P1

What is a power grid?

Imagine filling a small salt shaker from a large bag of salt. It would be an extremely difficult job and much of the salt would be spilled in the process. However, if a funnel is used, the large amount of salt being poured into the top of the funnel is reduced to a small manageable stream at the narrow end, making the task of filling the salt shaker much easier.

The power grid works in much the same way. Extra high voltage electricity generated at power stations is delivered through the power grid and along the way is reduced to much lower voltage levels which the customer is able to manage.

Perhaps the most recognisable part of the power grid is the network of high voltage transmission lines, supported by large metal pylons, which thread their way through the countryside. Other components of the grid include switching stations which connect the transmission lines together and substations within which the electricity is changed to lower voltages.

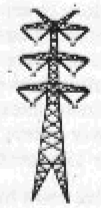
The two most common forms of energy used in the production of electricity in New South Wales are coal, which is burned in large boilers to produce steam and thence electricity, and water, which is stored in dams until it is needed. Power stations where the electricity is generated are almost always sited close to their source of energy.

Once the power is generated it is delivered to customers, who may live in the city or the country, by using the power grid.

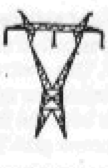
Extra high voltage transmission lines are needed to carry large amounts of electricity over long distances. In New South Wales most of the transmission lines operate at voltages of 330 kilovolts (one kilovolt equals one thousand volts) or 132 kilovolts, with other lines operating at 500 and 220 kilovolts. These extra high voltage lines have a higher energy efficiency than a large number of lower voltage lines. They are more economic to construct, operate and maintain.

Most transmission lines are overhead lines with aluminium conductors supported by steel lattice towers. The conductors are insulated from the towers by porcelain, glass or synthetic insulators. Transmission lines can also be laid underground but these are many times more expensive than overhead lines of equal capacity.

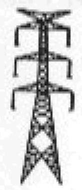
The power carried over the high voltage lines must be changed to a lower voltage before it can be used in the home or industry. This occurs in several stages.



500kV double circuit steel tower



330kV single circuit steel tower



330kV double circuit steel tower

132kV double circuit steel tower

PACIFIC POWER

P2

Firstly, the electricity is delivered to substations or switching stations, to either change the voltage level of the power or to provide a switching point for a number of transmission lines.

Your local county council (e.g. ENERGY AUSTRALIA) then uses sub-transmission lines to transfer the purchased electricity at 132 and 66 kilovolts from Pacific Power substations to zone substations. The sub-transmission lines generally have the conductors supported on wood or concrete poles. (Sometimes these poles also carry distribution lines of a lower voltage.) Some sub-transmission lines are also placed underground. Once the power arrives at a zone substation it is converted to 22 or 11 kilovolts (22kV or 11 kV).

From this point high voltage distribution lines transfer the electricity from zone substations to distribution substations sited close to homes and factories, where it is transformed to 240 volts for supply to customers.

The flow of high voltage electricity through the power grid is controlled from a single control centre in Sydney. This control centre uses computers and communications systems to enable the operators to monitor both the flow of electricity and the condition of the power grid. The power carried over the extra high voltage lines must be changed to a lower voltage before it can be used in the home or industry.

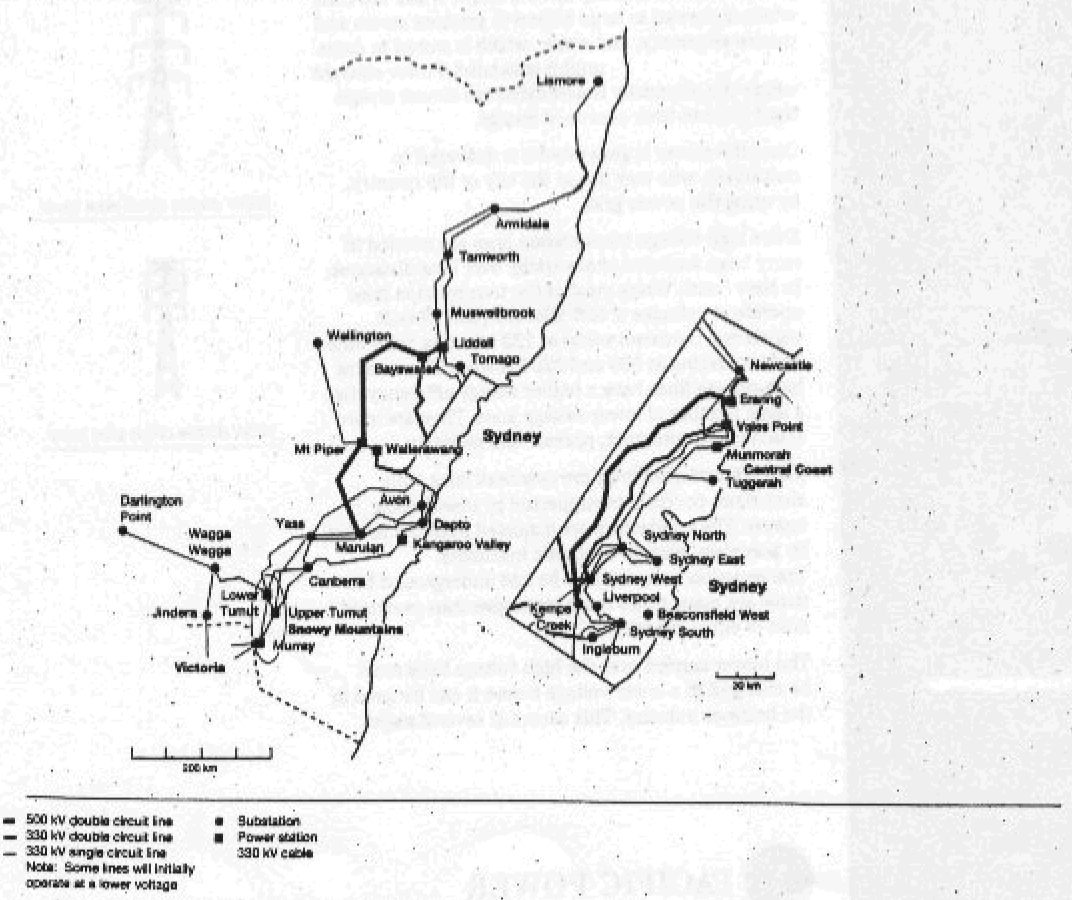
Electricity does not recognise state boundaries. The NSW power grid is joined to similar power grids in Victoria and South Australia. This enables the buying and selling of electricity between states.

The connection with the Victorian grid uses the 330 kilovolt transmission lines from the Snowy Mountains Hydro Scheme. In March 1990, the Victorian power grid was connected to the grid in South Australia by a 275 kilovolt line from a terminal station at Heywood in western Victoria to a substation near Mt Gambier in South Australia.

The South-Eastern Australian power grid extends from northern New South Wales to about 300 kilometres north of Adelaide, a distance of 2200 kilometres, making it one of the longest power grids in the world.

The giant three-state grid enables the more efficient use of resources and a reduced need for generating plant because generating capacity can be shared between the three states. Studies are presently being undertaken to see if it is possible to connect Queensland and Tasmania to the south-east Australian power grid.

New South Wales main power system



P3

ELECTRICITY SUPPLY SYSTEM

Electrical energy is generated and supplied to consumers (domestic, commercial and industrial), by way of an "Electricity Supply System".

The major divisions of the supply system are:

a) Generation,
b) Transmission,
c) Distribution,
d) Utilisation.

FIG 1 shows the relationship between these divisions in a simple block diagram.

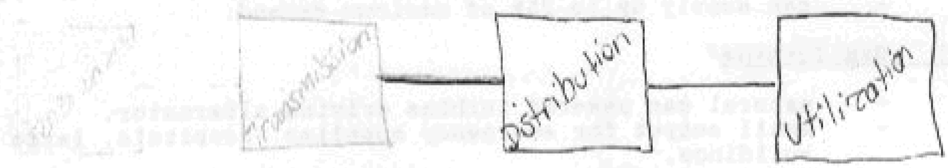


FIG 1

Generation

Conversion of a fuel or other source of energy to electrical energy.

Transmission

Moving large quantities of electrical energy over long distances between generating stations and load centres.

Distribution

Supplying electrical energy to individual consumers (domestic, commercial, industrial, transport).

Utilization

Use of electrical energy by consumer and conversion back to another energy form (heat, light, mechanical etc)

THE N.S.W. POWER SUPPLY SYSTEM

Refer to handout "What is a Power Grid?"

Generation of electrical energy

Carried out by "The Electricity Commission of N.S.W." (trading as Pacific Power)

P4

Methods used in N.S.W. to generate electricity in commercial quantitie:

a) Steam Thermal Cycle:

Refer to handout "How Electricity is Made":

- Coal fired boilers convert water to steam,
- steam drives steam turbine,
- steam turbine drives alternator to produce electricity.
- accounts for >90% of total state demand.

b) Hydro-Electric Cycle:

Refer to handout "Hydro Electric Generation":

- Flowing water drives water turbine,
- water turbine drives alternator to produce electricity.
- can supply up to 25% of maximum demand.

c) Gas Turbine

- natural gas powered turbine driving alternator.
- small output for emergency supplies, hospitals, large buildings,
- usually for emergency start-up of system or peak loading.

d) Internal Combustion Engine:

- diesel engine drives alternator.
- small output for emergency supplies, hospitals, large buildings, industrial complexes.

Note: More detail about other sources and generation in "Generation of Electrical Energy" topic.

Location of Power Stations in N.S.W.

Major Thermal Stations

Located on or near coalfields, to provide cheap supply of fuel. (Hunte. Valley, Central Coast, Lithgow).

Unfortunately, they are far from the major load centres (Sydney, Newcastle, Wollongong)

Major Hydro Stations

Located in the Snowy Mountains and Kangaroo Valley.
The output of Snowy Mountains is shared between N.S.W. and Victoria.

Gas Turbines

Located strategically throughout the state to provide emergency supply to re-start the system in the event of a major system fault or shutdown (known as a "Black Start").

P5

Diesel Internal Combustion

Located in industrial sites, large buildings, hospitals etc for providing Un-interrupted Power Supplies (UPS) for computers and emergency equipment when the normal supply fails.

Alternator (Generator) Size and Ratings

The size (rating) of Turbo-Alternators in power stations is specified for:

a) frequency (50Hz),
b) generated voltage (typical three phase 16.5kV or 23kV),
c) power output (typical 500 or 660 megawatts).

Electrical Power Transmission System in N.S.W.

The electrical power transmission system in N.S.W. consists of an interconnected grid of Extra High Voltage (EHV) and High Voltage (HV) overhead transmission lines, linking the major power stations with load centres.

Question??:
Why are EHV and HV lines used for power transmission?

Answer:
To reduce power losses in transmission.

Power loss in a transmission line $P = I^2R$ (power proportional to current squared), so that if the value of current flowing in the line is reduced, then power loss will also be reduced ($\frac{1}{2}$ current reduces power loss to $\frac{1}{4}$)

If the level of transmission voltage is increased, and the current level is decreased by the same proportion, then the same power will be transmitted since power $P = EI$.

Transformers are used to step-up and step-down voltage levels in the transmission system.

EHV (500kV and 330kV) is used in the transmission system.

The output voltage of the alternators (23kV) is stepped-up to 330kV or 500kV for transmission on the EHV overhead transmission lines.

The overhead (O/H) transmission lines carry the energy to large substations, located on the outer perimeter of major load centres.

In these large substations, transformers step-down the voltage level so that a Sub-Transmission system may supply smaller substations in each district. Voltages on the Sub-Transmission system are 132kV and 66kV.

Sub-Transmission substations also have transformers which step down the voltage further, for supply to the Distribution System through HV overhead lines and underground (UG) cables.

Note: Some large industrial consumers are supplied at Sub-Transmission voltages, through "Bulk Supply Points".

Electrical Power Distribution System in N.S.W.

The Distribution System is a series of smaller substations and HV O/H lines and UG cables to supply power to all consumers premises.

Distribution voltages range from 33kV - 22kV - 11kV - 415V - 240V.

Transformers are used to step-down to these different voltage levels in small substations in streets (on pole tops, or in green footpath cabinets), or in customer premises (factories and buildings).

Utilization of Electrical Energy

Customers receive supplies at various voltages, depending on their load requirements.

Domestic:

415 volts	3 phase
415 volts	2 phase
240 volts	1 phase

Commercial:

415 volts	3 phase
11kV	to own transformer on site (office block)

Industrial:

415 volts	3 phase (small factories)
11kV	to own transformer (larger factories)
33kV & 66kV	large industrial complex (oil refineries etc)
132kV	large power requirements to own substation on site (BHP steel works, ALCAN aluminium smelter)

Major Items of Plant in each Division of Supply System

Generation:

Boilers, Turbines, Alternators, Step-up transformers.

Transmission & Sub-Transmission:

Transmission lines (OH & UG), substations, bulk supply points, step-down transformers, circuit breakers.

Distribution:

Transmission lines (OH & UG), step-down transformers, metering equipment

Utilization:

Consumer items of machinery, lighting, transformers, motors, furnaces, boilers, heaters, appliances.

Block Diagram of Supply System

Refer to FIG 2 which shows a block diagram of the Electricity Supply System.

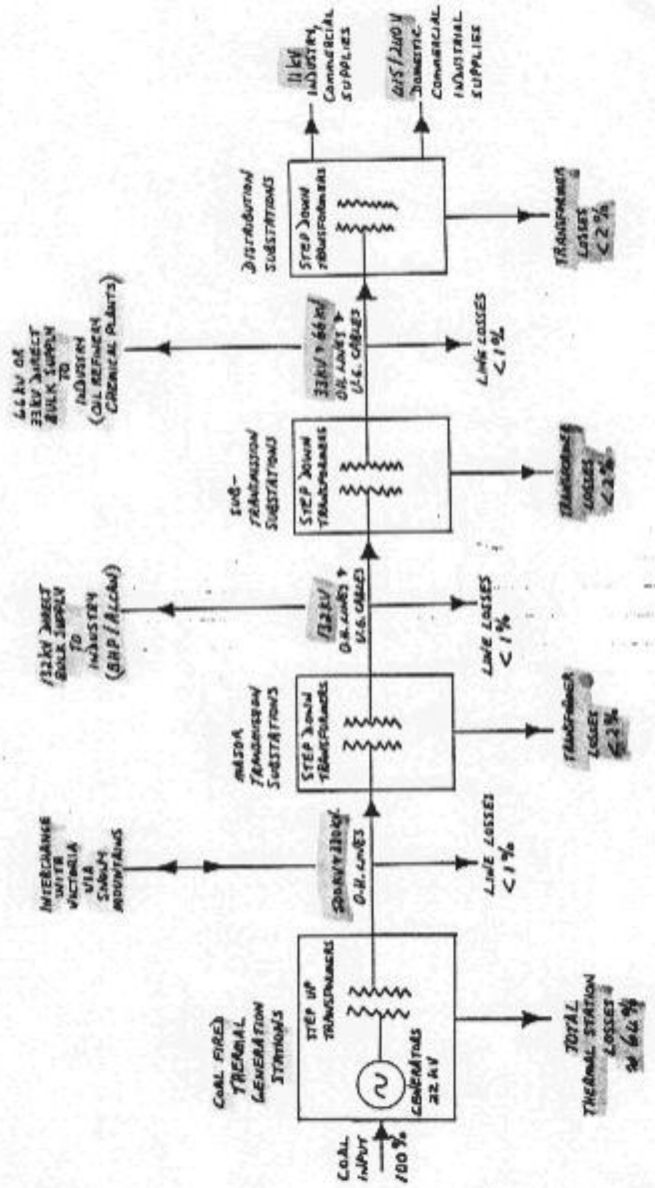


FIG 2

P8

POWER GENERATION

Definitions used in Generation

Refer to the total system demand curves shown in FIG 1.

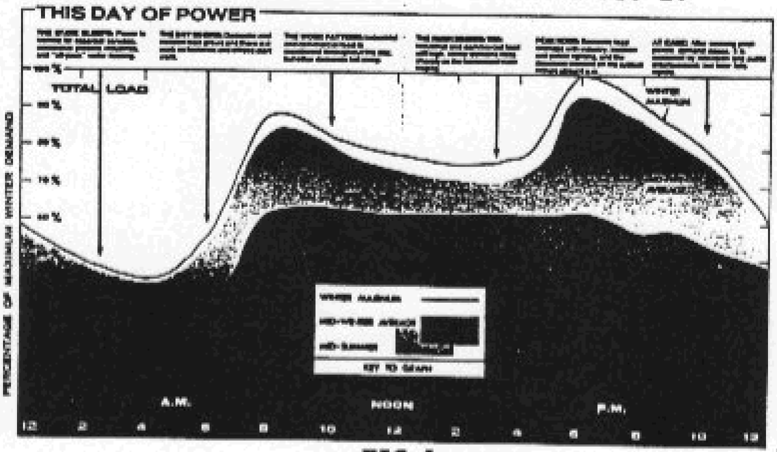


FIG 1

Base Load: Minimum total system demand that is required 24 hours a day.

Thermal stations are operated to supply this demand. The most efficient generators operated at maximum output continuously and are called base load generators.

Peak (Max) Load: Maximum loading (demand) for power on the system in a 24 hour period.

The peak loading is usually a short duration (2 hours) in morning and/or evening.

Hydro-electric and gas turbines have quick response times, and are used in addition to base load generators to supply the extra power at peak loading times.

Spinning Reserve: The extra output that can be supplied from an in service (spinning) generator that is not supplying its maximum output.

The most efficient generating plant is adjusted to give maximum output continuously.

Less efficient thermal plant is operated at less than its maximum output and is adjusted to meet the varying system load.

The reserve output available from these machines, can be obtained immediately it is required, in the event of a sudden increase in system load, or a breakdown of base load generators.

Steam Thermal Power Station

Can be:
a) coal fired boilers
b) nuclear reactor
c) geothermal (heat from within the earth)
- steam direct to turbine (2000MW in USA)
- hot water/warm water

a) **Coal Fired Power Station**

Refer to handout "How Electricity is Made" and FIG 2 below.

