Transmission Lines and Cables (Module 1(b)

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- IISc Bangalore
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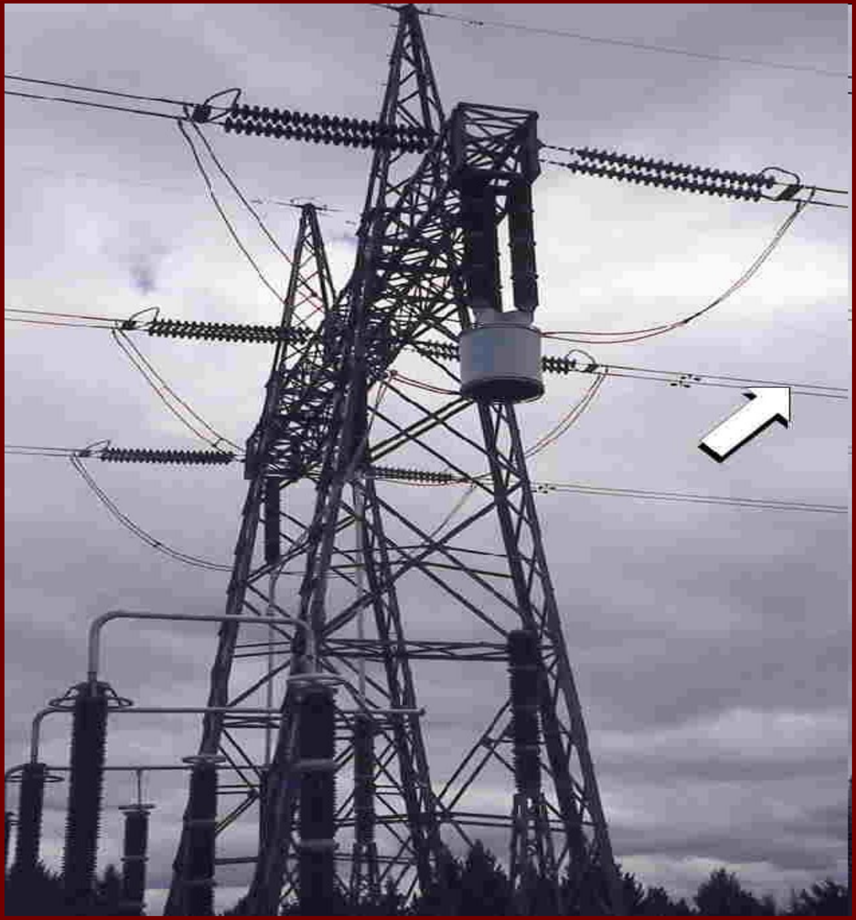
Overview

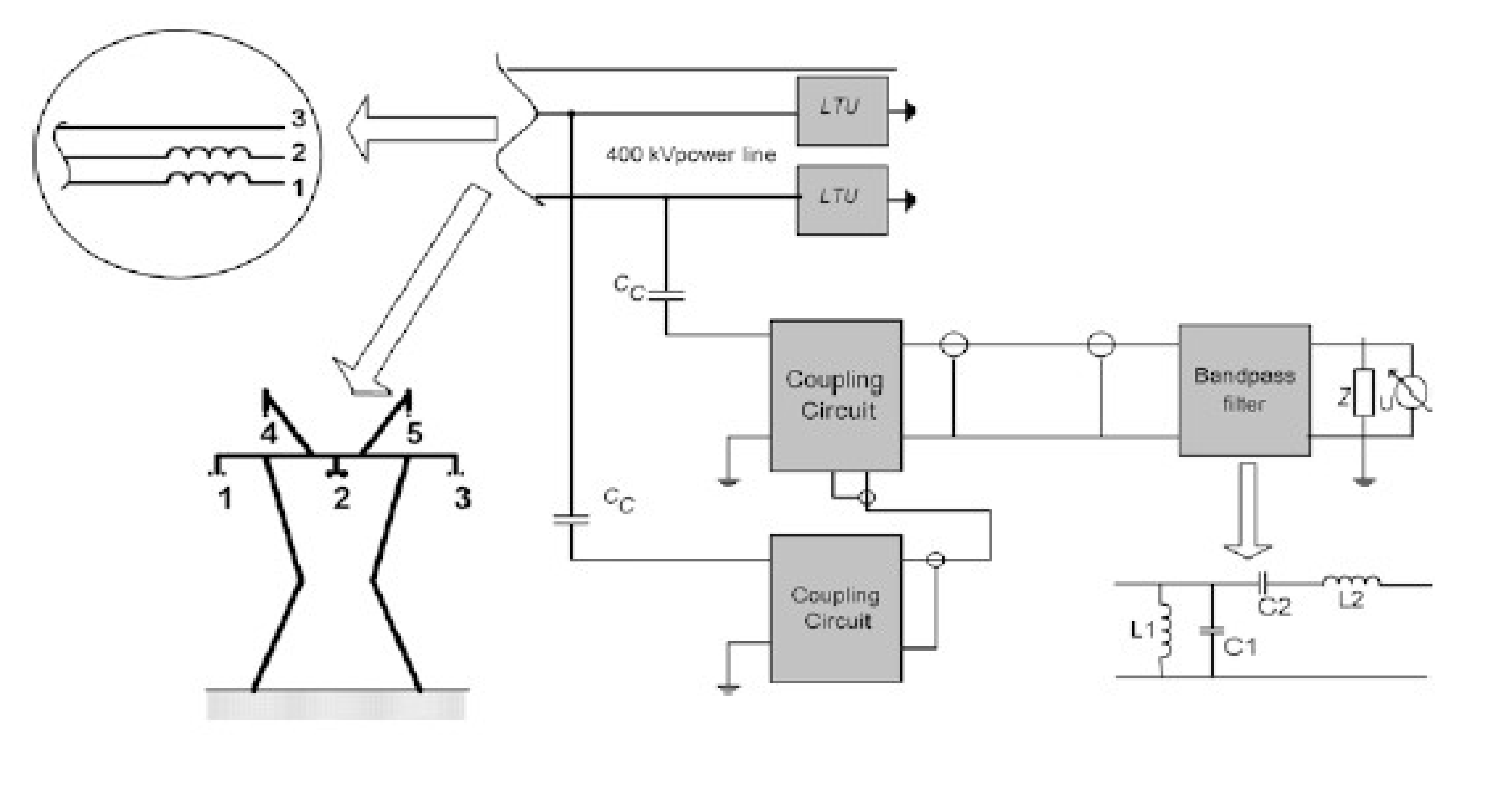
- Corona & RIV
- Cables
- DC Transmission

Corona



- Power lines produce an audible sound or buzz because they are producing something called a corona discharge that is interacting with the surrounding air.
- The corona discharge is a side-effect of the electric field the power line generates by carrying electricity.
- The discharge can be greater, and the buzzing louder if there is increased moisture or pollutants in the air.

Setup for corona noise measurements



- Corona discharge is often an indication of maintenance and safety problems that may cause severe deterioration in maintenance especially on insulators.
- Inspections with the corona camera detects and pinpoints corona, arcing, partial discharge and electrical flashes on high voltage (OHT) lines, cables and insulator components.
- Inspection for Corona enhances predictive maintenance procedures.

Corona

- In electricity, a corona discharge is an electrical discharge brought on by the ionization of a fluid surrounding a conductor, which occurs when the potential gradient (the strength of the electric field) exceeds a certain value, but conditions are insufficient to cause complete electrical breakdown or arcing.

- a process by which a current, perhaps sustained, develops from an electrode with a high potential in a neutral fluid, usually air
- by ionizing that fluid so as to create a plasma around the electrode.
- The ions generated eventually pass charge to nearby areas of lower potential, or recombine to form neutral gas molecules.

- When the potential gradient is large enough at a point in the fluid, the fluid at that point ionizes and it becomes conductive.
- If a charged object has a sharp point, the air around that point will be at a much higher gradient than elsewhere.
- Air near the electrode can become ionized (partially conductive), while regions more distant do not.
- When the air near the point becomes conductive, it has the effect of increasing the apparent size of the conductor.

- Since the new conductive region is less sharp, the ionization may not extend past this local region.
- Outside of this region of ionization and conductivity, the charged particles slowly find their way to an oppositely charged object and are neutralized.
- If the geometry and gradient are such that the ionized region continues to grow instead of stopping at a certain radius, a completely conductive path may be formed, resulting in a momentary spark, or a continuous arc.

- Corona discharge usually involves two asymmetric electrodes; one highly curved (such as the tip of a needle, or a small diameter wire) and one of low curvature (such as a plate, or the ground).
- The high curvature ensures a high potential gradient around one electrode, for the generation of a plasma.

- Coronas may be positive or negative.
- This is determined by the polarity of the voltage on the highly-curved electrode.
- If the curved electrode is positive with respect to the flat electrode we say we have a positive corona, if negative we say we have a negative corona.
- The physics of positive and negative coronas are strikingly different.

- This asymmetry is a result of the great difference in mass between electrons and positively charged ions, with only the electron having the ability to undergo a significant degree of ionising inelastic collision at normal temperatures and pressures.
- An important reason for considering coronas is the production of ozone around conductors undergoing corona processes.
- A negative corona generates much more ozone than the corresponding positive corona.

Applications of corona

- Removal of unwanted electric charges from the surface of aircraft in flight and thus avoiding the detrimental effect of uncontrolled electrical discharge pulses on the performance of avionic systems
- Manufacture of ozone
- Scrubbing particles from air in air-conditioning systems (Electrostatic precipitator)

- Removal of unwanted volatile organics, such as chemical pesticides, solvents, chemical weapons agents, from the atmosphere
- Surface Treatment of polymer films to improve compatibility with adhesives or printing inks.

- Photocopying
- Air ionisers perhaps benefiting health
- Kirlian photography uses photons produced by the discharge to expose photographic film.
- EHD thrusters, Lifters, and other ionic wind devices
- Nitrogen laser
- Surface Treatment for Tissue Culture (Polystyrene)

Problems caused by corona

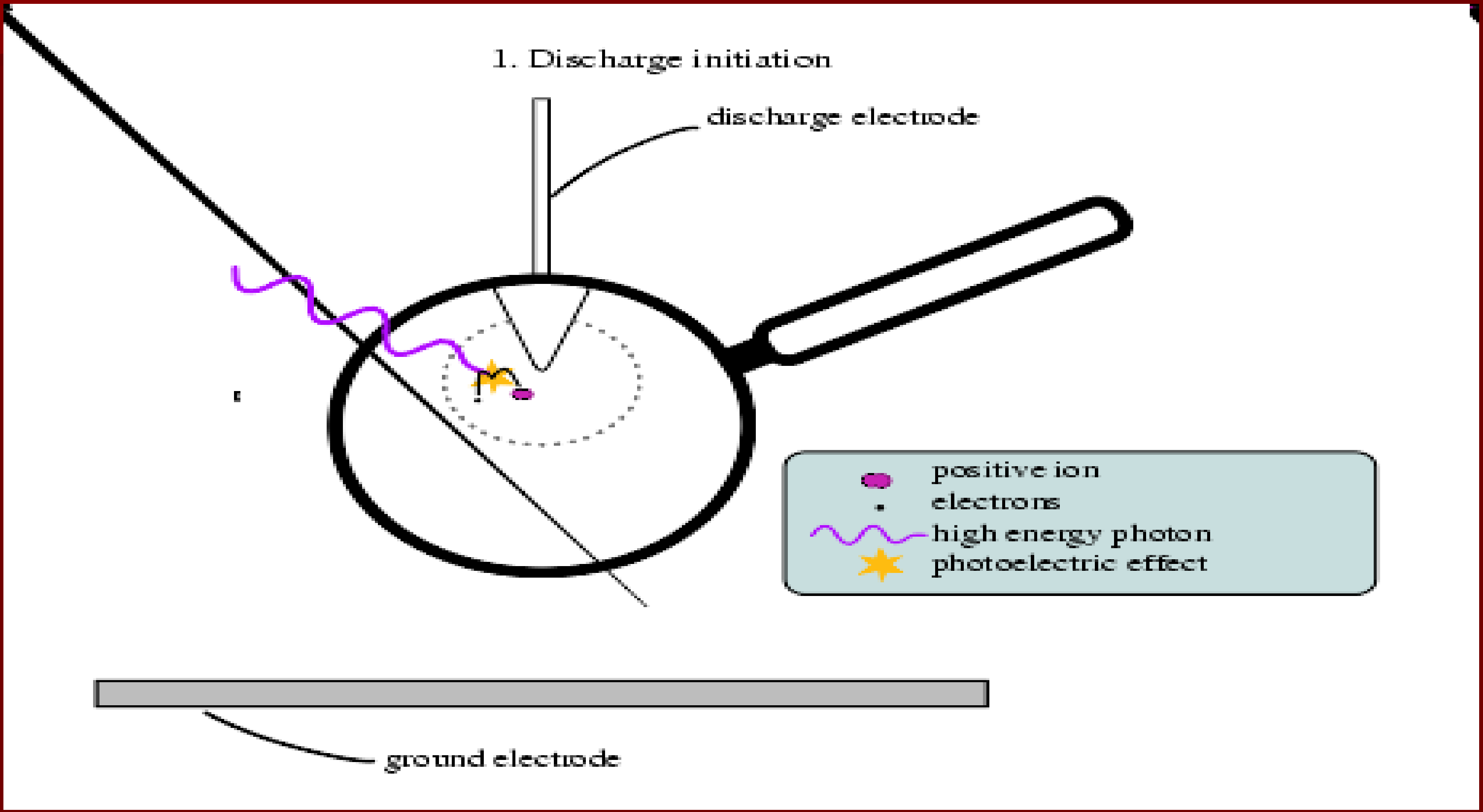
- Coronas can generate audible and radio-frequency noise, particularly near electric power transmission lines.
- They also represent a power loss, and their action on atmospheric particulates, along with associated ozone and NOx production, can also be disadvantageous to human health where power lines run through built-up areas.

Corona on Power lines causes

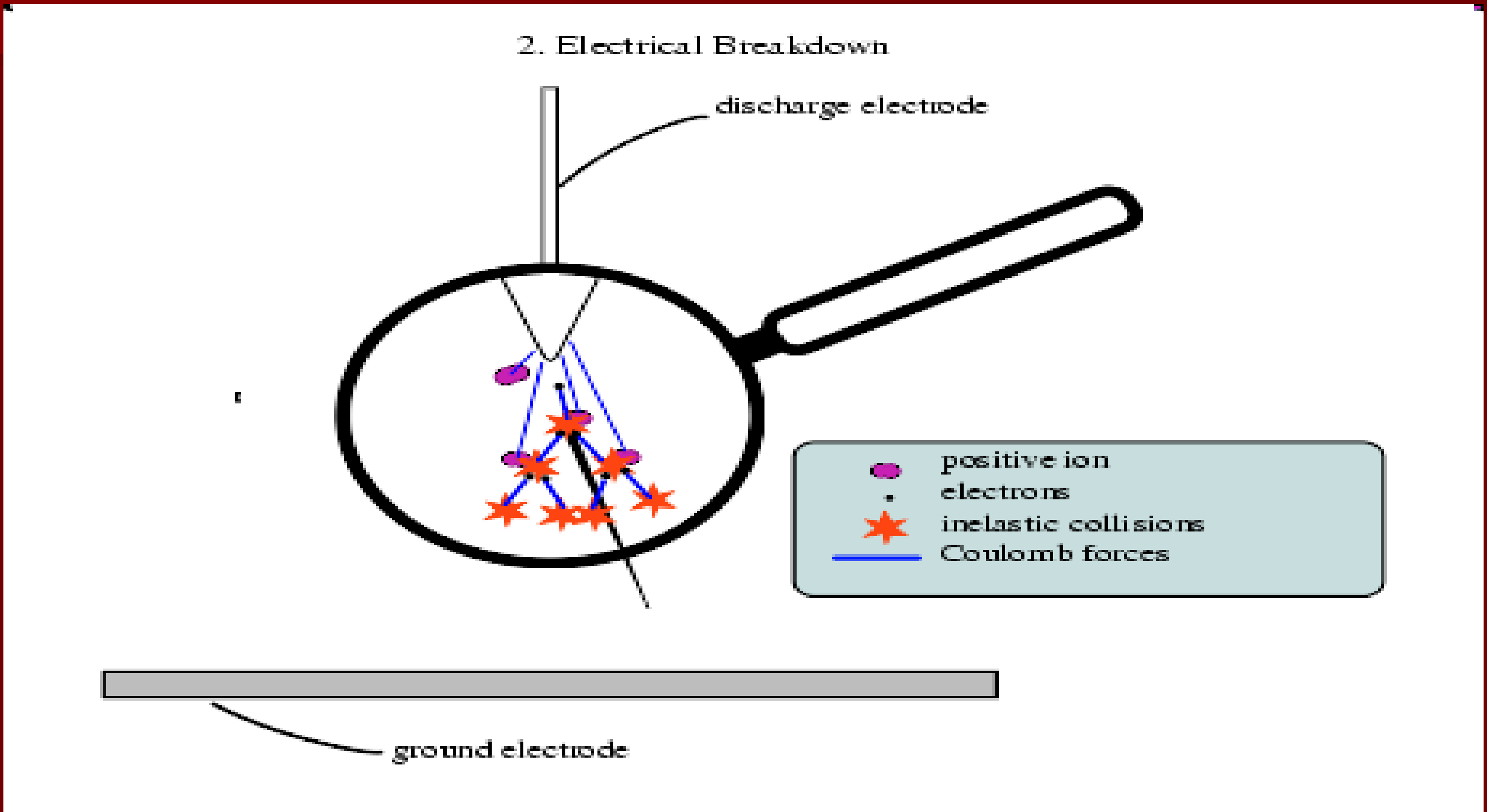
- Power loss
- Audible noise
- Electromagnetic interference (EMI)
- Purple glow
- Ozone production
- Insulation damage

- Inside electrical components such as transformers, capacitors, electric motors and generators - Corona progressively damages the insulation inside these devices, leading to premature equipment failure.

