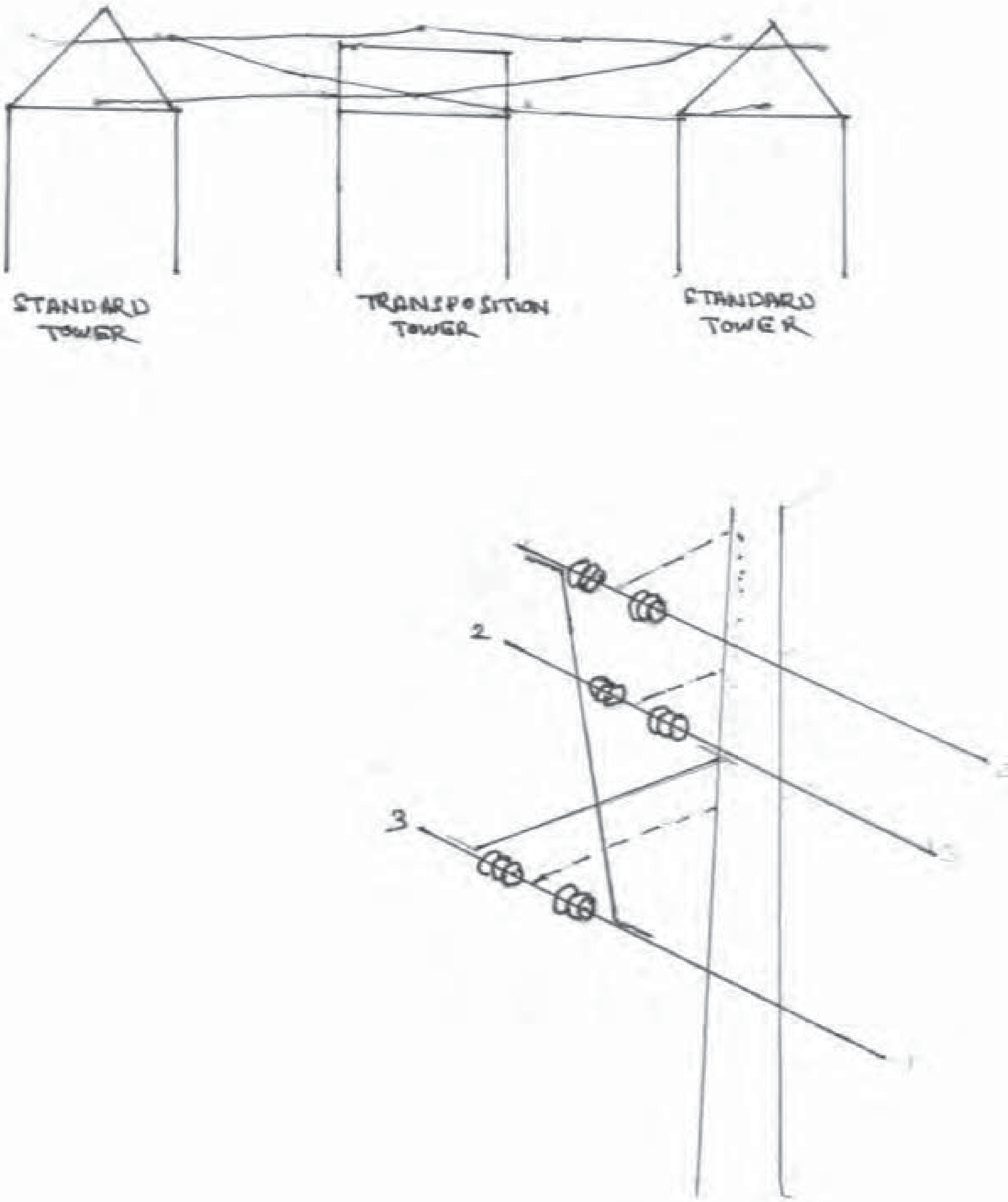

FIG.5. TWO METHODS OF TRANSPOSITION

It is to be noted that the electrostatic charging of the telephone line will also result in the flow of current, and this current also will tend to interfere with the clarity of the speech, an effect which cannot be eliminated entirely by transposition.

In extreme cases of electrostatic charging, as in single-phase electric railway systems with overhead trolley wires, it may be necessary completely to isolate the telephone apparatus from the telephone line by means of highly insulated transformers, and also to ensure the dissipation of the induced charges by means of such devices as earthed "drainage" coils and lightning arresters. One such scheme is shown below :

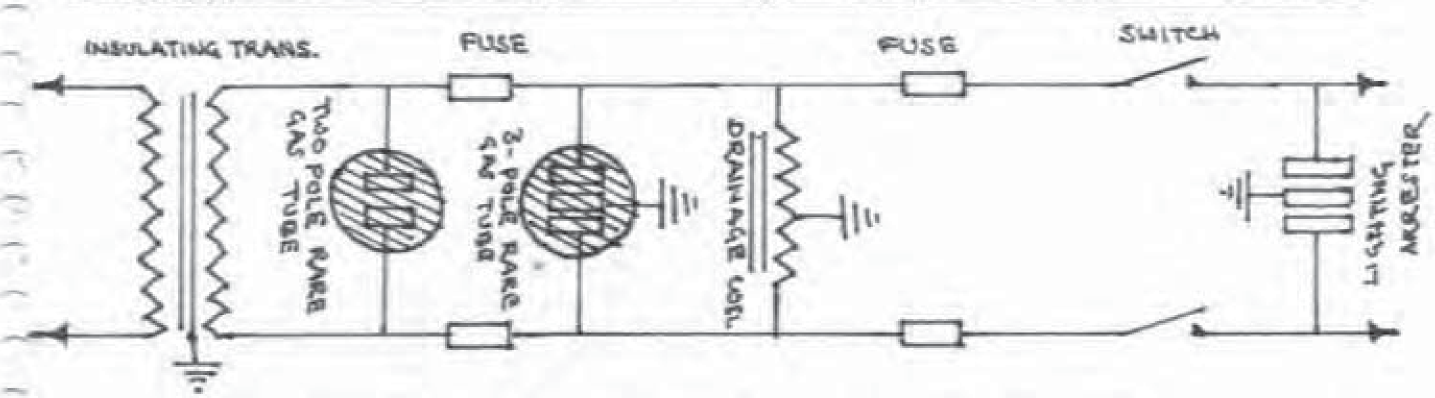

FIG.6. PROTECTIVE SYSTEM FOR COMMUNICATION CIRCUIT

Beginning from the line it consists of a switch with an air-gap arrester, high-tension fuses, drainage coil, three-pole rare-gas tube with the centre pole earthed, further fuses a two-pole rare-gas tube, and finally, an isolating transformer which completely isolates the receiving apparatus from the line. The three arresters are inserted so as to relieve the system of any excess voltages occuring between the line conductors, while the drainage coil, which is simply a choke with centre point connected to earth, prevents any accumulation of static charge. The rare-gas tubes are very sensitive to high-frequency disturbances such as might be produced by harmonics in the power line: they discharge freely as soon as the voltage reaches the neighbourhood of 300.

TV & RADIO INTERFERENCE

1. INTRODUCTION -

In case of HVDC line harmonic voltages (currents) are produced due to triggering pulses of thyristors and corona. In case of HVAC line, harmonic voltages (currents) are produced due to corona, partial discharges on insulators, and sparks across gaps.

TV interference occurs when the harmonic fields produced by transmission line is comparable to field due to TV station at the antenna in a particular frequency range. Due to similar reason RADIO intereference occurs.

Here we have found the electric field produced by HVDC source in the TV or Radio frequency range, then we have compared this field with the field due to DD (Bhubaneswar) & AIR (Cuttack). We have also tried to analyse the wave form received by antenna due to HVDC source.

2. FOURIER ANALYSIS OF HALF WAVE RECTIFIED SINE WAVE -

Fourier analysis of Half wave rectified sine waves required to find the harmonics produced by the HVDC source which is a combination of HV transformer and half wave rectifier. Let's consider the following wave form.

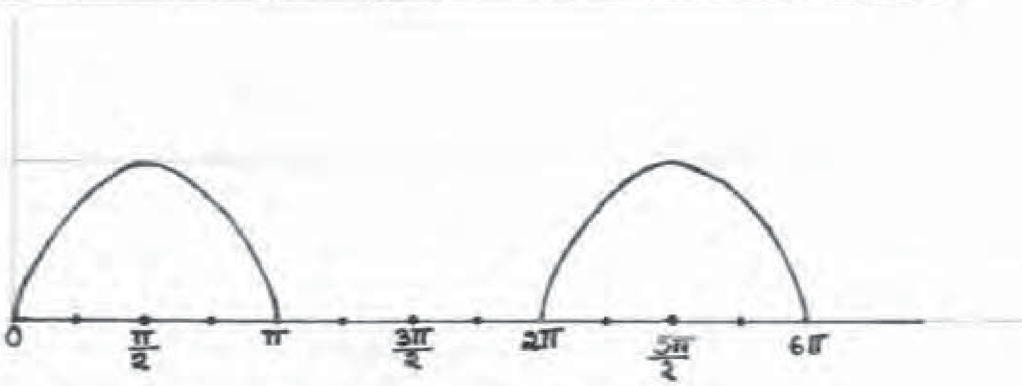

FIG.1. HALF WAVE RECTIFIED SINE WAVE

Here, $v(\theta) = \begin{cases} V_m \sin\theta & 0 \leq \theta \leq \pi \\ 0 & \pi \leq \theta \leq 2\pi \end{cases}$

We know the fourier series is

$$v(\theta) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\theta + b_n \sin n\theta) \qquad \text{..........(1)}$$

where $a_0 = \frac{1}{2\pi}\int_0^{2\pi} v(\theta)\,d\theta$

$$\left.\begin{aligned} a_n &= \frac{1}{\pi}\int_0^{2\pi} v(\theta)\cos n\theta\,d\theta \\ b_n &= \frac{1}{\pi}\int_0^{2\pi} v(\theta)\sin n\theta\,d\theta \end{aligned}\right\} \qquad \text{..........(2)}$$

$$\therefore \quad a_0 = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta\,d\theta$$

$$= \left(\frac{V_m}{\pi}\right) \qquad \text{..........(3)}$$

$$a_n = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta \cos n\theta\,d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\int_0^{\pi}\left[\sin(1+n)\theta + \sin(1-n)\theta\right]d\theta$$

$$= \left(-\frac{V_m}{2\pi}\right)\left[\frac{\cos(1+n)\theta}{1+n}\Big|_0^{\pi} + \frac{\cos(1-n)\theta}{1-n}\Big|_0^{\pi}\right]$$

$$= \left(-\frac{V_m}{2\pi}\right)\left[\frac{1}{1+n}\{\cos(1+n)\pi - 1\} + \frac{1}{1-n}\{\cos(1-n)\pi - 1\}\right]$$

$$= \left(-\frac{V_m}{2\pi}\right)\left[\frac{1}{1+n}(-\cos n\pi - 1) + \frac{1}{1-n}(-\cos n\pi - 1)\right]$$

$$= \left(\frac{V_m}{2\pi}\right)\left[\frac{2}{1-n^2}(1+\cos n\pi)\right]$$

$$= \left(\frac{V_m}{\pi}\right)\left[\frac{1}{1-n^2}(1+\cos n\pi)\right]$$

$$= \begin{cases} 0 & \text{when } n \text{ is odd, but } n \neq 1 \\ \dfrac{-2V_m}{\pi(n^2-1)} & \end{cases} \qquad \text{..........(4)}$$

Now, $a_1 = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta \cdot \cos\theta \cdot d\theta$

$$= \left(\frac{V_m}{2\pi}\right)\int_0^{\pi} \sin 2\theta \, d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\left[\left(\frac{-1}{2}\right)\cos 2\theta\right]_0^{\pi}$$

$$= 0 \qquad \text{..........(5)}$$

$$b_n = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta \cdot \sin n\theta \, d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\int_0^{\pi}\left[\cos(1-n)\theta - \cos(1+n)\theta\right] d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\left[\frac{\sin(1-n)\pi}{1-n} - \frac{\sin(1+n)\pi}{1+n}\right]$$

$$= \left(\frac{V_m}{2\pi}\right)\left[0\right] \text{ (when } n \neq 1\text{)}$$

$$= 0 \text{ (when } n \neq 1\text{)} \qquad \text{..........(6)}$$

when $n = 1$,

$$b_1 = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta \cdot \sin\theta \, d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\int_0^{\pi}(1-\cos 2\theta)\, d\theta$$

$$= \left(\frac{V_m}{2\pi}\right)\left[\theta\Big|_0^{\pi} - \frac{1}{2}\sin 2\theta\Big|_0^{\pi}\right]$$

$$= \left(\frac{V_m}{2}\right) \qquad \text{..........(7)}$$

from equation (3), (4), (5), (6), & (7),

$$v(\theta) = \left(\frac{V_m}{\pi}\right) + \left(\frac{V_m}{2}\sin\theta\right) - \left(\frac{2V_m}{\pi}\right)\sum_{n=2,4\cdots}^{\infty}\left(\frac{1}{n^2-1}\right)\cos n\theta$$

$$= V_m\left[\frac{1}{\pi} + \frac{1}{2}\sin\theta - \left(\frac{2}{\pi}\right)\sum_{n=2,4\cdots}^{\infty}\left(\frac{1}{n^2-1}\right)\cos n\theta\right] \qquad \text{..........(8)}$$

when $\theta = 0$,

$$v(\theta) = V_m\left[\frac{1}{\pi} - \left(\frac{2}{\pi}\right)\sum_{n=2,4..}^{\infty}\left(\frac{1}{n^2-1}\right)\right]$$

$$= \left(\frac{V_m}{\pi}\right)\left[1 + \sum_{n=2,4..}^{\infty}\left(-\frac{1}{n-1} + \frac{1}{n+1}\right)\right] \qquad \text{..........(9)}$$

But, for a half wave rectified sine wave

$$V_{dc} = \left(\frac{V_m}{\pi}\right) \qquad \text{..........(10)}$$

$$\therefore v(\theta) = V_{dc}\left[1 + \sum_{n=2,4..}^{\infty}\left(-\frac{1}{n-1} + \frac{1}{n+1}\right)\right] \qquad \text{..........(11)}$$

$$= V_{dc}\left[1 + \left(-1 + \frac{1}{3}\right) + \left(-\frac{1}{3} + \frac{1}{5}\right) + \left(-\frac{1}{5} + \frac{1}{7}\right) + \cdots\right] \qquad \text{..........(12)}$$

All the harmonies don't influence the communication system. Suppose

2p = Minimum harmonic &

2q = maximum harmonic.

that interfere in communication system.

The sum of harmonic voltages,

$$V_{harmonic} = V_{dc}\left[\left(-\frac{1}{2p-1} + \frac{1}{2p+1}\right) + \left(-\frac{1}{2p+1} + \frac{1}{2p+3}\right) + \cdots + \left(-\frac{1}{2q-1} + \frac{1}{2q+1}\right)\right]$$

$$= V_{dc}\left[-\frac{1}{2p-1} + \frac{1}{2q+1}\right] \qquad \text{..........(13)}$$

This is because the intermediate terms cancel each other.

Similarly, the harmonic field

$$E_{harmonic} = E_{dc}\left[-\frac{1}{2p-1} + \frac{1}{2q+1}\right] \qquad \text{..........(14)}$$

But we have found in previous chapter

$$E_{dc} = \left[\frac{V_{dc}\sin\theta}{d\cdot\ln\left(\frac{2h-a}{a}\right)}\right] \qquad \text{..........(15)}$$

Using equation (14) & (15)

$$E_{harmonic} = \left(-\frac{1}{2p-1} + \frac{1}{2q+1}\right)\left[\frac{V_{dc}\sin\theta}{d\cdot\ln\left(\frac{2h-a}{a}\right)}\right] \qquad \text{..........(16)}$$

3. FOURIER ANALYSIS OF A PERIODIC NON-SINUSOIDAL WAVE -

Given the waveform as a curve or an oscillogram or as a tabular set iof values, we cen't carry out an analytic process to find its Fourier series. In such cases graphical method is used.