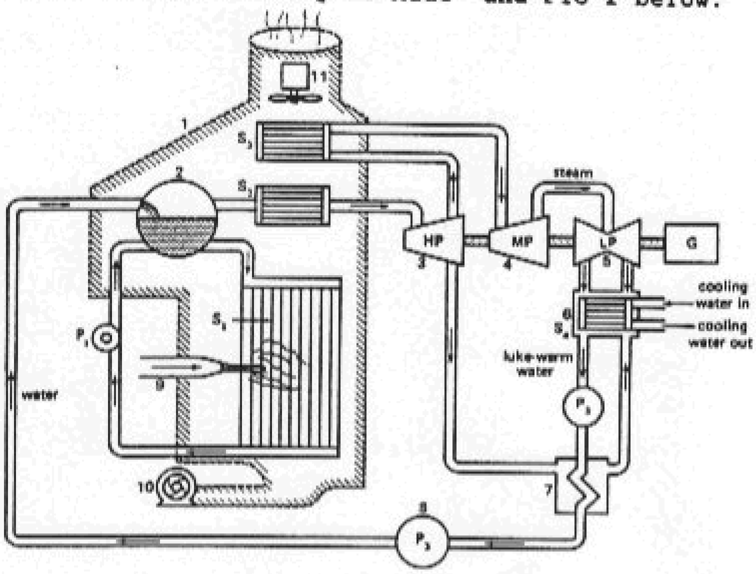


FIG 2

Main parts of plant:

Boiler(1): Converts water to steam in boiler tubes (S1) held in drum (2). Steam must be dry (no water) otherwise damage will be caused to the blades of the steam turbine, so steam is passed through superheater (S2) to remove water.
Steam is also passed back through boiler reheater (S3) to obtain extra heat, after passing through first stage of turbine.
Pulverised coal is blown into boiler (9) and burnt, the air supply being provided by forced draught (FD) fan (10).
Gases are removed from boiler to chimney by induced draught (ID) fan (11).

Turbine:

There are three stages of turbine, High Pressure (HP), Medium Pressure (MP), and Low Pressure (LP).
Steam impinges on blades of turbine, to cause rotation.
The turbine takes many hours to heat up before it can be operated, as there is only small clearance between fixed and moving blades and they must expand at the same rate otherwise damage will occur.

Electrical Alternator:

Rotating electrical machine driven by the steam turbine.
Produces a three phase set of AC voltages.
Voltages are induced into three sets of windings on the stato (stationary part of machine) by a magnetic field system on th rotor (rotating part of machine).
More details of alternators in AC Machines topic.

Condenser:

After steam has passed through the turbine, it is condensed back to water in condenser (6) reheated in reheater (7) so that it can be recycled and pumped back into the boiler with feedpump (8).
The condenser requires quantities of cooling water, and the availability of plentiful water will determine the method of cooling used.

Methods of Cooling Spent Steam

Fig 3 shows four different methods used to condense used steam before returning it to the boiler. If there are large quantities of cooling water available from lake, river or ocean, then wet cooling methods can be used, otherwise a dry cooling method must be used.

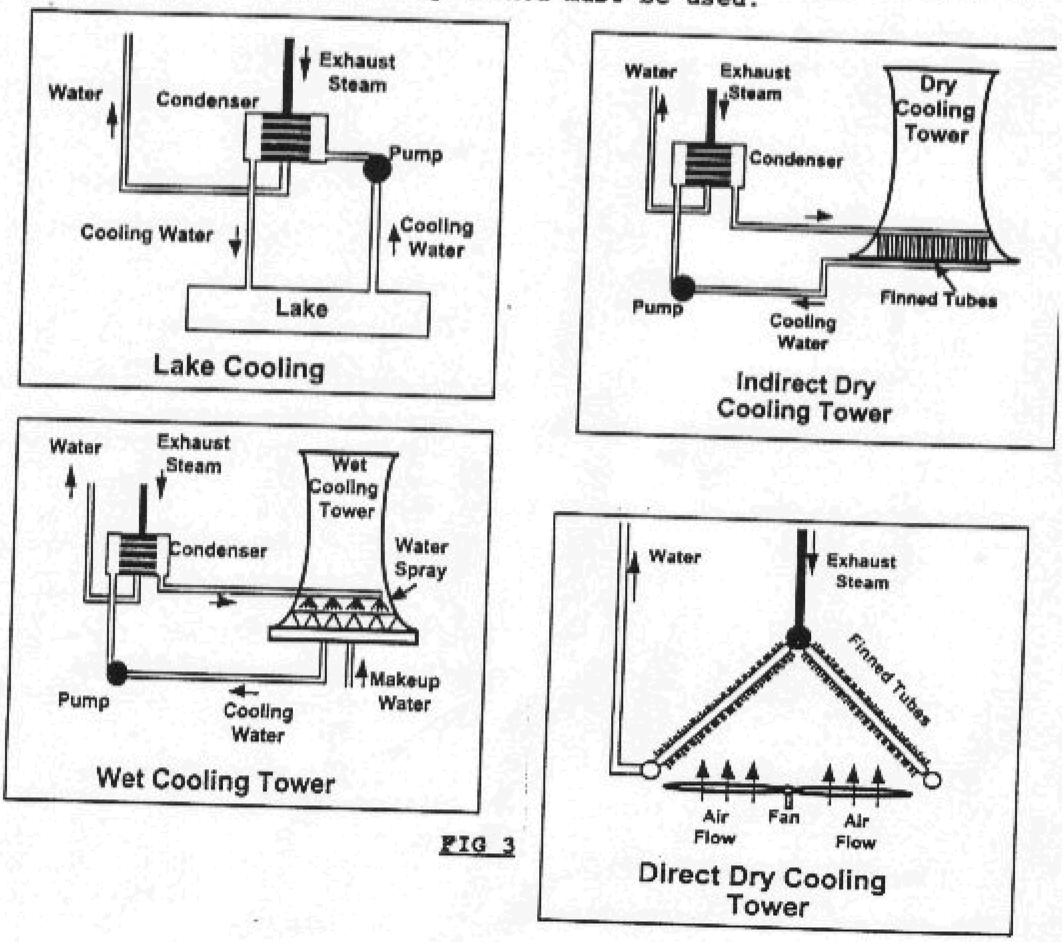


FIG 3

Environmental Effects of Coal Fired Power Stations

Environmental effects can include air pollution, disposal of coal ash and heating of waterways by the cooling water.

Coal Fired Station Efficiency

The overall efficiency of a modern coal fired steam thermal generating station is approximately 35%.
Mast heat is lost in the smoke stack and in condensing steam back to water.
FIG 4 shows the approximate proportions of power between each part of a coal fired thermal station.

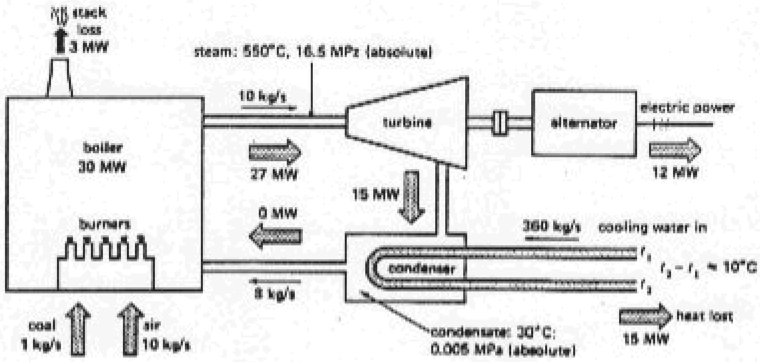


FIG 4

b) ## Nuclear Power Station

Similar to coal fired power station, except that heat is produced by a nuclear reactor. A coolant (heavy water, water or gas) circulates through the reactor and carries the heat away to a heat exchanger, where water is heated to produce steam to drive a steam turbine.

Refer to FIG 5 showing a schematic diagram of a nuclear power station.

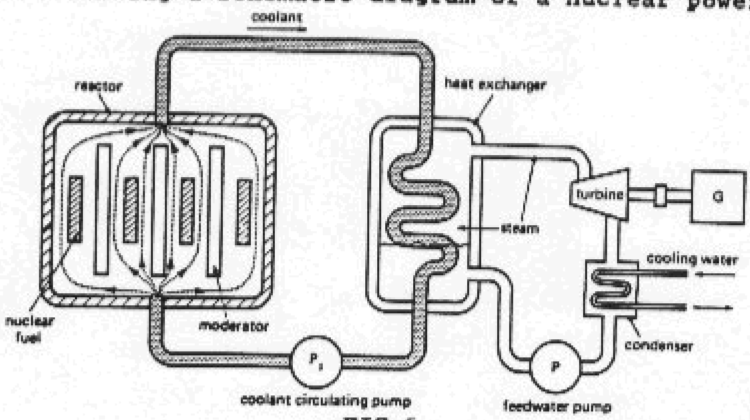


FIG 5

P12

Types of Nuclear Reactions

Nuclear Fusion:

Combining the nuclei of two light elements releases energy. This is done by making the two nuclei hit each other at high speed, and the fusing of the nuclei together will generate heat. (Hydrogen Bomb is an example)
At present the reaction cannot be controlled, so that it is unsuitable for use in nuclear reactors. Research continues.

Nuclear Fission:

Splitting the nucleus of an atom in two releases considerable amounts of energy.
Uranium 235 is suitable for fission because it contains many neutrons.
The nucleus of U_{235} is split by bombarding it with neutrons.
The splitting of the nucleus releases other neutrons which will cause a chain reaction by hitting other U_{235} nuclei and releasing much heat energy.
The reaction, (unlike an atomic bomb) is controlled within the reactor and heat is taken away by a circulating liquid to the heat exchanger.

Types of Nuclear Reactors

1.	Pressure Water Reactor	heat exchanger
2.	Boiling Water Reactor	turbine
3.	High Temperature Gas Reactor	heat exchanger
4.	Fast Breeder Reactor	also creates nuclear fuel while operating

c) Geothermal Power Station

Steam or hot water produced bu underground volcanic action is used to drive thermal generating plant.
Refer to FIG 6 which shows the principle of Geothermal energy.

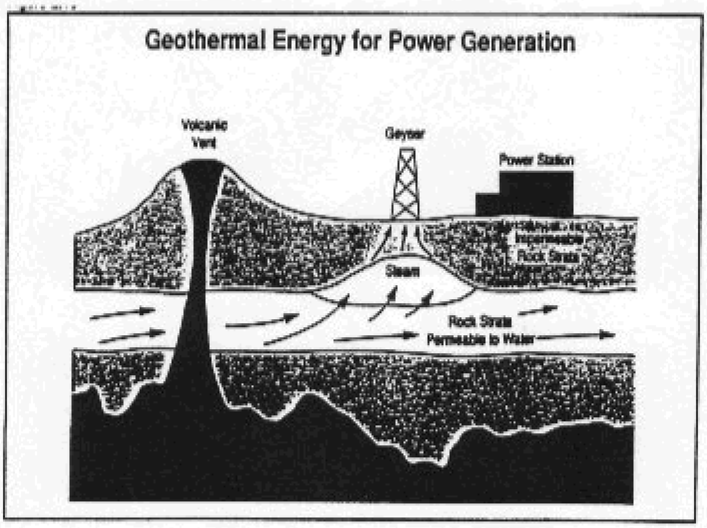
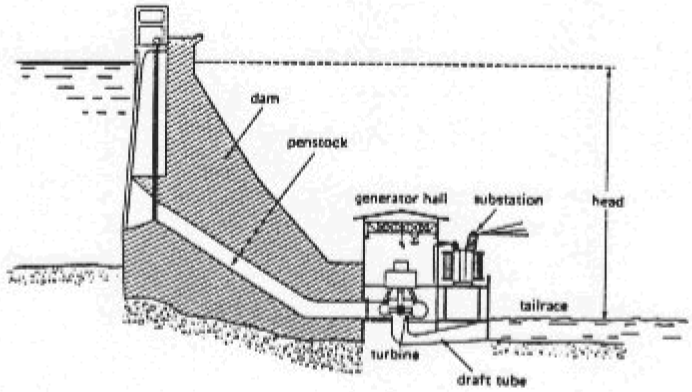


FIG 6

P13

Hydro-Electric Power Station

Refer to handout "Hydro Electric Generation" and FIG 7 below



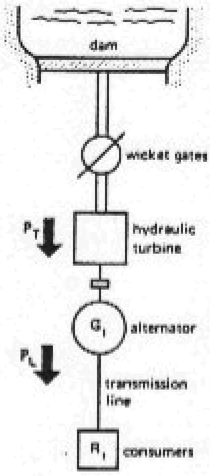


FIG 7

Hydro-electric power is produced by water stored in a dam being allowed to run through a pipe, turning a water turbine which drives an alternator

In NSW, the limited supply of water means that hydro power is not used continuously, but is used to assist thermal power stations during peak demand times or it times of emergency or breakdown.

Pumped Storage Hydro Generation

It is possible to recycle the water which passes through a hydro power station and use it again.
The water after passing through the water turbine is stored in another dam and then pumped back to the top water dam using the water turbine in reverse as a pump.
The pump uses electricity generated by thermal stations during off-peak times.
The water is then available to use again during the peak demand times the next day.
This conserves water.
FIG 8 shows how pumped storage hydro can be used to reduce the consumption of water and decrease the rating of the hydro generator.
In FIG a, a 100MW thermal base load station is supplemented by a 60MW rated hydro unit to meet the demand.
In FIG b, a 130MW thermal base load station is supplemented by a 30MW hydro station, and during low load times the thermal station excess power generation is used to pump water to the top reservoir at the pumped storage hydro station.
This results in less water being used and a lower rated hydro station b.

P14

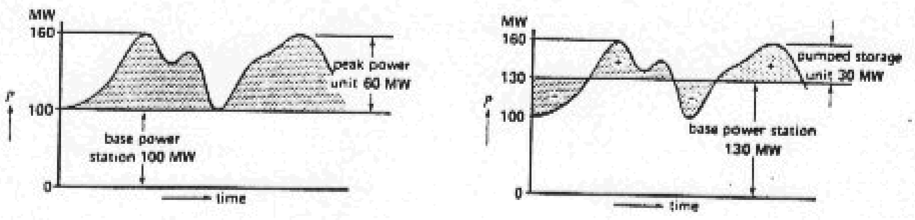


FIG 8

Gas Turbine Power Station

In NSW mainly small units used for emergency supplies in power stations in event of major equipment failure.

Internal Combustion Power Station

Small units, mainly used for and emergency.

Alternative Methods of Generating Power

There are other alternative methods of generating electricity used throughout the world, some of which are used in Australia, but not producing electricity in commercial quantities.

Magnetohydrodynamics (MHD)

Refer to FIG 9 which shows a MHD plant.

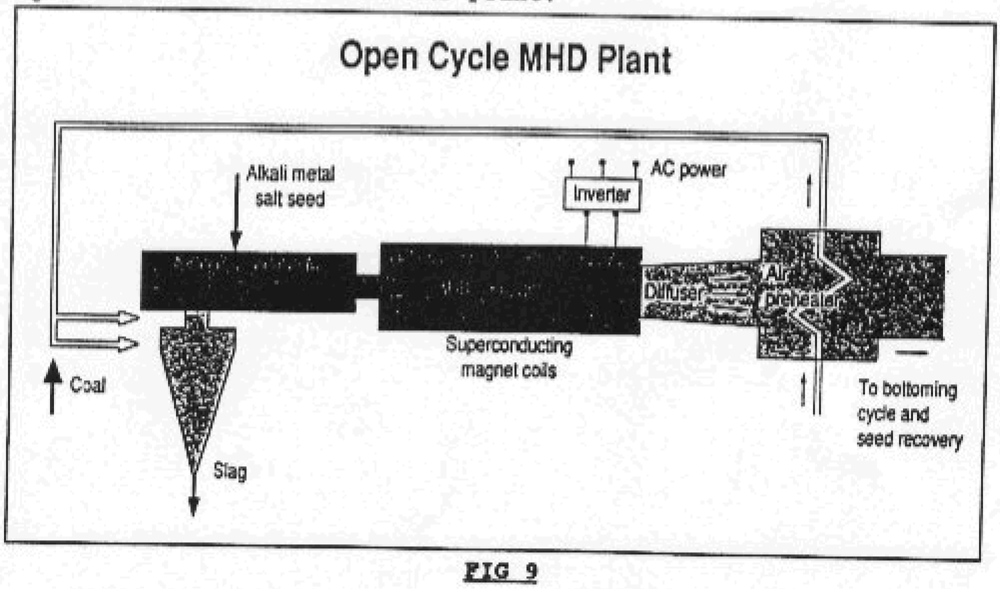


FIG 9

 P15

An DC emf is induced between the walls of a cylinder,if a hot conducting gas (plasma) expands at high velocity through the tube in the presence of a very strong magnetic field.
The hot gas can be produced from burning coal, and if the gas is "seeded" with potassium or caesium it will become conducting.
After passing through the MHD unit, the gas could be used to turn water to steam and increase efficiency.
Some MHD units are in service overseas (25 - 1000MW), but not yet in Australia.

Solar Electrical Generation (Solar Photo-voltaic)

Refer to FIG 10 below.

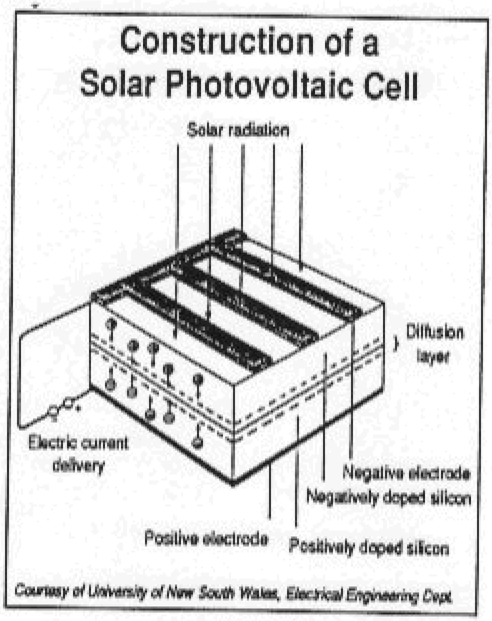


FIG 10

A P-N junction, if exposed to light, generates an emf.

Efficiency of units manufactured at present is about 14-18%.

Maximum theoretical efficiency is 30%.

Disadvantage is high cost of installation.

At present $6000/kW (large scale) compared to $1200/kW for coal fired thermal.

Requires backup at night (batteries etc).

Good for small supplies in remote areas or unmanned sites (navigation beacons, telephones).

Largest installation overseas is 1MW in the California desert (USA).

P16

Wind Electrical Generation

Wind turbines rotate at low speed and there are various designs.

The output depends on wind speed, with a wind of 8 metres/sec providi[illegible] twice the power of a wind of 6 metres/sec with the most economical generator size of 300-600 kW rating.

At present, the cost is twice that of coal fired thermal power.