- A neutral atom or molecule of the medium, in a region of strong electric field (such as the high potential gradient near the curved electrode) is ionized by an exogenous environmental event (for example, as the result of a photon interaction), to create a positive ion and a free electron.


1. Discharge initiation
discharge electrode
positive ion
electrons
high energy photon
photoelectric effect
ground electrode

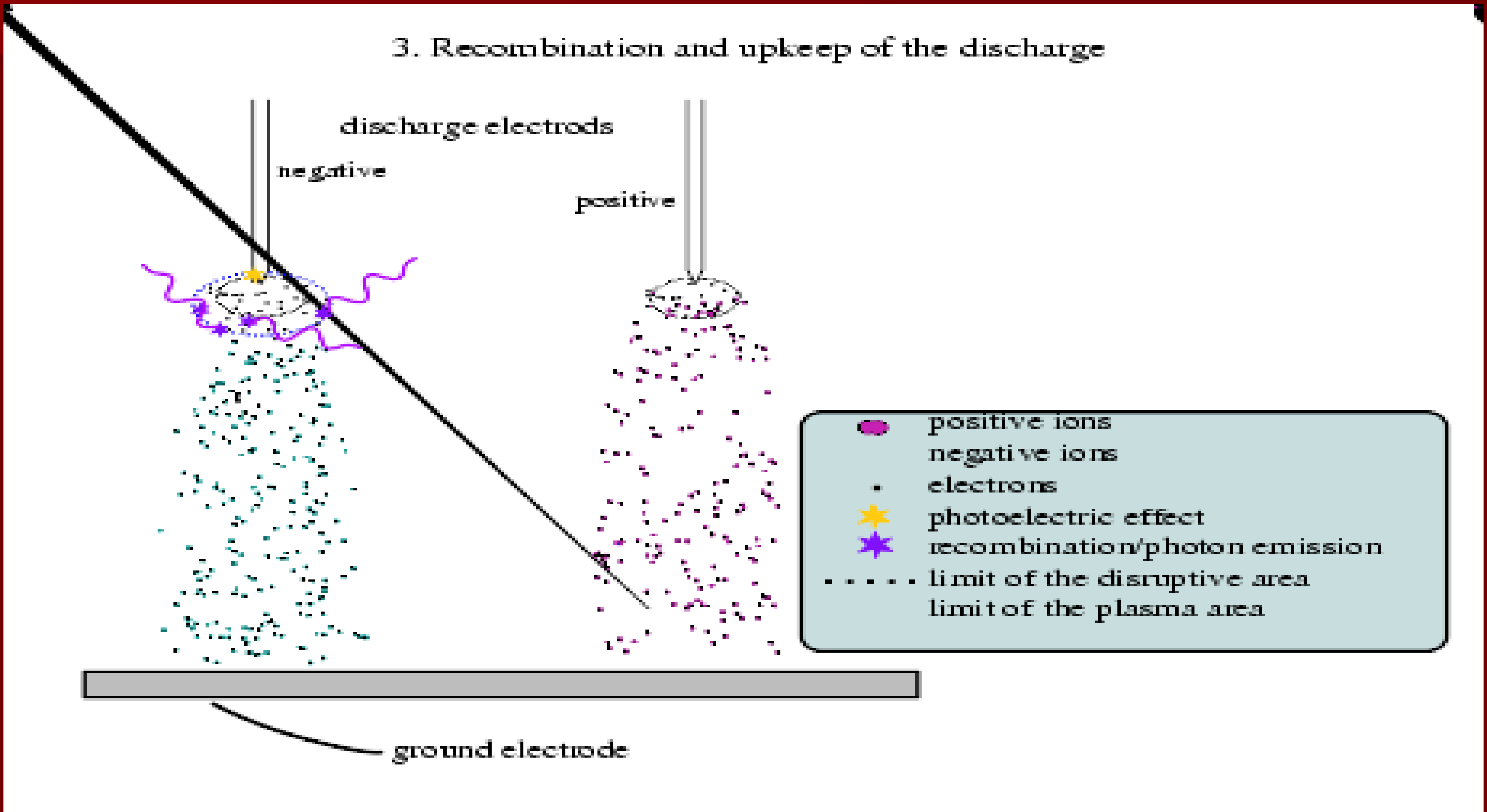
- The electric field then operates on these charged particles, separating them, and preventing their recombination, and also accelerating them, imparting each of them with kinetic energy.
- As a result of the energisation of the electrons (which have a much higher charge/mass ratio and so are accelerated to a higher velocity), further electron/positive-ion pairs may be created by collision with neutral atoms.



2. Electrical Breakdown
discharge electrode
positive ion
electrons
inelastic collisions
Coulomb forces
ground electrode

- These then undergo the same separating process creating an electron avalanche. Both positive and negative coronas rely on electron avalanches

- In processes which differ between positive and negative coronas, the energy of these plasma processes is converted into further initial electron dissociations to seed further avalanches.
- An ion species created in this series of avalanches (which differs between positive and negative coronas) is attracted to the un-curved electrode, completing the circuit, and sustaining the current flow.


3. Recombination and upkeep of the discharge
discharge electrods
negative
positive
positive ions
negative ions
electrons
photoelectric effect
recombination/photon emission
limit of the disruptive area
limit of the plasma area
ground electrode

- The onset voltage of corona or Corona Inception Voltage (CIV) can be found with Peek's law (1929), formulated from empirical observations. Later papers derived more accurate formulas.
- The current carried by the corona is determined by integrating the current density over the surface of the conductor.
- The power loss is determined by multiplying the current and the voltage.

Positive coronas

- A positive corona is manifested as a uniform plasma across the length of a conductor.
- It can often be seen glowing blue/white, though much of the emissions are in the ultraviolet.
- With the same geometry and voltages, it appears a little smaller than the corresponding negative corona, owing to the lack of a non-ionising plasma region between the inner and outer regions.

- There are many fewer free electrons in a positive corona, when compared to a negative corona, except very close to the curved electrode: perhaps a thousandth of the electron density, and a hundredth of the total number of electrons.

- the electrons in a positive corona are concentrated close to the surface of the curved conductor, in a region of high-potential gradient (and therefore the electrons have a high energy), whereas in a negative corona many of the electrons are in the outer, lower-field areas.
- Therefore, if electrons are to be used in an application which requires a high activation energy, positive coronas may support a greater reaction constants than corresponding negative coronas; though the total number of electrons may be lower, the number of a very high energy electrons may be higher.

- Coronas are efficient producers of ozone in air.
- A positive corona generates much less ozone than the corresponding negative corona, as the reactions which produce ozone are relatively low-energy.
- Therefore, the greater number of electrons of a negative corona leads to an increased production.
- Beyond the plasma, in the unipolar region, the flow is of low-energy positive ions toward the flat electrode.

Mechanism

- As with a negative corona, a positive corona is initiated by an exogenous ionisation event in a region of high potential gradient.
- The electrons resulting from the ionisation are attracted toward the curved electrode, and the positive ions repelled from it.
- By undergoing inelastic collisions closer and closer to the curved electrode, further molecules are ionized in an electron avalanche.

- In a positive corona, secondary electrons, for further avalanches, are generated predominantly in the fluid itself, in the region outside the plasma or avalanche region.
- They are created by ionization caused by the photons emitted from that plasma in the various de-excitation processes occurring within the plasma after electron collisions, the thermal energy liberated in those collisions creating photons which are radiated into the gas.

- As can be seen, the positive corona is divided into two regions, concentric around the sharp electrode.
- The inner region contains ionising electrons, and positive ions, acting as a plasma, the electrons avalanche in this region, creating many further ion/electron pairs.
- The outer region consists almost entirely of the slowly migrating massive positive ions, moving toward the uncurved electrode along with, close to the interface of this region, secondary electrons, liberated by photons leaving the plasma, being re-accelerated into the plasma.
- The inner region is known as the plasma region, the outer as the unipolar region.

- The electrons resulting from the ionisation of a neutral gas molecule are then electrically attracted back toward the curved electrode, attracted into the plasma, and so begins the process of creating further avalanches inside the plasma.

Negative coronas

- A negative corona is manifested in a non-uniform corona, varying according to the surface features and irregularities of the curved conductor.
- It often appears as tufts of corona at sharp edges, the number of tufts altering with the strength of the field.
- The form of negative coronas is a result of its source of secondary avalanche electrons .

- It appears a little larger than the corresponding positive corona, as electrons are allowed to drift out of the ionising region, and so the plasma continues some distance beyond it.
- The total number of electrons, and electron density is much greater than in the corresponding positive corona.

- However, they are of a predominantly lower energy, owing to being in a region of lower potential-gradient.
- Therefore, whilst for many reactions the increased electron density will increase the reaction rate, the lower energy of the electrons will mean that reactions which require a higher electron energy may take place at a lower rate.

Mechanism

- Negative coronas are more complex than positive coronas in construction.
- As with positive coronas, the establishing of a corona begins with an exogenous ionisation event generating a primary electron, followed by an electron avalanche.
- Electrons ionised from the neutral gas are not useful in sustaining the negative corona process by generating secondary electrons for further avalanches, as the general movement of electrons in a negative corona is outward from the curved electrode.

- For negative corona, instead, the dominant process generating secondary electrons is the photoelectric effect, from the surface of the electrode itself.
- The work-function of the electrons (the energy required to liberate the electrons from the surface) is considerably lower than the ionisation energy of air at standard temperatures and pressures, making it a more liberal source of secondary electrons under these conditions.
- Again, the source of energy for the electron-liberation is a high-energy photon from an atom within the plasma body relaxing after excitation from an earlier collision.

- The use of ionised neutral gas as a source of ionisation is further diminished in a negative corona by the high-concentration of positive ions clustering around the curved electrode.
- Under other conditions, the collision of the positive species with the curved electrode can also cause electron liberation.
- The difference, then, between positive and negative coronas, in the matter of the generation of secondary electron avalanches, is that in a positive corona they are generated by the gas surrounding the plasma region, the new secondary electrons traveling inward, whereas in a negative corona they are generated by the curved electrode itself, the new secondary electrons traveling outward.

- A further feature of the structure of negative coronas is that as the electrons drift outwards, they encounter neutral molecules and, with electronegative molecules (such as oxygen and water vapour), combine to produce negative ions.
- These negative ions are then attracted to the positive uncurved electrode, completing the 'circuit'.

- A negative corona can be divided into three radial areas, around the sharp electrode.
- In the inner area, high-energy electrons inelastically collide with neutral atoms and cause avalanches, whilst outer electrons (usually of a lower energy) combine with neutral atoms to produce negative ions.
- In the intermediate region, electrons combine to form negative ions, but typically have insufficient energy to cause avalanche ionisation, but remain part of a plasma owing to the different polarities of the species present, and the ability to partake in characteristic plasma reactions.
- In the outer region, only a flow of negative ions and, to a lesser and radially-decreasing extent, free electrons toward the positive electrode takes place.

- The inner two regions are known as the corona plasma. The inner region is an ionising plasma, the middle a non-ionising plasma. The outer region is known as the unipolar region.

What is Partial Discharge?

- Partial discharge is an electrical discharge that does not bridge the entire space between the two electrodes.

What is Corona?

- Corona discharge is a luminous partial discharge from conductors and insulators due to ionisation of the air, where the electrical field exceeds a critical value.
- Very little heat is created as a result of this discharge, and it cannot therefore be detected by infrared thermal cameras.

Corona has the following damaging effects:

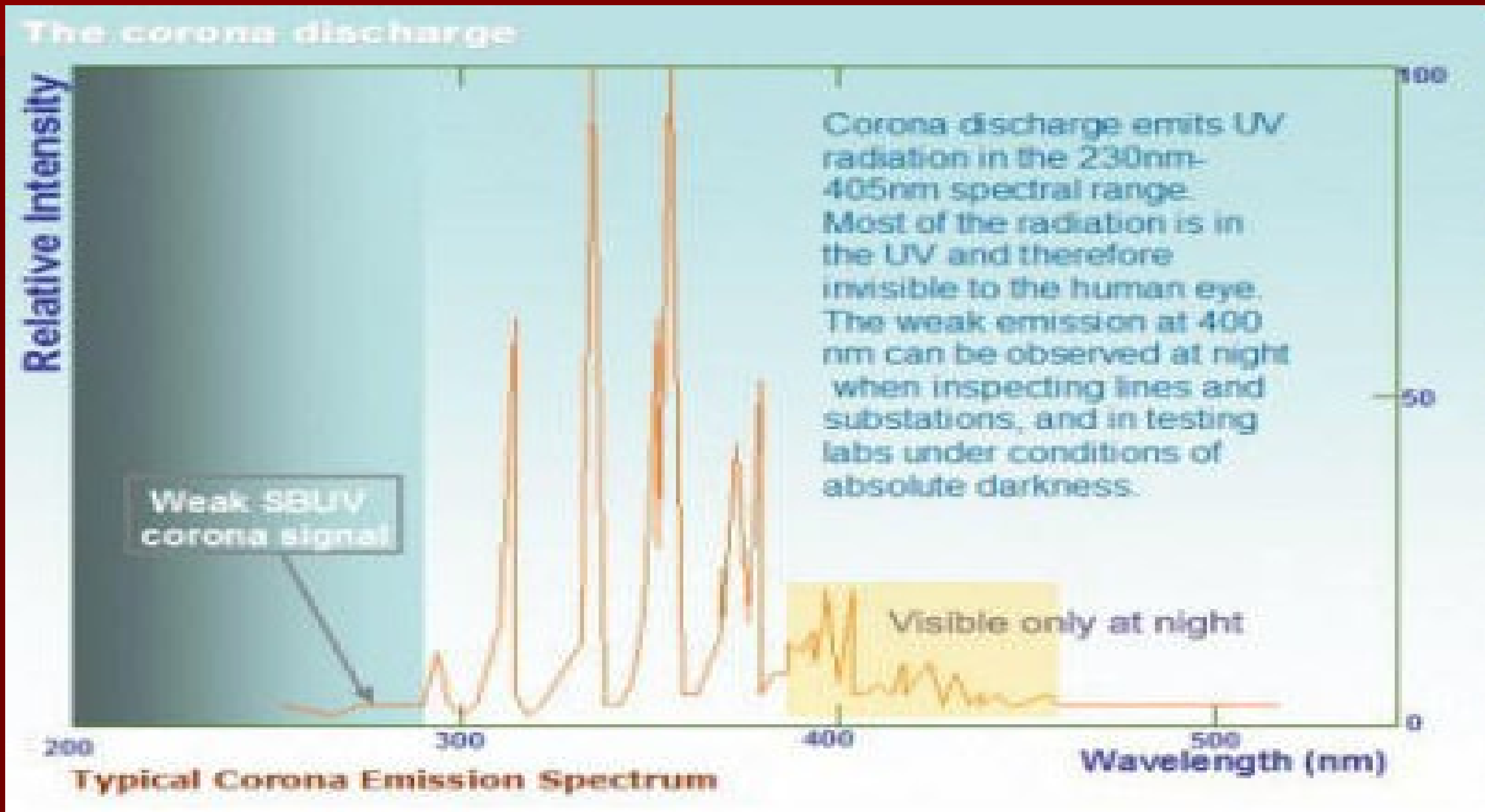
- Generation of corrosive materials, like ozone and nitrogen oxides that yields nitric acid under conditions of high humidity.
- These corrosive materials shorten the life span of lines and substations components.
- Corona causes damage to insulators, especially non-ceramic (NCI) insulators
- Radio interference (RI/ RFI) mainly to AM transmissions
- Audio noise
- Radio interference or TVI or EMI

What can Corona detect?

- Indication of the effectiveness of washing of components
- Indication of imminent Flashover or Tripping
- Indication of potential fault
- Indication of poor installation

Corona Light Emission

- The corona discharge emits radiation in the 280nm-405nm spectral range, mostly in the ultraviolet (UV) and therefore is invisible to the human eye, though relatively weak emission at about 400 nm might be observed at night under conditions of absolute darkness.
- The corona emission in the 280nm-405nm spectral range cannot be detected during daytime due to the highly disturbing background of solar radiation.


The corona discharge
Relative Intensity
Corona discharge emits UV radiation in the 230nm-405nm spectral range. Most of the radiation is in the UV and therefore invisible to the human eye. The weak emission at 400 nm can be observed at night when inspecting lines and substations, and in testing labs under conditions of absolute darkness.
Weak SBUV corona signal
Visible only at night
100
50
0
200
300
400
500
Wavelength (nm)
Typical Corona Emission Spectrum

Audible Noise

- The audible noise emitted from high-voltage lines is caused by the discharge of energy that occurs when the electrical field strength on the conductor surface is greater than the 'breakdown strength' (the field intensity necessary to start a flow of electric current) of the air surrounding the conductor.
- This discharge is also responsible for radio noise, a visible glow of light near the conductor, an energy loss known as corona loss and other phenomena associated with high-voltage lines.