In this method the waveform is divided into r number of uniformly spaced sections over a complete cycle and ordinates V_1, V_2, ..., V_{r+1} are erected as shown below :

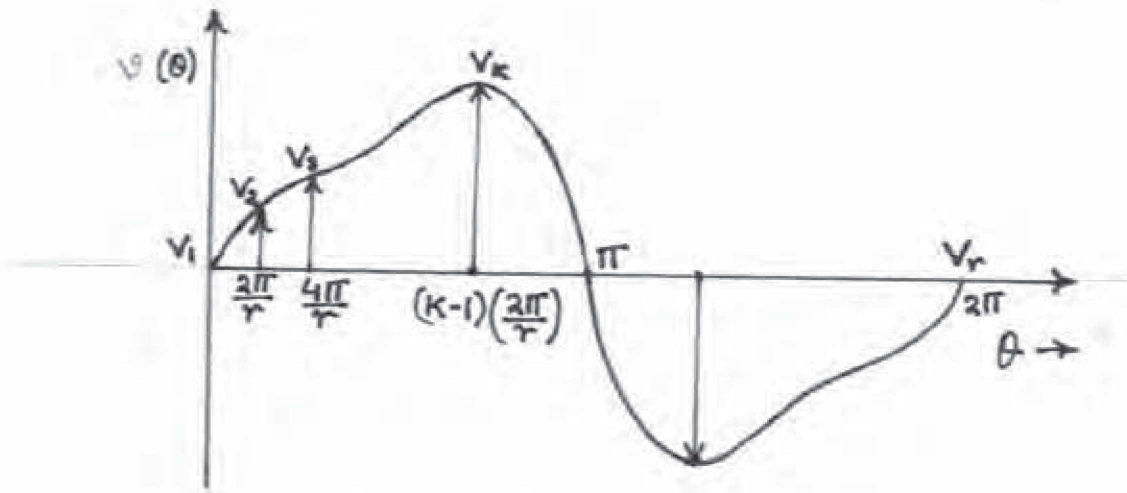

FIG.2. UNSYMMETRICAL WAVE ANALYSIS

The larger the number of these sections the greater is the accuracy in the values of the co-efficient. If the ordinates above θ axis are considered as positive, those below this axis are taken as negative.

DETERMINATION OF a_0 -

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} v(\theta)\,d\theta \qquad \text{.........(17)}$$

The integral can be evaluated by using Trapezoidal rule which is of the form,

$$\int_a^b y.dx = \frac{h}{2}\left[(y_1 + y_{r+1}) + 2(y_2 + y_3 + \cdots + y_r)\right] \qquad \text{...........(18)}$$

where, r is even & is the no. of intervals, &
h is the interval [= (b-a)/r]

$$\therefore a_0 = \left(\frac{1}{2\pi}\right)\cdot\left(\frac{2\pi}{2r}\right)\left[(V_1 + V_{r+1}) + 2(V_2 + V_3 + \cdots + V_r)\right]$$

$$= \left(\frac{1}{2r}\right)\left[V_1 + V_{r+1} + 2(V_2 + V_3 + \cdots + V_r)\right] \qquad \text{..........(19)}$$

DETERMINATION OF a_n -

$$a_n = \frac{1}{\pi}\int_0^{2\pi} v(\theta)\cos n\theta \cdot d\theta \qquad \text{.......... (20)}$$

$$= \frac{1}{\pi}\int_0^{2\pi} v_{cn}(\theta)\, d\theta \qquad \text{...........(21)}$$

where, $v_{cn}(\theta) = v(\theta)\cos n\theta$ ....(22)

Therefore,

$$a_n = \left(\frac{1}{\pi}\right)\left(\frac{2\pi}{2r}\right)\left[V_{cn1} + V_{cnr+1} + 2(V_{cn2} + \cdots + V_{cnr})\right]$$

$$= \left(\frac{1}{r}\right)\left[V_{cn1} + V_{cnr+1} + 2(V_{cn2} + \cdots + V_{cnr})\right] \qquad \text{...........(23)}$$

For any k (1 to r+1),

$$V_{cnk} = V_k \cos\left[(k-1)\left(\frac{2\pi}{r}\right)\right] \qquad \text{...........(24)}$$

DETERMINATION OF b_n -

$$b_n = \frac{1}{\pi}\int_0^{2\pi} v(\theta)\sin n\theta \cdot d\theta \qquad \text{........... (25)}$$

$$= \frac{1}{\pi}\int_0^{2\pi} v_{sn}(\theta)\, d\theta \qquad \text{...........(26)}$$

where, $v_{sn} = v(\theta)\sin n\theta$ ....(27)

$$\therefore \quad b_n = \left(\frac{1}{r}\right)\left[V_{sn1} + V_{snr+1} + 2(V_{sn2} + \cdots + V_{snr})\right] \qquad \text{..........(28)}$$

For any k (1 to r+1),

$$V_{snk} = V_K \sin\left[(k-1)\cdot\left(\frac{2n\pi}{r}\right)\right] \qquad \text{.............(29)}$$

4. **FLOW CHART FOR EVALUATION OF FOURIER CO-EFFICIENTS** -

R – No. of intervals
N – No. of harmonics
P : 1 → N
K : 1 → R+1

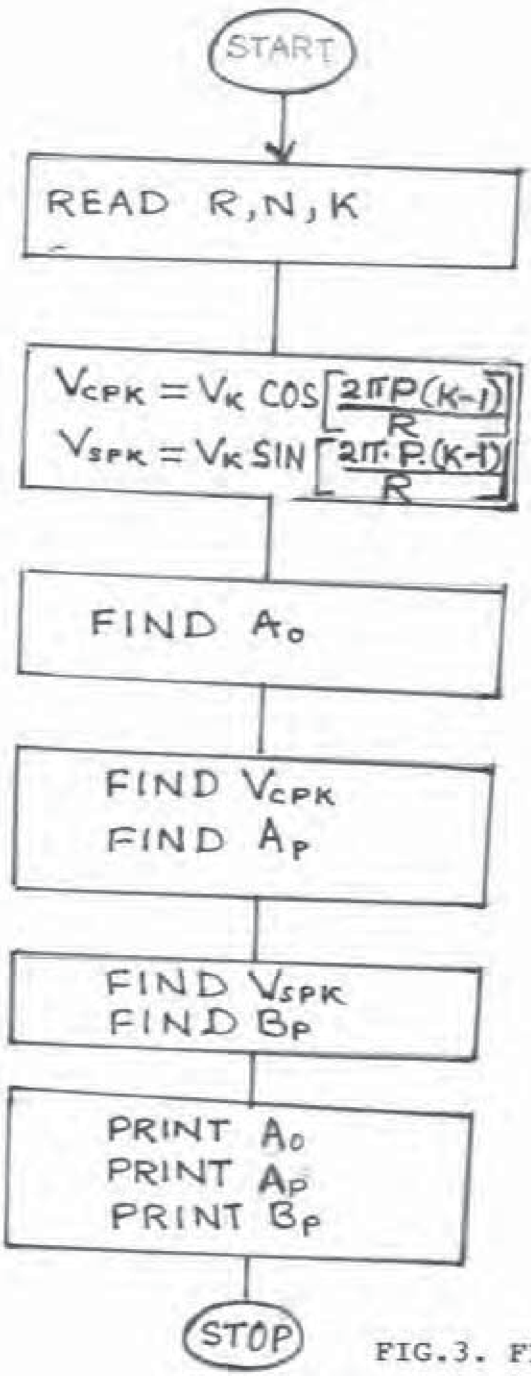

FIG.3. FLOW CHART

5. EXPERIMENTAL SET UP -

FIG.4. ACTUAL EXPERIMENTAL SET UP

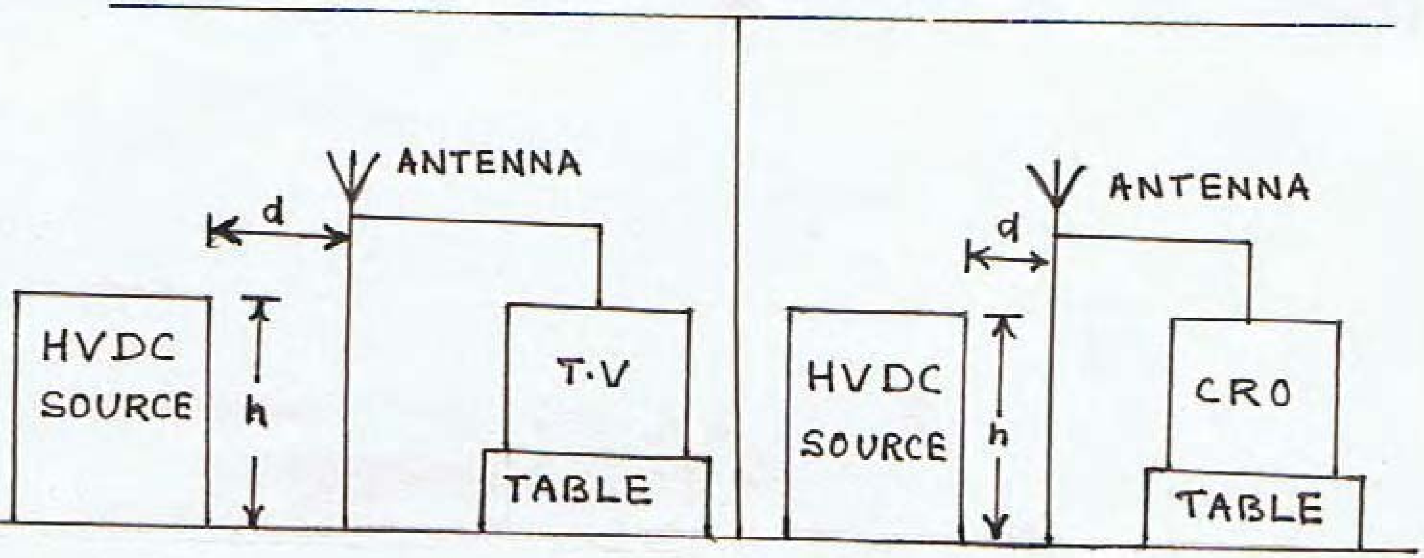

FIG.5. SCHEMATIC REPRESENTATION

The HVDC source consists of a HV transformer and a half wave rectifier. The half wave rectifier has two series connected diodes as the voltage rating of a single diode is less than the maximum voltage output of the transformer. The maximum rating of HVDC source is 140 kV.

FIG.6. THE HVDC SOURCE

The antenna consists of two arials and a circular disc to receive the noise signal from the HVDC source. The antinna is connected to either TV or CRO one at a time. The TV as its original antinna to receive programmes from TV stations.

FIG.7. THE ANTENNA.

The TV & CRO are made on after connection is done. Then the voltage lavel of HVDC source is varied gradually. Noise is found in TV that interfered with TV station programme. The waveform is also received in CRO & is traced in tracing paper for Fourier analysis.

6. OBSERVATION -

Due to harmonics produced noise was observed in TV as shown in the following Fig. For compairision with noiseless TV program another picture without noise is also given.

FIG.8. NOISELESS TV PROGRAMME

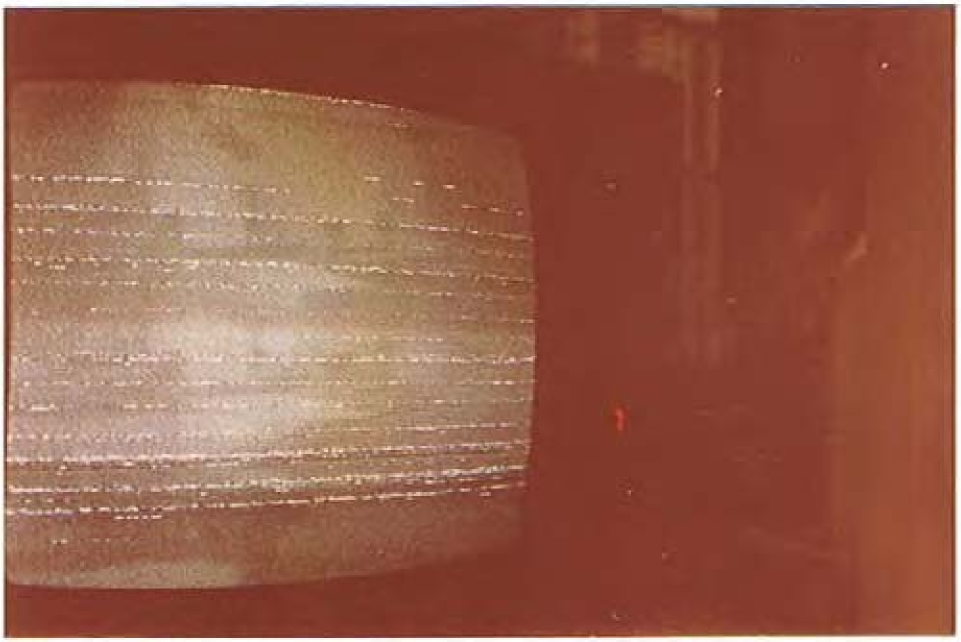

FIG.9. TV PROGRAMME WITH NOISE

After the voltage of HVDC source becomes more than 22 kV, the noise started appearing on TV. The noise are in the form of lines & dots on TV screen. There was no disturbance in audio signals even at higher voltages.

The signal received in CRO was of the form shown below :

FIG.10. WAVEFORM IN CRO.

Three different observations were taken at different voltages. The waveforms found in CRO were traced in tracing paper in each case. The waveforms are given below.

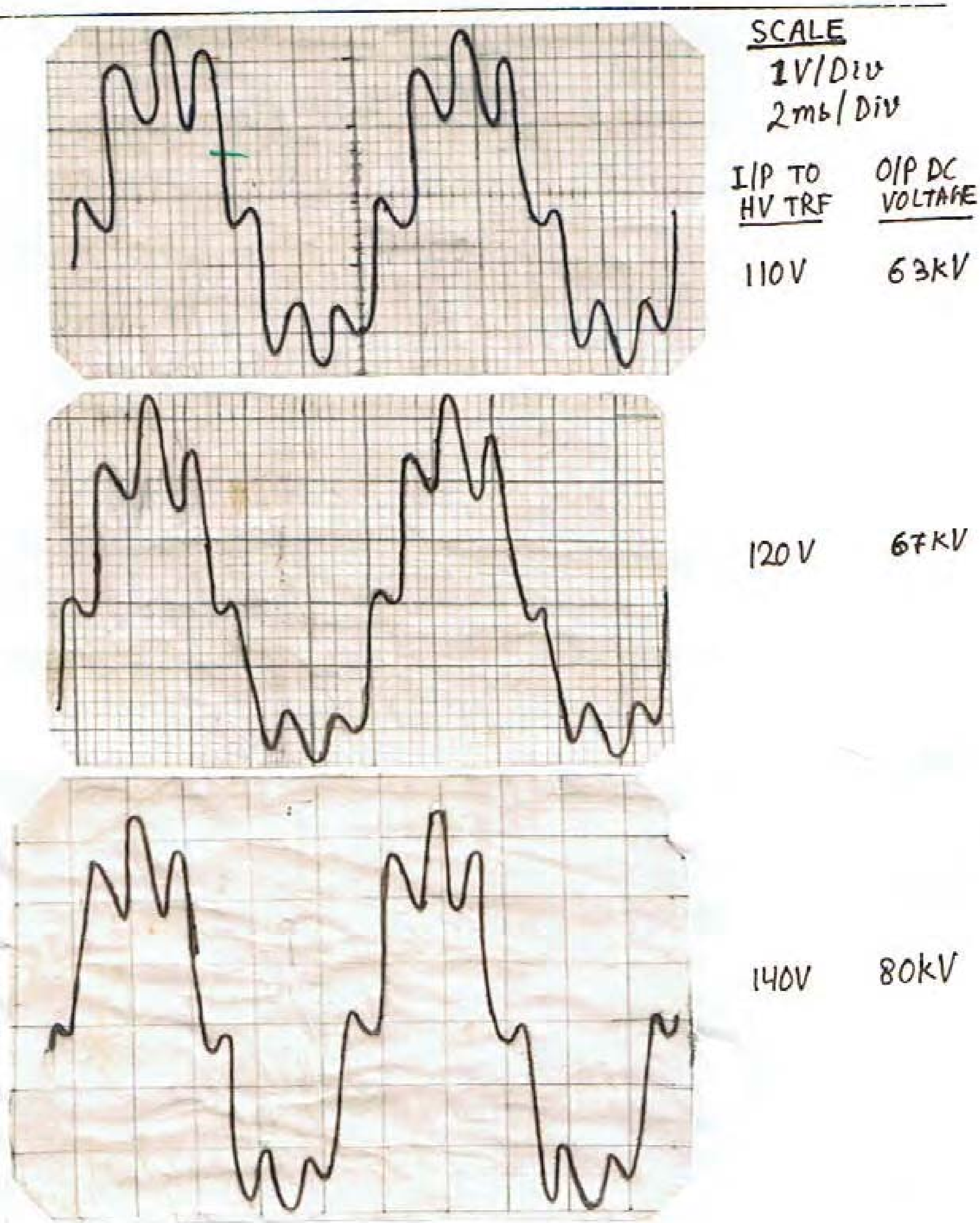

FIG.11. WAVEFORM RECEIVED IN CRO.