Worldwide, there is about 2000MW of wind generation installed, with Denmark having 250MW out of 2600 turbines.

FIG 11 shows the various designs of wind turbines.

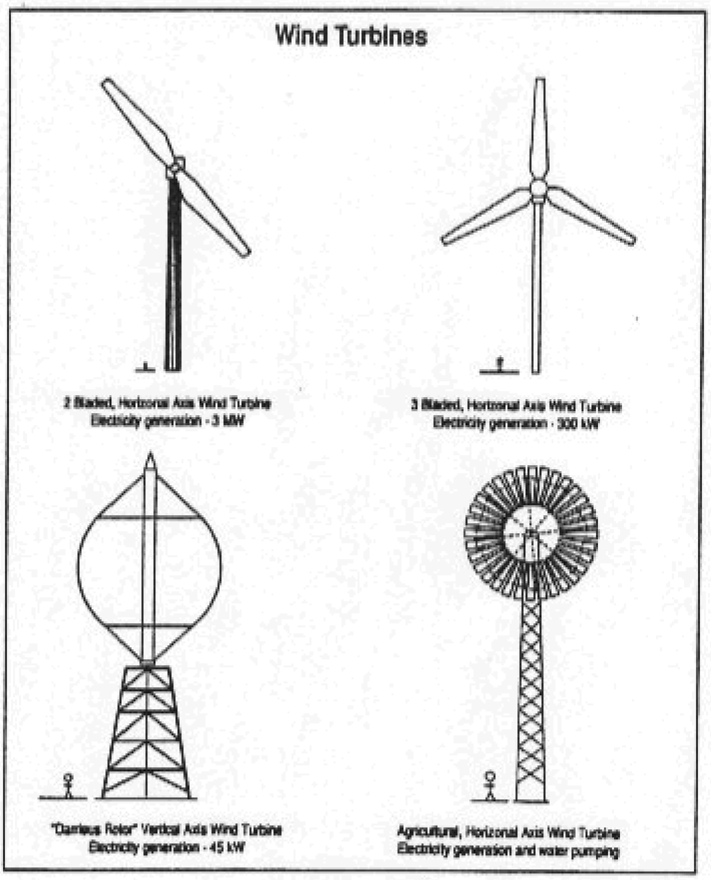


FIG 11

P17

Wave Electrical Generation

Wave energy depends on wave height and wave period.

In NSW, there is wave energy of about 12kW/metre of coastline.

The cost of $3000/kW of installation is high.

Types of Wave Generators

There are two types of wave generators.

Tapchan

Waves spill over into a reservoir and then water is allowed to run out through a water turbine.

Oscillating Wave Chamber (Wave Resonance Generation)

Refer to FIG 12.

Wave action causes air to be blown and sucked through an air turbine connected to a generator.
Blade profile ensures that turbine continues to rotate in the same direction.

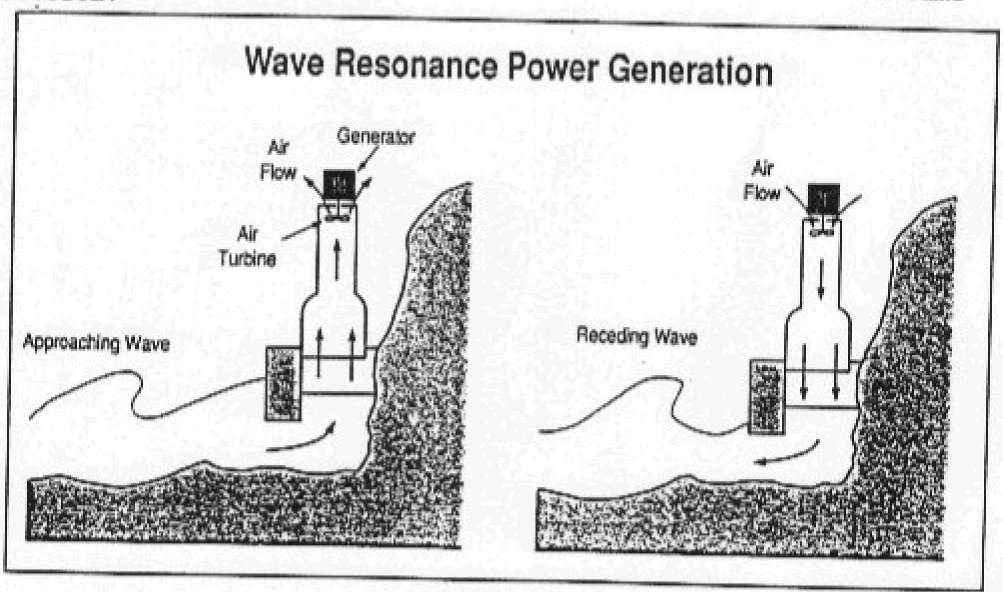
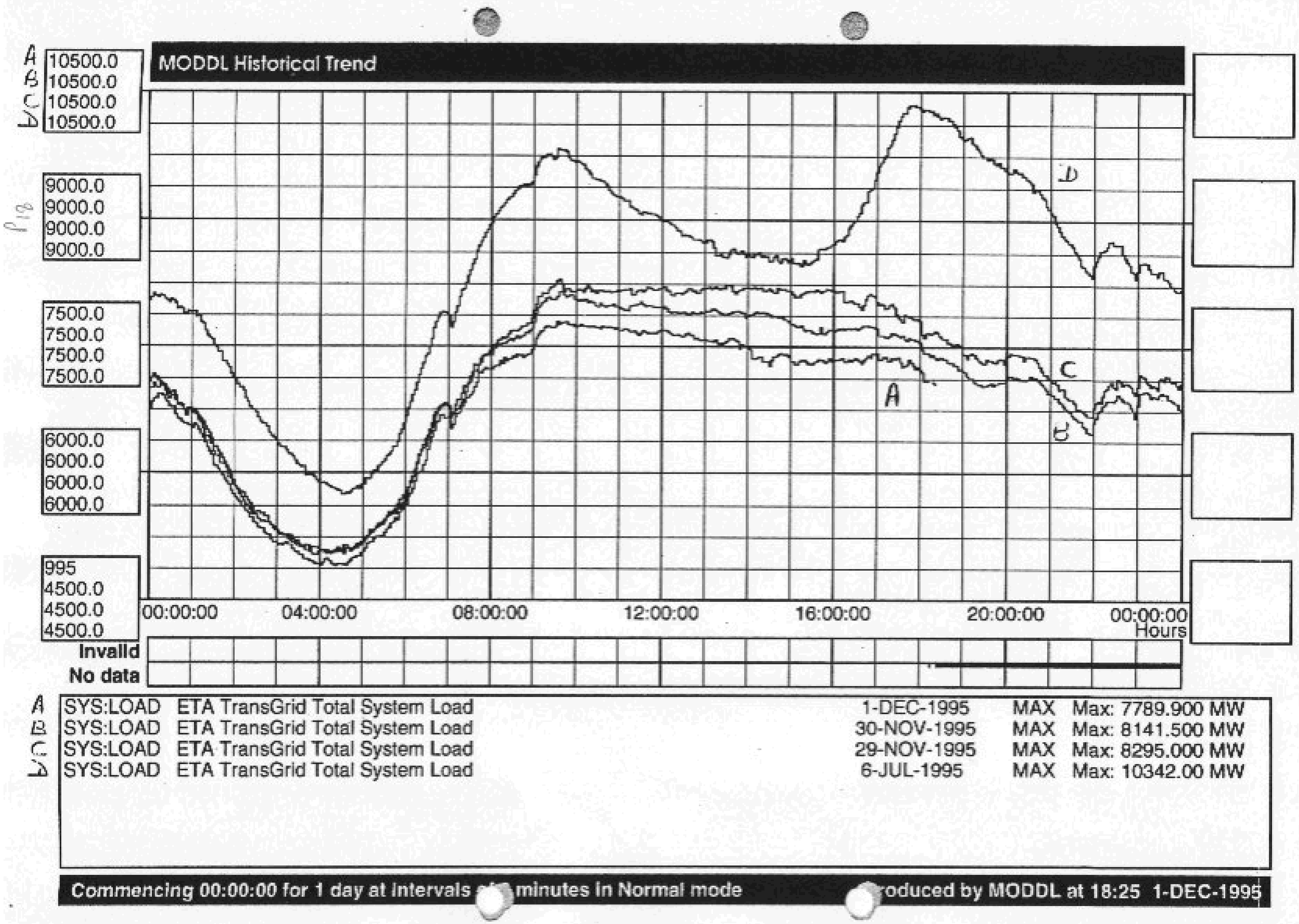


FIG 12

Tidal Electrical Generation

A reservoir is built on the shoreline, and as the tide comes in the reservoir is filled.
Gates are closed when the reservoir is filled.
When the tide goes out, water is released through a water turbine.


MODDL Historical Trend
A 10500.0
B 10500.0
C 10500.0
D 10500.0
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7500.0
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4500.0
00:00:00
04:00:00
08:00:00
12:00:00
16:00:00
20:00:00
00:00:00
Hours
Invalid
No data
D
C
A
B
A SYS:LOAD ETA TransGrid Total System Load 1-DEC-1995 MAX Max: 7789.900 MW
B SYS:LOAD ETA TransGrid Total System Load 30-NOV-1995 MAX Max: 8141.500 MW
C SYS:LOAD ETA TransGrid Total System Load 29-NOV-1995 MAX Max: 8295.000 MW
D SYS:LOAD ETA TransGrid Total System Load 6-JUL-1995 MAX Max: 10342.00 MW
Commencing 00:00:00 for 1 day at intervals of minutes in Normal mode
oduced by MODDL at 18:25 1-DEC-1995

p18

Voltage Stability

Voltage Security

- Voltage Security is the ability of a system, not only to operate stably, but also to remain stable (as far as the maintenance of system voltage is concerned) following any reasonably credible contingency or adverse system change.

(i)

Voltage Stability

- Voltage Stability is the ability of a system to maintain voltage so that when load admittance is increased, load power will increase, and so that both power and voltage are controllable.

Known factors contributing to Voltage Collapse

- Increase in loading
- Generators of SVC reaching reactive power limits
- Action of tap changing transformers
- Load recovery dynamics
- Line tripping or generator outages

Voltage Collapse

- Voltage Collapse is the process by which voltage instability leads to very low voltage profiles in a significant part of the system (voltage may collapse due to "angle instability" as well, and sometimes only a careful post-incident analysis can discover the primary cause).

Example of a system voltage collapse

Introduction

The following slides simulate a voltage collapse in a simple power system. The West generator has unlimited VAR (or reactive power) supply capability so it is able to keep the voltage at its bus constant at 1.0 per unit (or at the rated voltage). The East generator can only supply up to 1,200 MVARs (or 1,200 million VARs). There are 6,000 MWs of real power load and 1,000 MVARs of reactive power load at each bus. The West generator is transferring 3,000 MW to the East to help serve the 6,000 MW load in the East. Therefore, the outputs of the West and East generators are 9,000 MW and 3,000 MW respectively.

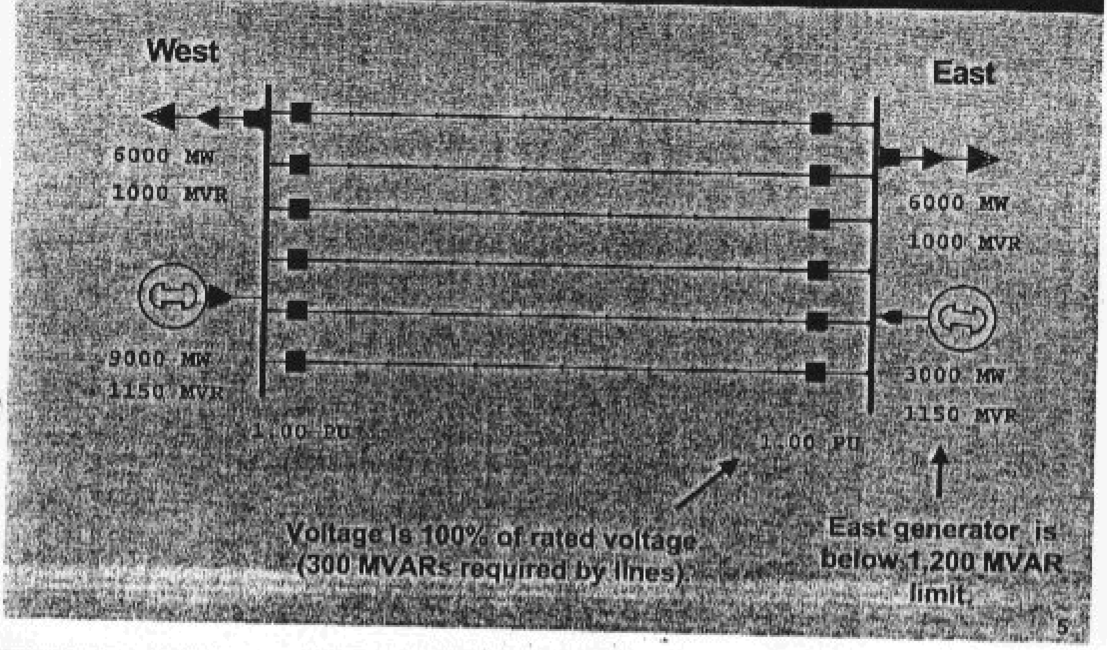
Six identical lines are initially in service and the 3,000 MWs of real power transfer are divided equally across the lines. The generators in the West and East are supplying reactive power (or VARs) to their local loads plus VARs to the transmission lines to support the transfer. The lines are assumed to be lossless (that is, they do not absorb real power). We have assumed that the individual line capacities (or thermal ratings) exceed 3,000 MW so the real power transfer could occur on one line if maintaining voltage (through sufficient VAR supply) is not a problem. Circuit breakers can open (or trip) the lines.