- "The degree or intensity of the corona discharge and the resulting audible noise are affected by the condition of the air--that is, by humidity, air density, wind and water in the form of rain, drizzle and fog.
- Water increases the conductivity of the air and so increases the intensity of the discharge.
- Also, irregularities on the conductor surface, such as nicks or sharp points and airborne contaminants, can increase the corona activity.
- Aging or weathering of the conductor surface generally reduces the significance of these factors.

- The higher voltages at which modern transmission lines operate have increased the noise problem to the point to which they have become a concern to the power industry.
- Consequently, these lines are now designed, constructed and maintained so that during dry conditions they will operate below the corona-inception voltage, meaning that the line will generate a minimum of corona-related noise.
- In foul weather conditions, however, corona discharges can be produced by water droplets, fog and snow.

- Corona emission occurs when the electric field gradient at the surface of high voltage current carrying conductors exceeds a certain critical voltage value known as the onset voltage for corona
- This onset voltage is dependent on factors such as the voltage of the conductor to ground, conductor surface conditions (particle deposition level, presence of protrusions, etc.), number of sub-conductors per phase used for the transmission, conductor characteristics of age, diameter, etc. and the prevailing meteorological conditions
- (Suda et al., 1988; CIGRE, 1993; Phillips et al., 1999; Maruvada, 2000; Nie et al., 2001; MacAlpine and Zhang, 2003).

- Apart from line conductors, other components of electrical installations including connectors, metal fittings between disc insulators, separators and line spacers, are also susceptible to corona discharge.
- Release of net unipolar ions, into the atmosphere by these infrastructures is often associated with variation in the earth's natural direct current (dc) electric field (e-field) of around 100 V m−1, and this effect is measurable at the ground level
- (CIGRE, 1993; Wilding et al., 2000; Abdel-Salam and Abdel-Aziz, 2001; Fews et al., 2002; Bracken et al., 2005)

- Once in the atmosphere, the ions are carried in the wind and depending on the prevailing wind velocity, their presence can be observed at some distance away from the source (Wilding et al., 2000).
- Various studies have been conducted on corona emission by high voltage powerlines (HVPLs) and their effect on the earth's dc e-field (Carter and Johnson, 1988; Abdel-Salam et al., 1990; Wilding et al., 2000; Fews et al., 2002); their impact on atmospheric chemistry (Delory et al., 2006; Farrell et al., 2006) and on biological systems (Guler and Seyhan, 2001).

- However, no attempt has yet been made to simultaneously quantify or investigate associations between parameters characterizing electrical environments (i.e. ion concentration, particle charge concentration, e-field, etc.) near corona ion-emitting sources such as HVPLs, and electricity substations.

EMI

- Electromagnetic interference (or EMI, also called radio frequency interference or RFI) is an unwanted disturbance that affects an electrical circuit due to electromagnetic radiation emitted from an external source.
- EMI or RFI may be broadly categorized into two types; narrowband and broadband

- Narrowband interference usually arises from intentional transmissions such as radio and TV stations, pager transmitters, cell phones, etc.
- Broadband interference usually comes from incidental radio frequency emitters.
- These include electric power transmission lines, electric motors, thermostats, bug zappers, etc.
- Anywhere electrical power is being turned off and on rapidly is a potential source.

- The spectra of these sources generally resembles that of synchrotron sources, stronger at low frequencies and diminishing at higher frequencies, though this noise is often modulated, or varied, by the creating device in some way.
- Included in this category are computers and other digital equipment as well as televisions.
- The rich harmonic content of these devices means that they can interfere over a very broad spectrum.
- Characteristic of broadband RFI is an inability to filter it effectively once it has entered the receiver chain

EMI Standards

- Special International Committee on Radio Interference (abbreviated CISPR from the French name of the organization, Comité international spécial des perturbations radioélectriques) is concerned with developing norms for detecting, measuring and comparing electromagnetic interference in electric devices.
- Its members are partially also in the International Electrotechnical Commission (IEC).
- It was founded in 1934.

CISPR is divided into six subcommittees

- A - measurement of radio interference and statistical methods
- B - measurement of interference regarding industrial, scientific or medical (ISM) equipment, high voltage equipment, power lines, or traction devices
- D - interference in motor vehicles (both gasoline and electric)

- F - interference in household appliances, tools, and lighting equipment
- H - limitations to protect radio frequencies
- I - electromagnetic compatibility of information technology (IT) equipment (e.g. computers), multimedia / hi-fi devices and radio equipment (receivers)

CISPR's publications

- basically norms regarding measurement of radiated and conducted interference.
- They specify cable lengths, measurement device configurations and grounding measures, so that results become more comparable.
- The norms also concern themselves with immunity from external interference.
- With the CISPR norms, companies can require compliance to a specific norm from a supplier, instead of doing all the measurements internally (and having to develop an internal norm to be able to compare their own measurements).

Important CISPR standards

- CISPR 10 - Organization, Rules and Procedures of the CISPR. (1971)
- CISPR 11 - Industrial, Scientific and Medical (ISM) Radio-Frequency Equipment -- Electromagnetic Disturbance Characteristics -- Limits and Methods of Measurement.
- CISPR 14 - Electromagnetic Compatibility -- Requirements for Household Appliance, Electric Tools, and Similar Apparatus: 1) Emissions, 2) Immunity.

- CISPR 22 - Information Technology Equipment -- Radio Disturbance Characteristics -- Limits and Methods of Measurement.
- CISPR 24 - Information Technology Equipment -- Immunity characteristics -- Limits and Methods of Measurement.
- CISPR 25 - Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices -- Limits and Methods of Measurement.

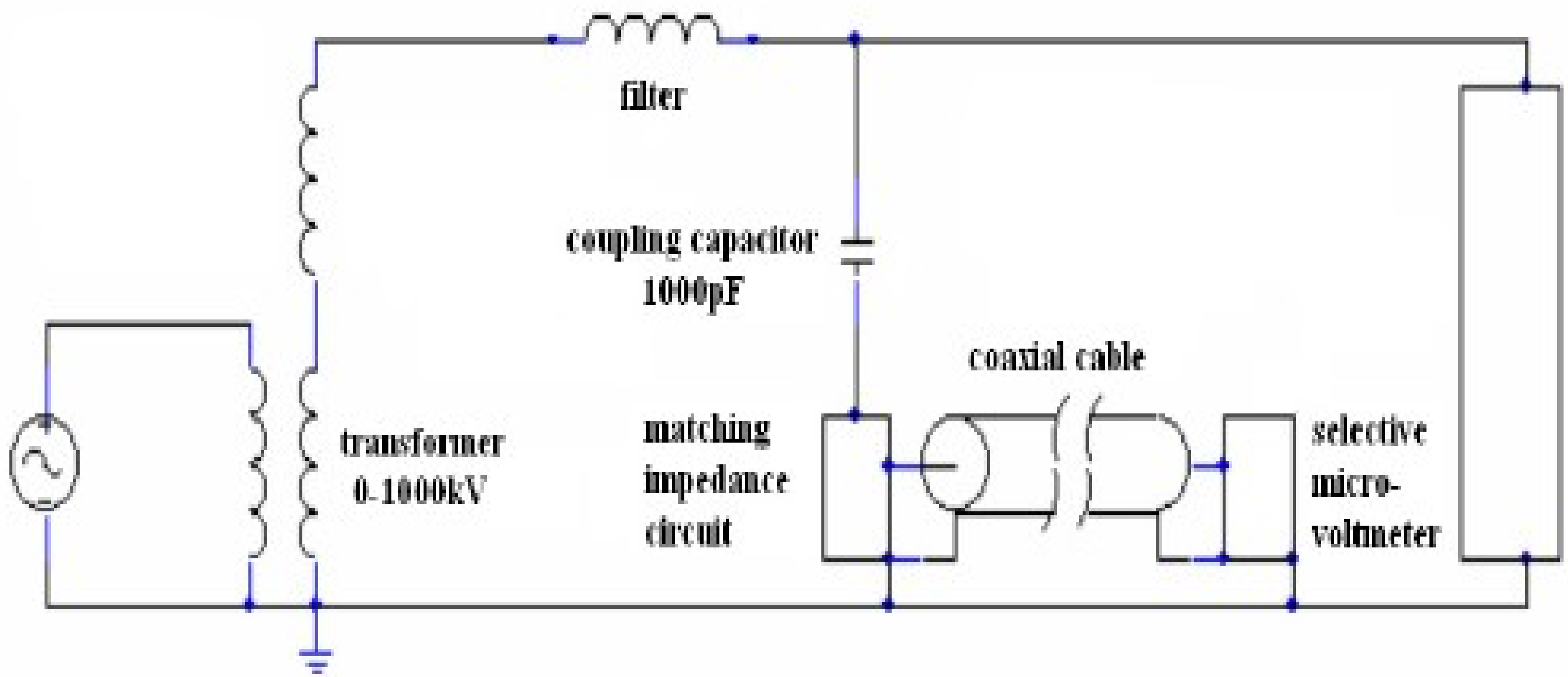


Fig. 5. Experimental setup for RIV measurents

A cable is one or more wires or optical fibers bound together, typically in a common protective jacket or sheath

Cables

- Used for Under-ground Power Transmission & Distribution
- two to four times the cost of an overhead power line
- Narrow right of way
- Cables used to be insulated with paper impregnated oil
- Today XLPE is used

Cables Enable Power Transmission

- Densely populated urban areas
- Areas where land is unavailable or planning consent is difficult
- Rivers and other natural obstacles
- Land with outstanding natural or environmental heritage
- Areas of significant or prestigious infrastructural development
- Land whose value must be maintained for future urban expansion and rural development

Cable Types - Application

- Wire rope (wire cable)
- Audiovisual cable
- Bicycle cable
- Communications cable
- Computer cable
- Mechanical cable
- Power Cable
- Submersible cable

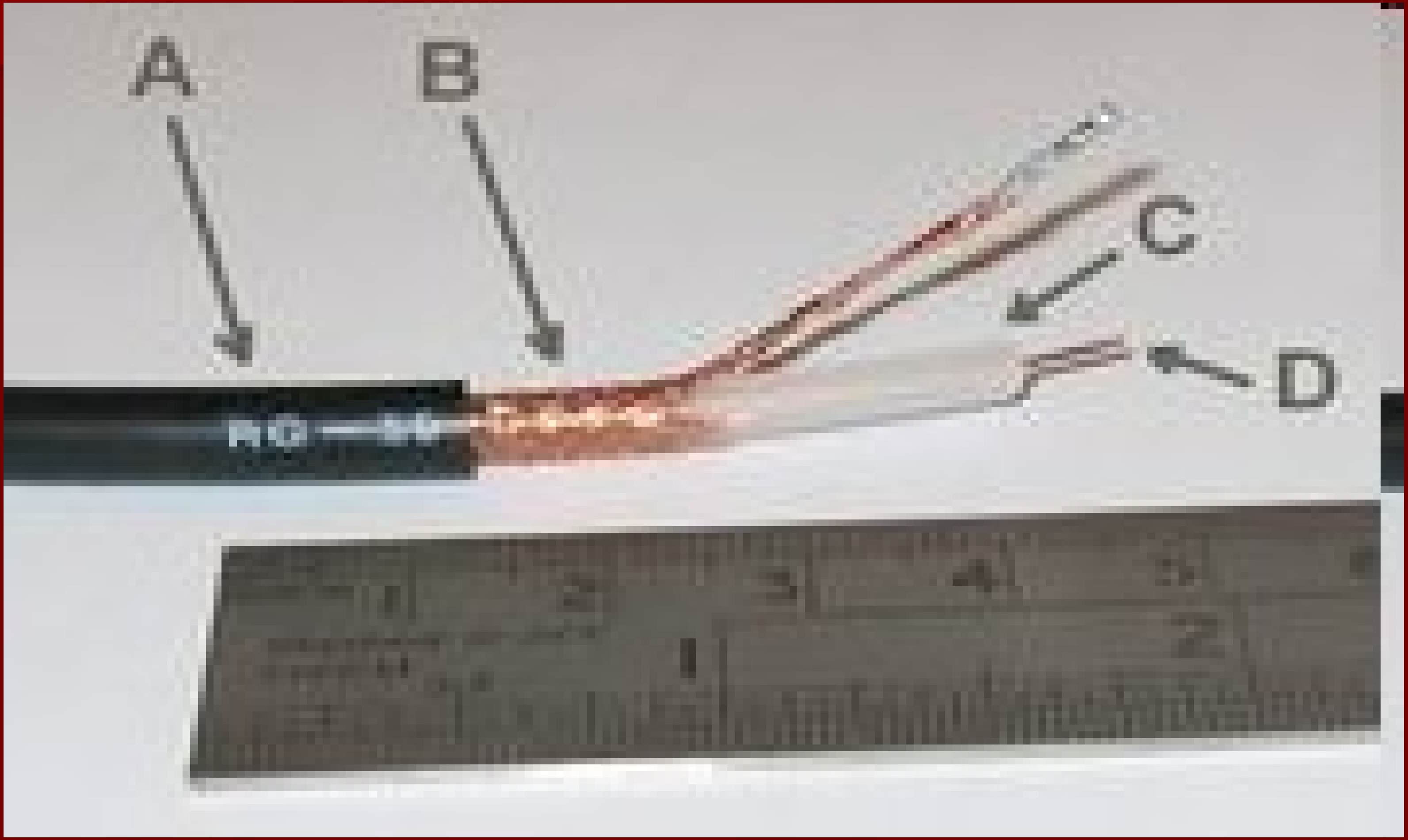
Cable Type - Basic

- Coaxial cable
- Multicore cable (consist of more than one wire and is covered by cable jacket)
- Optical fiber cable
- Ribbon cable
- Single cable (from time to time this name is used for wire)
- Twisting cable

Cable Type - Construction

- Mineral-insulated copper-clad cable
- Twinax cable
- Twisted pair cable
- Shielded cable
- Flexible cables

Coaxial Cable



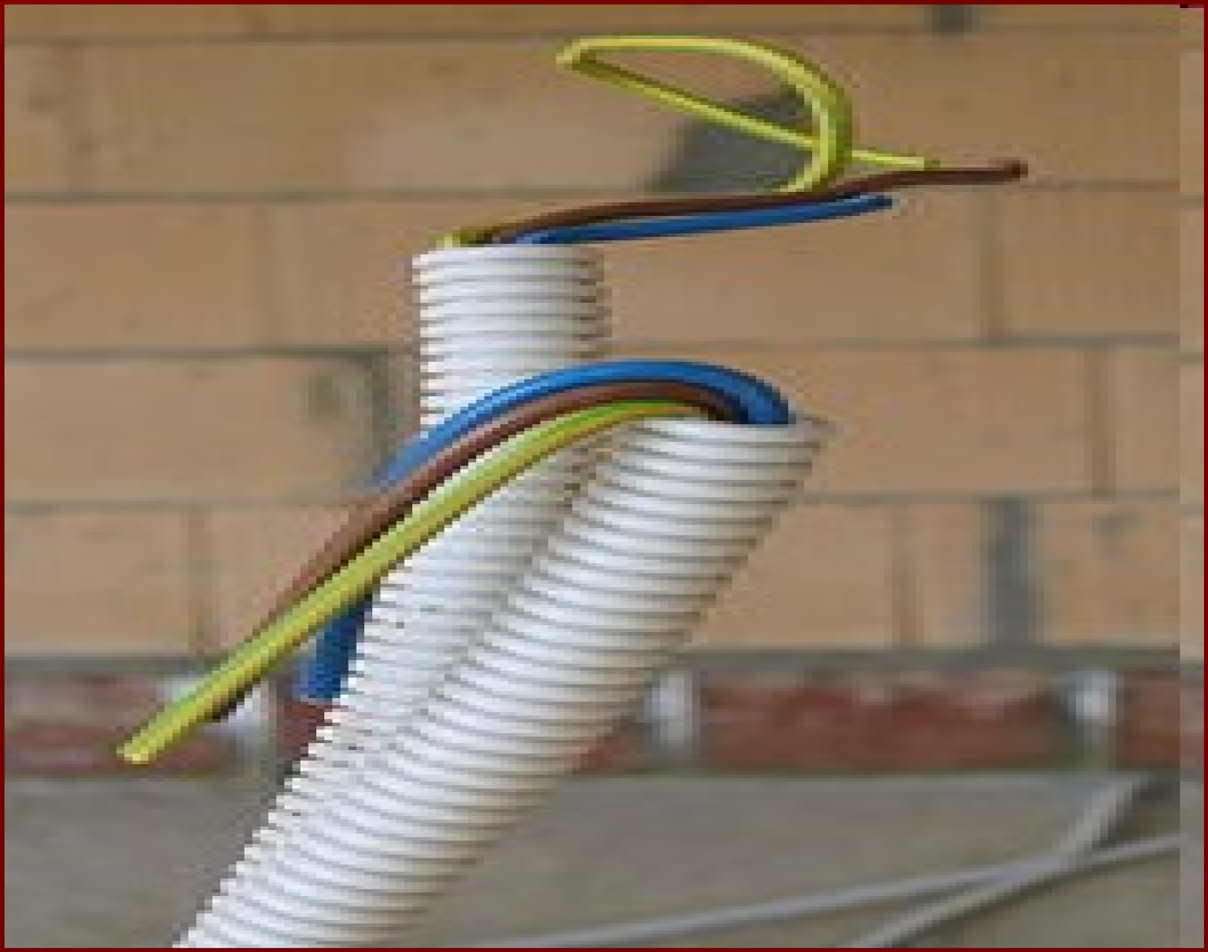
Components

- A: outer plastic sheath
- B: copper screen
- C: inner dielectric insulator
- D: copper core