By studying the waveform in each case it is found that **the time period of noise signal remains the same whereas its amplitude increases with increase in the voltage of the HVDC source.**

7. ANALYSIS -

To find the harmony voltages that interfered in TV & Radio signals, the waveform found in CRO was analysed by the help of Fourier analysis. For this purpose a computer programme was made. The programe was correct (tested by the help of standard half wave rectified sinewave). But due to technical difficulties we could not found the harmonics of order more than 50 as the number of divisions for each cycle was limited to 50.

As it was not possible to find the harmonics from the programme we have found the harmonics from the fourier series of HVDC voltage source waveform which was half wave rectified sine wave.

The programme is given in the following pages.

```
C       PROGRAM IN FORTRAN FOR FINDING FOURIER SERIES
C
        INTEGER R,P,RR
         DIMENSION V(100),A(100),B(100)
         PI=3.1415927*2
C       R=NO.OF EVEN INTERVALS & N=NO.OF HARMONICS
C       (R+1) NO.OF VALUES OF FUNCTION IS TO BE ENTERED
C
        WRITE(*,10)
10      FORMAT(1X,'PLEASE ENTER NO. OF INTERVALS & NO.OF HARMONICS',/ )
        READ(*,*)R,N
        PP=2*3.1415927/R
        WRITE(*,20)
20      FORMAT(1X,'PLEASE  ENTER VALUES OF FUNCTION FOR A CYCLE',/)
        RR=R+1
        DO 30 K=1,RR
           READ(*,*)V(K)
30      CONTINUE
C
C       TO FIND A0
        SUM=0
        DO 40 K=2,R
           SUM=SUM+V(K)
40      CONTINUE
        A0=(V(1)+V(RR)+2*SUM)/(2*R)
C
C       TO FIND THE LOWER ORDER HARMONICS
        DO 50 P=1,N
           SUMA=0
           SUMB=0
           DO 60 K=2,R
            SUMA=SUMA+V(K)*COS(PP*(K-1)*P)
            SUMB=SUMB+V(K)*SIN(PP*(K-1)*P)
60         CONTINUE
           A(P)=(V(1)+V(RR)+2*SUMA)/R
           B(P)=2*SUMB/R
50      CONTINUE
C
C       TO PRINT THE LOWER ORDER HARMONICS
        WRITE(*,80)A0
80      FORMAT(1X,'THE FOURIER SERIES IS',/ 5X,F9.5)
        DO 90 P=1,N
           WRITE(*,100)A(P),P,B(P),P
100        FORMAT(5X,'+(',F9.5,'cos',I3,'wt)','+(',F9.5,'sin',I3,'wt)')
90      CONTINUE
C
```

```
      CALL MAJOR(A,B,N)
C     TO FIND THE TV INTERFERENCE HARMONICS
      CALL TV(R,N,V)
C     TO FIND THE RADIO INTERFERENCE HARMONICS
      CALL RADIO(R,N,V)
      STOP
      END
C
C
      SUBROUTINE MAJOR (A,B,N)
      INTEGER P
      DIMENSION A(100),B(100),AP(100),BP(100)
      APP=ABS(A(1))
      BPP=ABS(B(1))
      DO 110 P=2,N
         IF(APP.GE.ABS(A(P))) GO TO 120
           APP=ABS(A(P))
120      IF(BPP.GE.ABS(B(P))) GO TO 110
            BPP=ABS(B(P))
110   CONTINUE
      I=1
      J=1
      DO 130 P=1,N
         IF(APP.EQ.0) GO TO 140
            IF(ABS(A(P))/APP.LE.0.1) GO TO 140
               AP(I)=A(P)
               I=I+1
140      IF(BPP.EQ.0) GO TO 130
            IF(ABS(B(P))/BPP.LE.0.1) GO TO 130
               BP(J)=B(P)
               J=J+1
130   CONTINUE
      WRITE(*,150)
150   FORMAT(1X,'THE MAJOR COMPONENTS ARE',/)
      DO 160 P=1,I
         WRITE(*,170)AP(P),P
170      FORMAT(5X,'(',F9.5,'cos',I3,'wt)')
160   CONTINUE
      DO 180 P=1,J
         WRITE(*,190)BP(P),P
190      FORMAT(5X,'(',F9.5,'sin',I3,'wt)')
180   CONTINUE
      RETURN
      END
C
C
      SUBROUTINE TV(R,N,V)
```

```
      DOUBLE PRECISION X,Y,PI,PP,LL,LLL
      INTEGER P,R,RR
      DIMENSION AT(50),BT(50),V(100)
      WRITE(*,200)
200   FORMAT(1X,'SOME OF THE TV INTERFERENCE HARMONICS ARE',/)
      X=10**6
      PI=3.1415927*2
      PP=PI/R
      Y=DMOD(X,PI)
      LLL=170
      L=170
      LL=DMOD(LLL,PI)
      DO 210 P=1,30
         SUMAT=0
         SUMBT=0
         DO 220 K=2,R
            SUMAT=SUMAT+V(K)*DCOS(PP*LL*Y*(K-1)*P)
            SUMBT=SUMBT+V(K)*DSIN(PP*LL*Y*(K-1)*P)
220      CONTINUE
      AT(P)=(V(1)+V(RR)+2*SUMAT)/R
        BT(P)=2*SUMBT/R
         IF(AT(P).EQ.0) GO TO 230
           WRITE(*,240) AT(P),L
240        FORMAT(5X,'(',F12.7,2X,'cos',I3,'*10e6 wt',1X,')')
230      IF(BT(P).EQ.0) GO TO 210
           WRITE(*,250)BT(P),L
250        FORMAT(5X,'(',F12.7,2X,'sin',I3,'*10e6 wt',1X,')')
         L=L+1
         LLL=LLL+1
         LL=DMOD(LLL,PI)
210   CONTINUE
      RETURN
      END
C

      SUBROUTINE RADIO(R,N,V)
      DOUBLE PRECISION X,Y,PI,PP,LL,LLL
      INTEGER P,R,RR
      DIMENSION AT(50),BT(50),V(100)
      WRITE(*,200)
200   FORMAT(1X,'SOME OF THE RADIO INTERFERENCE HARMONICS ARE',/)
      X=10**3
      PI=3.1415927*2
      PP=PI/R
      Y=DMOD(X,PI)
       LLL=970
       L=970
```

```
      LL=DMOD(LLL,PI)
      DO 210 P=1,30
         SUMAT=0
         SUMBT=0
         DO 220 K=2,R
            SUMAT=SUMAT+V(K)*DCOS(PP*LL*Y*(K-1)*P)
            SUMBT=SUMBT+V(K)*DSIN(PP*LL*Y*(K-1)*P)
220      CONTINUE
      AT(P)=(V(1)+V(RR)+2*SUMAT)/R
        BT(P)=2*SUMBT/R
         IF(AT(P).EQ.0) GO TO 230
           WRITE(*,240) AT(P),L
240        FORMAT(5X,'(',F12.7,2X,'cos',I3,'*10e3 wt',1X,')')
230      IF(BT(P).EQ.0) GO TO 210
C          WRITE(*,250)BT(P),L
250        FORMAT(5X,'(',F12.7,2X,'sin',I3,'*10e3 wt',1X,')')
         L=L+1
         LLL=LLL+1
         LL=DMOD(LLL,PI)
210   CONTINUE
      RETURN
      END
```

```
ANALYSIS OF HALF-WAVE RECTIFIED SINE WAVE


PLEASE ENTER NO. OF INTERVALS & NO.OF HARMONICS

72
100
PLEASE  ENTER VALUES OF FUNCTION FOR A CYCLE

0.0
0.0872
0.1736
0.2588
0.3420
0.4226
0.5
0.5735
0.6428
0.7071
0.7660
0.8192
0.8660
0.9063
0.9397
0.9659
0.9848
0.9962
1.0
0.9962
0.9848
0.9659
0.9397
0.9063
0.8660
0.8191
0.7660
0.7071
0.6428
0.5736
0.5
0.4226
0.3420
0.2588
0.1736
0.0871
```

```
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
THE FOURIER SERIES IS
      .31810
    +(   .00000cos  1wt)+(   .49999sin  1wt)
    +(  -.21261cos  2wt)+(   .00000sin  2wt)
    +(   .00000cos  3wt)+(  -.00001sin  3wt)
    +(  -.04285cos  4wt)+(   .00000sin  4wt)
    +(   .00001cos  5wt)+(   .00000sin  5wt)
    +(  -.01860cos  6wt)+(   .00000sin  6wt)
    +(   .00001cos  7wt)+(  -.00001sin  7wt)
    +(  -.01052cos  8wt)+(   .00001sin  8wt)
```

```
+(    .00000cos  9wt)+(   .00000sin  9wt)
+(  -.00685cos 10wt)+(   .00000sin 10wt)
+(    .00000cos 11wt)+(   .00000sin 11wt)
+(  -.00488cos 12wt)+(   .00000sin 12wt)
+(    .00000cos 13wt)+(   .00000sin 13wt)
+(  -.00370cos 14wt)+(   .00000sin 14wt)
+(    .00000cos 15wt)+(   .00000sin 15wt)
+(  -.00294cos 16wt)+(   .00000sin 16wt)
+(    .00000cos 17wt)+(   .00000sin 17wt)
+(  -.00243cos 18wt)+(   .00000sin 18wt)
+(    .00000cos 19wt)+(   .00000sin 19wt)
+(  -.00207cos 20wt)+(   .00000sin 20wt)
+(    .00000cos 21wt)+(   .00000sin 21wt)
+(  -.00181cos 22wt)+(   .00000sin 22wt)
+(    .00000cos 23wt)+(   .00000sin 23wt)
+(  -.00162cos 24wt)+(   .00000sin 24wt)
+(    .00000cos 25wt)+(   .00000sin 25wt)
+(  -.00147cos 26wt)+(   .00000sin 26wt)
+(    .00000cos 27wt)+(   .00001sin 27wt)
+(  -.00138cos 28wt)+(   .00001sin 28wt)
+(  -.00001cos 29wt)+(   .00000sin 29wt)
+(  -.00130cos 30wt)+(   .00000sin 30wt)
+(  -.00001cos 31wt)+(   .00000sin 31wt)
+(  -.00125cos 32wt)+(   .00000sin 32wt)
+(    .00000cos 33wt)+(   .00000sin 33wt)
+(  -.00122cos 34wt)+(   .00000sin 34wt)
+(    .00000cos 35wt)+(   .00000sin 35wt)
+(  -.00121cos 36wt)+(   .00000sin 36wt)
+(    .00000cos 37wt)+(   .00000sin 37wt)
+(  -.00122cos 38wt)+(   .00000sin 38wt)
+(    .00000cos 39wt)+(   .00000sin 39wt)
+(  -.00125cos 40wt)+(   .00000sin 40wt)
+(  -.00001cos 41wt)+(   .00000sin 41wt)
+(  -.00130cos 42wt)+(   .00000sin 42wt)
+(  -.00001cos 43wt)+(   .00000sin 43wt)
+(  -.00138cos 44wt)+(  -.00001sin 44wt)
+(    .00000cos 45wt)+(  -.00001sin 45wt)
+(  -.00147cos 46wt)+(   .00000sin 46wt)
+(    .00000cos 47wt)+(   .00000sin 47wt)
+(  -.00162cos 48wt)+(   .00000sin 48wt)
+(    .00000cos 49wt)+(   .00000sin 49wt)
+(  -.00181cos 50wt)+(   .00000sin 50wt)
+(    .00000cos 51wt)+(   .00000sin 51wt)
+(  -.00207cos 52wt)+(   .00000sin 52wt)
+(    .00000cos 53wt)+(   .00000sin 53wt)
+(  -.00243cos 54wt)+(   .00000sin 54wt)
+(    .00000cos 55wt)+(   .00000sin 55wt)
```

```
+(   -.00294cos 56wt)+(   .00000sin 56wt)
+(    .00000cos 57wt)+(   .00000sin 57wt)
+(   -.00370cos 58wt)+(   .00000sin 58wt)
+(    .00000cos 59wt)+(   .00000sin 59wt)
+(   -.00488cos 60wt)+(   .00000sin 60wt)
+(    .00000cos 61wt)+(   .00000sin 61wt)
+(   -.00685cos 62wt)+(   .00000sin 62wt)
+(    .00000cos 63wt)+(   .00000sin 63wt)
+(   -.01052cos 64wt)+(  -.00001sin 64wt)
+(    .00001cos 65wt)+(   .00001sin 65wt)
+(   -.01860cos 66wt)+(   .00000sin 66wt)
+(    .00001cos 67wt)+(   .00000sin 67wt)
+(   -.04285cos 68wt)+(   .00000sin 68wt)
+(    .00000cos 69wt)+(   .00001sin 69wt)
+(   -.21262cos 70wt)+(   .00000sin 70wt)
+(    .00000cos 71wt)+(  -.49999sin 71wt)
+(    .63620cos 72wt)+(   .00000sin 72wt)
+(    .00000cos 73wt)+(   .49999sin 73wt)
+(   -.21261cos 74wt)+(   .00000sin 74wt)
+(    .00000cos 75wt)+(   .00000sin 75wt)
+(   -.04285cos 76wt)+(   .00000sin 76wt)
+(    .00001cos 77wt)+(   .00000sin 77wt)
+(   -.01860cos 78wt)+(   .00000sin 78wt)
+(    .00001cos 79wt)+(  -.00001sin 79wt)
+(   -.01052cos 80wt)+(   .00001sin 80wt)
+(    .00000cos 81wt)+(   .00000sin 81wt)
+(   -.00685cos 82wt)+(   .00000sin 82wt)
+(    .00000cos 83wt)+(   .00000sin 83wt)
+(   -.00488cos 84wt)+(   .00000sin 84wt)
+(    .00000cos 85wt)+(   .00000sin 85wt)
+(   -.00370cos 86wt)+(   .00000sin 86wt)
+(    .00000cos 87wt)+(   .00000sin 87wt)
+(   -.00294cos 88wt)+(   .00000sin 88wt)
+(    .00000cos 89wt)+(   .00000sin 89wt)
+(   -.00243cos 90wt)+(   .00000sin 90wt)
+(    .00000cos 91wt)+(   .00000sin 91wt)
+(   -.00207cos 92wt)+(   .00000sin 92wt)
+(    .00000cos 93wt)+(   .00000sin 93wt)
+(   -.00181cos 94wt)+(   .00000sin 94wt)
+(    .00000cos 95wt)+(   .00000sin 95wt)
+(   -.00162cos 96wt)+(   .00000sin 96wt)
+(    .00000cos 97wt)+(   .00000sin 97wt)
+(   -.00147cos 98wt)+(   .00000sin 98wt)
+(    .00000cos 99wt)+(   .00001sin 99wt)
+(   -.00138cos100wt)+(   .00001sin100wt)
THE MAJOR COMPONENTS ARE
```

```
( -.21261cos  1wt)
( -.21262cos  2wt)
(  .63620cos  3wt)
( -.21261cos  4wt)
(  .00000cos  5wt)
(  .49999sin  1wt)
( -.49999sin  2wt)
(  .49999sin  3wt)
(  .00000sin  4wt)
SOME OF THE TV INTERFERENCE HARMONICS ARE

(   -.1863592  cos170*10e6 wt )
(   -.0029419  cos171*10e6 wt )
(   -.0009428  cos172*10e6 wt )
(   -.0004921  cos173*10e6 wt )
(   -.0020268  cos174*10e6 wt )
(   -.0006285  cos175*10e6 wt )
(   -.0012273  cos176*10e6 wt )
(   -.0008678  cos177*10e6 wt )
(   -.0012025  cos178*10e6 wt )
(   -.0000379  cos179*10e6 wt )
(   -.0015892  cos180*10e6 wt )
(   -.0886418  cos181*10e6 wt )
(   -.0005317  cos182*10e6 wt )
(   -.0000319  cos183*10e6 wt )
(   -.0034501  cos184*10e6 wt )