P20

P21

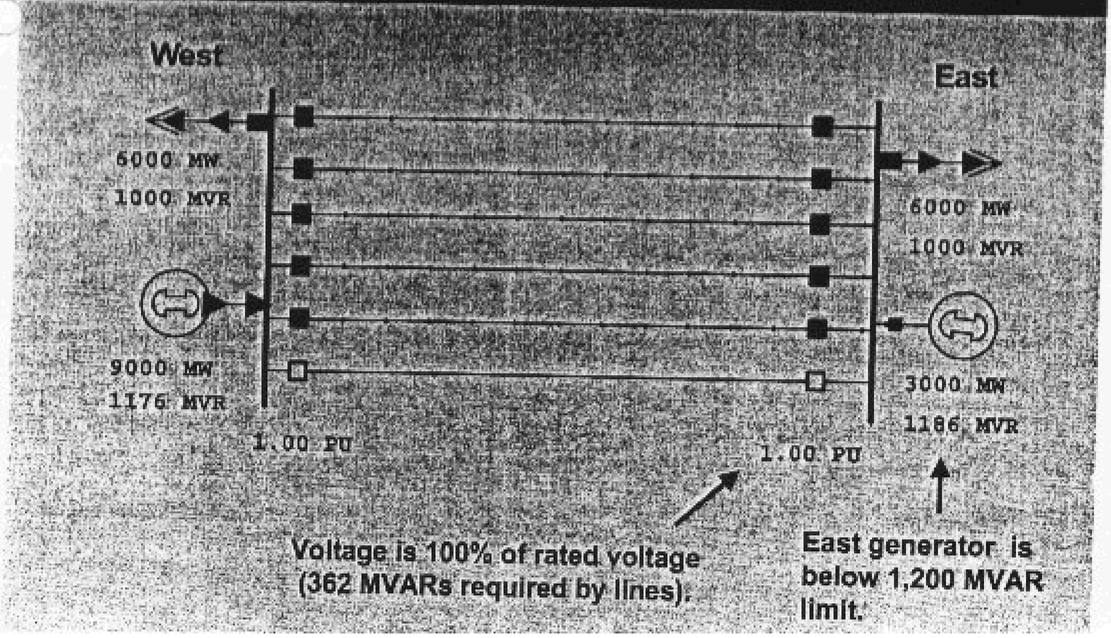
Case 1: All Lines In-Service

3,000 MW transfer – 500 MW per line



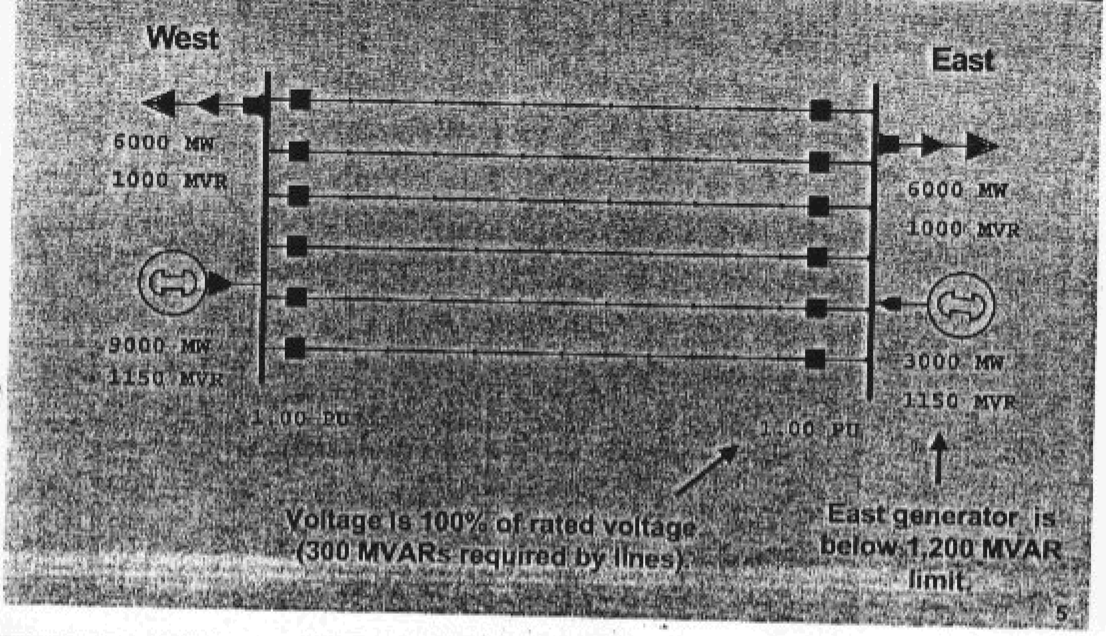
Case 2: One Line Out

3,000 MW transfer – 600 MW per line

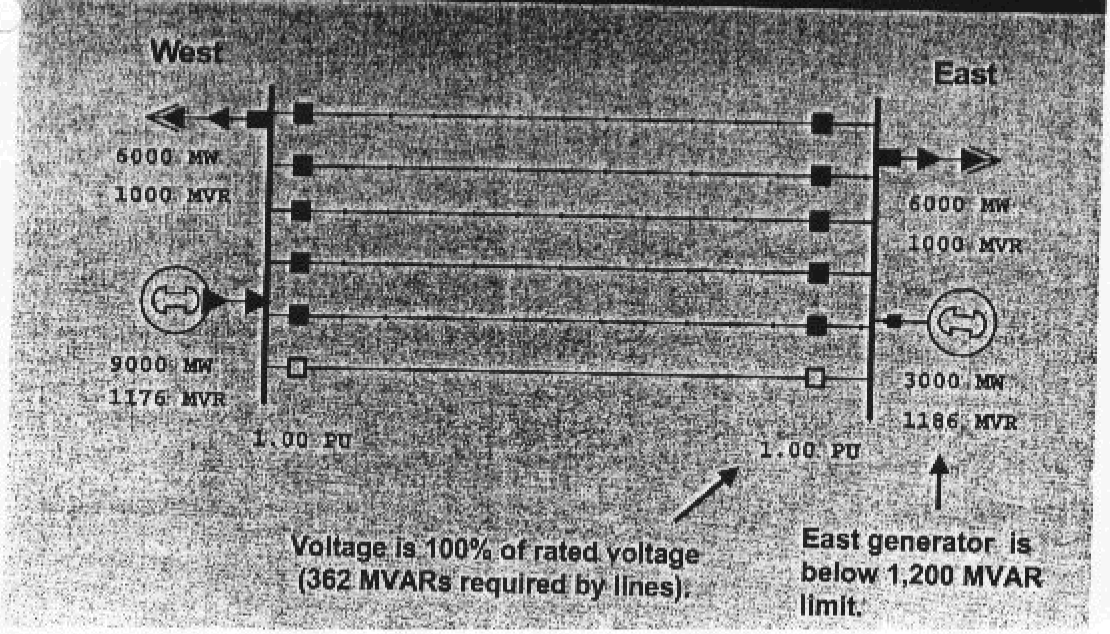


P21

Case 1: All Lines In-Service
3,000 MW transfer – 500 MW per line



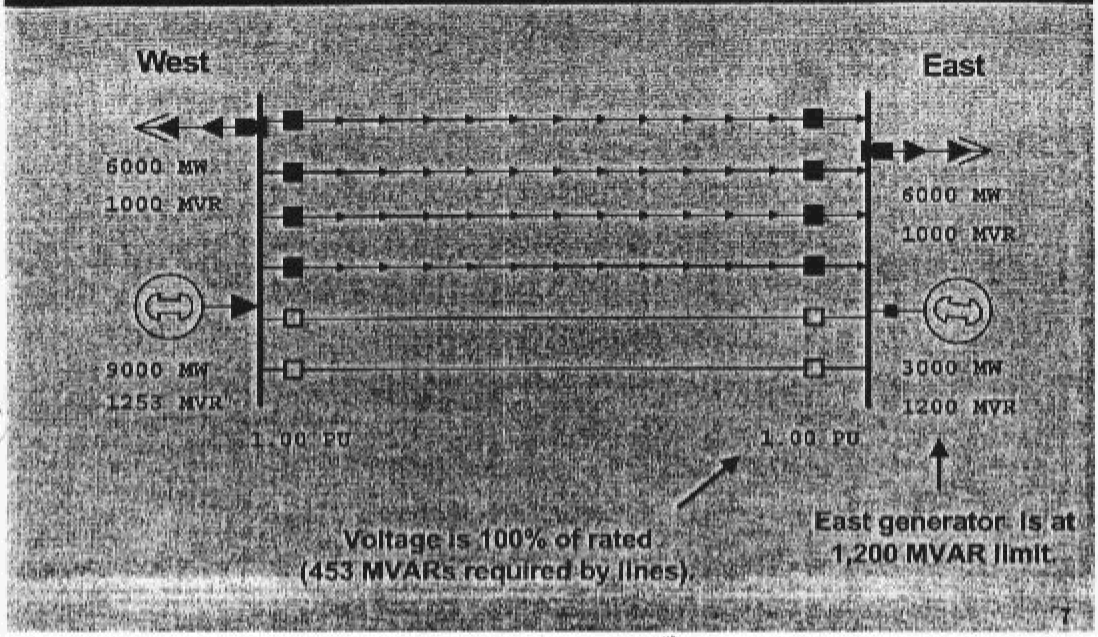
Case 2: One Line Out
3,000 MW transfer – 600 MW per line



P22

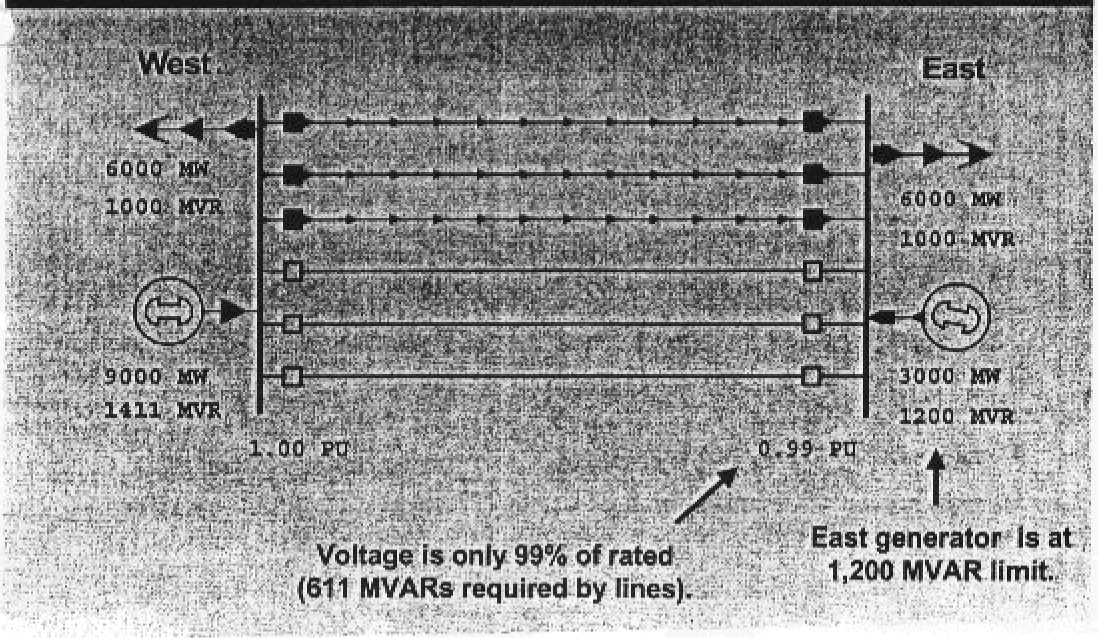
Case 3: Two Lines Out

3,000 MW transfer – 750 MW per line



Case 4: Three Lines Out

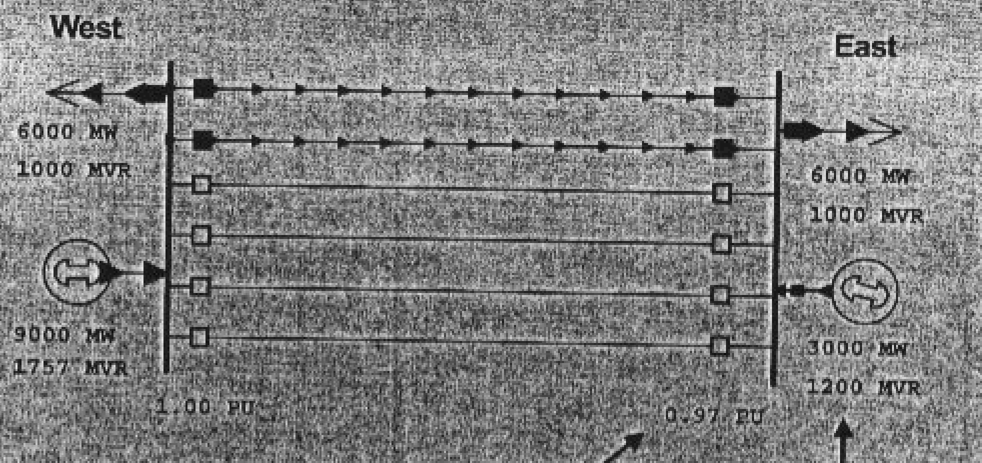
3,000 MW transfer – 1,000 MW per line



P23

Case 5: Four Lines Out

3,000 MW transfer – 1, 500 MW per line

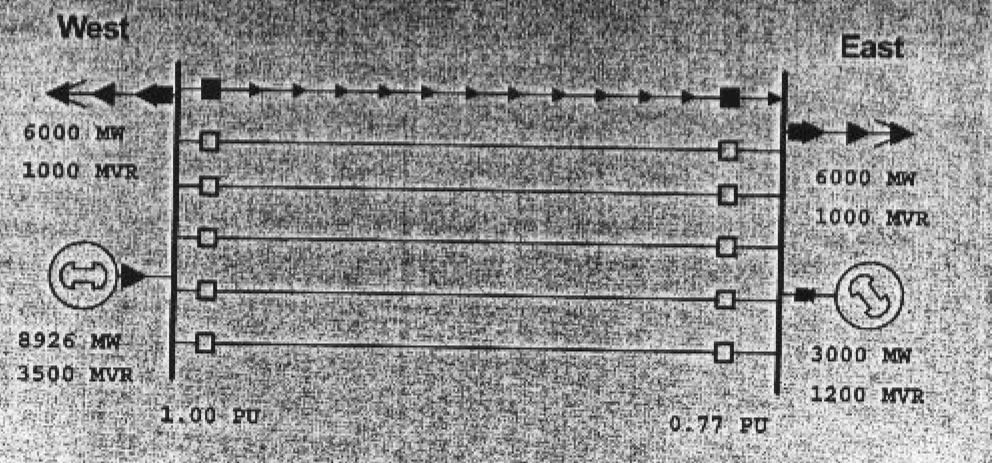


Voltage has dropped to 97% of rated voltage (957 MVARs required by lines).

East generator is at 1,200 MVAR limit.

Case 6: Five Lines Out

Voltage Collapse



This simulation could not solve the case of 3,000 MW transfer with five lines out. Numbers shown are from the model's last attempt to solve. The West generator's unlimited supply of VARs is still not sufficient to maintain the voltage at the East bus.

 P24

SYNCHRONOUS ALTERNATORS

All three phase AC machines consists of two parts:

a) The Stator - stationary or outer part of the machine
b) The Rotor - rotating or inner part of the machine.

Three Phase Alternators

The rotor and the stator are magnetic circuits, and must be made from stacked laminated magnetic steel, with slots provided to place in the electrical windings.

The laminations are required to reduce eddy current losses due the alternating flux.

Refer to FIG 1 which shows how laminations for stators and rotors are stamped.

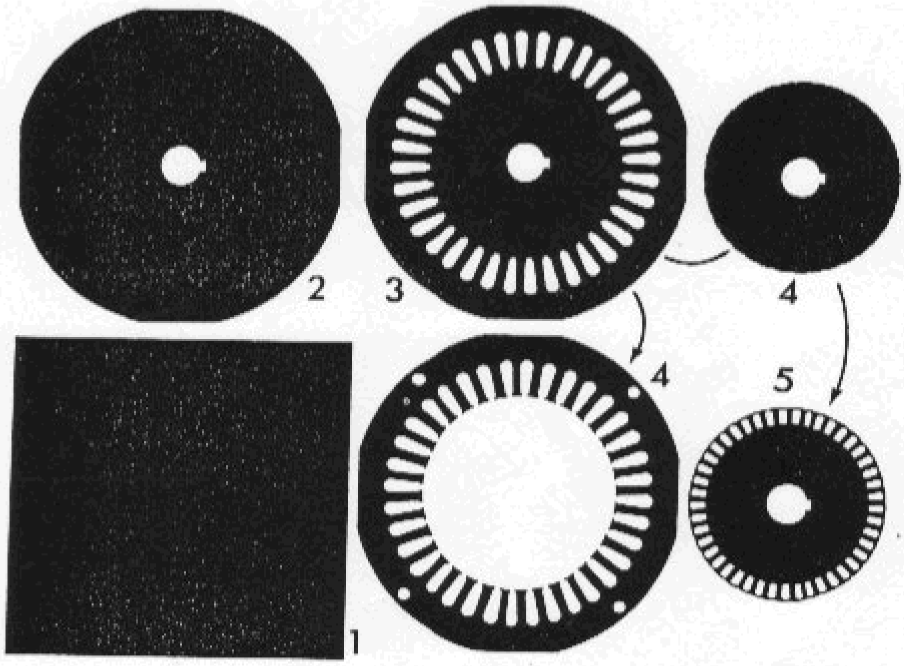


FIG 1 WI133b

The stator consists of three sets of windings distributed around the circumference and displaced from each other by 120°.

The windings are placed in the slots provided in the stator laminations.

Refer to FIG 2 which shows the position of the three sets of windings and how they fit into the stator slots.

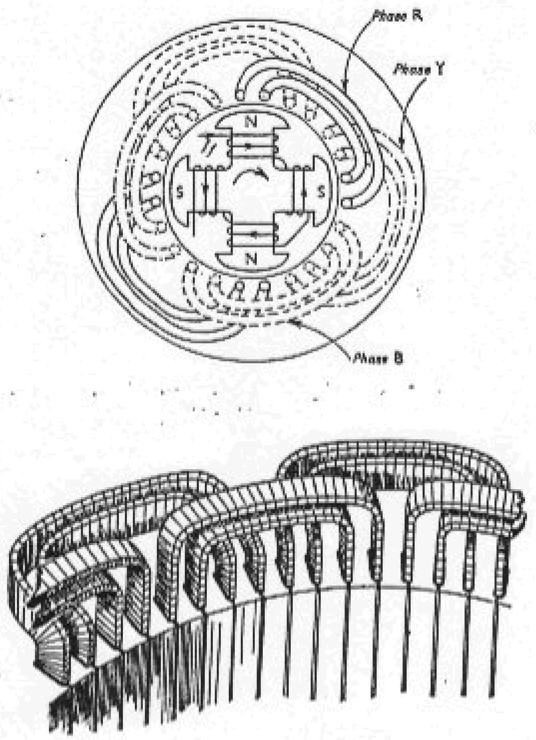


FIG 2

HU154/155

The rotor consists of DC windings which provide a set of magnetic poles.

When the rotor is driven mechanically by a motor, steam turbine or water turbine, as the magnetic poles rotate, they cut the stator windings and induce into them alternating voltages.

Separate voltages are induced into each winding and because of their 120° displacement from each other, the three voltages are 120° out of phase with each other (three separate phase voltages).

A pair of poles passing a winding will induce one cycle of emf.

The four pole rotor shown on the machine in FIG 2, will induce <u>two</u> cycles of emf into each set of coils for each revolution of the rotor.

P27

For this reason, the large DC Main Exciter requires a DC supply for its own field coils and the DC supply for the Main Exciter, is supplied by a smaller DC generator called a "Pilot Exciter".

The output voltage of the alternator is varied by changing the DC field strength of the alternator rotor poles usually by changing the output of the Pilot Exciter.

The DC supply to rotor windings of smaller alternators can be applied from an external source through sliprings and brushes.

Refer to FIG 4 which shows the connections of the large Alternator, Main Exciter and Pilot Exciter.

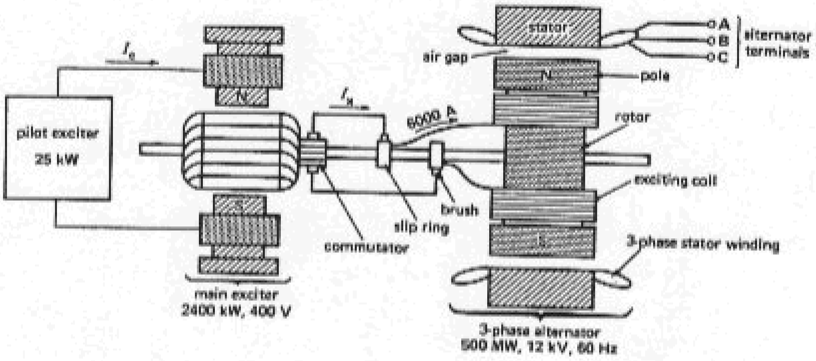


FIG 4

WI161

Alternator Stator Windings

The stator windings of a Synchronous Alternator have resistance and inductive reactance.

Usually the winding inductive reactance (called **Synchronous Reactance**) is very much (10-100 times) greater than the resistance, and a single phase equivalent circuit of the alternator stator windings is as shown in FIG 5.

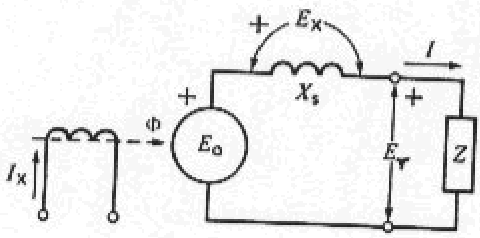


FIG 5

WI1619

P28

The excitation current I_x produces the flux in the rotor which induces the emf E_0 in the stator windings.

The stator winding resistance is neglected and only the synchronous reactance X_s is shown.

The alternator terminal voltage E_T will be determined by the generated emf E_0 and the voltage drop across the reactance X_s caused by the load current I supplied by the alternator.

Phasor Diagram of an Alternator supplying Lagging Power Factor Load

Refer to FIG 6 which shows the phasor diagram of an alternator supplying a lagging power factor load.

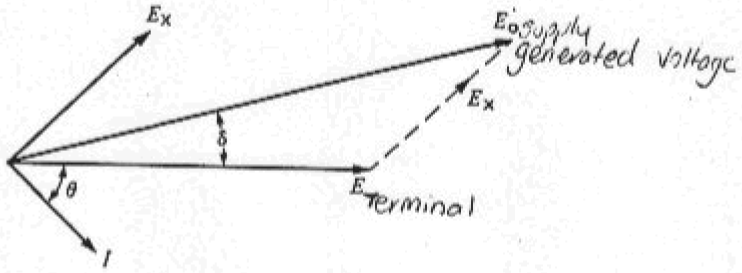


FIG 6 WI1620

The internal generated voltage E_0 is greater than the terminal voltage E_T, and requires the field windings on the rotor to be excited at a high level (over excited).