- Inner Conductor may be solid or stranded
- Silver plated for better High Frequency Performance @times copper plated
- Insulator may be solid PILC or XLPE – or foam plastic or gas (GITLs)
- Shield is usually formed of Copper braid – enables flexibility - but air gaps exist (to improve performance silver plated and a second layer provided in signal cables)

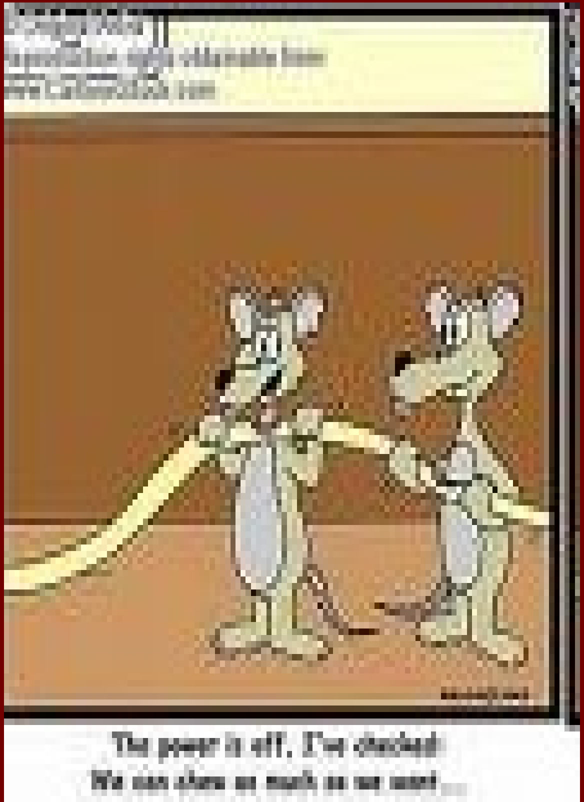
- electromagnetic field carrying the signal exists only in the space between the inner and outer conductors
- Practical cables achieve this objective to a high degree
- coaxial cable provides protection of signals from external electromagnetic interference(EMI), and effectively guides signals with low emission along the length of the cable

Domestic Power Cable

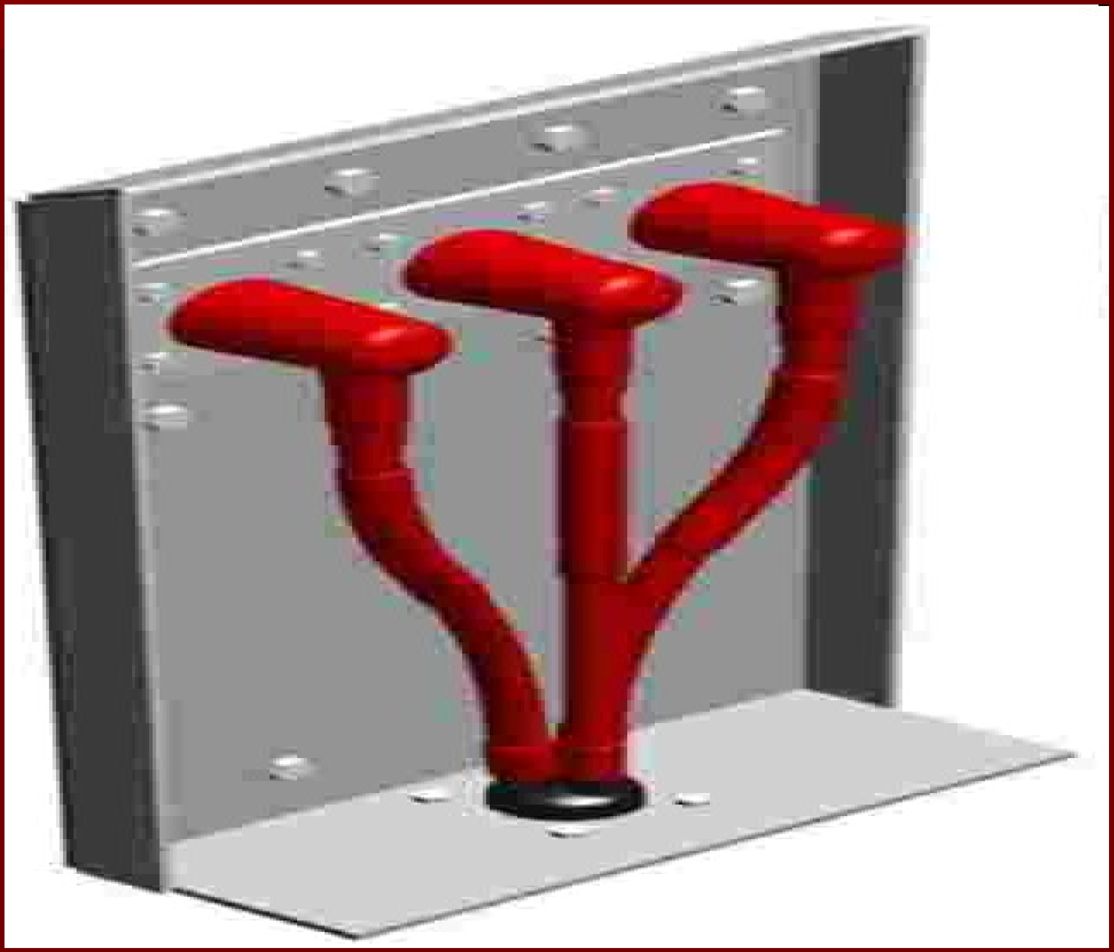


0.6-1kV PVC Insulated Power Cable

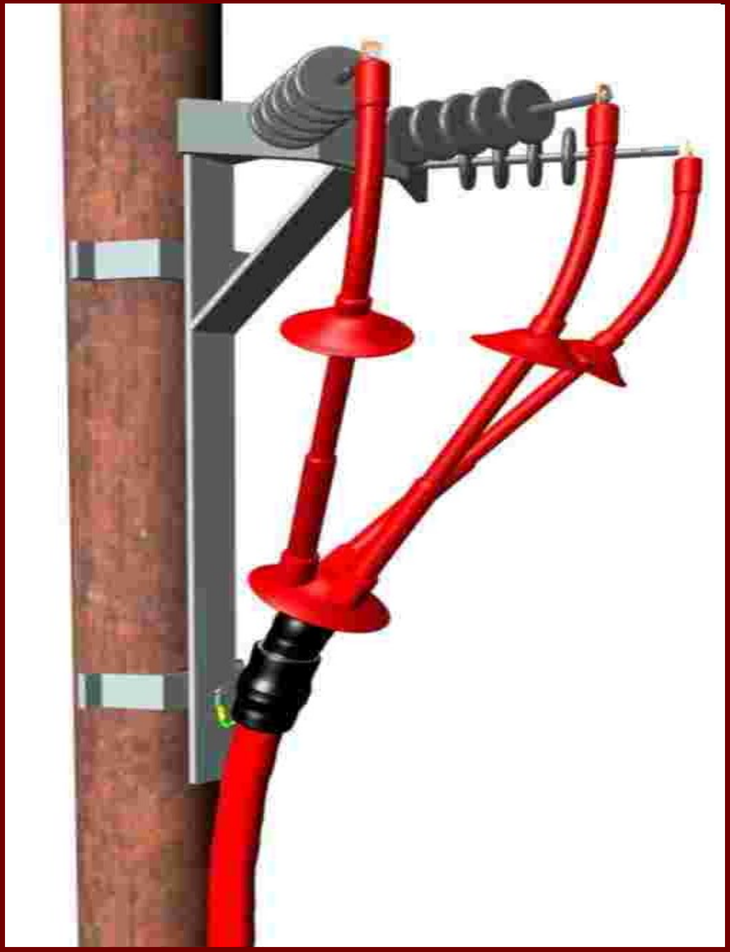
Multi-core Cable


The power is off. I've checked!
We can chew as much as we want...