(   -.0000088  cos185*10e6 wt )
(   -.0018110  cos186*10e6 wt )
(   -.0318898  cos187*10e6 wt )
(    .3850125  cos188*10e6 wt )
(   -.0022696  cos189*10e6 wt )
(   -.0009937  cos190*10e6 wt )
(   -.0000084  cos191*10e6 wt )
(   -.0004196  cos192*10e6 wt )
(   -.0040572  cos193*10e6 wt )
(   -.0013953  cos194*10e6 wt )
(   -.0012077  cos195*10e6 wt )
(   -.0010133  cos196*10e6 wt )
(   -.0012024  cos197*10e6 wt )
(   -.0000072  cos198*10e6 wt )
(   -.0000459  cos199*10e6 wt )
SOME OF THE RADIO INTERFERENCE HARMONICS ARE

(   -.1099621  cos970*10e3 wt )
(   -.0053274  cos971*10e3 wt )
(   -.0003347  cos972*10e3 wt )
(   -.0000036  cos973*10e3 wt )
```

```
   (     .4109002   cos974*10e3  wt  )
   (    -.0089807   cos975*10e3  wt  )
   (    -.0025621   cos976*10e3  wt  )
   (    -.0014612   cos977*10e3  wt  )
   (    -.0012123   cos978*10e3  wt  )
   (    -.0014349   cos979*10e3  wt  )
   (    -.0050502   cos980*10e3  wt  )
   (    -.0049918   cos981*10e3  wt  )
   (    -.0000257   cos982*10e3  wt  )
   (    -.0006609   cos983*10e3  wt  )
   (    -.0026797   cos984*10e3  wt  )
   (    -.0027657   cos985*10e3  wt  )
   (    -.0011100   cos986*10e3  wt  )
   (    -.0033303   cos987*10e3  wt  )
   (    -.0007185   cos988*10e3  wt  )
   (    -.0007468   cos989*10e3  wt  )
   (     .5161230   cos990*10e3  wt  )
   (    -.0001896   cos991*10e3  wt  )
   (    -.0020652   cos992*10e3  wt  )
   (    -.0186166   cos993*10e3  wt  )
   (    -.0004777   cos994*10e3  wt  )
   (    -.0001148   cos995*10e3  wt  )
   (    -.0025546   cos996*10e3  wt  )
   (    -.0013744   cos997*10e3  wt  )
   (    -.0226032   cos998*10e3  wt  )
   (    -.0002117   cos999*10e3  wt  )
Stop - Program terminated.
```

```
ANALYSIS OF WAVE RECEIVED IN ANTENNA


PLEASE ENTER NO. OF INTERVALS & NO.OF HARMONICS

50
100
PLEASE  ENTER VALUES OF FUNCTION FOR A CYCLE

12.5
12.4
12.0
10.0
8.5
8.0
10.0
10.5
11.0
7.5
5.0
1.5
1.5
2.5
2.2
2.0
0.0
-5.0
-9.0
-10.0
-5.0
-5.0
-6.0
-7.0
-10.0
-11.5
-12.0
-7.0
-6.0
-5.5
-6.0
-7.0
-9.0
-9.0
0.0
2.0
```

```
2.5
2.0
1.5
1.0
0.5
5.0
9.0
9.5
10.0
9.5
9.0
8.5
10.0
11.0
12.0
THE FOURIER SERIES IS
      1.55700
    +( 10.17217cos  1wt)+(   .48808sin  1wt)
    +(  -.51662cos  2wt)+(   .22356sin  2wt)
    +(  -.17340cos  3wt)+(  -.06009sin  3wt)
    +(   .11514cos  4wt)+(  -.20350sin  4wt)
    +(  -.43095cos  5wt)+(  -.01773sin  5wt)
    +(  -.15609cos  6wt)+(   .27261sin  6wt)
    +(  2.69829cos  7wt)+(   .67742sin  7wt)
    +(  -.79409cos  8wt)+(   .01323sin  8wt)
    +(  -.19234cos  9wt)+(   .02823sin  9wt)
    +(   .08360cos 10wt)+(   .13521sin 10wt)
    +(  -.35062cos 11wt)+(  -.11033sin 11wt)
    +(   .07915cos 12wt)+(   .06777sin 12wt)
    +(   .41507cos 13wt)+(   .15751sin 13wt)
    +(  -.42095cos 14wt)+(  -.57193sin 14wt)
    +(  -.01504cos 15wt)+(   .22651sin 15wt)
    +(   .03516cos 16wt)+(   .04838sin 16wt)
    +(  -.05207cos 17wt)+(  -.02496sin 17wt)
    +(   .01726cos 18wt)+(   .13123sin 18wt)
    +(   .12958cos 19wt)+(  -.14386sin 19wt)
    +(   .03440cos 20wt)+(  -.07416sin 20wt)
    +(  -.30468cos 21wt)+(   .30380sin 21wt)
    +(   .22890cos 22wt)+(  -.09339sin 22wt)
    +(  -.14200cos 23wt)+(  -.06908sin 23wt)
    +(   .11216cos 24wt)+(  -.05342sin 24wt)
    +(   .24200cos 25wt)+(   .00000sin 25wt)
    +(   .11216cos 26wt)+(   .05341sin 26wt)
    +(  -.14199cos 27wt)+(   .06907sin 27wt)
    +(   .22890cos 28wt)+(   .09339sin 28wt)
    +(  -.30468cos 29wt)+(  -.30379sin 29wt)
    +(   .03440cos 30wt)+(   .07415sin 30wt)
```

```
+(   .12958cos 31wt)+(   .14385sin 31wt)
+(   .01726cos 32wt)+(  -.13122sin 32wt)
+(  -.05207cos 33wt)+(   .02496sin 33wt)
+(   .03517cos 34wt)+(  -.04838sin 34wt)
+(  -.01504cos 35wt)+(  -.22651sin 35wt)
+(  -.42097cos 36wt)+(   .57192sin 36wt)
+(   .41507cos 37wt)+(  -.15751sin 37wt)
+(   .07914cos 38wt)+(  -.06777sin 38wt)
+(  -.35063cos 39wt)+(   .11032sin 39wt)
+(   .08360cos 40wt)+(  -.13520sin 40wt)
+(  -.19234cos 41wt)+(  -.02824sin 41wt)
+(  -.79411cos 42wt)+(  -.01324sin 42wt)
+(  2.69828cos 43wt)+(  -.67740sin 43wt)
+(  -.15610cos 44wt)+(  -.27262sin 44wt)
+(  -.43096cos 45wt)+(   .01773sin 45wt)
+(   .11513cos 46wt)+(   .20351sin 46wt)
+(  -.17342cos 47wt)+(   .06008sin 47wt)
+(  -.51667cos 48wt)+(  -.22355sin 48wt)
+( 10.17215cos 49wt)+(  -.48800sin 49wt)
+(  3.11400cos 50wt)+(   .00002sin 50wt)
+( 10.17218cos 51wt)+(   .48816sin 51wt)
+(  -.51658cos 52wt)+(   .22354sin 52wt)
+(  -.17338cos 53wt)+(  -.06009sin 53wt)
+(   .11515cos 54wt)+(  -.20351sin 54wt)
+(  -.43094cos 55wt)+(  -.01775sin 55wt)
+(  -.15608cos 56wt)+(   .27261sin 56wt)
+(  2.69830cos 57wt)+(   .67744sin 57wt)
+(  -.79408cos 58wt)+(   .01320sin 58wt)
+(  -.19234cos 59wt)+(   .02821sin 59wt)
+(   .08360cos 60wt)+(   .13520sin 60wt)
+(  -.35061cos 61wt)+(  -.11033sin 61wt)
+(   .07914cos 62wt)+(   .06776sin 62wt)
+(   .41508cos 63wt)+(   .15750sin 63wt)
+(  -.42098cos 64wt)+(  -.57194sin 64wt)
+(  -.01505cos 65wt)+(   .22651sin 65wt)
+(   .03517cos 66wt)+(   .04837sin 66wt)
+(  -.05207cos 67wt)+(  -.02496sin 67wt)
+(   .01725cos 68wt)+(   .13122sin 68wt)
+(   .12959cos 69wt)+(  -.14389sin 69wt)
+(   .03441cos 70wt)+(  -.07415sin 70wt)
+(  -.30468cos 71wt)+(   .30378sin 71wt)
+(   .22890cos 72wt)+(  -.09340sin 72wt)
+(  -.14199cos 73wt)+(  -.06908sin 73wt)
+(   .11217cos 74wt)+(  -.05342sin 74wt)
+(   .24200cos 75wt)+(   .00000sin 75wt)
+(   .11216cos 76wt)+(   .05341sin 76wt)
+(  -.14199cos 77wt)+(   .06907sin 77wt)
```

```
     +(   .22890cos 78wt)+(   .09341sin 78wt)
     +(  -.30469cos 79wt)+(  -.30380sin 79wt)
     +(   .03440cos 80wt)+(   .07415sin 80wt)
     +(   .12956cos 81wt)+(   .14386sin 81wt)
     +(   .01724cos 82wt)+(  -.13122sin 82wt)
     +(  -.05208cos 83wt)+(   .02496sin 83wt)
     +(   .03518cos 84wt)+(  -.04838sin 84wt)
     +(  -.01503cos 85wt)+(  -.22650sin 85wt)
     +(  -.42097cos 86wt)+(   .57193sin 86wt)
     +(   .41506cos 87wt)+(  -.15751sin 87wt)
     +(   .07914cos 88wt)+(  -.06777sin 88wt)
     +(  -.35064cos 89wt)+(   .11030sin 89wt)
     +(   .08355cos 90wt)+(  -.13521sin 90wt)
     +(  -.19234cos 91wt)+(  -.02824sin 91wt)
     +(  -.79411cos 92wt)+(  -.01326sin 92wt)
     +(  2.69829cos 93wt)+(  -.67738sin 93wt)
     +(  -.15610cos 94wt)+(  -.27262sin 94wt)
     +(  -.43102cos 95wt)+(   .01775sin 95wt)
     +(   .11508cos 96wt)+(   .20352sin 96wt)
     +(  -.17345cos 97wt)+(   .06007sin 97wt)
     +(  -.51670cos 98wt)+(  -.22357sin 98wt)
     +( 10.17213cos 99wt)+(  -.48792sin 99wt)
     +(  3.11400cos100wt)+(   .00003sin100wt)
THE MAJOR COMPONENTS ARE

     ( 10.17217cos  1wt)
     (  2.69829cos  2wt)
     (  2.69828cos  3wt)
     ( 10.17215cos  4wt)
     (  3.11400cos  5wt)
     ( 10.17218cos  6wt)
     (  2.69830cos  7wt)
     (  2.69829cos  8wt)
     ( 10.17213cos  9wt)
     (  3.11400cos 10wt)
     (   .00000cos 11wt)
     (   .48808sin  1wt)
     (   .22356sin  2wt)
     (  -.20350sin  3wt)
     (   .27261sin  4wt)
     (   .67742sin  5wt)
     (   .13521sin  6wt)
     (  -.11033sin  7wt)
     (   .06777sin  8wt)
     (   .15751sin  9wt)
     (  -.57193sin 10wt)
     (   .22651sin 11wt)
```

```
(    .13123sin 12wt)
(   -.14386sin 13wt)
(   -.07416sin 14wt)
(    .30380sin 15wt)
(   -.09339sin 16wt)
(   -.06908sin 17wt)
(    .06907sin 18wt)
(    .09339sin 19wt)
(   -.30379sin 20wt)
(    .07415sin 21wt)
(    .14385sin 22wt)
(   -.13122sin 23wt)
(   -.22651sin 24wt)
(    .57192sin 25wt)
(   -.15751sin 26wt)
(   -.06777sin 27wt)
(    .11032sin 28wt)
(   -.13520sin 29wt)
(   -.67740sin 30wt)
(   -.27262sin 31wt)
(    .20351sin 32wt)
(   -.22355sin 33wt)
(   -.48800sin 34wt)
(    .48816sin 35wt)
(    .22354sin 36wt)
(   -.20351sin 37wt)
(    .27261sin 38wt)
(    .67744sin 39wt)
(    .13520sin 40wt)
(   -.11033sin 41wt)
(    .06776sin 42wt)
(    .15750sin 43wt)
(   -.57194sin 44wt)
(    .22651sin 45wt)
(    .13122sin 46wt)
(   -.14389sin 47wt)
(   -.07415sin 48wt)
(    .30378sin 49wt)
(   -.09340sin 50wt)
(   -.06908sin 51wt)
(    .06907sin 52wt)
(    .09341sin 53wt)
(   -.30380sin 54wt)
(    .07415sin 55wt)
(    .14386sin 56wt)
(   -.13122sin 57wt)
(   -.22650sin 58wt)
```

```
    (   .57193sin 59wt)
    (  -.15751sin 60wt)
    (  -.06777sin 61wt)
    (   .11030sin 62wt)
    (  -.13521sin 63wt)
    (  -.67738sin 64wt)
    (  -.27262sin 65wt)
    (   .20352sin 66wt)
    (  -.22357sin 67wt)
    (  -.48792sin 68wt)
    (   .00000sin 69wt)
SOME OF THE TV INTERFERENCE HARMONICS ARE

    (     .4078323  cos170*10e6 wt )
    (    -.2221917  cos171*10e6 wt )
    (     .3218938  cos172*10e6 wt )
    (    -.3626350  cos173*10e6 wt )
    (     .0466264  cos174*10e6 wt )
    (    -.0924680  cos175*10e6 wt )
    (    -.9853725  cos176*10e6 wt )
    (     .9874084  cos177*10e6 wt )
    (    -.2906954  cos178*10e6 wt )
    (    -.1805916  cos179*10e6 wt )
    (    -.2776774  cos180*10e6 wt )
    (    -.6494874  cos181*10e6 wt )
    (     .2200474  cos182*10e6 wt )
    (    -.2436866  cos183*10e6 wt )
    (    -.2489416  cos184*10e6 wt )
    (     .2454903  cos185*10e6 wt )
    (     .2423633  cos186*10e6 wt )
    (     .1810644  cos187*10e6 wt )
    (    1.5950930  cos188*10e6 wt )
    (     .1937588  cos189*10e6 wt )
    (    -.7755440  cos190*10e6 wt )
    (     .0087550  cos191*10e6 wt )
    (     .2661708  cos192*10e6 wt )
    (     .2290561  cos193*10e6 wt )
    (     .1303645  cos194*10e6 wt )
    (    -.1310477  cos195*10e6 wt )
    (     .5709268  cos196*10e6 wt )
    (    -.2638565  cos197*10e6 wt )
    (    9.4248260  cos198*10e6 wt )
    (     .4718802  cos199*10e6 wt )
SOME OF THE RADIO INTERFERENCE HARMONICS ARE

    (    1.3985140  cos970*10e3 wt )
    (     .9007809  cos971*10e3 wt )
```

```
(    .0006094  cos972*10e3 wt )
(   -.5337845  cos973*10e3 wt )
(    .9289935  cos974*10e3 wt )
(    .4284645  cos975*10e3 wt )
(    .6411324  cos976*10e3 wt )
(   -.0145612  cos977*10e3 wt )
(   -.5788376  cos978*10e3 wt )
(   1.0190270  cos979*10e3 wt )
(    .2037313  cos980*10e3 wt )
(   -.0558610  cos981*10e3 wt )
(   -.3368815  cos982*10e3 wt )
(    .2397786  cos983*10e3 wt )
(   -.2425172  cos984*10e3 wt )
(    .0496559  cos985*10e3 wt )
(   -.5657661  cos986*10e3 wt )
(    .2636970  cos987*10e3 wt )
(    .0025328  cos988*10e3 wt )
(   1.2678840  cos989*10e3 wt )
(    .2338405  cos990*10e3 wt )
(  -1.5600100  cos991*10e3 wt )
(   -.1252488  cos992*10e3 wt )
(   -.3965214  cos993*10e3 wt )
(    .3496031  cos994*10e3 wt )
(   2.4322650  cos995*10e3 wt )
(    .7039732  cos996*10e3 wt )
(   -.1792620  cos997*10e3 wt )
(  -1.9056880  cos998*10e3 wt )
(    .1402139  cos999*10e3 wt )
Stop - Program terminated.
```