There is an angular difference between E_0 and E_T measured as angle δ which is called the "Torque or Load Angle".

Phasor Diagram of an Alternator supplying Leading Power Factor Load

Refer to FIG 7 which shows the phasor diagram of an alternator supplying a leading power factor load.

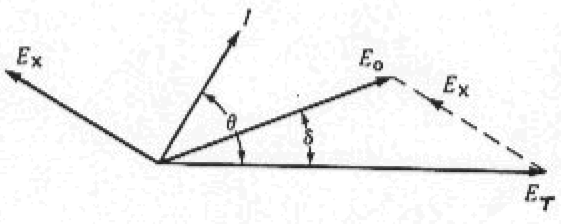


FIG 7 WI1621

P29

The internal generated voltage E_0 is <u>less</u> than the terminal voltage E_T, and requires the field windings on the rotor to be excited at a low level (<u>under excitation</u>) to generate a lower voltage.

There is partial resonance between the alternator synchronous reactance and the capacitance of the load.

$$E_{TERMINAL} = E_0 - E_X \text{ volts}$$
$$= E_0 - IxX_s$$

<u>Regulation % of an Alternator</u>

$$\text{Regulation \%} = \frac{(E_0 - E_T)}{E_T} \times 100$$

<u>Example</u>: Calculate the % regulation of an alternator which has terminal voltage of 12kV at full load and a no load voltage of 15kV.

<u>Solution</u>:

$$\text{Regulation \%} = \frac{(E_0 - E_T)}{E_T} \times 100$$

$$= \frac{(15 - 12)}{12} \times 100$$

$$= 25\%$$

<u>Note</u>: This value is quite high, due to the high value of X_s.

<u>Synchronising Alternators</u>

Before any two AC voltages sources (alternators) can be connected in parallel, the voltages must:

a) be the same magnitude,

b) be in phase with each other,

c) have the same frequency,

d) have the same phase rotation.

In other words, the two voltages must be identical in every way.

Th action of making the outputs of two alternators <u>identical</u> before connecting them in parallel is called "<u>Synchronising</u>" the machines.

P30

Connecting an Alternator to an Infinite Busbar

An "Infinite Busbar" is a power system so powerful, that it imposes its own voltage and frequency upon any alternator connected to its terminals.

Once a power system has a number of large alternators connected to it, the voltage and frequency cannot be altered by any additional machine connected to it.

An interconnected power system has a large number of alternators connected in parallel, synchronised with each other, and sharing the total load.

Additional alternators are connected to and disconnected from the power system as the total load varies.

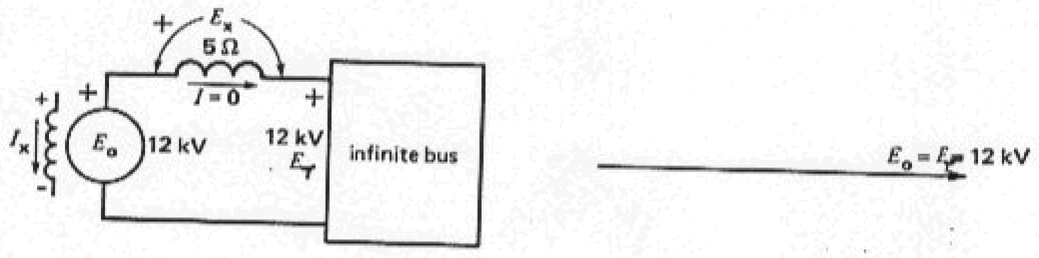
When an alternator is connected to an infinite busbar, there are only two machine parameters that be altered:

a) the rotor exciting current I_x

b) the mechanical torque of the turbine.

Effect of Varying Excitation of an Alternator on an Infinite Busbar

Refer to FIG 8 which shows the connections of, and phasor diagram for an alternator connected to an infinite busbar, with machine excitation adjusted so that there is no current flow from the terminals.



WI1626a

FIG 8

The alternator is "floating" on the infinite busbar and E_0 and E_T are equal and in phase.

No real power in WATTS and no reactive power in VARS flows into or out of the alternator.

Refer to FIG 9 which shows the connections of, and phasor diagram for an alternator connected to an infinite busbar, with machine excitation adjusted so that generated voltage E_0 is greater than terminal voltage E_T ("over excited").

P31

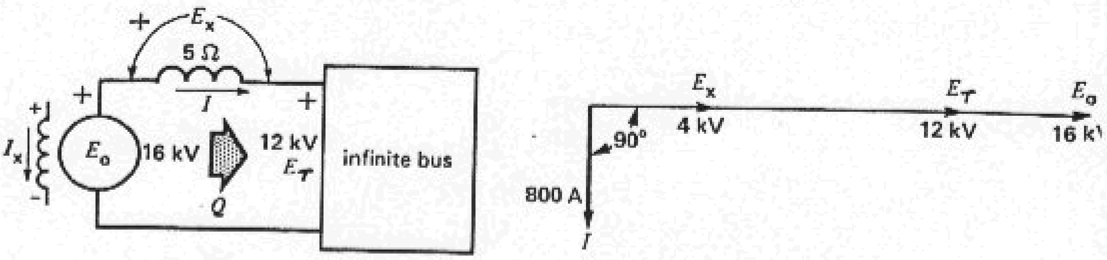


FIG 9 WI1626b

Reactive power (VARS) are supplied to the system which appears to be inductive.

E_o and E_T are in phase.

No real power in watts is supplied.

Refer to FIG 10 which shows the connections of, and phasor diagram for an alternator connected to an infinite busbar, with machine excitation adjusted so that generated voltage E_o is <u>less</u> than terminal voltage E_T ("<u>under excited</u>").

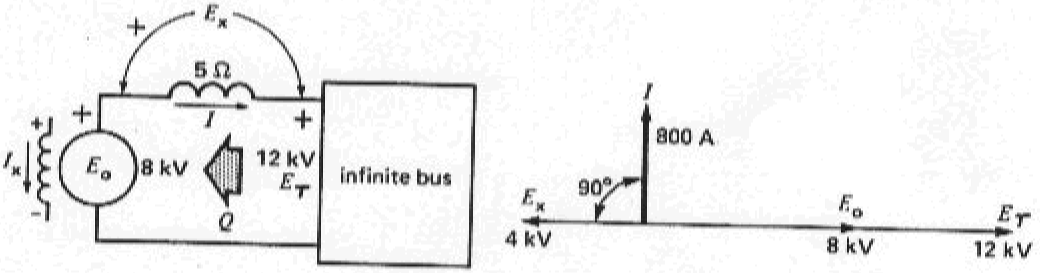


FIG 10 WI1626c

Reactive power (VARS) will flow from the system which appears to be capacitive.

E_o and E_T are in phase.

No real power in watts is supplied.

<u>Note</u>: Variation in excitation will only change the VAR flow from the machine, and will not change the real power in watts supplied by the machine.

Real Power Flow from an Alternator on an Infinite Busbar

Assume that the excitation of an alternator is adjusted so that the machine is "floating" on the system, and then mechanical torque of the turbine is increased by opening the steam valve on turbine.

The increased mechanical torque will accelerate the rotor so that the flux lines between the rotor and stator will be stretched from their normal "floating" position as shown in FIG 11.

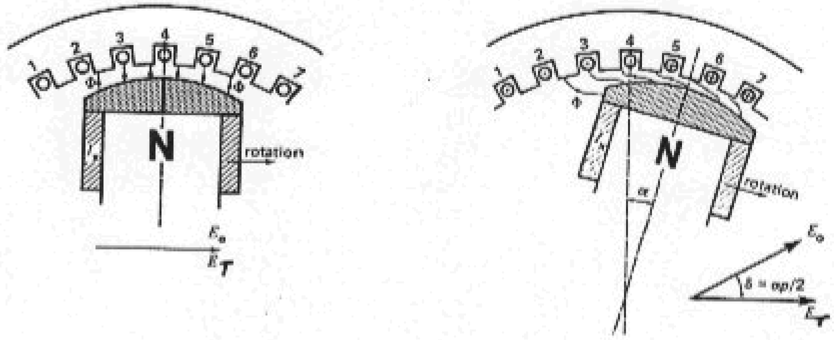


FIG 11

WI1628

The axis of the rotor poles is advanced by mechanical angle α, and also the generated voltage E_0 will become leading the terminal voltage E_T by the load or torque angle δ.

The relationship between α and δ is given by

$$\delta \quad = \quad \alpha \times p/2$$

where p = number of magnetic poles on the machine.

Note: On a two pole machine, $\delta = \alpha$.

Refer to FIG 12 which shows the connection diagram and phasor diagram for a machine connected to an infinite busbar and increased mechanical power input.

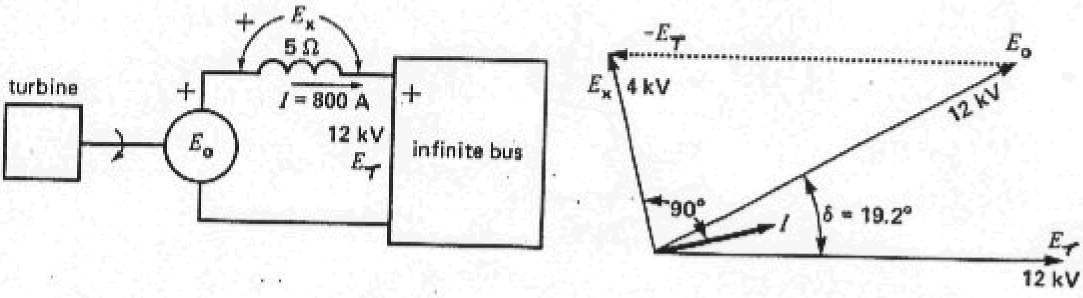


FIG 12

WI1627

P33

Notes: The leading angle δ of E_0 with reference to E_T will cause real power in watts to be delivered from the machine to the system.
If this machine had not been connected to an infinite busbar, then the machine speed would increase, thus increasing the supply frequency.

Calculation of Real Power Flow between Sources

Assume that an alternator is connected to a system as shown in FIG 13. (Single phase equivalent circuit)

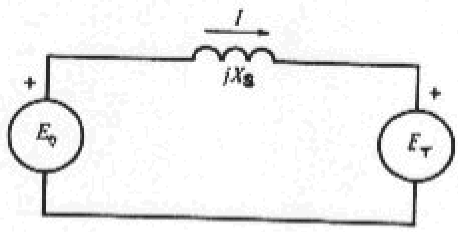


FIG 13 WI1633

Assuming that system E_T is consuming real power in watts, and the load has a lagging power factor angle θ.

The resulting single phase phasor diagram is as shown in FIG 14.

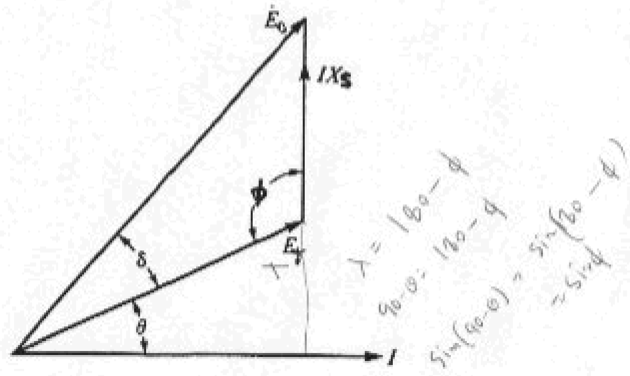


FIG 14 WI1633

From the phasor diagram:

$$E_0 = E_T + jIX_s \text{ volts} \quad V_T + jIX_S$$

Real Power consumed by the system is:

$$P = E_T \times I \times \cos\theta \quad \text{watts}$$

$$V_T I \cos\theta$$

 P34

Applying the sine rule to the triangle ABC:

$$\frac{IX_s}{\sin\delta} = \frac{E_0}{\sin\phi}$$

$$\text{where } \phi = (90 - \theta)$$

$$\frac{IX_s}{\sin\delta} = \frac{E_0}{\sin(90 - \theta)}$$

$$\frac{IX_s}{\sin\delta} = \frac{E_0}{\cos\theta}$$

Rearranging

$$I\cos\theta = \frac{E_0 \times \sin\delta}{X_s}$$

$$\text{Power out} = E_T I\cos\theta \text{ watts per phase}$$

$$\boxed{\text{Power} = \frac{E_0 E_T \sin\delta}{X_s} \text{ watts per phase}}$$

where:

E_0 = generated voltage
E_T = terminal voltage
X_s = alternator synchronous reactance in ohms
δ = phase angle between E_0 and E_T in degrees.

Example: An alternator has the following single phase equivalent values.

E_0 = 12kV
E_T = 14kV
X_s = 2Ω
E_0 leads E_T by 30°.

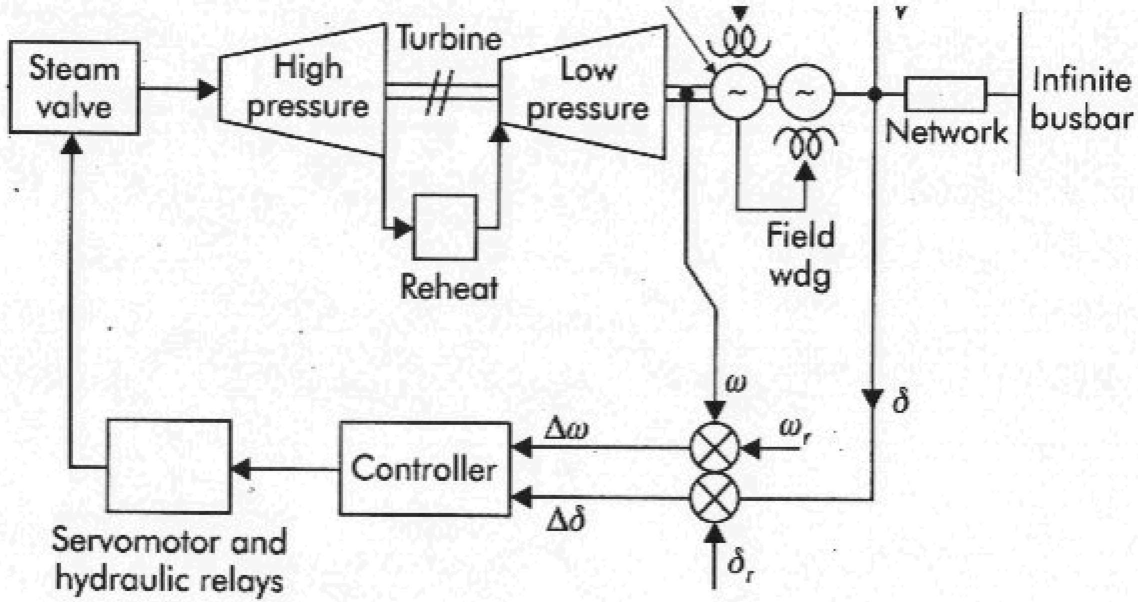
a) Calculate the total real power output of the alternator,
b) Draw a single phase phasor diagram.

Solution:

$$\text{Power} = \frac{E_0 E_T \sin\delta}{X_s}$$

$$= \frac{12\times10^3 \times 14\times10^3 \times \sin 30^\circ}{2}$$

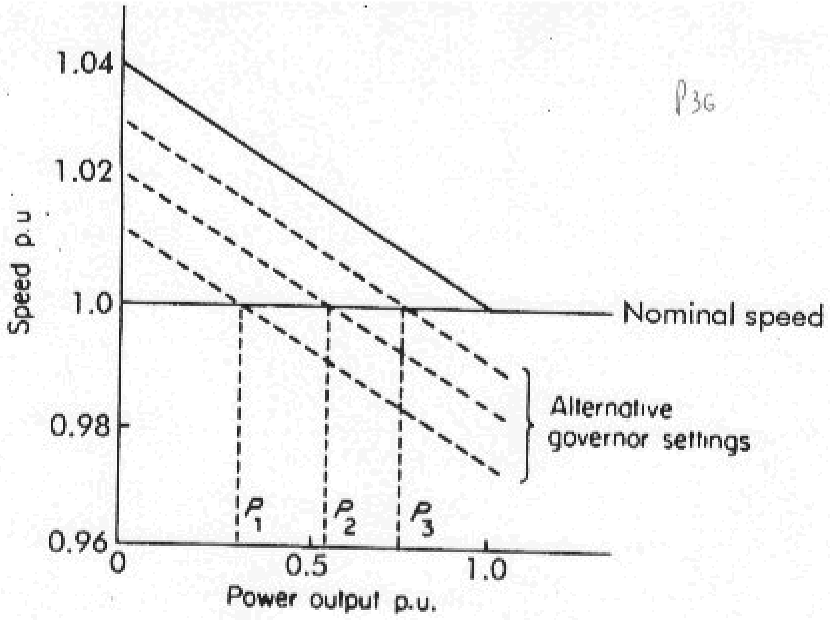
$$= 42\text{MW per phase}$$



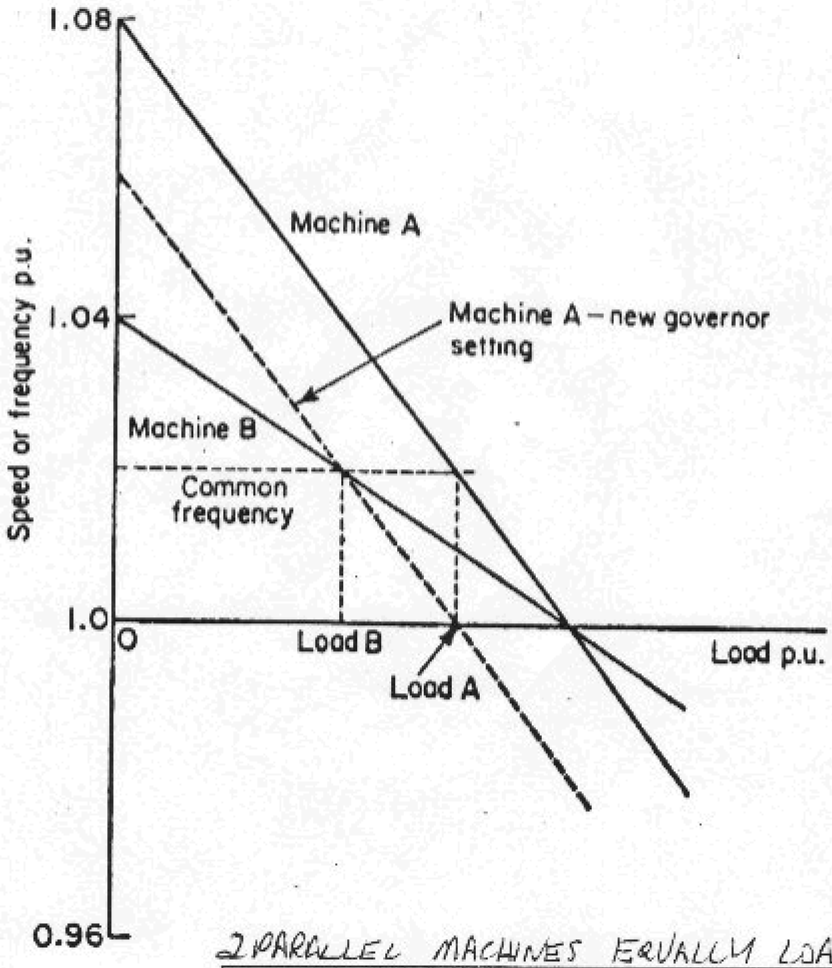
Block diagram of complete turboalternator control systems.