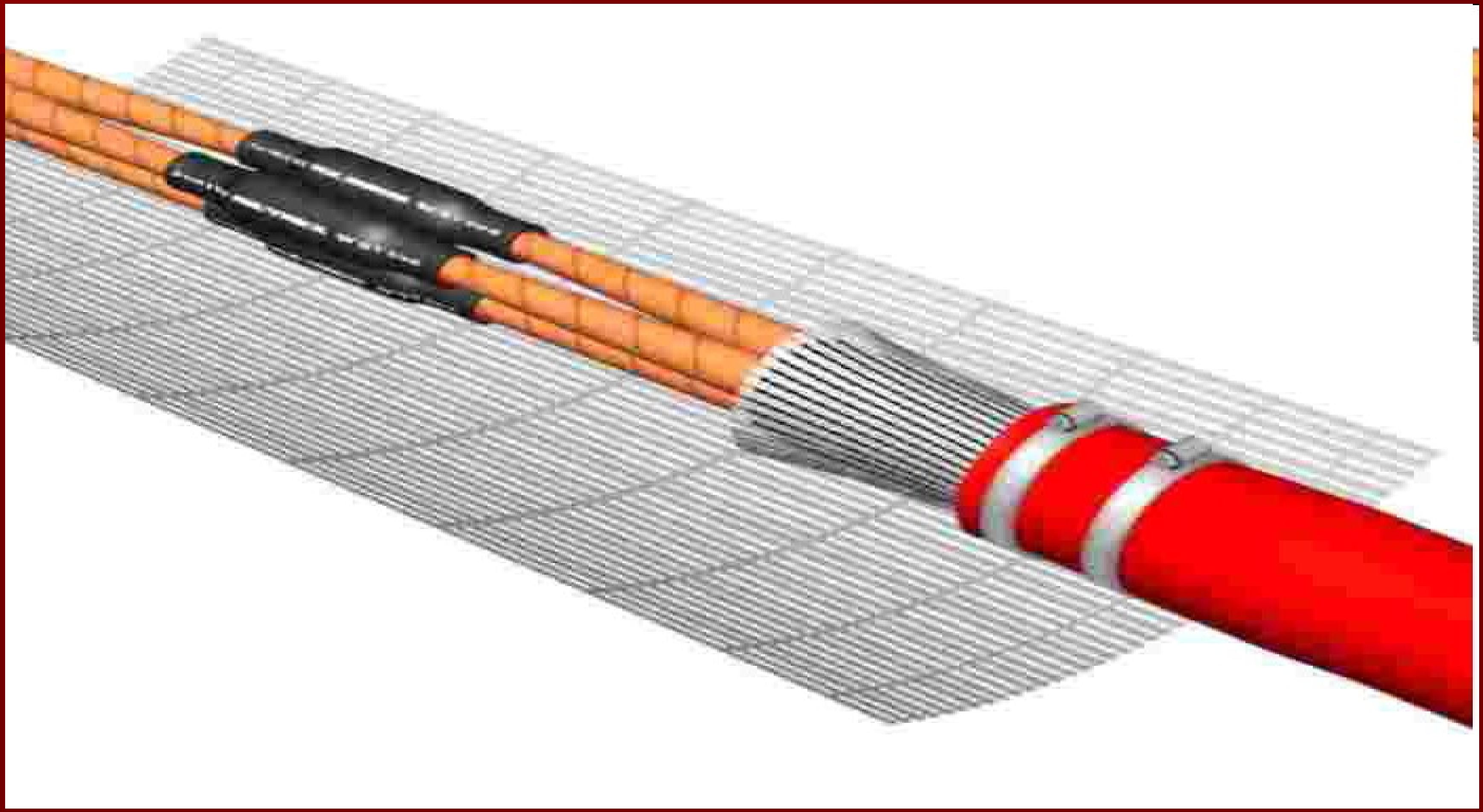
Heatshrink Terminations



Heatshrink Terminations

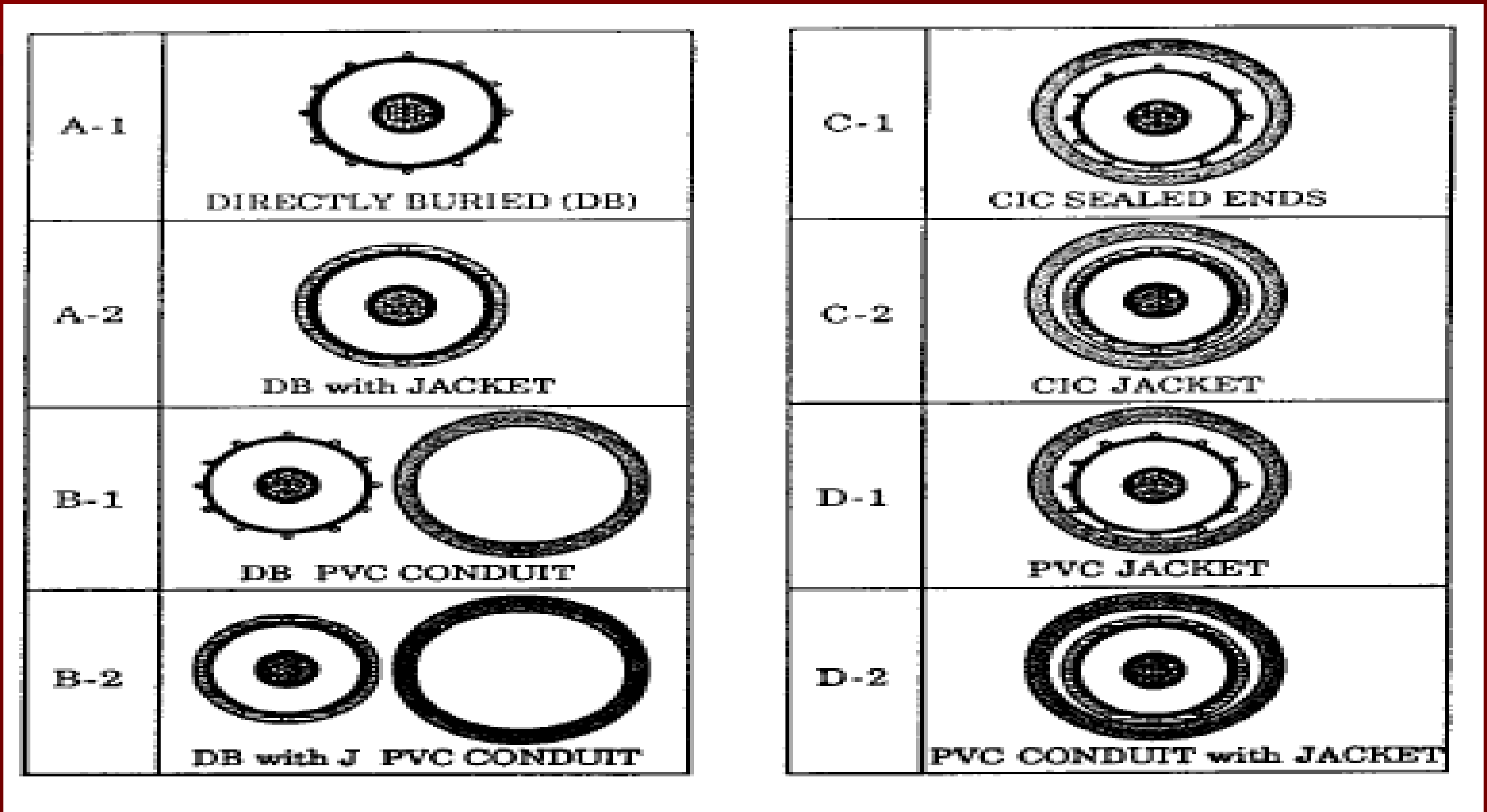


Heatshrink Joints

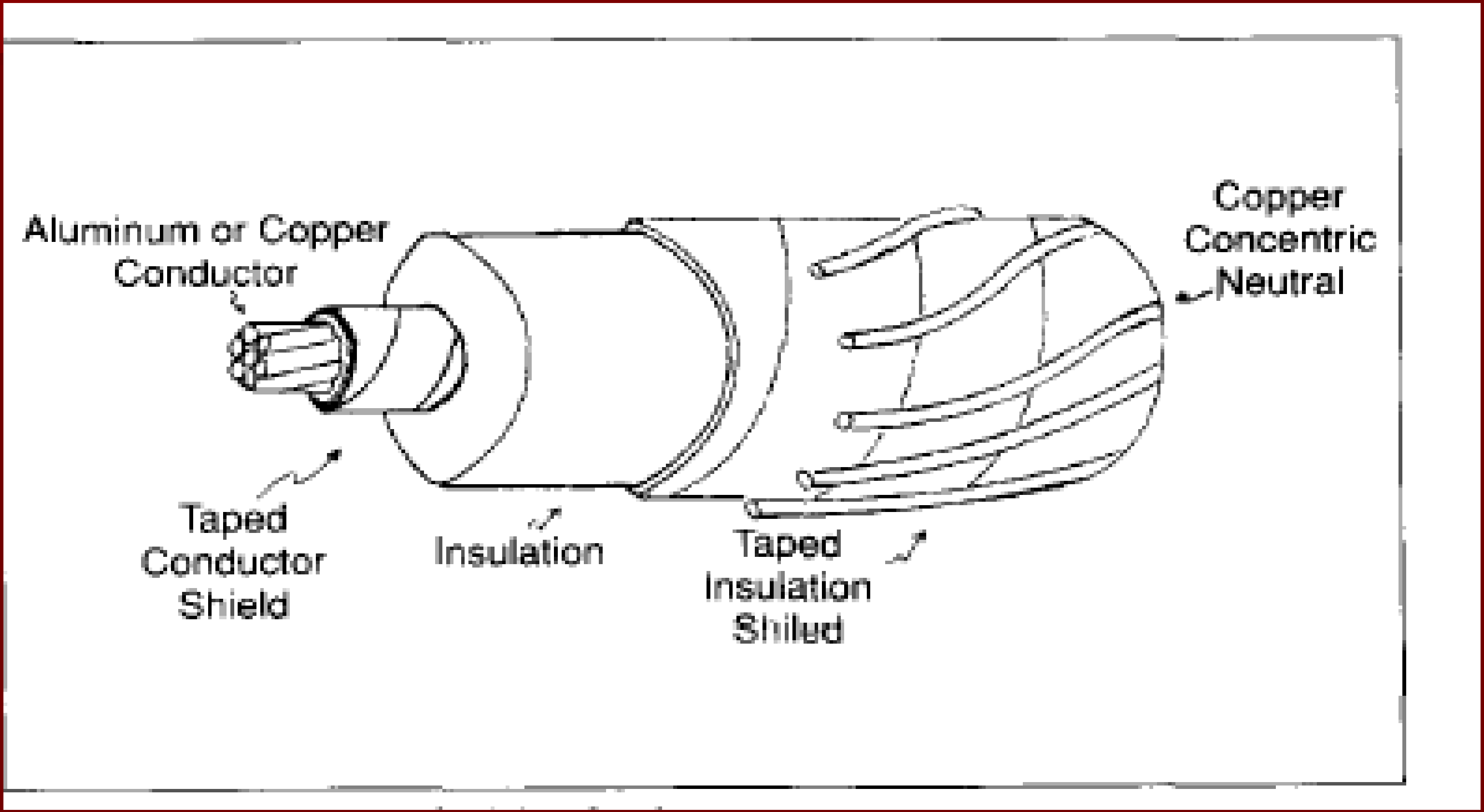


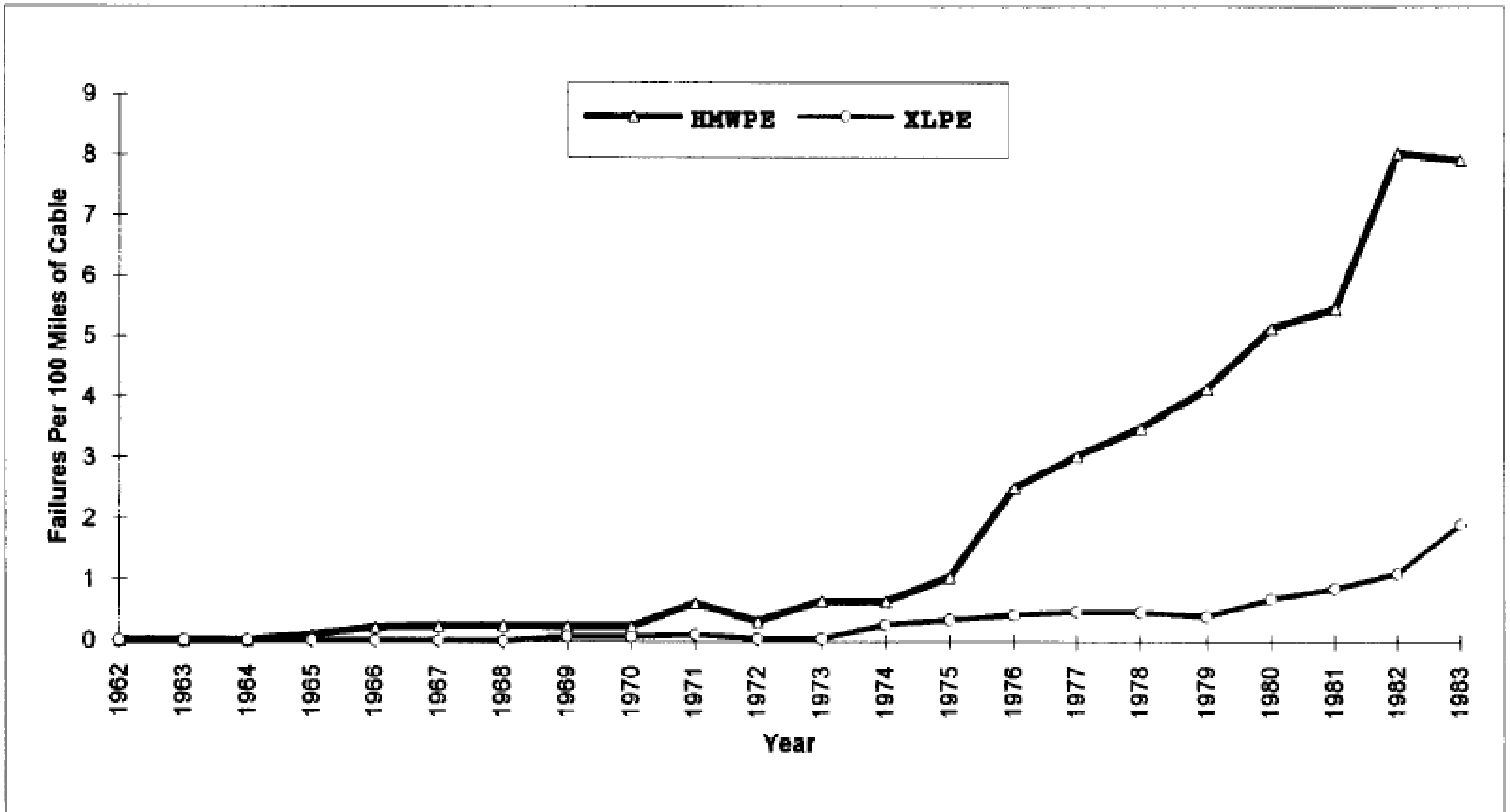
Coldshrink Terminations

URD CABLE DESIGN OPTIONS



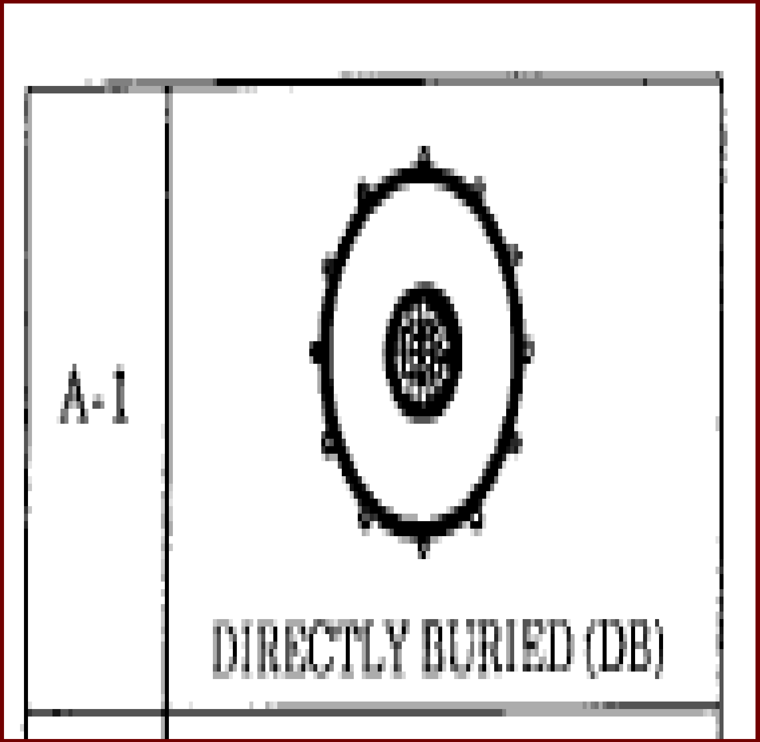
Early URD Cable design



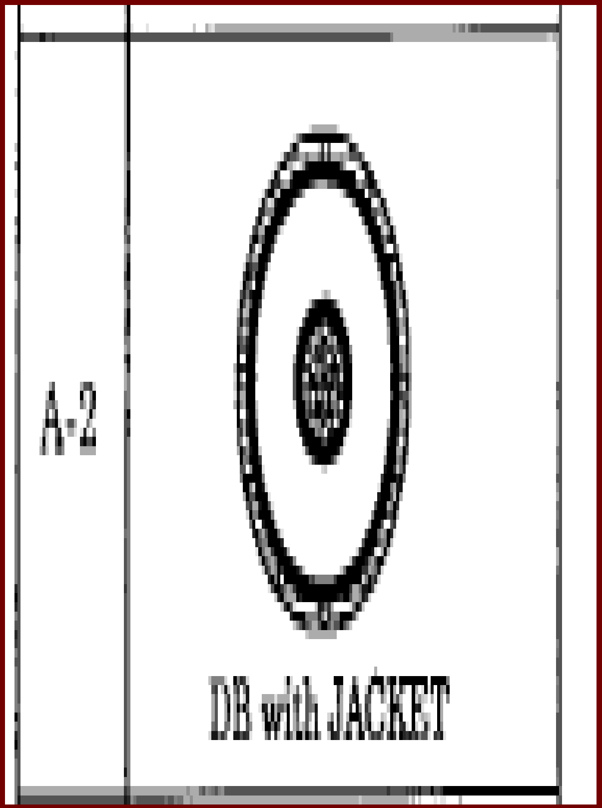


HMWPE
XLPE
Failures Per 100 Miles of Cable
9
8
7
6
5
4
3
2
1
0
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
Year

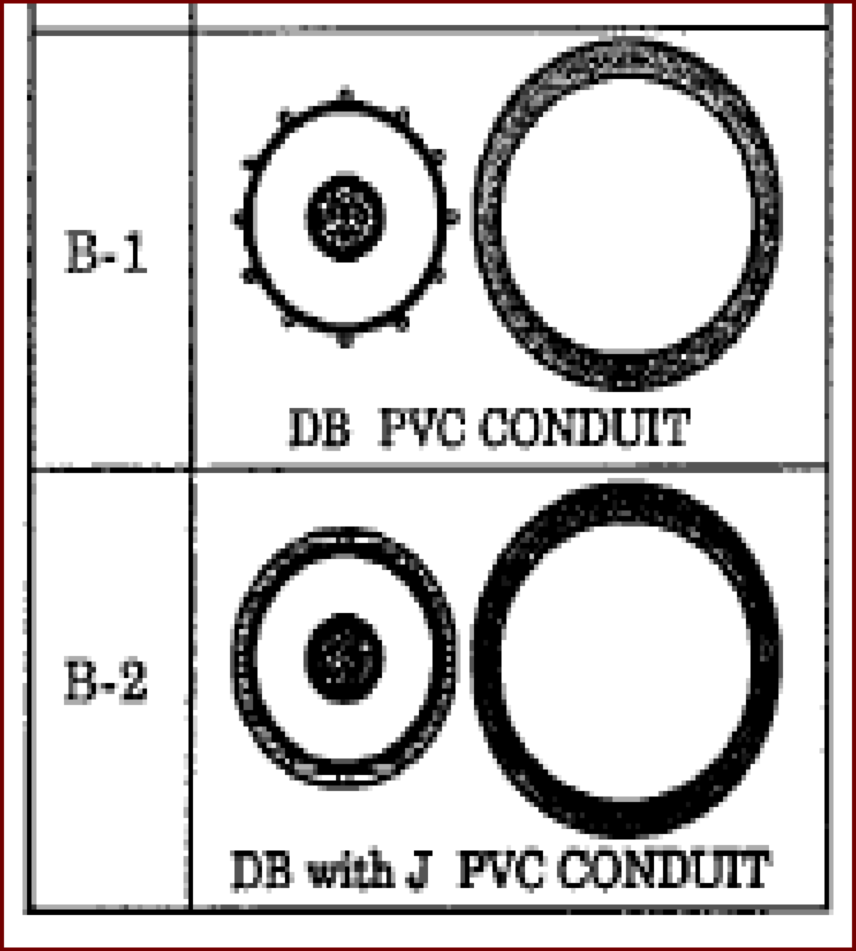
- directly buried unjacketed cable - least costly - permits direct migration of moisture into the insulation - potential corrosion of concentric neutral wires - affords noprotection against mechanical damage



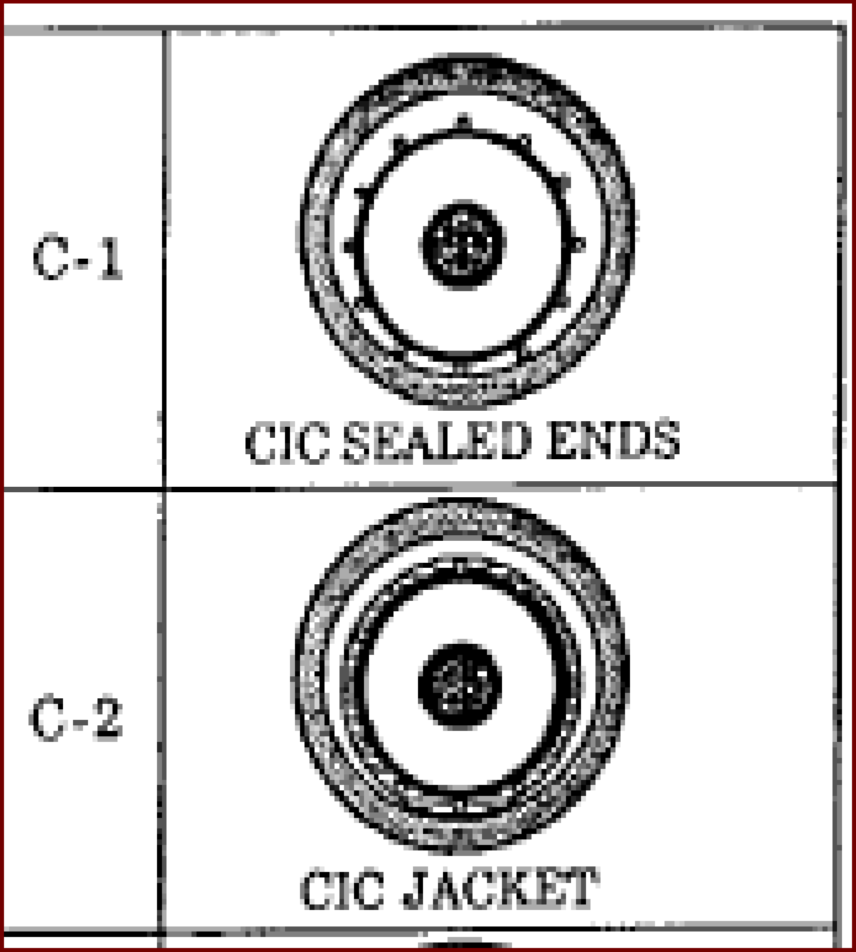
- Directly buried cable containing a jacket
- eliminates corrosion of the concentric neutral wires and
- reduces water migration.
- provides some mechanical protection.
- Polyethylene jackets more resistant to water migration than PVC jacket



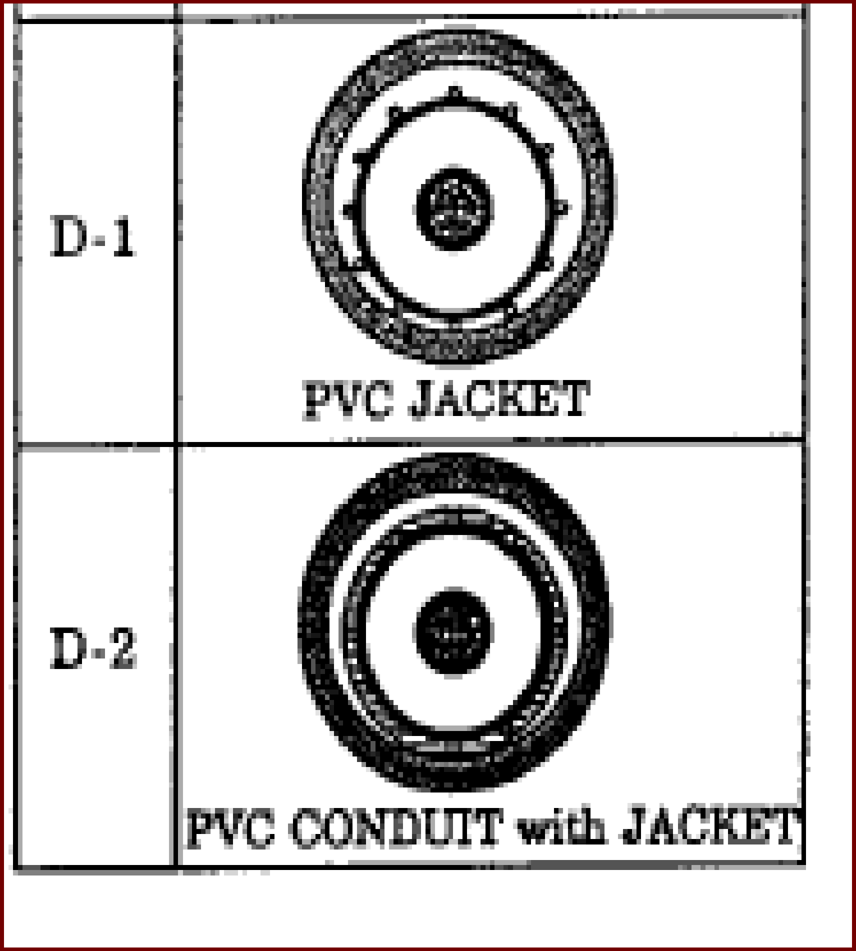
- B- 1 and B-2 incorporate a spare conduit next to the DB cable
- which permits cable installation at the end of life without excavation