TV INTERFERENCE FIELD -

For channel 8 DD 1 :

Minimum frequency = 181 MHz

Maximum frequency = 188 MHz

Referring to equation (16)

$$2p = \frac{\text{Minimum frequency}}{\text{Fundamental Frequency}}$$

$$= (181 \text{ MHz}/50 \text{ Hz})$$

$$= 3.62 \times 10^6 \qquad \text{.............(30)}$$

$$2q = \frac{\text{Maximum frequency}}{\text{Fundamental Frequency}}$$

$$= (188 \text{ MHz}/50 \text{ Hz})$$

$$= 3.76 \times 10^6 \qquad \text{.............(31)}$$

Let's take the value of the HVDC source voltage for analysis purpose

$$V_{dc} = 63 \text{ kV} \qquad \text{..........(32)}$$

$$d = 1.75 \text{ m} \qquad \text{..........(33)}$$

$$h = .75 \text{ m} \qquad \text{..........(34)}$$

$$a = 0.0175 \text{ m} \qquad \text{..........(35)}$$

$$r = [d^2 + (2h)^2]^{\frac{1}{2}}$$

$$= 2.305 \text{ m} \qquad \text{..........(36)}$$

$$\sin\theta = (2h/r)$$

$$= 0.6508 \qquad \text{..........(37)}$$

$$E_{TV \text{ harmonic}} = \left(-\frac{1}{2P-1} + \frac{1}{2q+1}\right)\left[\frac{V_{dc}\sin\theta}{d\cdot\ln\left(\frac{2h-a}{a}\right)}\right]$$

$$= -10.2856 \times 10^{-9} \times 5.2776 \text{ kV/m}$$

$$= -54.2833 \times 10^{-9} \text{ kV/m}$$

$$= 54.2833 \ \mu V/m \text{ (in magnitude)} \qquad \text{..........(38)}$$

This is the value of harmonic field that interferred in TV signal.

RADIO INTERFERENCE FIELD -

For AIR Cuttack :

Minimum frequency = 987 KHz

Maximum frequency = 1007 KHz

$$2p = 87\ \text{KHz}/50\ \text{Hz} = 19.74 \times 10^{3} \qquad \text{..........(39)}$$

$$2q = 1007\ \text{KHz}/50\ \text{Hz} = 20.14 \times 10^{3} \qquad \text{...........(40)}$$

Taking the other parameters same as in case of TV interference and using equation (16) :

$$E_{\text{RADIO Harmonic}} = \left(-\frac{1}{2p-1} + \frac{1}{2q+1}\right)\left[\frac{V_{dc}\sin\theta}{d \cdot \ln\left(\frac{2h-a}{a}\right)}\right]$$

$$= -1.011 \times 10^{-6} \times 5.2776\ \text{kV/m}$$

$$= -5.3365 \times 10^{-6}\ \text{kV/m}$$

$$= 5336.5\ \mu\text{V/m} \qquad \text{.........(41)}$$

This is the value of harmonic field that interferred in RADIO signal.

FIELD DUE TO TV STATION

Power of TV station (Bhubaneswar) = 100 W

Distance of TV station = 10 km

Power density p = (Power/Area)

$$= \left[\frac{100}{4\pi (10 \times 10^{3})^{2}}\right]$$

$$= 7.958 \times 10^{-8}\ \text{w/m}^{2} \qquad \text{...........(42)}$$

But Power density p = EH

$$p = E \cdot \sqrt{\frac{\epsilon_0}{\mu_0}} \cdot E$$

$$= \sqrt{\frac{\epsilon_0}{\mu_0}}\, E^{2}$$

$$\Rightarrow E = \sqrt{\sqrt{\epsilon_0/\mu_0} \cdot P} \qquad \text{...........(43)}$$

So field due to TV station

$$E_{TV} = \sqrt{\frac{8.854\times10^{-12}}{4\pi\times10^{-7}} \times 79.5775\times10^{-9}}$$

$$= 0.0000145 \text{ v/m} = 14.533\,\mu V/m \qquad \ldots\ldots\ldots(44)$$

FIELD DUE TO RADIO STATION -

Power of RADIO Station (Cuttack) = 1 MW

Distance of RADIO Station = 30 km

$$\text{Power Density} = \left[\frac{1\times10^{6}}{4\pi\times(30\times10^{3})^{2}}\right]$$

$$= 88.42\times10^{-6}\ W/m^{2} \qquad \ldots\ldots\ldots(45)$$

Sc field due to RADIO station

$$E_{RADIO} = \sqrt{\frac{8.854\times10^{-12}}{4\pi\times10^{-7}} \times 88.42\times10^{-6}}$$

$$= 0.000484 \text{ V/m} = 484\,\mu V/m \qquad \ldots\ldots\ldots(46)$$

6. DISCUSSION -

As the field produced due to HVDC source is comparable to the field produced by TV (RADIO) station interference occurs. For no interference, field produced due to HVDC source has to be negligible in comparision to field produced due to TV (RADIO) station.

To find the distance of which a particular transmission line can't produce interference, we have to find the field due to TV (RADIO) station at that point and then we can find distance at which the field produced by the transmission line is negligible incomparision to this field.

In our case, V_{dc} = 63 kV

$$E_{TV} = 0.0000145 \text{ V/m}$$

Suppose for no interference

$E_{TV\ Harmonic} = 0.01\ E_{TV}$

$= 0.000000145$ V/m ....(47)

But, $E_{TV\ Harmonic} = \left|\left(-\frac{1}{2p-1}+\frac{1}{2q+1}\right)\right|\left[\frac{V_{dc}\sin\theta}{d\cdot \ln\left(\frac{2h-a}{a}\right)}\right]$

=> $0.000000145 = 10.2856\times10^{-9}\left[\frac{63\times10^{3}\cdot\sin\theta}{d\times 4.4393}\right]$ ....(48)

Now, $r = \sqrt{d^2+(2h)^2}$

for $d>>h$ $r \simeq d$

$\sin\theta = 2h/r$

$\simeq 2h/d$ ....(49)

Using equation (48) & (49)

$0.000000145 = 0.000146\left(\frac{2h}{d^2}\right)$

=> $d = 0.99\ m \simeq 1$ ....(50)

Similarly we can find distance for no RADIO interference.

CORONA

1. INTRODUCTION -

Let's consider a pair of parallel conductors to which is applied an alternating voltage. Let, the spacing between the parallel conductors be smaller as compared to their diameters. Let, the applied potential to the conductors be gradually increased, it will result into a gradual increase of potential gradient which will be maximum at any instant over the surface of the conductor. When the potential gradient reaches the critical value about 30kV/cm., the air in the immediate vicinity of the conductor becomes conducting and a hissing sound is heard along with vibration of conductor. If it happens in dark, a violet glow occurs around the conductor. Along with the cracking noise ozone is also produced which can be detected by its characteristic odour. The phenomena having above properties is called **corona.** The minimum voltage at which the ionization just takes place is called the **disruptive critical voltage(E_o).** The minimum voltage at which the corona just becomes visible is called the **visul critical voltage.**(E_v).

The corona glow is brightest at those surfaces of the conductor where the conductor surface is rough or dirty.

The effects of corona can be summarized as follows :

(i) A violet glow is observed around the conductor.

(ii) Hissing sound is produced

(iii) It produces ozone which can be detected by its characteristic odour.

(iv) The glow is maximum over rough and dirty surfaces of the conductor.

(v) If a wattmeter is connected in the electric circuit, it will show a reading; thus corona is accompanied by a power loss.

(vi) The charging current under corona condition increases because the corona introduces harmonic current.

2. THEORY OF CORONA FORMATION -

The formation of corona can be explained on the basis of electron theory. According to this theory even under normal condition the air around the conductor contains a number of free electrons. When the potential is gradually applied between the two conductors a potential gradient is established and under its influence the electrons acquire a uniformly increasing acceleration. The velocity attained by the free electrons in a given time depends upon :

(i) the mass of electrons,
(ii) its charge,
(iii) the potential gradient,
(iv) the field(potential) which causes acceleration of electrons.

Thus, the free electrons attain speed and these free electrons collide with the other slow moving or neutral molecules and in the process dislodge an electron from it. The average distance which an electron travels before striking is called the mean free path, it depends upon the number of molecules per unit volume of air which in turn depends upon temperature and barometric pressures.

When the potential gradient reaches about 30 kV (max.value) per cm., the velocity acquired by the free electrons is sufficient to strike the neutral molecule with sufficient force to dislodge one or more electrons from it. Then, these dislodged electrons and the previous free electrons strike other neutral molecules producing more number of electrons, so the effect is cumulative. When the saturation point is reached the insulating property of the air is destroyed. The air becomes conducting and corona forms or there may occur a spark between the two conductors.

3. CORONA PULSES -

There are in general two types of corona discharge from transmissionline conductors :

(i) Pulseless or Glow Corona ;
(ii)Pulse Type or Streamer Corona.

Both these give rise to energy loss, but only the pulse type of corona gives interference to radio broadcast in the range of 0.5 MHz to 1.6 MHz. In addition to corona generated on line conductors, there are spark discharges from chipped or broken insulators and loose guy wires which interfere with TV reception in the 80-200 MHz range. Audible noise caused by rain drops and high humidity conditions. Corona on conductors also causes interference to Carrier Communication and Signalling in the frequency range 30 KHz to 500 KHz.

In the case of Radio and TV interference the problem is one of locating the receivers far enough from the line in a lateral direction such that noise generated by the line is low enough at the receiver location in order to yield a satisfactory quality of reception. In the case of carrier interference, the problem is one of determining the transmitter and receiver powers to combat line-generated noise power.

Radio Interference (RI) level is governed not only by the amplitude and waveshape of a single pulse but also by the repetitive nature of pulses in a train. On an ac transmission line, as mentioned earlier, positive pulses from one single point in corona occur once in a cycle or at the most 2 or 3 pulses are generated near the peak of the voltage. In rain, the number of pulses in one positive half cycle shows an increase. Therefore, the number of pulses per second on a 50 Hz line from a single point in fair weather range from 50 to 150 and may reach 500 in rain. Since there exist a very large number of points in corcna, and the pulses occur randomly in time without correlation, the frequency spectrum is band-type and not a line spectrum. It is also found that in fair weather there exists a certain shielding effect when one source in corona does not permit another within about 20 to 50 cm. This is verified by photographs taken at night when plumes of bluish discharges occur at discrete points. However, in rain, there is a continuous luminous envelope around a conductor. It is therefore a matter of some difficulty in actually ascertaining the repetition rate of pulses as seen by the input end of a noise meter, which is either a rod antenna or a loop antenna. Fortunately, this is not as serious as it looks, since the integrated resonse of a standard noise-meter circuit is practically independent of the pulse repetition rate if the number of pulses per second (pps) is less than the bandwidth frequency of the filter in the meter weighting circuit.

4. CRITICAL VOLTAGE -

Let's consider a two conductor trasmission line and let the center plane be regarded as the neutral plane :

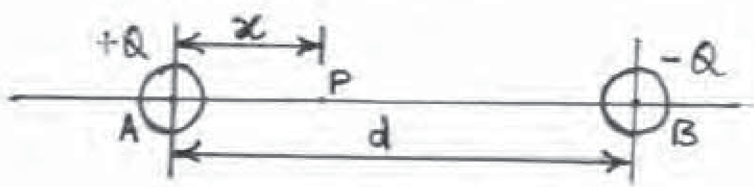

FIG.1. TWO CONDUCTOR TRANSMISSION LINE

Let r = tadius of each conductor

d = distance between two conductors

q = charge carried by each conductor /meter length.

Let P be any point at a distance x from A. Then potential at P

$$v = \frac{Q}{2\pi\epsilon_0} \ln\left(\frac{d-x}{x}\right) \qquad \text{..........(1)}$$

Potential between A & B

$$V = \frac{Q}{\pi\epsilon_0} \ln\left(\frac{d-r}{r}\right) \qquad \text{..........(2)}$$

From equation (1) & (2)

$$v = \frac{V \ln\left(\frac{d-x}{x}\right)}{2 \ln\left(\frac{d-r}{r}\right)} \qquad \text{..........(3)}$$

Potential at A = V/2 & at B = (-V/2).

Potential gradient at any point P is the intensity of the electrostatic field at that point & is given by (g= -dv/dx). So from equation (3)

$$g = \frac{V}{2\ln\left(\frac{d-r}{r}\right)}\left(\frac{x}{d-x}\right) \cdot \frac{x(-1)-(d-x)\cdot 1}{x^2}$$

$$= \frac{V}{2\ln\left(\frac{d-r}{r}\right)} \cdot \frac{d}{x(d-x)}$$

$$= \frac{E}{\ln\left(\frac{d-r}{r}\right)} \cdot \left[\frac{d}{x(d-x)}\right]$$

where E = V/2, the voltage between line and ground.

For small values of x & r,

$d - x \simeq d$ & $d - r \simeq d$

So $$g = \frac{E}{x \ln\left(\frac{d}{r}\right)} \qquad \text{..........(4)}$$

At the conductor surface, x = r so maximum potential gradient,

$$g_o = \frac{E_o}{r \cdot \ln(d/r)} \qquad \text{...........(5)}$$

where, E_o is known as disruptive critical voltage.

In the practical formula for E_o density factor of atmosphere and irregularity factor of conductor are taken into consideration.

5. <u>EXPERIMENTAL SET UP</u> -

In the experiment, we have tried to find the signal generated due to corona that affect the communication system. The experiment was conducted both for HVAC & HVDC. The arrangement are shown below.

FIG.1. EXPERIMENTAL SET UP FOR AC CORONA

FIG.2. EXPERIMENTAL SET UP FOR DC CORONA

For the study of AC corona the wire was connected between the transformer and an insulater (bushing). For the study of DC corona the wire was connected between the rectifier and the bushing.

In both cases signal was received in antenna. First CRO is connected with antenna to find noise signal waveform. Then TV is connected with antenna (along wtih the original antenna) to observe the noise in TV.

6. OBSERVATION -

The following observations were made :

(i) The wire used was vibrating & audioable noise was produced.

(ii) The waveform received in CRO was non-sinusoidal.