P35

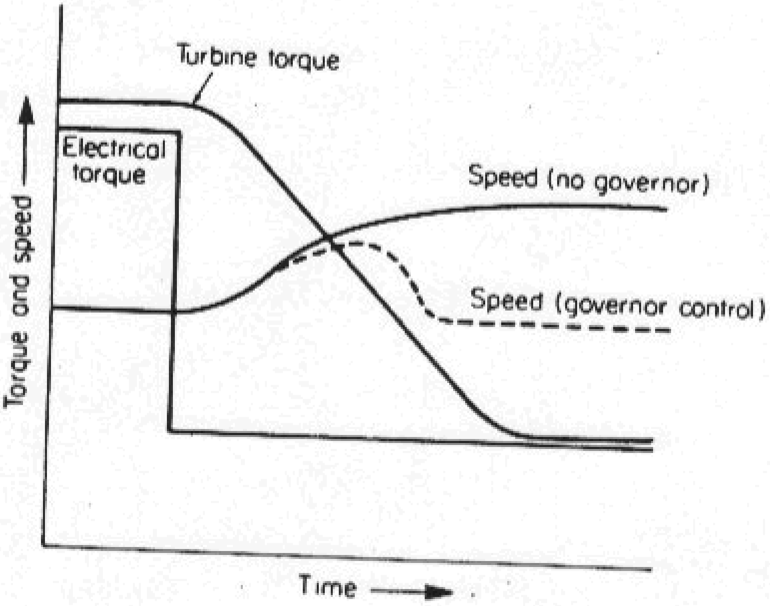
P36



GENERATOR OUTPUT AT VARIOUS GOVERNOR SETTINGS

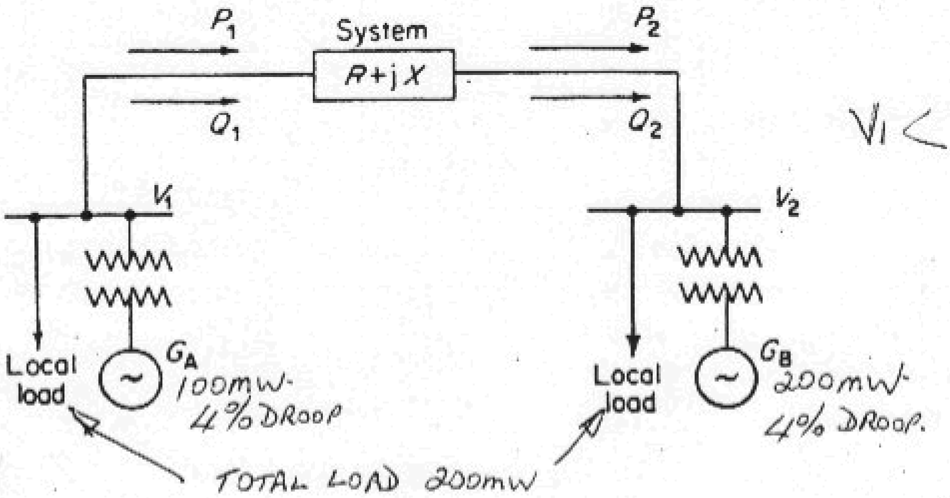


2 PARALLEL MACHINES EQUALLY LOADED



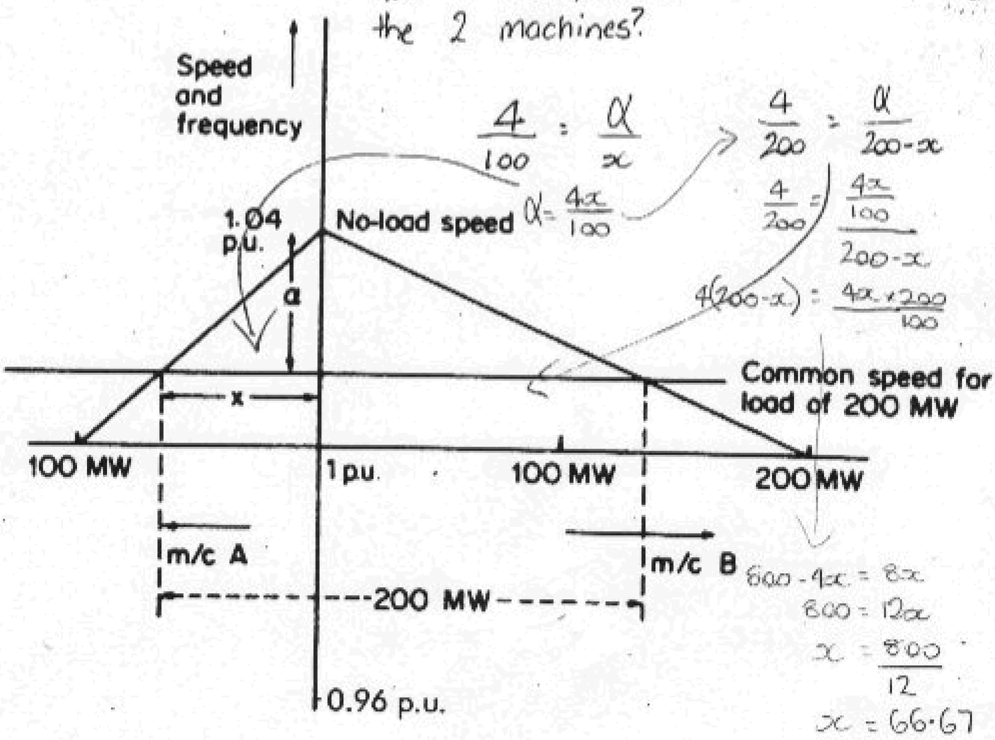
GENERATOR LOAD SUDDENLY REDUCED

2 GENERATING STATIONS LINKED BY INTERCONNECTOR



$V_1 < V_2$

How is the 200mw load shared by the 2 machines?



$$\frac{4}{100} : \frac{\alpha}{x} \qquad \alpha = \frac{4x}{100}$$

$$\frac{4}{200} = \frac{\alpha}{200-x}$$

$$\frac{4}{200} = \frac{\frac{4x}{100}}{200-x}$$

$$4(200-x) = \frac{4x \times 200}{100}$$

$$800 - 4x = 8x$$

$$800 = 12x$$

$$x = \frac{800}{12}$$

$$x = 66.67$$

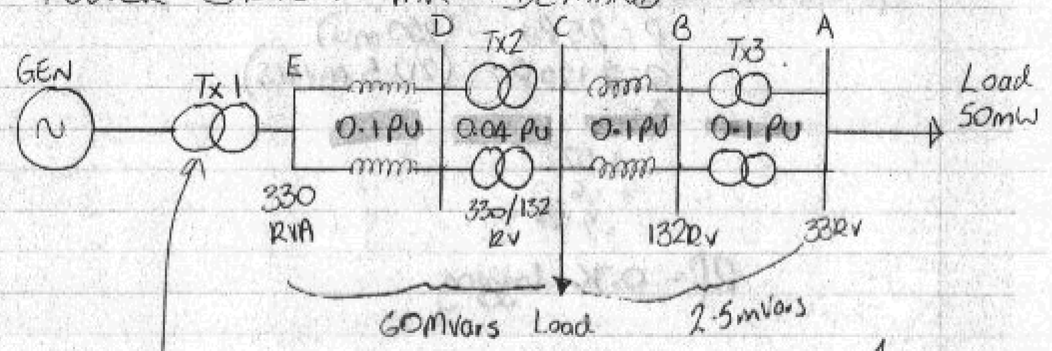
Speed–load diagram for Example

100mW AC machine supplies = 66.66mW

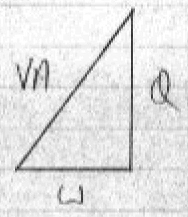
200mW AC machine supplies = 200 − 66.6

= 133.3mW

POWER SYSTEM VAR DEMAND



BASE = 100MVA



Q. What total MW and MVAR must the generator supply and at what power factor.

① At busbar A

$P = 50mW = 0.5PU$

Vars $Q = 0$

Vars lost in 132kV

$= I^2 X_T$

$= \frac{(VA)^2}{V^2} \times X_T$

$= \frac{Q^2 + P^2}{V^2} \times X_T$

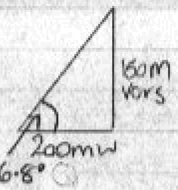
$= \frac{0^2 + 0.5^2}{1^2 PU} \times 0.2//0.2$

$= 0.025$ PU VARS

$= 2.5$ MVAR's inductive

② At busbar C

200mW @ 0.8 pf lag



$\tan\theta = \frac{VARS}{Watts}$

Vars $=$ Watts $\times \tan\theta$

$= 200 \times \tan 36.6$

$= 150$ mvars

③ $P_{TOTAL} = 2 + 0.5$

$= 2.5 PU = 250 mW$

$Q_{TOTAL} = 1.5 + 0.025$

$= 1.525 PU = 152.5 MVARs$

∴ VARs required for 330kV lines + Tx's

$\frac{P^2 \times Q^2}{V^2} \times X_{Total}$

$= \frac{2.5^2 \times 1.525^2}{1^2} \times 0.14//0.14$

$= 0.6 PU$ (60mVars) P.T.O

GENERATOR LOAD =

$P = 2.5\ pu$ (250 mw)

$Q = 2.125\ pu$ (212.5 mvars)

1.525
+ .6
= 2.125

P.f = 0.76 lagging

$$Vars = \frac{0^2 + 0.5^2}{V^2} \times 0.2$$

Bus A

$= 0.05$ PU Vars

$P_{TOTAL} = 0.5 + 2.0 = 2.5pu$

$Q_{TOTAL} = 0.05 + 1.5 = 1.55\,pu$

Bus C

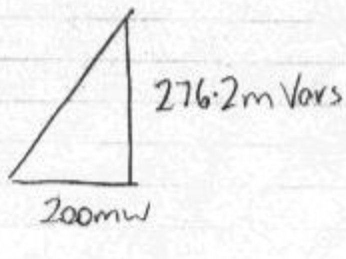
VARS in 330kV system

$$\frac{P^2 + Q^2}{V^2} \times X_{TOTAL}$$

$$= \frac{2.5^2 + 1.55^2}{1^2} \times 0.14$$

$= 1.21$ mVars

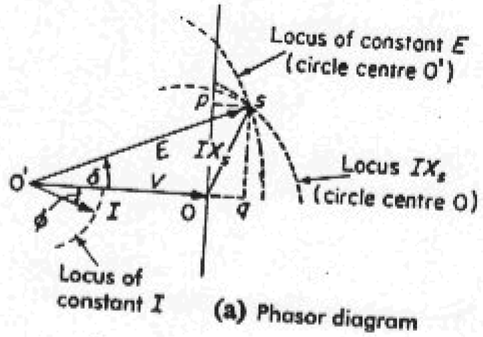
Total Vars $= 5 + 121.2 + 150$
$= 276.2$ mVars



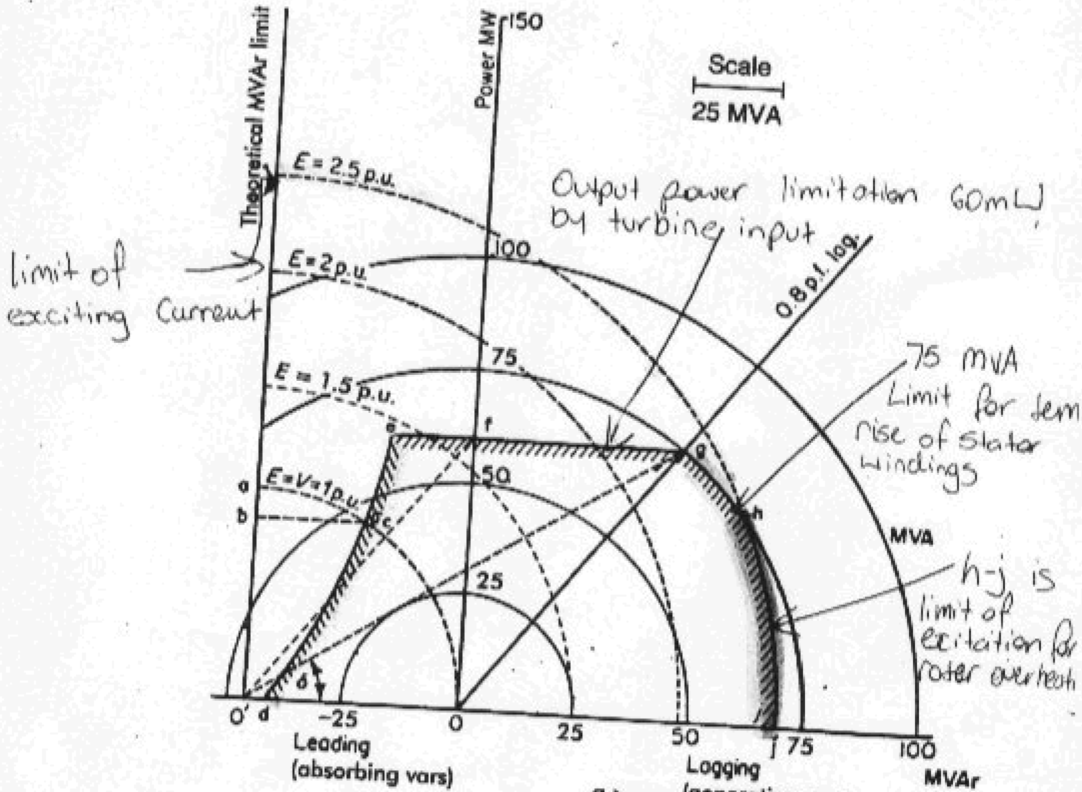
$$p.f = Q = \frac{276.2}{200}$$

$= \tan^{-1} 1.381$

$= 54.1°$



(a) Phasor diagram



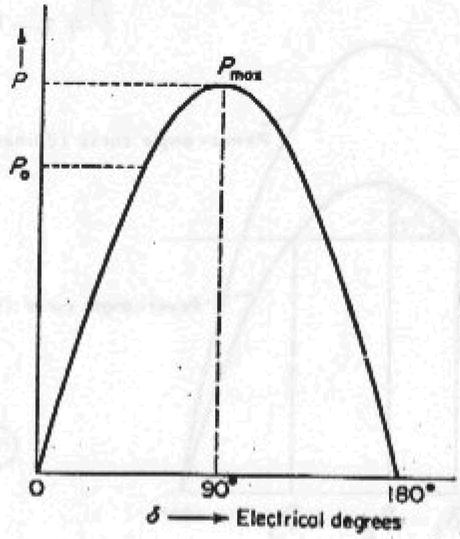
(b)

Performance chart of a synchronous generator

MACHINE DATA:

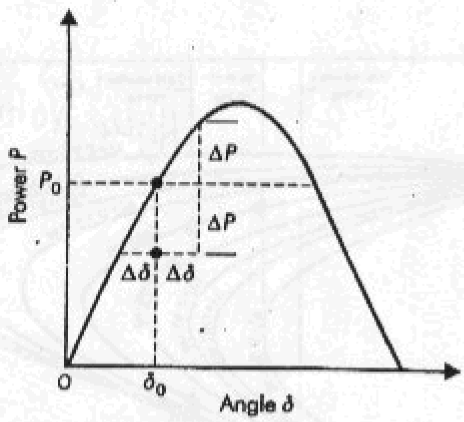
60 MW 0.8 pf 75 MVA

MAIN EXCITER CURRENT 500A



Q10.