- C- 1 and C-2 consist of a cable within a continuous factory-extruded (HDPE) conduit.
- Sealing the ends of the conduit provides an initial *dry* environment for the cable.
- It also provides protection from mechanical damage before, during and after installation



- D-1 andD-2 are conventional cable/conduit systems, and are the most costly



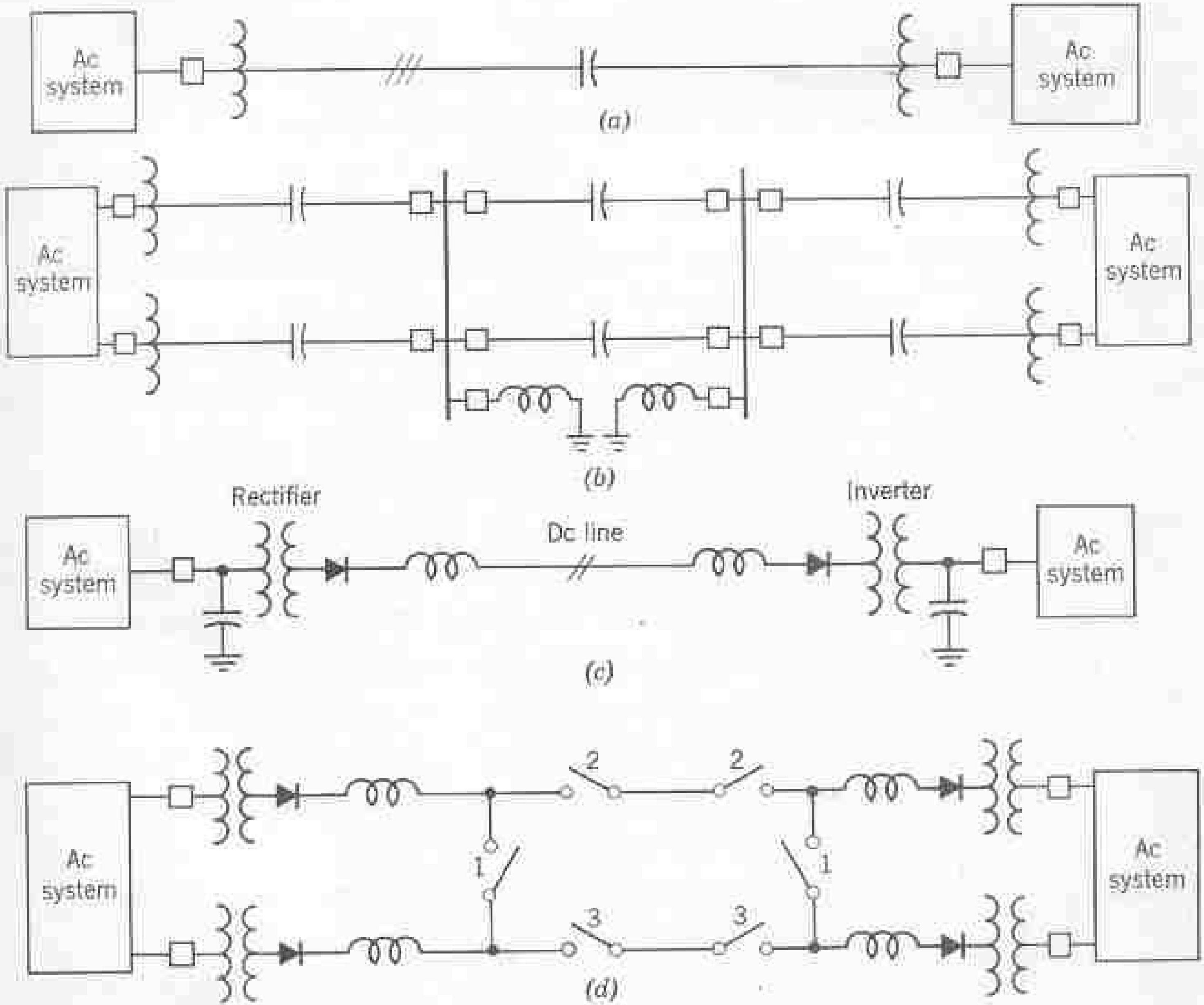


Fig. 1. Constitution of ac and dc EHV links shown by single-line diagrams.

HVDC TERMINALS

- Two Approaches – Back to Back Terminals – DC Links for Bulk Power Transfer
- Back to Back Terminals – Rectification and Inversion at one terminal (or Station) without any DC lines
- Bulk Power Transfer - DC Transmission with lines or 2 terminal DC Links.

Advantages of HVDC

- DC Transmission results – lower losses & costs (No doubt terminal costs & losses higher!)
- No restriction on Length for DC Transmission over Cables (Which is the case with AC)
- Forms an Asynchronous tie - reduces fault level
- High Speed Power Flow Control
- Useful for interconnection of AC systems

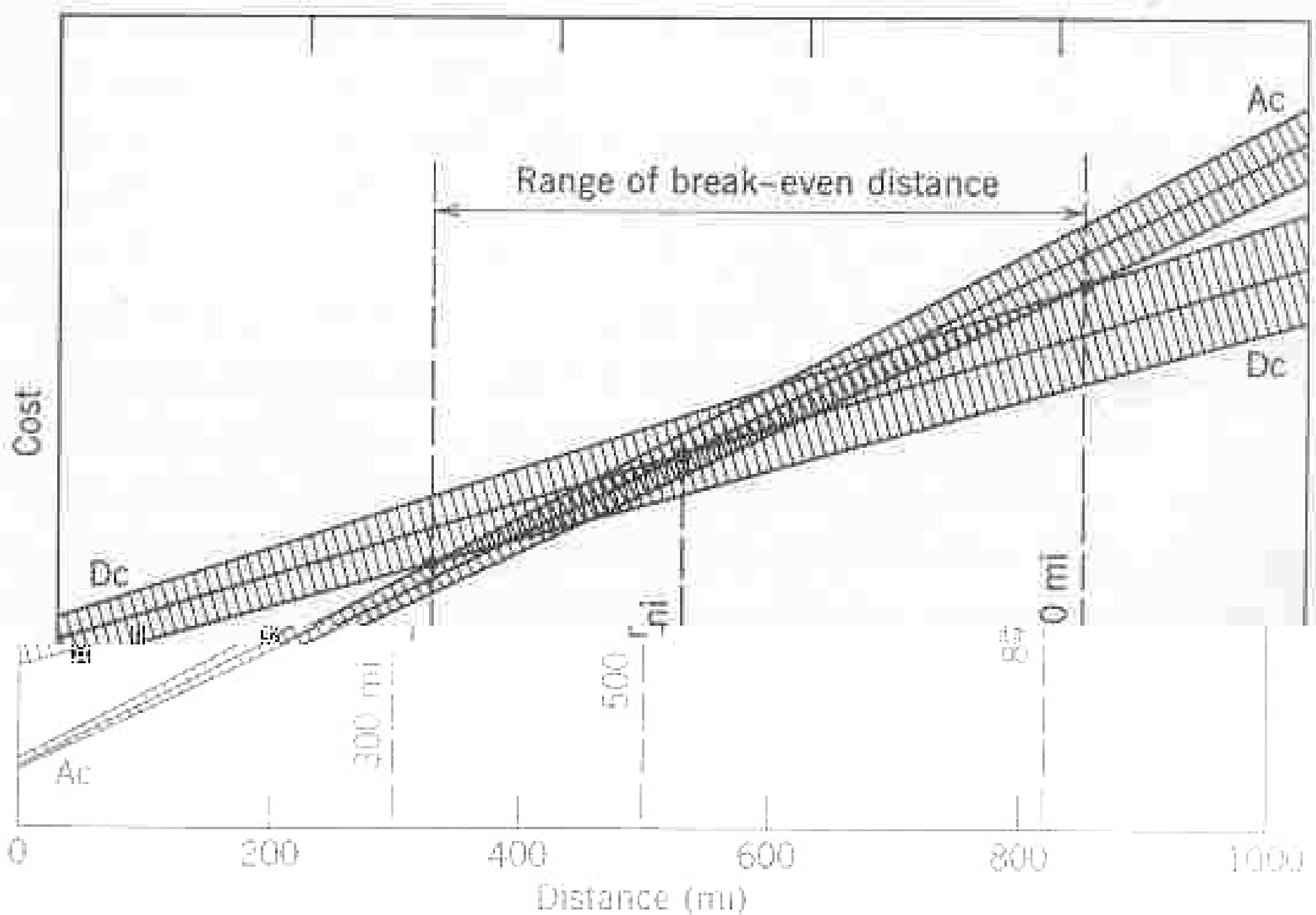


Fig. 10. Effect of variation of costs on break-even distance.

DC LINKS

- Mono-polar - Negative Conductor with sea or ground return.
- Bi-polar – One Negative – Other Positive – Neutral Grounded.
- Homo-polar – two or more Conductors all negative with ground return.

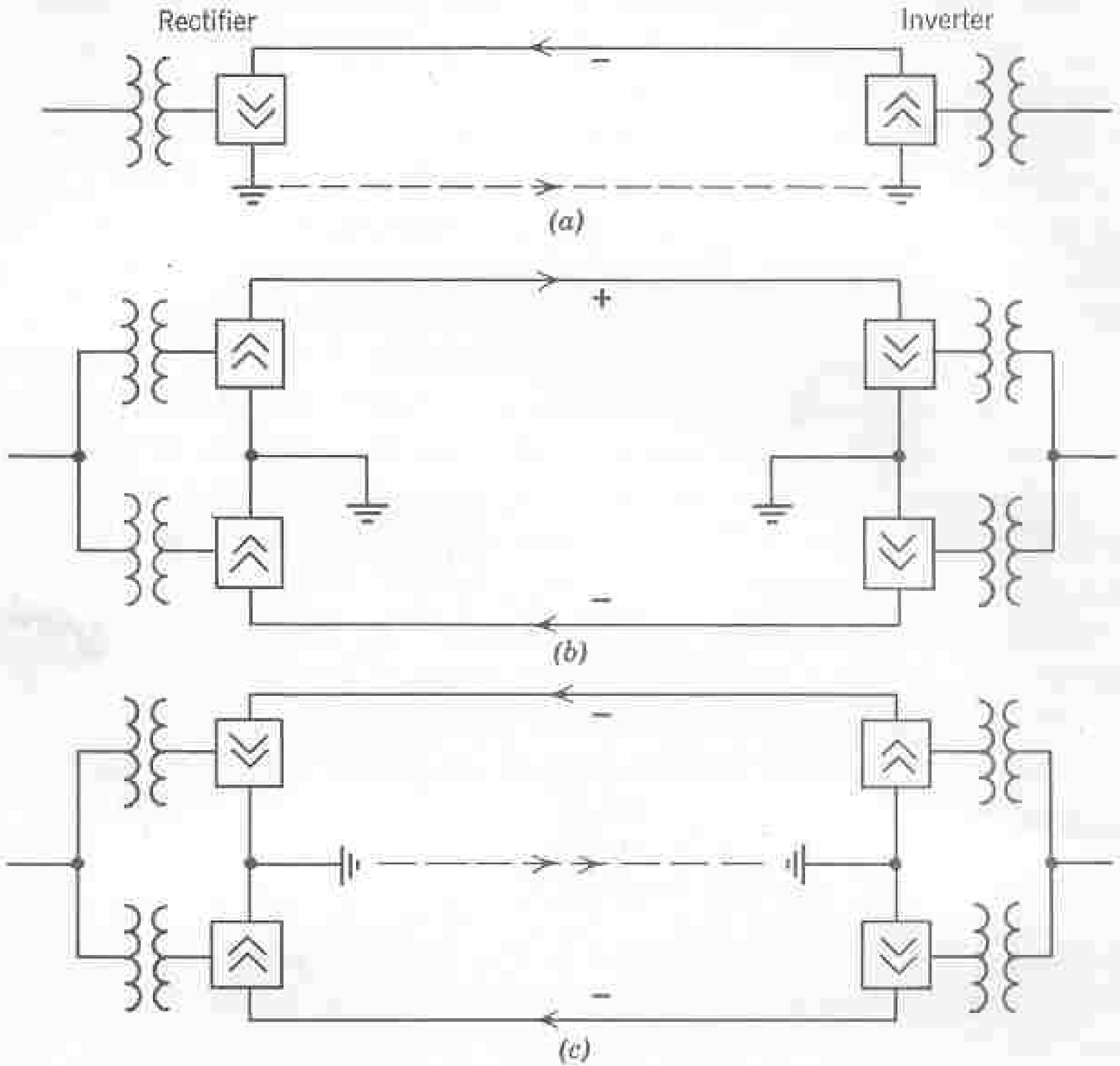


Fig. 2. Kinds of dc links.

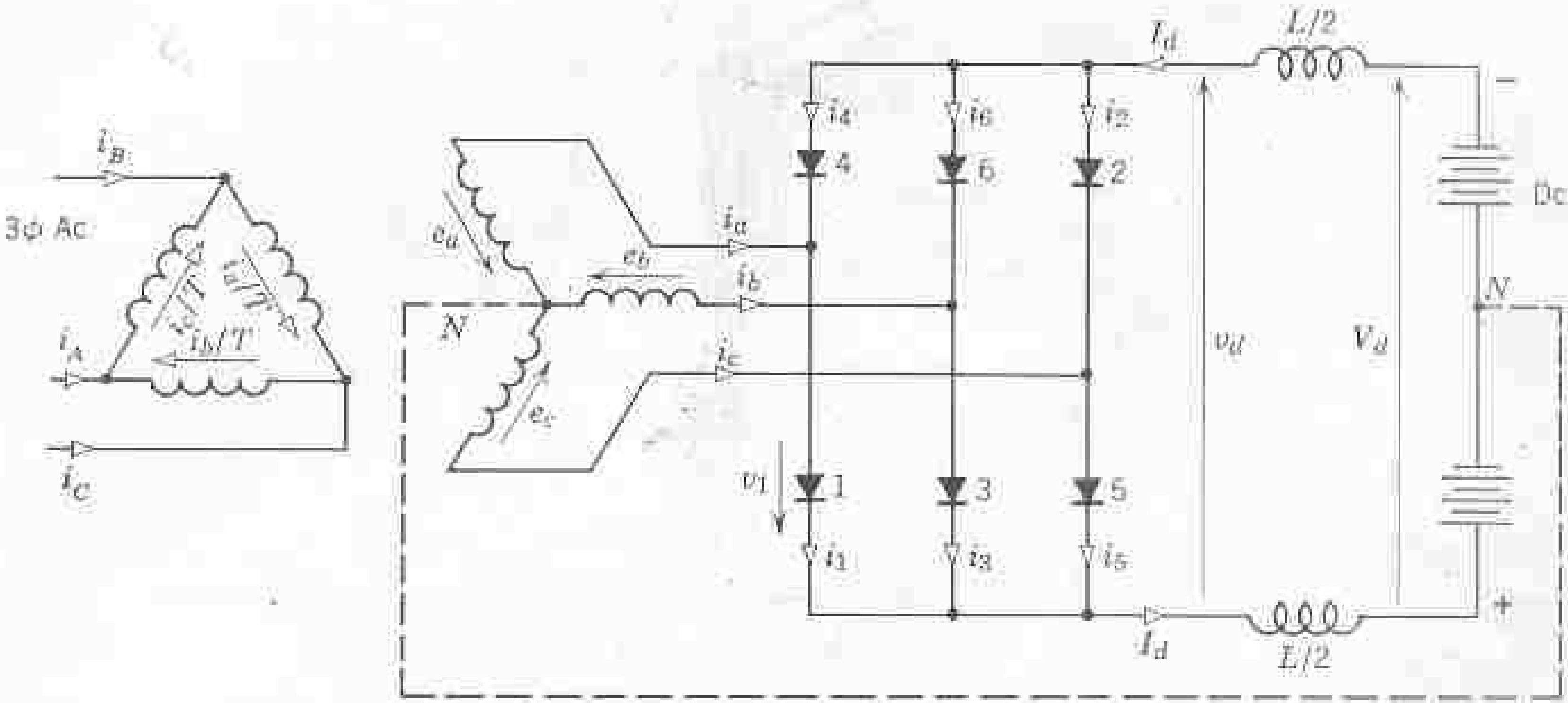


Fig. 9. Three-phase two-way, three-phase bridge, or Graetz rectifier circuit.