(iii) Different waveforms are seen in AC & DC corona.

(iv) TV intereference observed.

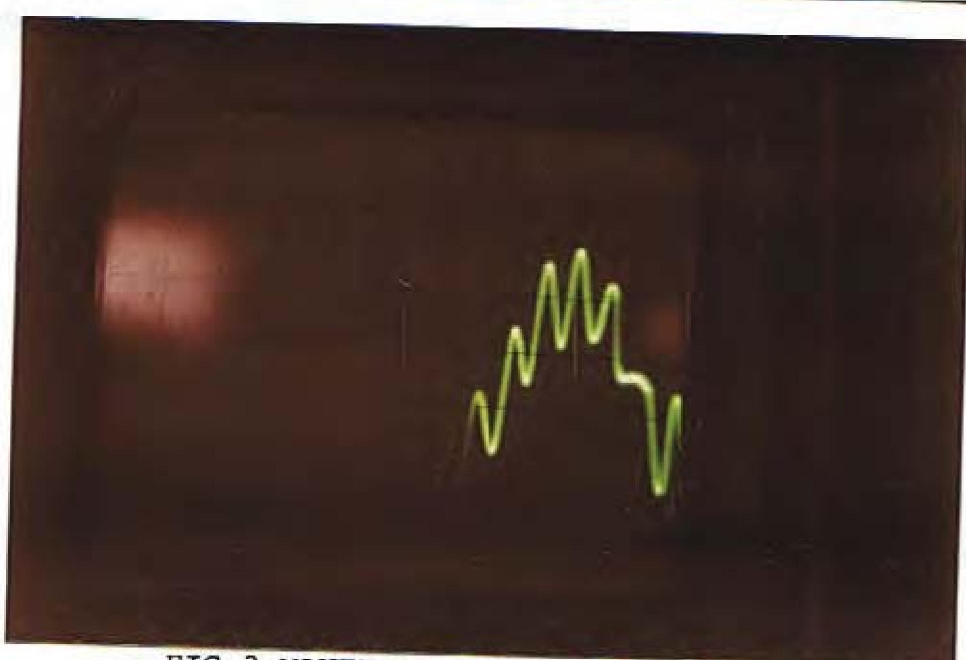

FIG.3 WAVEFORM FOR AC CORONA

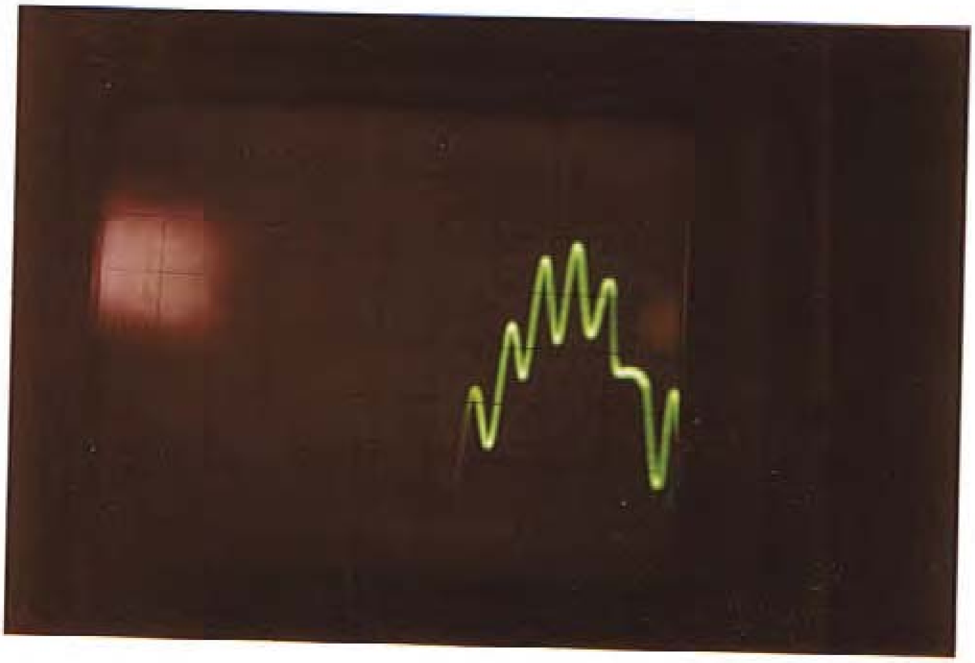

FIG.4. WAVEFORM FORM FOR DC CORONA

FIG.5. TV INTERFERENCE IN DC CORONA

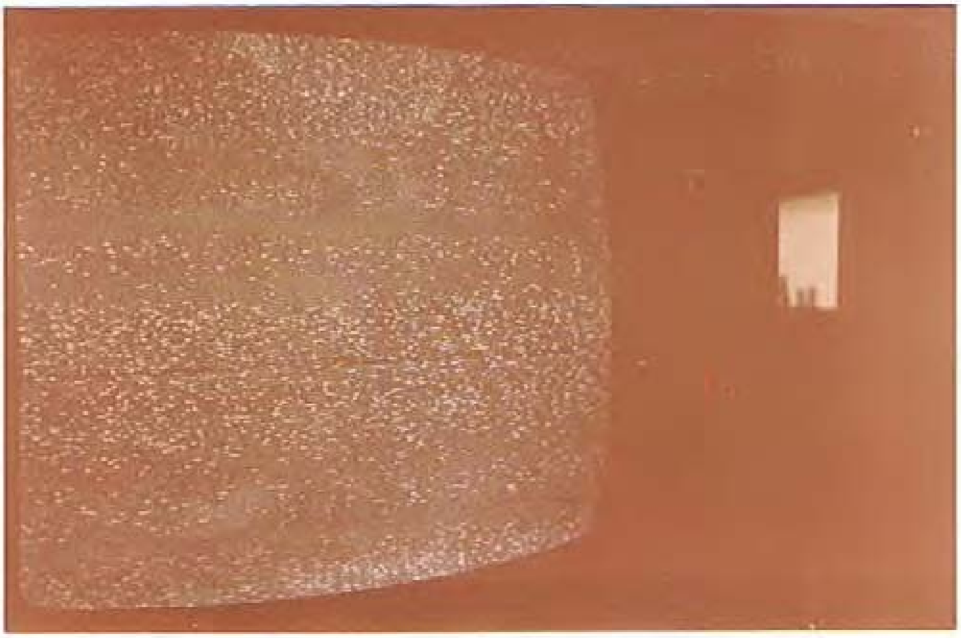

FIG.6. TV INTERFERENCE IN CASE OF AC CORONA

7. **EXPLANATION** -

When corona is present on the conductors, e.h.v. lines generate audible noise which is especially high during foul weather. The noise is broadband, which extends from very low frequency to about 20 KHz. Corona discharges generate positive and negative ions which are alternately attracted and repelled by the periodic reversal ofpolarity of the ac excitation. Their movement gives rise to sound-pressure waves at frequencies of twice the power frequency and its multiples, in addition to the broadband spectrum which is the result of random motions of the ions. **The sound-pressure waves are responsible for vidration of conductor.**

Due to differences in ionic motion between AC & DC excitations, DC lines exhibit only a broad band noise. **That is why the waveforms are different in AC & DC corona.**

5. **CALCULATION** -

Breakdown strength of air g_o = 21.1 kV/cm.

Height of conductor h = 0.75 m

Radius of conductor r = 0.00075 m = 0.075 cm

So, disruptive critical voltage

$E_o = g_o\, r \ln (2h/r)$

$= 21.1 \times 0.15 \times \ln (2 \times 0.75/0.00075)$

$= 24.0$

6. **CONCLUSION** -

The value of disruptive critical voltage found by calculation was confirmed by experiment.

Corona can be reduced by using bundle or hollow conducters.

COMPUTATION OF ELF ENERGY DISTRIBUTION OF AN EHV TRANSMISSION LINE TO STUDY THE BIOLOGICAL HAZARDS

1. INTRODUCTION -

Very recently 400 KV EHV transmission lines are in service in some of the states in India. Many such overhead transmission lines are likely to be erected in all other states. Even larger rating lines are under development and might be in operation in the near future. The advent of such EHV lines invite the problem of the field interaction with life form in close promimity to the transmission line. Hence it becomes increasingly important to have a thorough study on the pattern of the emanating ELF energy of such a transmission system.

The associated electric and magnetic fields of such lines give rise to appreciable ELF energy which is exposed to the environment. The existence of such energy flux, though at power frequency, has considerably effect on human body. The investigation of the physiological effects like tissue heating, heart fibrillation etc. due to ELF energy are of recent field of research. But unlike the U.S.A. and U.S.S.R. there is no ELF standard for India which will provide a guideline for designers of EHV Transmission lines.

Thus in the present investigation an attempt has been made in this regard by plotting the energy flux profiles in the lateral and vertical directions. These informations will aid the biomedical and environmental engineers to study the consequences of such exposures of ELF fields. Accordingly human exposure standards for India under ELF field may be fixed which will facilitate the power engineers to take safety measures during thedesign of EHV towers.

2. METHOD OF ESTIMATING THE ENERGY FLUX PROFILE -

Fig.1 shows a three phase EHV system with an array of four conductors in each phase which are suspended at the same height above the ground level. The method of image is used in determining the electric and magnetic fields of such a system. The different symbols employed in the analysis have been indicated in the same figure.

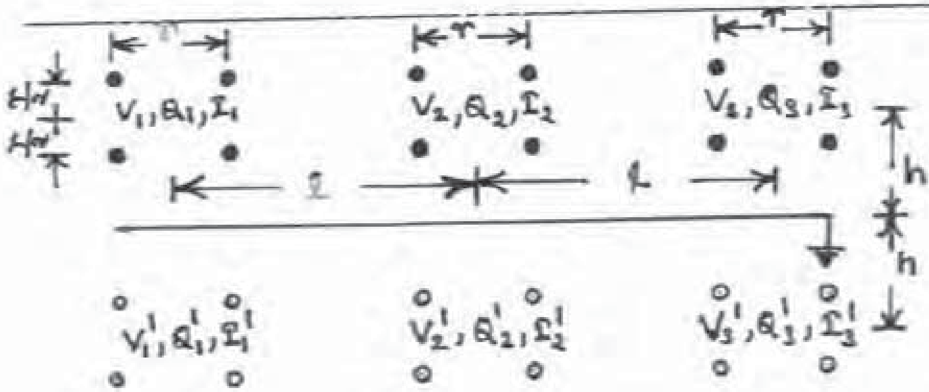

FIG 1.SCHEMATIC REPRESENTATION OF A THREE PHASE EHV SYSTEM WITH IMAGE ARRAYS.

The assumptions made in the analysis are :

(a) The earth is a good conductor.

(b) The height above the ground level and the phase spacings are very large compared to the conductor spacing.

(c) The origin of the co-oridinate system is chosen on the ground level just below the middle phase.

(d) The transmission line is modeled by parallel, infinitely long wires located above a flat hemogenous earth.

3. ANALYTICAL FORMULATION OF ELECTRIC FIELD -

Let's consider the first array of conductors as shown below : Fig.2

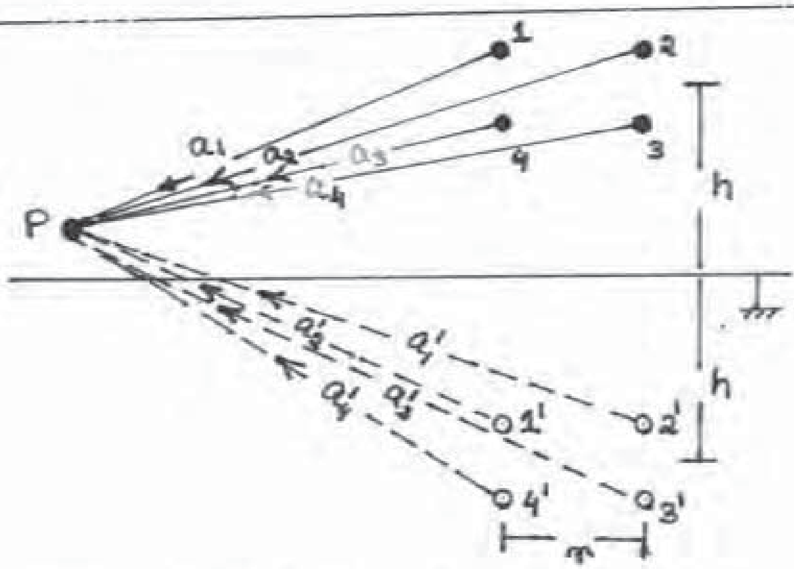

FIG.2.AN ARRAY OF FOUR CONDUCTORS & ITS IMAGE

The potential at any point P

$$V(P) = (1/2\pi\varepsilon_0)\sum_{n=1}^{4} q_n\, l_n\, (a_n'/a_n) \quad \text{..........(1)}$$

where

q_n = linear charge density of the nth wire

E_o = permittivity of the free space

a_n, a_n' =radial distances between the individual conductors and the point under consideration.

l = distance between two phase

Assuming V_1 as the potential of the first phase and setting this value at the position of each conductor of the first array four different equations of V_1 are obtained as follows :

$$V_1 = (1/2\pi\varepsilon_0)\left[A-(q_2+q_3+q_4)l_n a-(q_1 l_n C+q_3 l_n\sqrt{2})\right] \quad \text{..........(2)}$$

$$V_1 = (1/2\pi\varepsilon_0)\left[A-(q_1+q_2+q_4)l_n a-(q_3 l_n C+q_1 l_n\sqrt{2})\right] \quad \text{..........(3)}$$

$$V_1 = (1/2\pi\varepsilon_0)\left[A-(q_1+q_2+q_4)l_n a-(q_3 l_n C+q_1 l_n\sqrt{2})\right] \quad \text{..........(4)}$$

$$V_1 = (1/2\pi\varepsilon_0)\left[A-(q_1+q_2+q_3)l_n a-(q_4 l_n C+q_2 l_n\sqrt{2})\right] \quad \text{..........(5)}$$

where $\quad A = \sum_{n=1}^{y} q_n l_n a'_n$ ....(6)

and $\quad C$ = radius of individual wire.

Comparing equations (2) to (5) in succession, we have

$$q_1 = q_2 = q_3 = q_4 \qquad \text{..........(7)}$$

Since, the total linear charge density at the surface of each array is four times the corresponding charge density at the surface of each conductor, the potential of the first phase due to the first array system can be expressed as

$$V_1 = Q_1 C_1 \qquad \text{..........(8)}$$

where, $Q_1 = 4q_1$

and $\quad C_1 = (1/2\epsilon_0) l_n [(8\sqrt{2h^4})/r^3]$ ....(9)

Using the principle of superposition, the potentials of three phases can be obtained by taking the contributions of all the twelve conductors. Letting Q_i as the charge density of the ith array and V_i and I_i as the corresponding voltage and current, the expressions for Q_i in terms of the phase voltages are found out to be :

$$Q_1 = K_1V_1 + K_2V_2 + K_3V_3$$
$$Q_2 = K_4V_1 + K_5Q_1 + K_6V_3 \qquad \text{..........(10)}$$

and $\quad Q_3 = K_7V_3 + K_8Q_1 + K_9Q_2$

where $\quad K_1 = (C_1^2 - C_2^2)/B$

$$K_2 = C_2(C_3 - C_1)/B$$
$$K_3 = (C_2^2 - C_1C_3)/B$$
$$K_4 = C_1/D$$
$$K_5 = (C_3^2 - C_1^2)/D$$
$$K_6 = - C_3/D \qquad \text{..........(11)}$$
$$K_7 = 1/C_1$$
$$K_8 = - C_3/C_1$$
$$K_9 = - C_2/C_1$$
$$B = (C_1 - C_3)(C_1^2 - 2C_2^2 + C_2C_3)$$

and $\quad D = C_2(C_1 - C_3)$

In equation (11), C_1 is defined by equation (9) and C_2 and C_3 are defined by equation (12)

$$C_2 = (2/\pi\epsilon_0)\, l_n \left[(\sqrt{(4h^2+l^2)}/l\right]$$
$$C_3 = (2/\pi\epsilon_0)\, l_n \left[(\sqrt{(h^2+l^2)}/l\right] \qquad \text{..........(12)}$$

The horizontal and vertical components of the resultant electric field at any point in the X - Y plane produced due to the three phase transmission system are found out to be (as shown in Fig.3).

$$E_{tx} = (2hy/\pi\epsilon_0 \left[\sum_{m=1}^{3} Q_m x/(b_m b'_m)^2 + \right.$$
$$\left. l(Q_3/(b_3 b_3')^2 - Q_1/(b_1 b_1')^2)\right. \qquad \text{..........(13)}$$

and

$$E_{ty} = (1/2\pi\epsilon_0)\left[\sum_{m=1}^{3} Q_m (h-y)/b_m^2 + (h+y)/b_m'^2\right] \text{..........(14)}$$

where

B_m = Radial distance measured between each phase and the point of consideration (P).