Figure 1 Power-angle curve of a synchronous machine. Resistance and saliency are neglected



Q10

Figure 2 Small disturbance—initial operation on power-angle curve at P_0, δ_0. Linear movement assumed about P_0, δ_0

$$\frac{\Delta P}{\Delta \delta}$$

P42-b

Q10

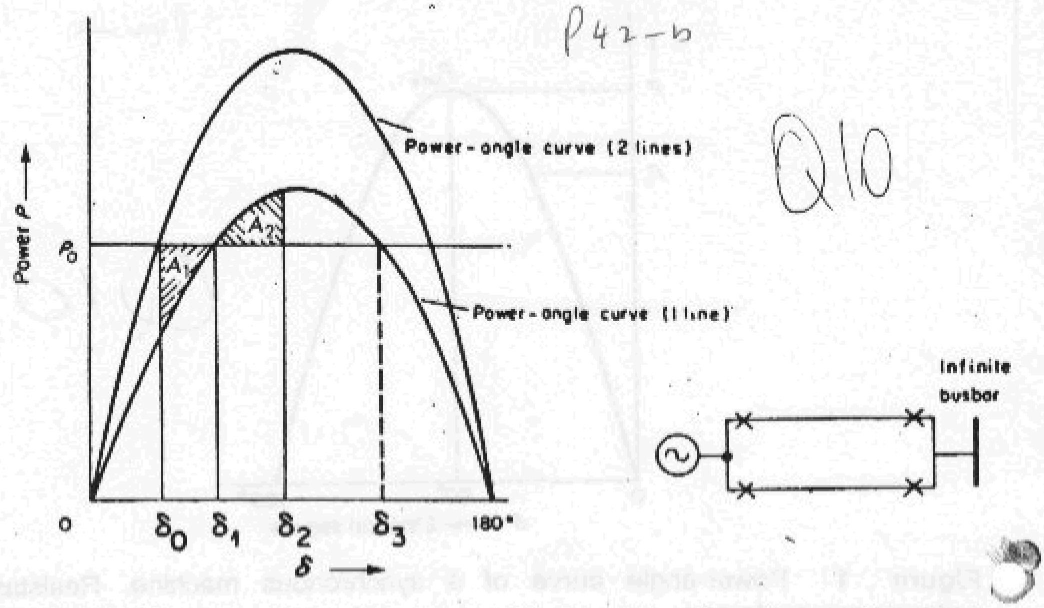


Figure 3. Power-angle curves for one line and two lines in parallel. Equal-area criterion. Resistance neglected

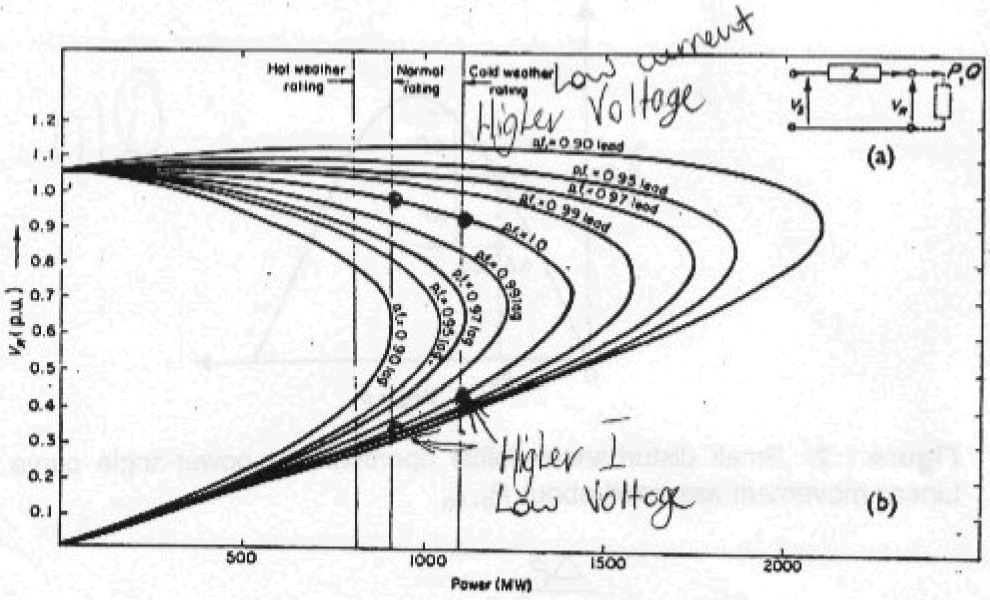


Figure 4 (a) Equivalent circuit of a line supplying a load $P + jQ$. (b) Relation between load voltages and received power at constant power factor for a 400 kV, $2 \times 260\,mm^2$ conductor line, 160 km in length. Thermal ratings of the line are indicated

Voltage Control Methods

① Alternator excitation, Generator excitation

② VAR Balance

VAR injection - static cap, cap banks ⟩ course control
- inductors
- static VAR compensation fine control
- synchronous condensers

③ Power transformer tap changers

Generator excitation

Transformer Tap Changers ⟩ steps up + down output voltage course control

Capacitor Banks

Shunt reactor, for too much capacitance. fine control

Static Var compensation.

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TRANSMISSION LINE CONSTRUCTION

Transmission involves moving large quantities of electrical energy over long distances between generating stations and load centres. The transmission system consists of 500kV and 330kV overhead transmission lines of steel tower construction.
The sub-transmission system consists of 132kV and 66kV overhead lines on steel towers and wood poles and also underground cables.

Route Selection for Transmission Lines

The easement space required for overhead transmission lines means that the route taken by a line is an environmentally sensitive issue.

Ideally, the transmission line should take the shortest route to reduce its capital and installation cost.

However, the selection of the route of a transmission line, will depend on a number of important considerations:

a) shape of the terrain, affecting cost of construction,
b) acquisition of easement land,
c) proximity to housing,
d) ease of maintenance and access to easement.

Components of Transmission Lines

Conductor Support Structures

Support structures are required to keep the conductors at a safe height above the ground and also to keep them apart.

Refer to FIG 1 which shows various arrangements of support structures.

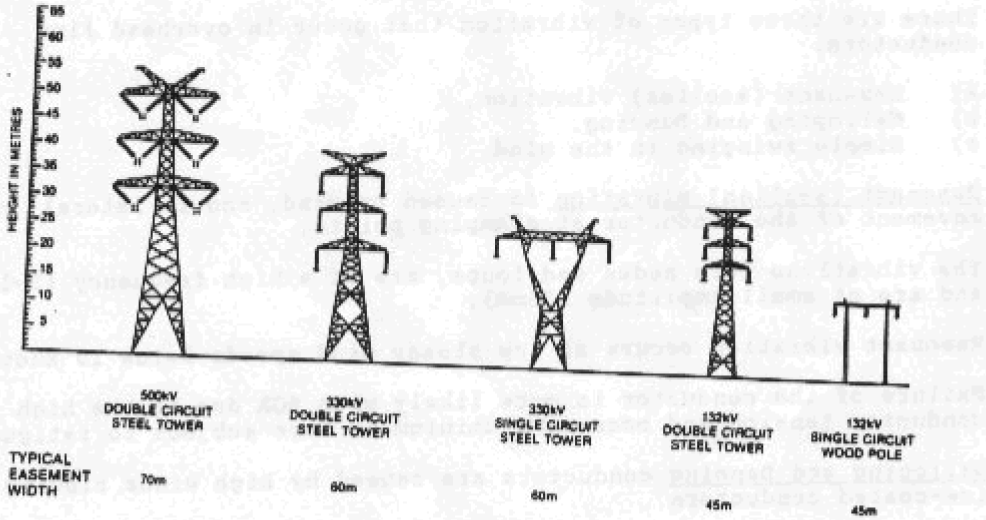

FIG 1

EASE

COMMUNICATION METHODS

① Telecommunication lines e.g Telstra

② Solid conductors - pilot cables
- control cables
- buried adjacent to H.V power cables

③ Fibre optics - underground
- overhead

④ Power line carrier - using H.V conducts to transmit comms info at higher frequencies.
- Wave traps allow H.F. signals to be injected + filtered at remote end of line.

⑤ Microwave system

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HIGH VOLTAGE CABLES

Factors influencing Installation of Cables

a) Environmental - appearance of overhead lines

b) Space - no casement available for overhead lines in built up areas.

Cost Relative to Overhead Lines

Higher capital cost (10-20 times that of an overhead line)

Advantages:

a) protected from lightning strikes

b) reduced maintenance of cable since it is protected from environment.

Disadvantages:

a) higher repair cost after failure

b) maintenance of auxiliary equipment (oil/gas supplies etc)

Types of Cable Construction

Paper Insulated - Metal Sheathed

a) **Solid type** (up to 66kV)

Oil impregnated paper is wrapped around the conductor in concentric layers.

A lead or aluminium sheath is extruded over the paper to prevent ingress of moisture and mechanical damage to the cable.

Oil impregnated paper has a high dielectric strength than plain paper.

Typical dielectric strength of plain paper is 70kV peak/cm while oil impregnated paper has a typical strength of 600kV peak/cm.

Disadvantage: Voids (spaces) may occur in the paper insulation over a period of time, and this will lead to local electrical stress, ionisation of the air in the void and eventual failure of the insulation.

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Refer to FIG 1 which shows solid insulated cables

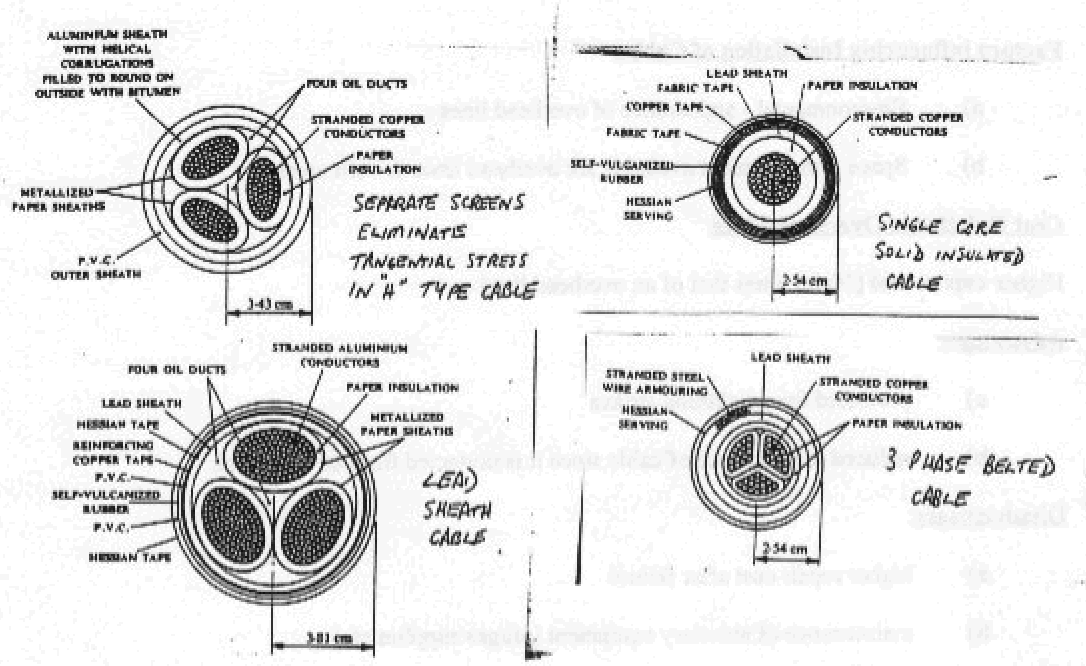


FIG 1

b) **Pressurised type**

The paper insulated cable is sealed so that a pressure above atmospheric pressure is maintained by gas or insulating oil.

Advantages:

i) Any voids in the paper insulation are filled with gas or oil, and so ionisation is prevented.

ii) Moisture is prevented from entering the cable,

iii) Loss of oil pressure is an early indication of cable damage.

Oil Filled Cables (up to 500kV)

The thin high quality insulating oil used in cables is not intended for cooling, but is used to increase the dielectric strength of the cable insulation.

Reservoirs of oil are installed along the route to maintain supply of oil pressure and to allow for the expansion and contraction of the oil during heating and cooling cycle of the cable.

The oil system is sealed, and pressure is applied to the oil by gas (nitrogen) filled bellows in the oil pressure tanks.

Pressure switches are installed to detect loss of oil pressure and are used to initiate alarms at the remote ends of the cable when oil pressure is lost.

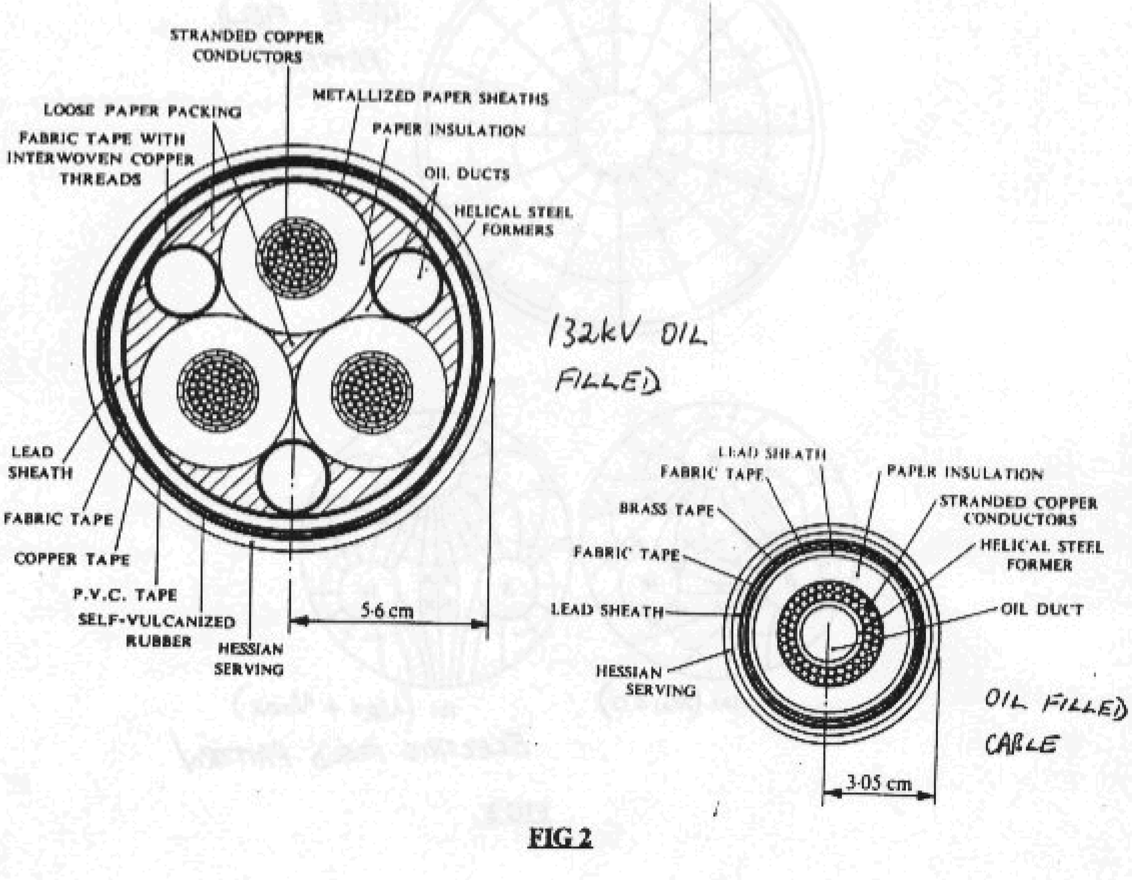
The cable is divided into hydraulic sections depending on the cable route profile, to ensure that excessive pressure is not developed at the lowest section of the cable.

If the cable is damaged with subsequent loss of oil pressure, the cable must be de-energised because if air is drawn into the cable, electrical failure will result due to ionisation of the air.

If air has entered the cable, either due to damage or after jointing, all air must be removed from the cable by applying a vacuum pump before the cable is energised.

<u>Disadvantage</u>: Higher initial cost of installation and more complicated jointing procedure than with solid cables.

Refer to FIG 2 which shows single and three core oil filled cables



<u>FIG 2</u>

Gas filled Cables (up to 132kV)

Similar to oil filled cables except that the cable is pressurised with nitrogen.

Requires gas pressure tanks, pressure switches and alarm systems to monitor the cable condition.

Sheath and Armouring Materials

Metal armouring is applied over the sheath of some cables to provide additional mechanical strength.

Stranded steel wire is used to allow more flexibility of the cable.

PVC serving over the outside of the cable provides protection against corrosion.

Electrical Stress in Dielectric Materials

Refer to FIG 3 which shows the electrical stress diagrams for single and three core cables.

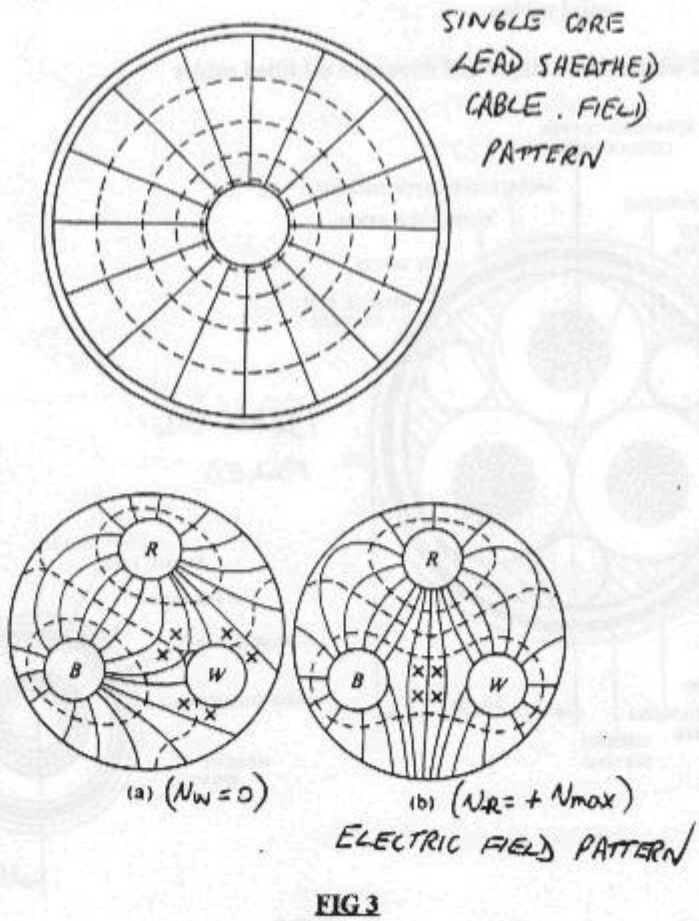


FIG 3

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Cable Inductance

The overhead line inductance equation shown below can be applied to a cable:

$$\boxed{L = \frac{\mu_0 \log_e(d/r_m)}{2\pi} \quad \text{henry/metre}}$$

where r_m = geometric mean radius = $re^{-0.25}$

However, this calculation does not take into account mutual coupling with the sheath and mutual coupling with the armour wires which will add 10-20% to the inductance value.

Conductor Resistance

Affected by temperature, skin effect and proximity effect.

Induced Voltage in Cable Sheaths

Emfs will be induced into the metallic sheath of HV power cables when current flows in the HV conductor.

Three phase HV cable installations will have induced voltages in the sheaths of the cables and these voltages cause circulating currents in the sheaths which will heat the cable.

The sheaths must be earthed so that the circulating currents will flow.

The effect of circulating currents in sheaths is reduced by electrically insulating sections of the cable sheath from each other and by transposing the 3 phase sheaths to help balance out the induced emfs and circulating currents.

This transposing of cable sheaths is called "**Cross Bonding**".

Cable sheaths also protect the cable against over voltage spikes caused by lightning and switching transients.

Breakdown of Insulation

Breakdown of cable insulation can occur due to:

a) puncture - mainly during testing in the laboratory,

b) thermal instability,

c) tracking - across insulation following void ionisation causing burning of insulation in "treeing" patterns,

d) loss of oil in oil filled cables.

Cable Rating

The thermal conductivity of soil in which the cable is buried, is important to ensure that the heat generated by the cable in service is conducted away from the cable.

Three phase cables in particular have high electrical stress points in the dielectric material due to varying field strengths.

Stress can be reduced by screening each phase conductor separately by metallised paper sheaths connected together and to the overall aluminium sheath.

This connection equalises the potential gradient and produces a radial stress in each cable similar to a single core cable.

The dielectric strength of paper insulation is greater across the layer than along the layer and so tangential stress fields should be avoided.