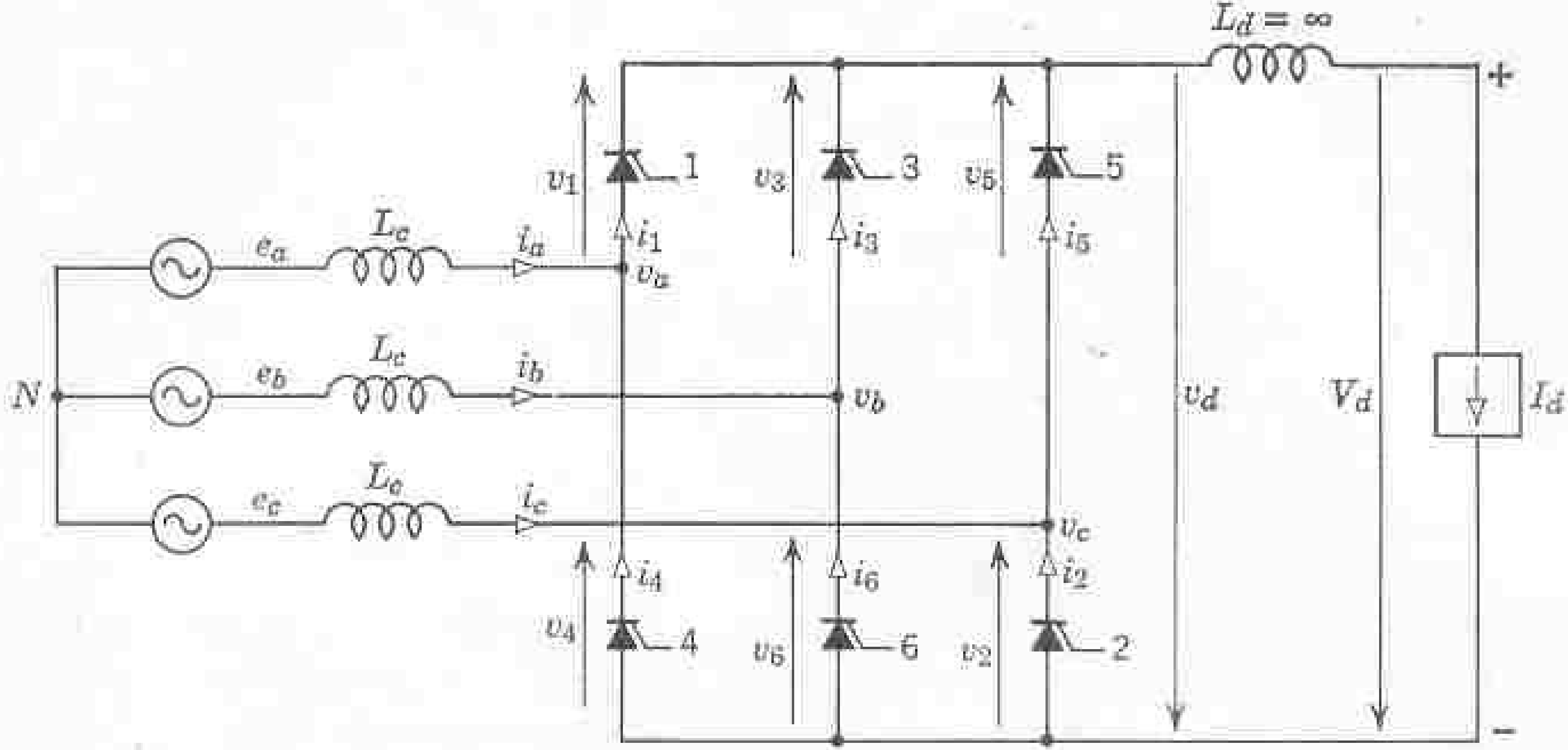


Fig. 1. Bridge converter—schematic circuit for analysis. The valves are numbered in their firing order.

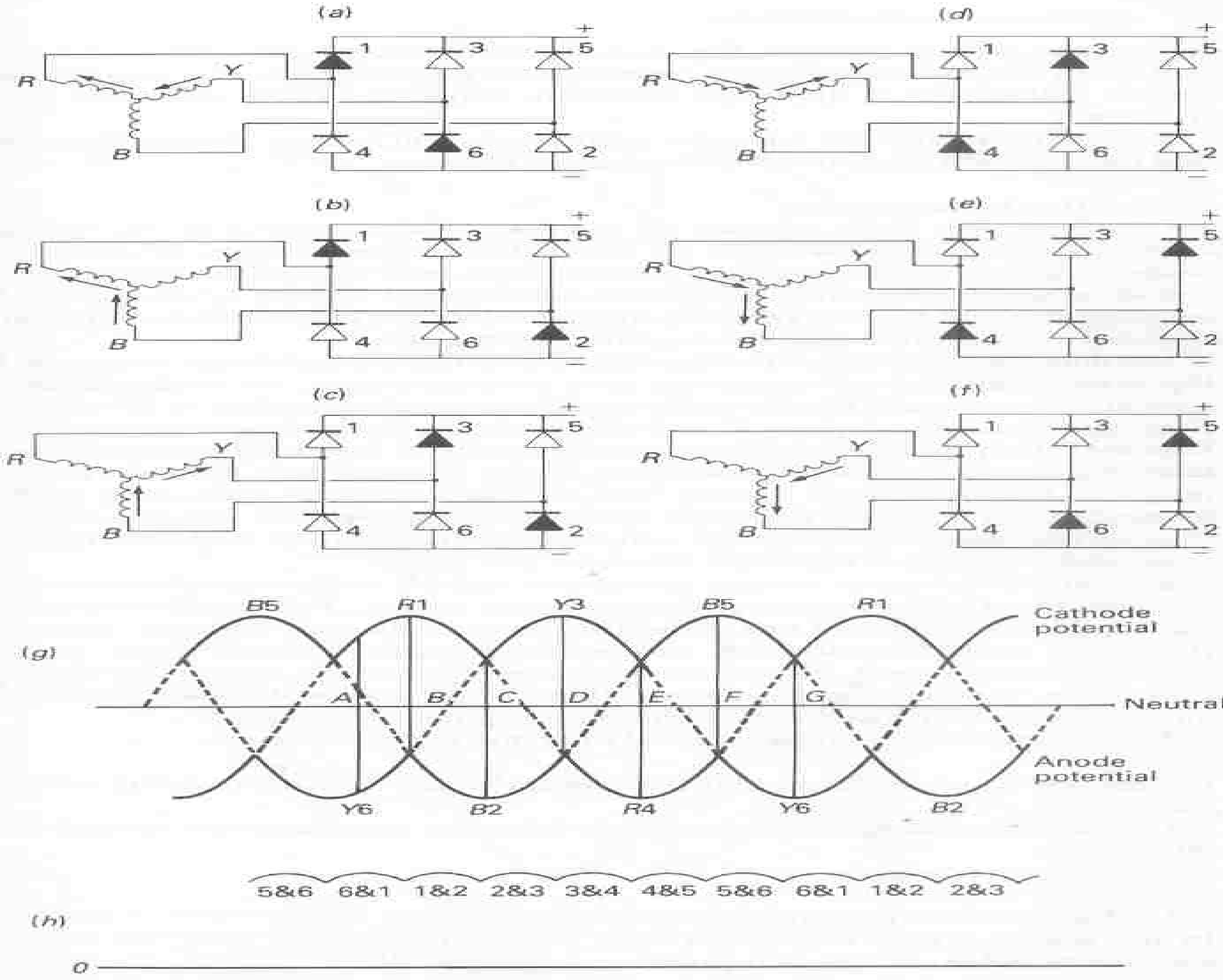


Fig. 2.2 *Bridge conducting sequence and d.c. voltage waveforms*

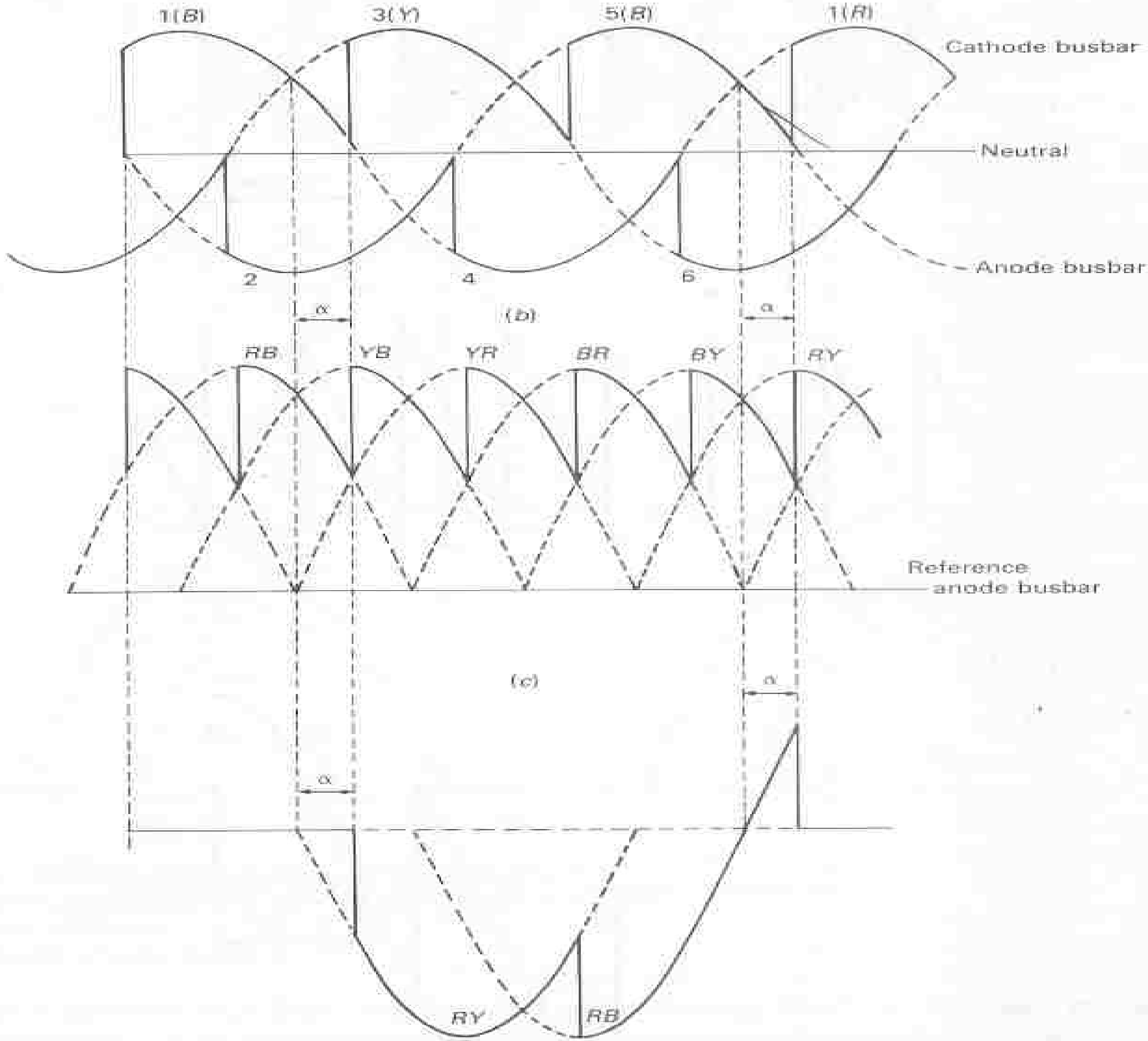


Fig. 2.3 *Effect of firing delay on voltage waveforms*
(a) Common anode and common cathode voltages
(b) Direct voltage
(c) Voltage across valve 1

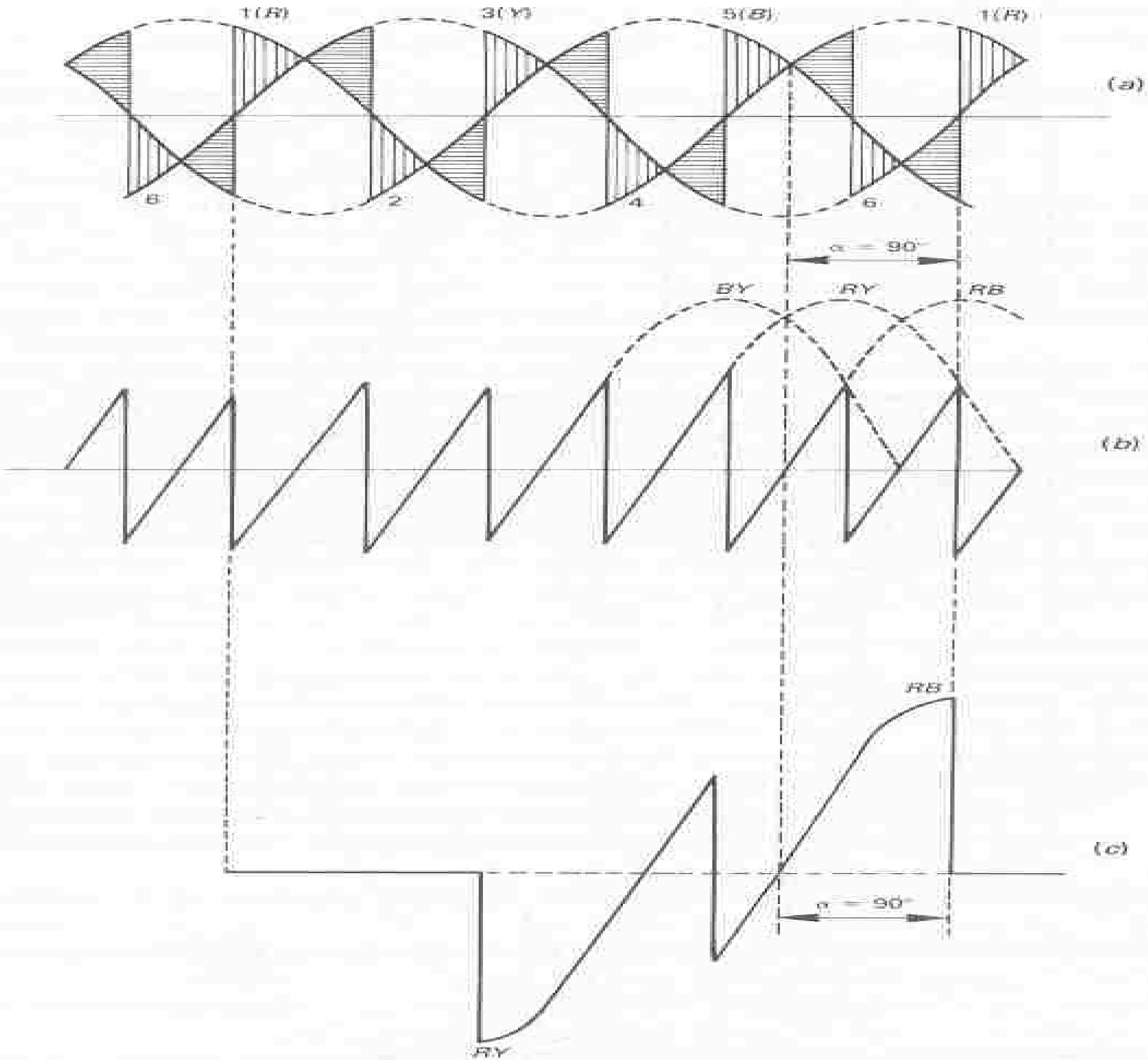


Fig. 2.4 *Voltage waveforms with 90° firing delay*
(a) Common anode and common cathode voltages
(b) Direct voltage
(c) Voltage across valve 1