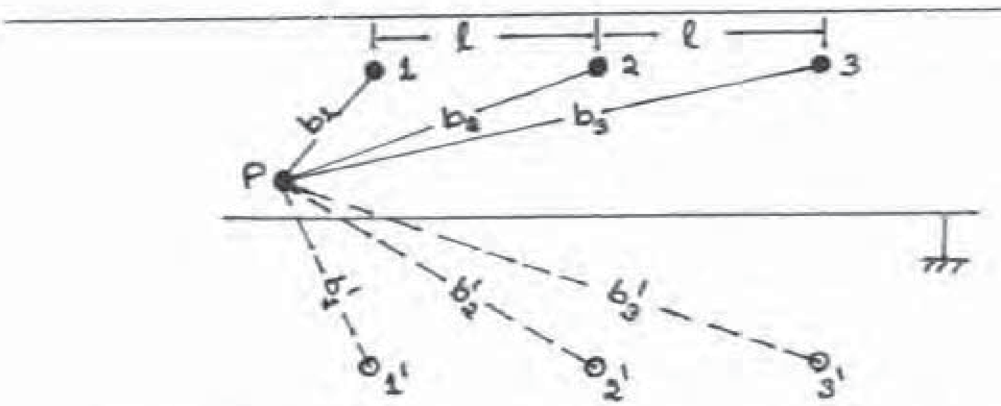

FIG.3. THREE PHASE SYSTEM WITH THE ARRAY OF CONDUCTORS BANDED TOGETHER IN THEIR RESPECTIVE PHASES.

At the earth surface $y = 0$ & $b_m = b_m$ & thus we have,

E_{tx} at $y = 0 = 0$

and $\quad$ Ety at $y = 0 = (h/\pi\epsilon_0)\sum_{m=1}^{3} Q_m/b_m^2$ ....(15)

Equation (15) implies that the horizontal component of the total electric field at the earth surface vanishes and only the vertical component exists. From equation (13), the electric field at x = 0 may be obtained as :

$$E_{tx\ at\ x=0} = (2hyl/\pi\epsilon_0\theta)\ (Q_3 - Q_1) \quad ....(16)$$

where $\theta = [l^2 + (h + y)^2]\ [l^2 + (h - y)^2]$ ....(17)

Assuming the supply voltage to be a three phase balanced one and taking V as the peak voltage relative to ground, equations (150 and (16) may be solved to yield

$$E_{ty\ at\ y=0} = (4hV/\pi\epsilon_0)\ (F \cos wt + G \sin wt) ....(18)$$

where $F = (\frac{1}{2})[[K_{10}\ (2K_1 - K_2 - K_3] + 2K_4[(1/b_2^2\ ) + (K_9/b_3^2\ )] - (K_{11}]$

$G = (\sqrt{3}/2)[K_{10}\ (K_3 - K_2) + K_{11}]$ ....(19)

$K_{10} = (1/b_1^2\ ) + (K_5/b_2^2\ ) + (K_8 + K_5K_9)/b_3^2$

and $K_{11} = (K_6/b_2^2\ ) + (K_7 + K_6K_9)/b_3^2$

and, $E_{tx\ at\ x=0} = (2hylV/\pi\epsilon_0\theta)\ [M \cos wt + N \sin wt)$ ....(20)

where, $M = (\frac{1}{2})\ [(K_8 - 1)\ (2K_1 - K_2 - K_3) - K_7]$

$N = (\sqrt{3}/2)\ [(K_3 - K_2)\ (K_8 - 1 + K_9K_5) + K_7 + K_9K_6]$ ...(21)

4. ANALYTICAL FORMULATION OF MAGNETIC FIELD -

In a similar way corresponding equations for the magnetic fields may be obtained, which are given below :

$H_{ty\ at\ y=0} = (h\bar{I}/\pi)\ [R \cos wt + S \sin wt]$ ....(22)

where $R = (1/b_1^2\ ) - \frac{1}{2}[(1/b_2^2\ ) + (1/b_3^2\ )]$

$S = (\sqrt{3}/2)\ [(1/b_3^2\ ) - (1/b_2^2\ )]$ ....(23)

and $H_{tx\ at\ x=0} = (\sqrt{3}hyl\ I/\pi\theta)\ [\sin wt - \sqrt{3} \cos wt]$ ....(24)

5. COMPUTATION OF THE ENERGY FLUX -

To obtain the energy flux in the lateral and vertical directions, the corresponding poynting vectors are determined and given by :

$$P(x,t)=E_{ty \text{ at } y=0} \times H_{ty \text{ at } y=0}$$
$$=(2h^2VI/\pi^2\epsilon_0)\ [(FR + GS) + (FS + GR)$$
$$\sin 2wt + (FR - GS) \cos 2wt] \qquad ....(25)$$

and
$$P(y,t)=E_{tx \text{ at } x=0} \times H_{tx \text{ at } x=0}$$
$$=(3h^2y^2l^2\ VI/\pi^2E_0\theta^2)\ [(N - \sqrt{3}M) + (M - \sqrt{3}N)$$
$$\sin 2wt - (N + \sqrt{3}M) \cos 2wt] \qquad ....(26)$$

The time integrals of the Poynting vectors [c.f.eqns. (25) and (26)] over a cycle give rise to the corrosponding energy fluxes which are expressed as :

$$P(x) = W(FR + GS)$$

and $$P(y) = (3Wy^2l^2/\theta^2)\ (N - \sqrt{3}M) \qquad ....(27)$$

where $$W = (h^2Vl/\pi^2\epsilon_0) \qquad ....(28)$$

Taking the standard data (4) for a 400 KV EHV transmission line, equation (27) is computed and plotted in fig.4 & Fig.5.

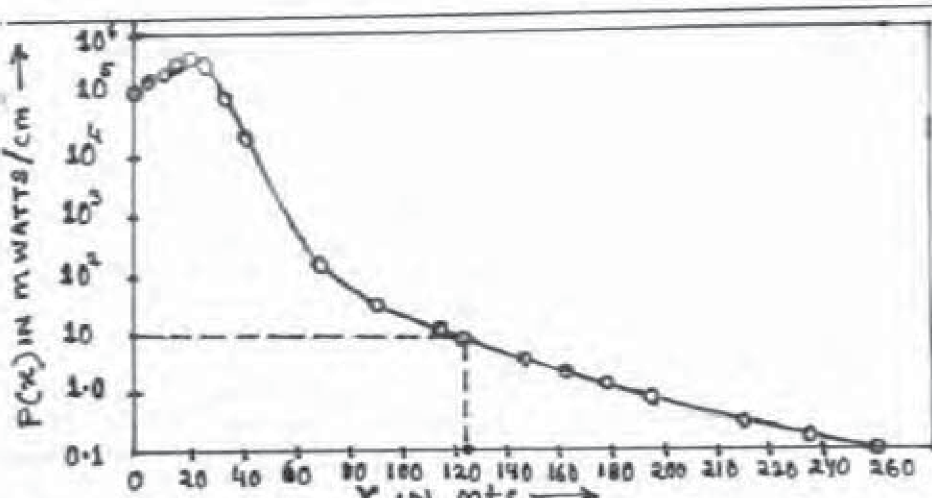

FIG.4. VARIATION OF GROUND LEVEL ENERGY FLUX IN THE LATERAL DIRECTION.

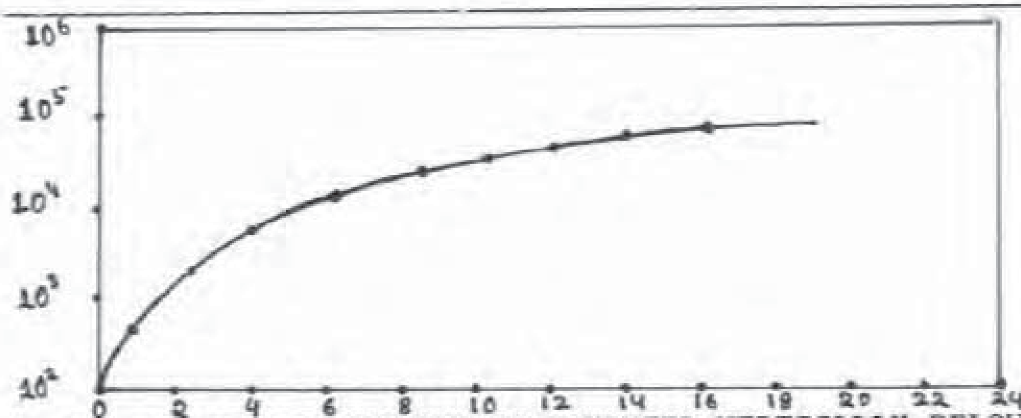

FIG.5. ENERGY FLUX DISTRIBUTION COMPUTED VERTICALLY BELOW THE T.L.

6. **RESULTS & DISCUSSIONS** -

The calculated energy flux in the lateral direction indicates that a person perceives an appreciable energy flux beyond the edge of the extreme phase. Computation also shows that the associated energy of such a system does not decrease to the level of U.S.A micro-wave exposure standard (10mw/cm^2) until 125 m & that of USSR microwave upto exposure standard (0.1mw/cm^2) until about 255m (Fig.3). Since no such exposure standard is provided in India, the energy flux profiles plotted in fig.4 & 5 will provide a guideline in assessing a suitable exposure level for India conditions. From Fig.4, it is also observed that a man standing below the transmission line experiences an energy flux of 460mw/cm^2 approx. It is expected that if the man is unprotected, such magnitude of energy flux is sufficient enough to produce a carona at the ends of the finger tips. When a ;man is exposed to such a field, the existence of acute electrical hazards like body-tissue heating,excitation of cellular membrane etc. are also to be examined. Thus the results obtained here will serve as a basic tool to the biomedical & environmental engineers for ascertaining whether such field is biologically innocuous and possibly allay the potential fear iof the public.

BIOLOGICAL EFFECTS OF ELF FIELDS FROM EHV TRANSMISSION LINES USING THE SPHERICAL MODEL OF MAN

1. INTRODUCTION -

The extremely low frequency (ELF)-EHV transmission lines radiate electromagnetic waves which interact with the biological systems. Recently, the potential hazards of such radiation to man attracted great public attention andmany investigations have been carried out to provide a radiation safety stadard.

A person standing beneath an EHV line is intercepted by its electric and magnetic fields. This results in the development of voltage stress and current density inside the body. A number of analytical studies for assessing these quantities, without considering their effects on human systems, have been reported. As the configuration of humanbody is complex in nature, the soltion of electromagnetic fields inside the body for exact models is not possible. Thus, simplified human models permitting mathematically tractable solution are employed to provide an understanding of the field interaction. Among such human models are planar layers of tissue, homogeneous and layered spherical models, tensor integral equation technique for analyzing irregular shaped heterogeneous models constructed of cubical subvolumes, perturbation theory approach for homogeneous prolate spheroidal and ellipsoidal models, and collection of straight cylinder sections of varying radii using methods of moments. Development of these sophisticated mathematical models of human body helps accurate evaluation of electrical hazards. To achieve this goal, the simplified spherical model has been considered taking only the electric field coupling into account. As the magnetic field coupling is equally important for predicting the induced values, work has been carried out considering both the fields of the EHV transmission line using a quasi-static approximation. But it assumes typical earth surface fields for estimating the induced current density, induced transmembrane potential, induced electric field and absorbed power.

In the investigation reported in this paper, the necessary equations of electric and magnetic fields of the EHV transmission line in terms of its dimensions and rating are applied using the image theory and quasi-static approximations. These expressions are directly used to simplify realistic spherical models in the whole-body tirradiation studies. Such models are still being used to study the power deposition characteristics in the heads of men and animals.

2. ANALYTICAL FORMULATION

The effect of the induced ELF fields inside the human beings and animals, due to their large wavelengths, are practically the same irrespective of their shapes and sizes. This can be observed from the fact that the calculations for the electrostatic fields based on the prolate spheroidal model of amanyield the internal field strength at best four times from those obtained for a spherical model. Hence in the present analysis the spherical model of a man is chosen in estimating induced fields.

The schematic representations of a three phase EHV system iwith image arrays and the arrays of conductors bundled together in their respective phases are shownin Fig.1 and 2, respectively. Assuming the transmission line to be modelled by parallel infinitely long wires lkocated above a flat, homogeneous earth; the total earth surface electric field of equation (1) due to this sytem has been derived elsewhere.

$$E_t = \frac{4hV}{\pi\epsilon_0} (F \cos wt + G \sin wt) \qquad \text{...........(1)}$$

where $G = 0.866\ [K_{10}\ (K_3 - K_2) + K_{11}]$

$$F = 0.5 \left[K_{10} \left(2K_1 - K_2 - K_3\right) + 2K_4 \left(\left(\frac{1}{b_2^2}\right) + \left(\frac{K}{b_3^2}\right)\right) - K_{11}\right]$$

where K_1 to K_9 are defined in previous chapter.

$$K_{10} = \left(\frac{1}{b_1^2}\right) + \left(\frac{K_5}{b_2^2}\right) + \left(\frac{1}{b_3^2}\right)\left(K_8 + K_5 K_9\right)$$

$$K_{11} = \left(\frac{K_6}{b_2^2}\right) + \frac{1}{b_3^2}\left(K_7 + K_6 K_9\right) \qquad \text{..........(2)}$$

h is the height above the ground level, V, the peak voltage relative to the ground and b_m, the radial distance measured between each phase and the point under consideration.

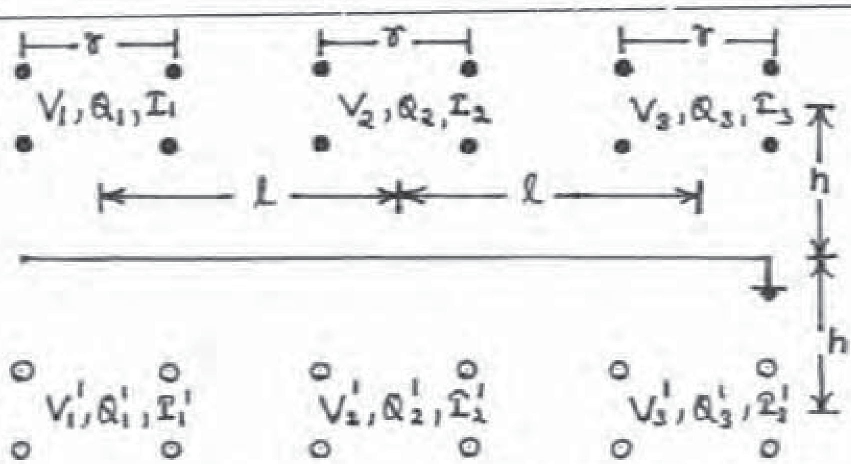

FIG.1 SCHEMATIC REPRESENTATION OF A THREE-PHASE EHV SYSTEM WITH IMAGE ARRAYS.