Capacitance of single Core cable

The capacitance of a single core cable can be determined using the following equation:

$$\boxed{C = \frac{2\pi\varepsilon_0\varepsilon_r}{\log_e(R/r)} \quad \text{farad/metre length}}$$

where ε_0 = permittivity of air = 8.85×10^{-12}

ε_r = relative permittivity of dielectric material

R = radius of cable outer sheath in metres

r = radius of conductor in metres

Electrical Stress in Single core Cables

Potential Gradient at radius x is:

$$\boxed{E_x = \frac{V}{x\log_e(R/r)} \quad \text{volts/ metre} \quad \text{(1 phase equivalent)}}$$

where

V = potential difference between sheath and conductor in volts

R = radius of cable outer sheath in metres

r = radius of conductor in metres

Maximum stress occurs at the surface of the conductor ($x = r$) and can be calculated from:

$$\boxed{E_r = \frac{V}{r\log_e(R/r)} \quad \text{volts/ metre} \quad \text{(1 phase equivalent)}}$$

from this equation it can be seen that the smaller the conductor size, the higher is the electrical stress.

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HV cables are buried in "stabilised backfill" which is a mixture of sand and cement which helps to protect the cable, prevent movement and has a high thermal conductivity.

Cable Current Rating depends on:

a) thickness of dielectric,

b) ambient temperature,

c) proximity of other cables,

d) load cycle,

e) depth of burial,

f) soil conductivity.

Cable Termination

Cables terminated in switchgear or connecting to an overhead line must have the insulation removed and replaced by a graded insulation to allow the HV conductor to be brought out to the air.

This is done in a cable "sealing end" where the oil, gas or solid insulated cable end is sealed and the conductor is available to connect.

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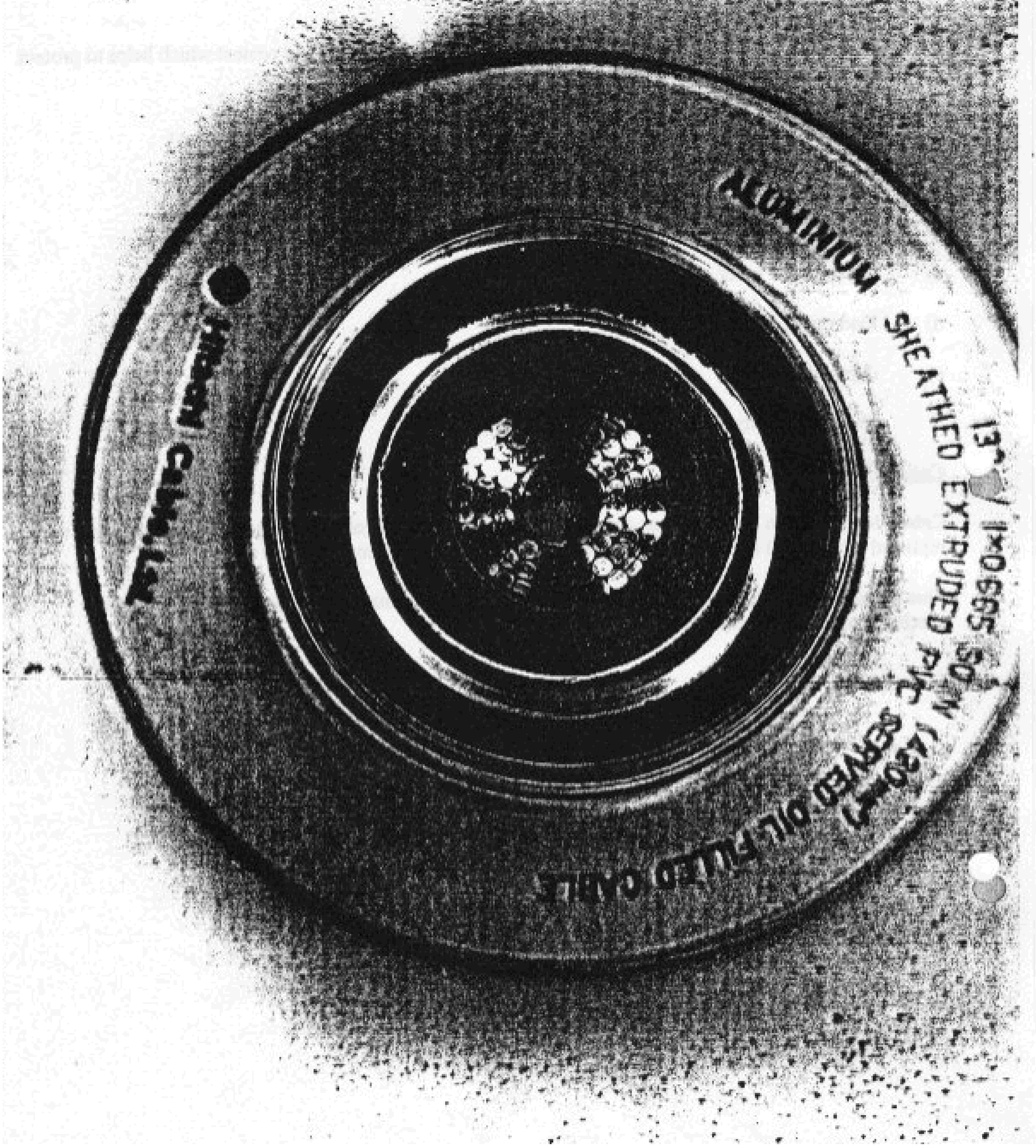
ALUMINIUM
SHEATHED EXTRUDED PVC SERVED OIL FILLED CABLE
1×0.665 SQ IN
Hitachi Cable, Ltd.

INSULATION COORDINATION

Insulation coordination is the correlation of the insulation strengths of components of the high voltage power system, to minimise damage and loss of supply caused by over voltages.

Steps taken to minimise supply interruptions due to overvoltage are;

a) to ensure that system insulation will withstand all normal stresses and most abnormal stresses,

b) to discharge or divert overvoltages which exceed the withstand strength of apparatus,

c) to ensure that breakdowns occur by external flashover, rather than internal failure of equipment such as puncture or breakdown of solid or liquid dielectrics,

d) and to control points at which breakdowns occur, thus avoiding important items of equipment.

Sources of Overvoltage

Overvoltages can be either at system frequency or due to transient surges with higher frequency components.

System Frequency Overvoltages

Overvoltages at the power frequency can be caused by:

a) sudden loss of load on a generator (20%-30% overvoltage),

b) energising an unloaded transmission line (up to 90% overvoltage),

c) unbalanced system faults which may cause unfaulted phase voltages to rise above normal.

Transient Overvoltages

Power system transient overvoltages may be generated either internally or externally.

Internal generation is from switching surges.

External generation is from lightning strikes.

On equipment rated at between 200-300kV, switching surges are about the same intensity as lightning strikes.

On equipment rated over 300kV, switching surges produce larger transients than lightning strikes.

Lightning Strikes

Lightning strikes on HV equipment may be either direct or indirect.

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Lightning strikes can range in size from a few kA to 100kA.

The current waveform is a unidirectional pulse rising to a peak value in ≈ 3μsec and falling away in 30-40μsec.

Direct Lightning Strike

A direct strike occurs when lightning strikes the line conductor and causes a flashover of the line insulators or is rapidly attenuated by corona along the line.

Any discharge current flowing through the towers to earth may set up a large voltage drop due to tower footing resistance and tower inductance.

There may result a back flashover from the tower to the line.

Indirect Lightning Strike

An indirect strike occurs where a voltage is induced into the line by a nearby object being struck by lightning.

This is usually only a problem on lower voltage lines rated at less than 33kV.

Effect of Lightning Strikes on Overhead Lines

If lightning strikes an overhead line, the excessive voltage can cause damage to line insulators and the wave can travel along the line to cause damage to terminal equipment in substations.

FIG 1 shows how charge moves along the line in a wave after a lightning strike.

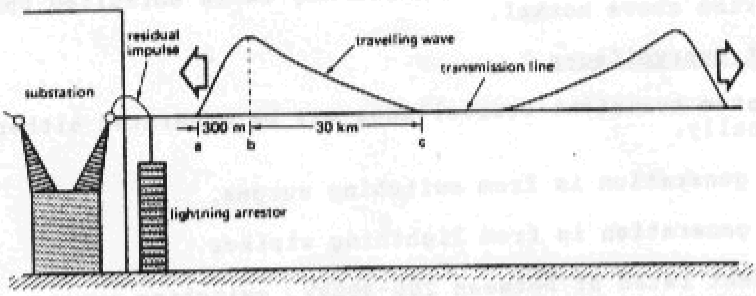

FIG 1

Electrical Testing of HV Equipment

Electrical testing of HV equipment is carried out to ensure that insulation can withstand normal and surge voltages.

The two main tests carried out are:

a) HV impulse test,

b) HV power frequency test.

HV Impulse Test

The standard impulse test is intended to reproduce the effects of switching transients and lightning strikes.

Refer to FIG 2 which shows the standard 1/50 impulse test waveform.

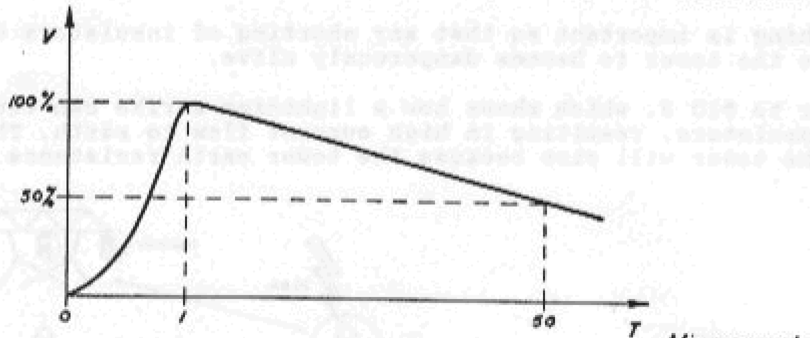

FIG 2

The wave specification of 1/50 indicates that the test voltage rises to the peak value in 1μsec and then drops to 50% of the peak value by 50μsec.

Typical value of test voltage for 330kV equipment is 1050kV (peak).

HV Power Frequency Test

A voltage of ≈ 150% of the rated voltage at power frequency is applied to the apparatus under test for 1 minute, and leakage current measured.

Typical value of test voltage for 330kV equipment is 460kV rms.

Protection of Overhead Lines and Substation Equipment from Surges

Surge Protection Devices

HV equipment is protected against surges by Surge Arrestors (also called Surge Diverters) and Rod or Arc Gaps.

These devices limit the surge voltage and conduct the surge energy away from the protected equipment.

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In particular, they are installed and located for protecting transformers and cables that are expensive the repair, if their paper insulation is damaged by impulse voltages.

Overhead Earthwire (Shield Conductor)

At the very top of each tower on each side, are installed earthing conductors, which run the whole length of the line, and are earthed at each tower.

They provide an earthed shield above the live conductors and attract lightning away from the line.

Tower Earthing

Each tower must be solidly connected to earth and earthing rods and an earth grid are installed at the base of each tower.

Earthing is important so that any shorting of insulators does not cause the tower to become dangerously alive.

Refer to FIG 3. which shows how a lightning strike can cause flashover of insulators, resulting in high current flow to earth. The potential of the tower will rise because the tower earth resistance is high.

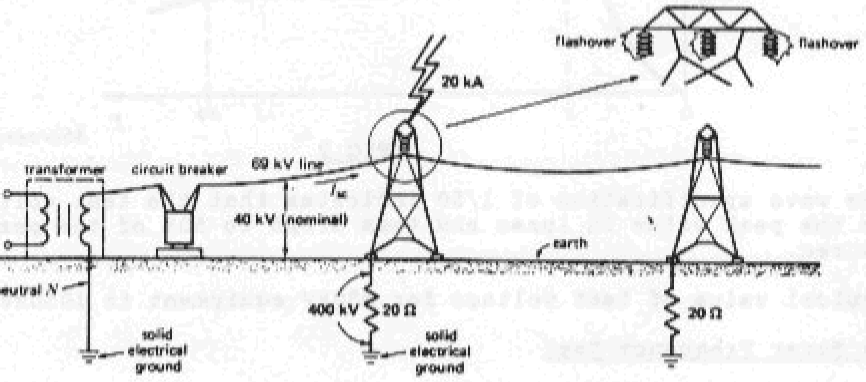

FIG 3

Lightning/Surge Arrestors and Diverters

Surge arrestors and diverters are protective devices which are connected between HV conductors and earth, to divert any surge to earth.

They protect valuable equipment such as transformers or cables from being damaged or destroyed by excessive high voltage surges travelling along a line after a lightning strike.

They are connected as close as possible to the terminals of the transformer or equipment to be protected.

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The surge diverter <u>does not conduct</u> at <u>normal</u> system voltage level, but is designed to conduct at a pre-determined level of voltage above normal voltage.

Refer to FIG 4 which shows the construction of a typical non-linear resistor type surge diverter.

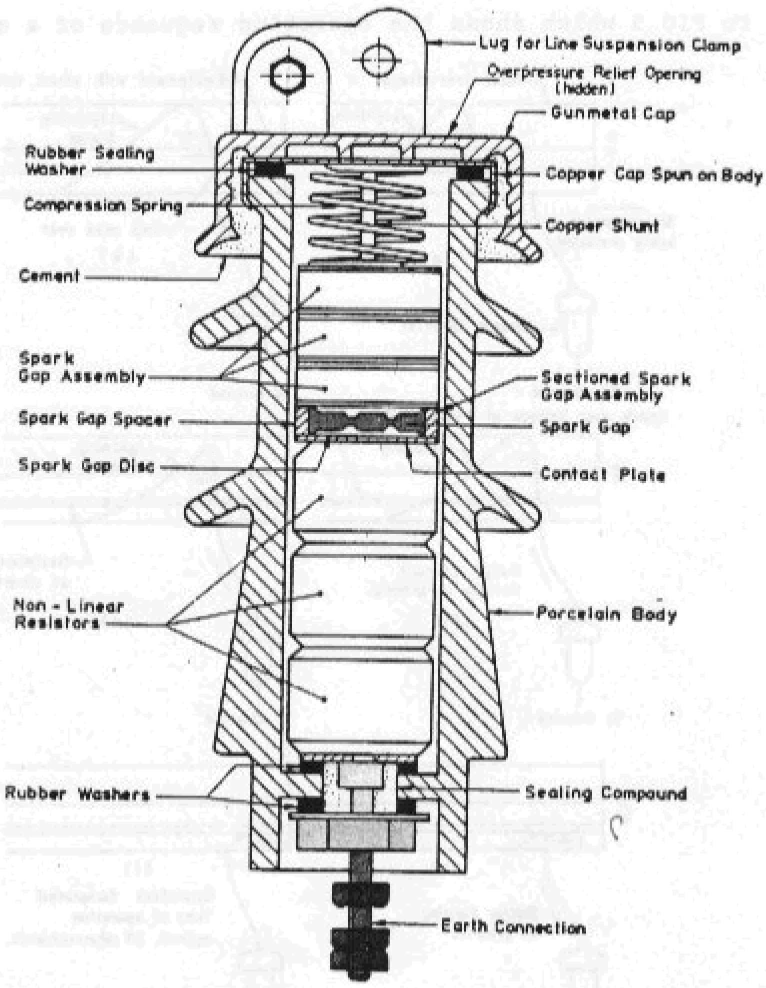

FIG 4

The non-linear resistor, usually made of silicon carbide, acts as a low resistance to the flow of high discharge voltages and a high resistance at normal power frequency voltage.

The series spark gaps keep the circuit open under normal conditions.

Sometimes grading resistors are connected in parallel with multiple gaps to assist in voltage distribution.

The assembly is usually evacuated and filled with dry nitrogen at atmospheric pressure to ensure that the operation is not affected by surrounding atmospheric conditions.

Refer to FIG 5 which shows the operating sequence of a surge diverter.

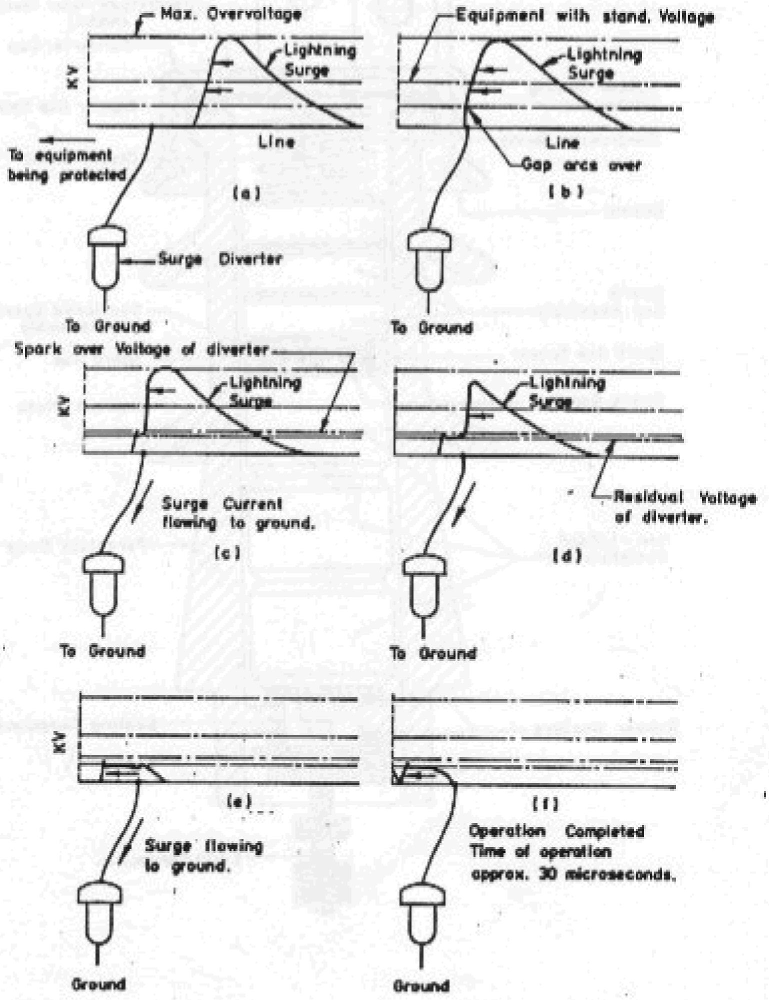

FIG 5

When a surge reaches the surge diverter, the excessive voltage causes the diverter to conduct, diverting the energy to earth and when the voltage drops back to normal, the diverter ceases conducting.