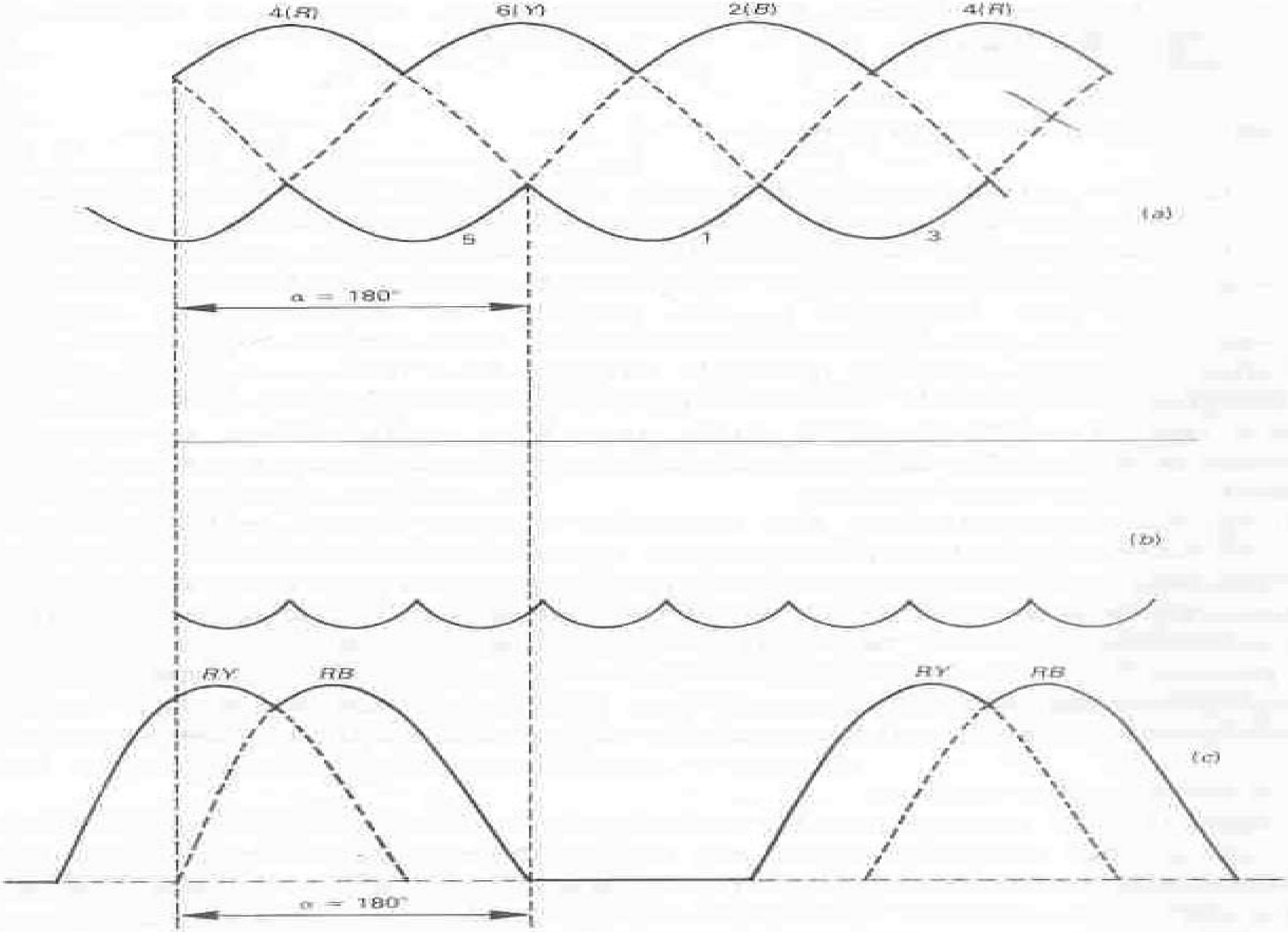


Fig. 2.5 *Voltage waveforms on full inversion*
(a) Common anode and common cathode voltages
(b) Direct voltage
(c) Voltage across valve 1

A 2000 A 250 kV thyristor valve at the Manitoba Hydro Henday converter station, April 2001

HVDC Distance Pylon near the terminus of the Nelson River Bipole

HVDC CONTROL

- Current Conversion for Rectifiers & Invertors in DC systems together with on load tap changers
- Power Flow requires Higher Natural Voltage Characteristics at Sending End
- Constant Current Control for Rectifier
- Constant Extinction Angle for Invertor
- Sending End Station with higher current setting

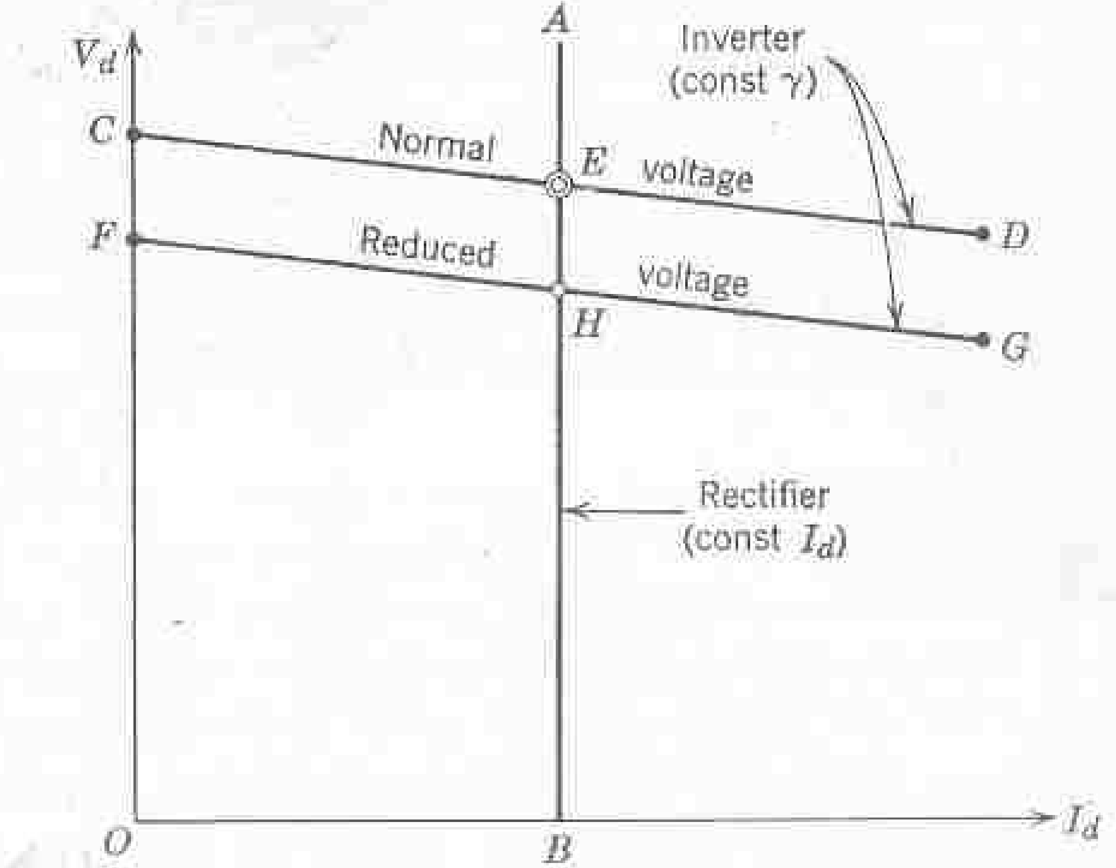


Fig. 6. Characteristics of control scheme—first step of explanation.

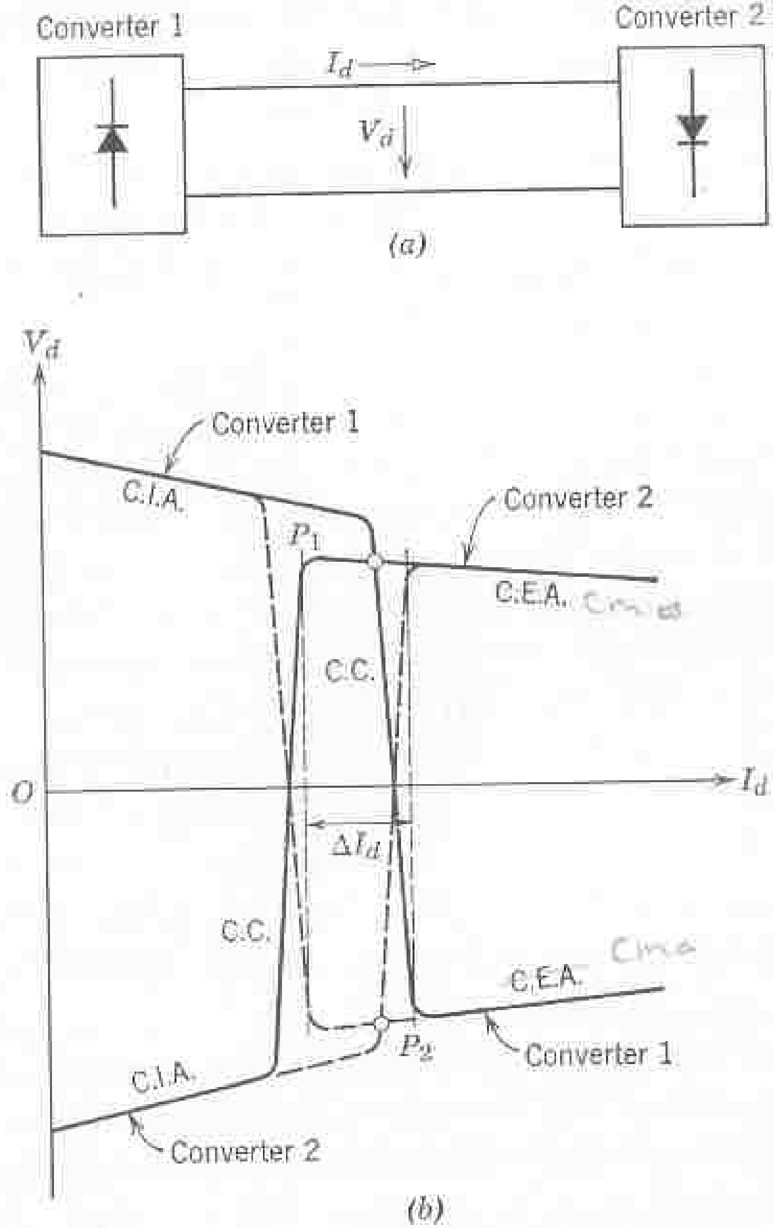


Fig. 8. Control characteristics permitting reversal of power flow: C.I.A., constant ignition angle; C.C., constant current; C.E.A., constant extinction angle.

DC Links in India

- Existing Back to Back Terminals :

2. West & North – Vindhyachal – 500 MW
3. East & South – Gazuwaka – 500 MW
4. East & North – Sasaram – 500 MW
5. West & South – Chandrapur – 1000 MW

- Bulk Power Transfer Links:

7. 2000 MW Talcher – Kolar Bi-pole
8. 2500 MW Hirma – Jaipur Bi-pole

(other bulk power transfers at 400 kV AC)

MTDC SYSTEMS

- More than two Convertors forms a MTDC
- Applications:

3. Bulk Power Transfer – Several Generators – Several Loads
4. Asynchronous Inter-Connection

   - MTDC more economical than several two terminal DC links.

3. Reinforcement of AC Network that is heavily loaded

MTDC SYSTEMS Contd..

- Types of MTDC – Series – Parallel
- Parallel – Ring – Mesh
- **<u>Series :</u>**
- Natural Extension of 2 terminal link
- Current is set by one convertor & is same for all others
- Other Terminals Operate at Constant Angle or Voltage Control
- Sum of the Voltages across the rectifier stations > sum of the Voltages across the invertor stations

Fig. 10.5 *Line with parallel tap*

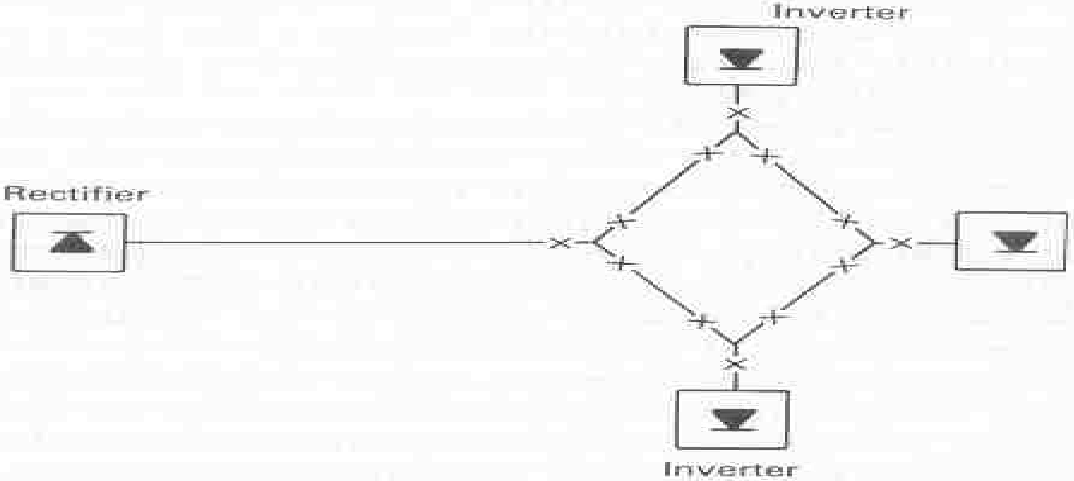


Fig. 10.6 *H.v.d.c. ring system*

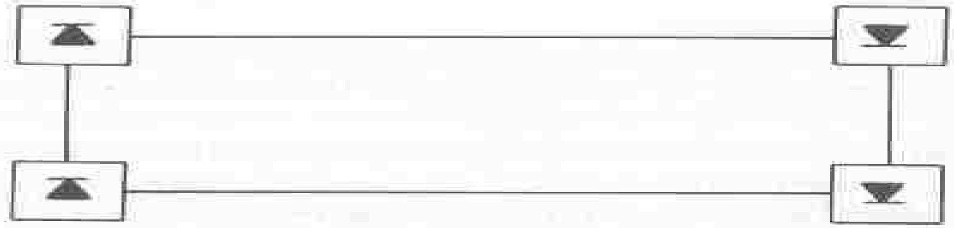


Fig. 10.7 *Series-connected system*

MTDC SYSTEMS Contd..

- If there be a drop in Current at Rectifier (Controlling Station) the Convertor with larger current takes over.
- **Parallel:**
- Extension of constant AC Voltage System Philosophy to DC
- One terminal acts as Voltage Setting Terminal at Constant Angle or Voltage
- Currents in all other terminals adjusted according to power requirement

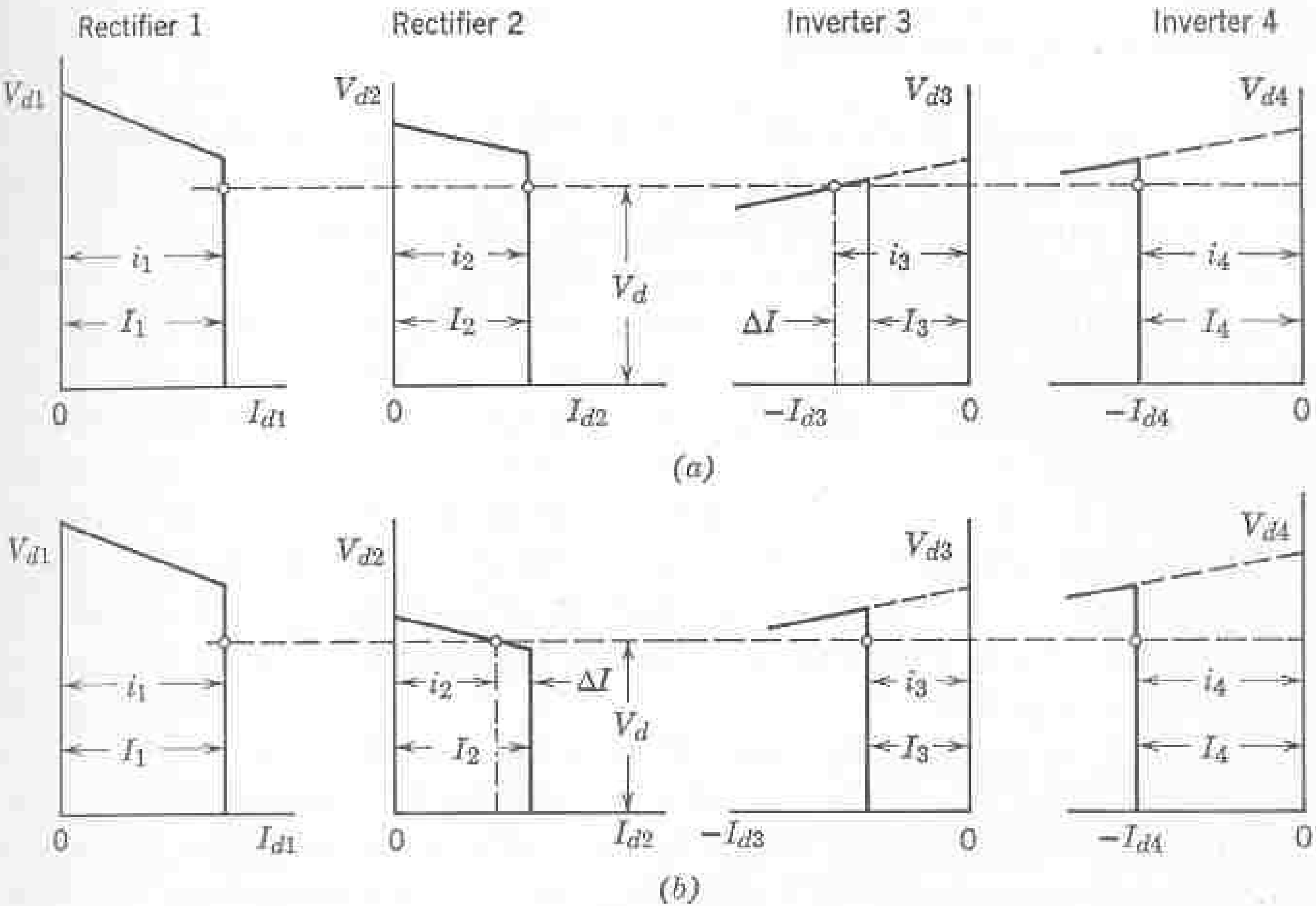


Fig. 25. Control diagrams of four-terminal dc lines. Line voltage is controlled (*a*) by inverter station 3; (*b*) by rectifier station 2.

MTDC SYSTEMS Contd..

- Radial System / Tapped – Disconnection of one line would result in interruption of Power from more than one Convertor
- In a Mesh System or Ring System such a thing would not cause disruption.

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Thank you