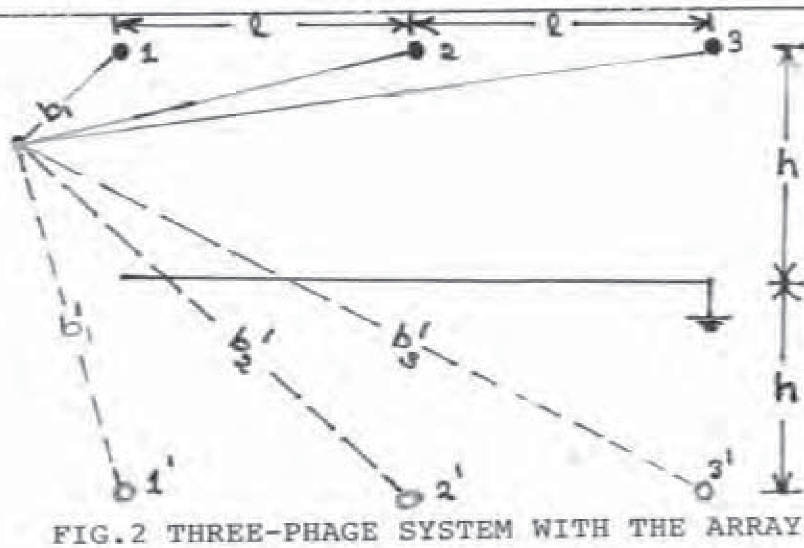

FIG.2 THREE-PHAGE SYSTEM WITH THE ARRAY OF CONDUCTORS BUNDLED TOGETHER IN THEIR RESPECTIVE PHASES.

The total earth surface field just below the middle phase of the conductor system is obtained by setting x = 0 in equation (1). The general form of equation (1) remains unchanged with the expressions for F, K_{10}, and K_{11} of equation (2) getting modified to :

$$F = 0.5 \left[K_{10} (2K_1 - K_2 - K_3) + \left(\frac{2K_4K_{12}}{d^2}\right) - K_{12} \right]$$

$$K_{10} = \frac{1}{d^2} (1 + K_8 + K_5K_{12})$$

$$K_{11} = \frac{1}{d^2} (K_7 + K_6K_{12})$$

$$K_{12} = 1 + K_9 + \left(\frac{1^2}{h^2}\right) \qquad \text{..........(3)}$$

In a similar manner, the corresponding earth surface magnetic field has been derived as :

$$H_t = \frac{hI}{\pi} (R \cos wt + S \sin wt) \qquad \text{..........(4)}$$

where $R = \left(\frac{1}{b_1 2}\right) - 0.5 \left[\left(\frac{1}{b_2 2}\right) + \left(\frac{1}{b_3 2}\right)\right]$

$$S = 0.866 \left[\left(\frac{1}{b_3 2}\right) - \left(\frac{1}{b_2 2}\right)\right] \qquad \text{..........(5)}$$

From equation (4), the total earth surface magnetic field just below the centre phase is obtained to be :

$$H_t = \frac{-I1^2}{2\pi h d^2 2}(\cos wt + \sqrt{3} \sin wt) \qquad \text{..........(6)}$$

The dielectric properties of the biological objects assumed to be homogeneous to be homogeneous and issotropic having similar values with muscle tissues. The induced electric field inside a dielectric sphere when exposed to external uniform electric and magnetic fields are[18].

$$\overline{E}_i = \frac{3\overline{E}_t}{(\epsilon_T} + j \left(\frac{w\mu_0}{2}\right) (\overline{H}_t \times \overline{r}) \qquad \text{............(7)}$$

Where $\overline{E}_i$ is the induced electric field, $\overline{E}_t$, the external electric field due to transsmission line, $\epsilon_T = 2 + (\epsilon_i/\epsilon_e)$, ϵ_e, the external relative complex dielectric constant, sphere relative complex dielectric constant, H_t, the external magnetic field due to transmission line, and $\bar{r} = \hat{x}x + \hat{y}y + \hat{z}z$ = position vector meaksured from thecentre of the sphere.

Since the external fields are not uniform, the largest value is taken in order to assume a worst case limit for internal field strength.

Evaluating equation (7) along the three axes,

$$E_x = \frac{3E_t}{\epsilon_T} - j\left(\frac{W\mu_0}{2}\right)H_t z$$

$$E_y = \frac{3E_t}{\epsilon_T}$$

$$E_z = \left(\frac{3E_t}{\epsilon_T}\right) + j\left(\frac{W\mu_0}{2}\right)H_t x$$

As the exterior medium is air, $E_c = 1$, and, therefore, $E_T \_ 2 + E_i \_ E_i$ (since $E_i > 2$). Also, E_i'' is atleast ten times greater than E_i' of equation (8) can safely be replaced by jE_i''. Substituting the values E_t and H_t from equations (1) and (6), the expressions of the three induced fields of equation (8) are :

$$|E_x| = (u^2 + 2x(2\psi^2 x + p^2))^{0.5}$$

$$|E_y| = u \qquad \text{..........(9)}$$

$$|E_z| = (u^2 + 2z(2\psi^2 z - p^2))^{0.5}$$

where

$$u^2 = \theta^2(F^2 + G^2)$$

$$p^2 = \theta\psi(F + \sqrt{3}G)$$

$$\theta = \frac{12hV}{\pi\epsilon_0 \epsilon_i''} \qquad \text{............(10)}$$

$$\psi = \frac{\omega\mu_0 I l^2}{4\pi h d^2}$$

and l is the spacing between two consecutive phases

$$b_1 = b_3 = (l^2 + h^2)^{0.5} = d$$

Equation (9) is computed and plotted in Fig.3 for obtaining the total internal field strength for 26 cm radius sphere representing a 70 kg man. The induced current density in the body J, is given by the relation

$$J = \sigma E \qquad \text{...........(11)}$$

where   is the electrical conductivity =
E, the total induced field corresponding to a 70 kg man

$$= \sqrt{E_{xm}^2 + E_{ym}^2 + E_{zm}^2}$$

Hence, equation (11) can be written as

$$J = \omega \epsilon_0 \epsilon_t'' \left(E_{xm}^2 + E_{ym}^2 + E_{zm}^2 \right)^{0.5} \qquad \text{..........(12)}$$

Excitation of cellular membrane gives rise to the low frequency electrical hazards like painful exposure, loss of muscular control and fibrillation. Therefore, an estimate of the transmembrane potential, 0, assists in knowing the possibility of exciting a neural membrane. For this, the human nervous tissue is modelled as a collection of hollow cylinders immersed in a conducting fluid. The transmembrane potential can be expressed as

$$\phi = \left(\frac{\xi}{g}\right) J \qquad \text{..........(13)}$$

where 'ξ' is a multiplying factor and is a function of neural diameter, neural membrane conductance, packing density and the conductivity of extra and intracellular fluid, g, the membrane conductance and J, the current density given in equation (12).

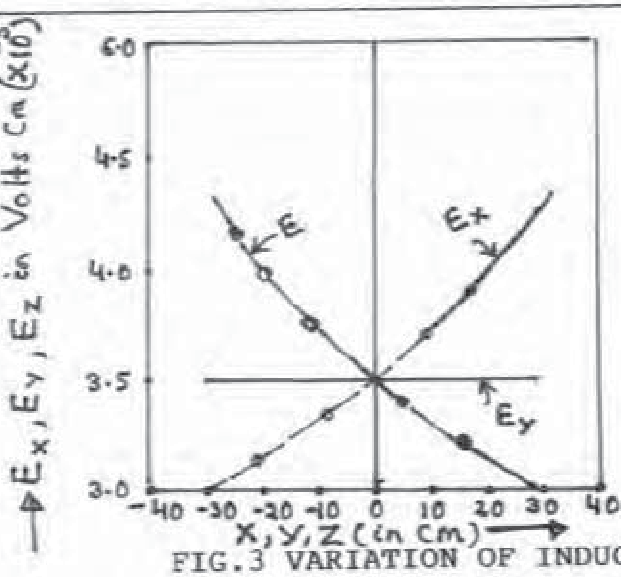

FIG.3 VARIATION OF INDUCED ELECTRIC FIELDS AS A FUNCTION OF SPHERE RADIUS.

The two extreme values of g are 0.001 (mho/cm^2) and 0.1 (mho/cm^2), the first for passive membrane & the second corresponds to excited membrane. The multiplying factor as a function of neural diameter is obtained and is plotted in Fig.4 as a function of the diameter iof neural process.

The average power density is given by $\frac{\sigma}{2}|E_i^2|$. Thus, use of equation (7) yields the following expression of the absorbed power

$$P(t) = \pi\sigma m^3(\alpha \cos 2\omega t + \beta \sin 2\omega t + \delta) \qquad \text{..........(14)}$$

Where

$$\alpha = \frac{48}{\pi^2\epsilon_0^2}\,\frac{(F^2-G^2)}{|\epsilon_T|^2}\,h^2V^2 - \frac{I^2\ell^4\omega^2m^2}{60\pi^2h^2d^4}$$

$$\beta = \frac{96}{\pi^2\epsilon^2}\,\frac{(FGh^2V^2)}{|\epsilon_T|^2} - \frac{I^2\ell^4\omega^2m^2}{20\sqrt{3}\,\pi^2h^2d^4}$$

$$\gamma = \frac{48}{\pi^2\epsilon_0^2}\,\frac{(F^2+G^2)h^2V^2}{|\epsilon_T|^2} + \frac{I^2\ell^4\omega^2m^2}{30\pi^2h^2d^4}$$

$$\text{..........(15)}$$

and m= radius of the sphere.

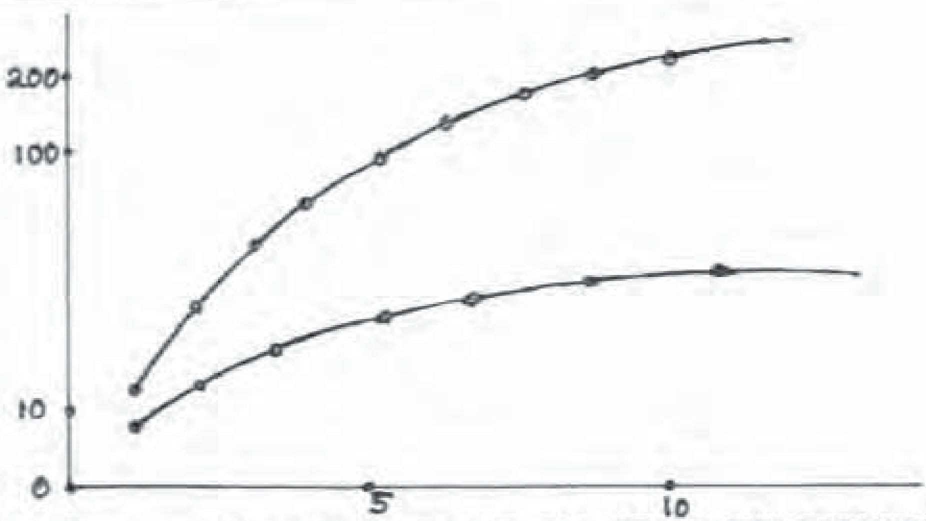

FIG.4 VARIATION OF TRANSMEMBRANE POTENTIAL WITH DIAMETER OF NEURAL NEURAL PROCESS.

The time averaged power density is defined as :

$$P = \frac{\int_0^T P(t)\,dt}{\int_0^T dt}\,; \quad T = \left(\frac{2\pi}{\omega}\right) \qquad \text{..........(16)}$$

Solution of equation (16) in the light of equation (14) gives rise to the time aerage power density as

$$P = \Upsilon m^3 , \Upsilon = 0.333 \pi \sigma m^3 (u^2 + 1.6 \psi^2 m^2) \quad \text{..........(17)}$$

where u and ψ are defined in equation (10)

It is observed here that the value of u^2 is at least ten times higher than $1.6 \psi^2 m^2$ for m corresponding to normal human size. Thus, the expression of average power density may be approximated to

$$P = K m^3 \quad \text{..........(18)}$$

where $K = 0.333 \pi \sigma u^2$ is a constant

The variation of the absorbed power with the size of human being (taken as equivalent sphere radius) is plotted in Fig.5.

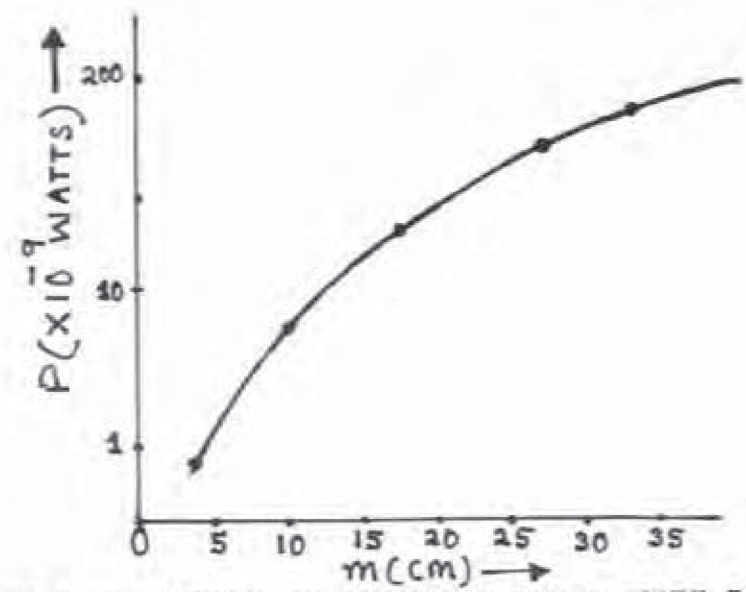

FIG.5 VARIATION OF ABSORBED POWER WITH RADIUS OF THE SPHERE BELOW AN EHV TRANSMISSION LINE.

3. **RESULTS & DISCUSSIONS** -

The following results are obtained from the plots of Fig.3.

(i) A 20 g mouse is represented by 1.6 cm radius sphere and for this order of radius the electric field coupling is mostly dominating. But for man's equivalent sphere-radius, both the fields are of same order of magnitude. This observation clearly indicates that magnetic field coupling cannot be neglected for man and large animals.

(ii) At the centre of the sphere, the induced field is mostly due to external electric field (E_t).

(iii) The maximum field intensity always exists at the edge of the sphere.

Induced voltage in the millivolt range is required for influencing neural activity. It is observed from the curves of Fig.4 that the maximum clculated transmembrane potential for a passive membrane is 112×10^{-9}V which is atleast four orders of magnitude below that needed to influence neural activity. The result obtained is in agreement with those of Spiegel.

Fig.5 illustrates the absorbed power as a function of sphere size. It is seen that the larger the size of the object, the more the power absorbed. This curve can be compared with the human basal metabolic rate. Assuming a 70 kg man to take 2 500 calorie diet, the metabolic heat production is about 4×10^{-4} cal/g. From the Fig.5, the computed value of the absorbed power for a man of 26 cm sphere-radius is of the order of 120×10^{-9} watts or of the order of 1.2×10^{-9} cal/g. This is atleast nine order of magnitude below the basal metabolic rate.

4. CONCLUSION -

(i) Transmembrane potential needed for neural activity is 10^{-3} V, whereas maximum transmembrane potential induced by the fields of EHV transmission lines = 1.12×10^{-7}V. Also, typical metabolic heat production = 4×10^{-4} cal/g, whereas, the induced heat producion due to EHV transmission line is 1.2×10^{-13} cal/g.

(ii) The results obtained agree fairly well with those of spiegel.

(iii) Thus, neigther transmembrane potential nor the induced heat production estimated in this paper (obtained directly from the EHV transmission line) are large enough to interfere with normal biological functions of the human body. This procedure should also be applied to the more sophisticated mathematical human models for better estimate of the above findings. Simultaneously, the results obtained from these theoretical analyses should be experimentally verified by suing phantom models of man.

- * -

Bibliography

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Somehow did not get the bibliography page. As far as I remember some well known books and papers were referred. It has been 10-11 years since I wrote this report.

Saraju P. Mohanty
07/19/2006