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ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

(Approved by AICTE, New Delhi. Affiliated to Anna University, Chennai)
(Accredited by NAAC)
ANGUCHETTYPALAYAM, PANRUTI – 607 106.

EE3037 **POWER SYSTEM TRANSIENTS** **LT P C**
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OBJECTIVES:

- To study the generation of switching transients and their control using circuit – theoretical concept.
- To study the mechanism of lighting strokes and the production of lighting surges.
- To study the propagation. reflection and refraction of travelling waves.
- To study the impact of voltage transients caused by faults, circuit breaker action. load rejection on integrated power system.

UNIT I INTRODUCTION AND SURVEY (7+2 Skill) 9

Sources of different types of transients - RL circuit transient with sine wave excitation - double frequency transients - basic transforms of the RLC circuit transients - study of transients in system planning - Importance of grounding.

UNIT II SWITCHING TRANSIENTS (7+2 Skill) 9

Basic concept of switching transients - resistance switching and equivalent circuit for interrupting the resistor current - load switching and equivalent circuit - waveforms for transient voltage across the load and the switch - normal and abnormal switching transients. Current suppression – current chopping - effective equivalent circuit - capacitance switching with a restrike, with multiple restrikes - ferro resonance.

UNIT III LIGHTNING TRANSIENTS (7+2 Skill) 9

Theories of cloud formation - mechanism of lightning discharges and characteristics of lightning strokes - model for lightning stroke - factors contributing to good line design - protection using ground wires - tower footing resistance - Interaction between lightning and power system.

UNIT IV TRAVELING WAVES ON TRANSMISSION LINE COMPUTATION OF TRANSIENTS (7+2 Skill) 9

Computation of transients - transient response of systems with series and shunt lumped parameters and distributed lines. Traveling wave concept - step response - Bewely's lattice diagram - standing waves and natural frequencies - reflection and refraction of travelling waves. Computation of overvoltages using EMTP

UNIT V TRANSIENTS IN INTEGRATED POWER SYSTEM 9

The short line and kilometric fault - distribution of voltages in a power system - Line dropping and load rejection - voltage transients on closing and reclosing lines - overvoltage induced by faults - switching surges on integrated system Qualitative application of EMTP for transient computation.

TOTAL: 45 PERIODS

SKILL DEVELOPMENT ACTIVITIES (Group Seminar/Mini Project/Assignment/Content Preparation / Quiz/ Surprise Test / Solving GATE questions/ etc) 8

1. Simulation of circuit transients.
2. Computation of over voltages for switching surges.
3. Computation of over voltages for lightning surges.
4. Computation of transients.

COURSE OUTCOMES:

After completing the course, the students will be above to

CO1: Explain the principles of transients and its concepts.
CO2: Know the different types of switching transients and the way to draw the necessary equivalent circuit.
CO3: Explain the concepts behind lighting and the way to protect the same.
CO4: Compute the transient behavior in transmission line.
CO5: Explain the behavior of the Circuit during switching and to learn the simulation tool.

TEXT BOOKS:

1. Allan Greenwood, 'Electrical Transients in Power Systems', Wiley Inter Science, New York, 2nd Edition, 1991.
2. Pritindra Chowdhari, "Electromagnetic transients in Power System", John Wiley and Sons Inc., Second Edition, 2009.
3. C.S. Indulkar, D.P.Kothari, K. Ramalingam, 'Power System Transients – A statistical approach', PHI Learning Private Limited, Second Edition, 2010.

REFERENCES:

1. M.S. Naidu and V. Kamaraju, 'High Voltage Engineering', Tata McGraw Hill, Fifth Edition, 2013.
2. R.D. Begamudre, 'Extra High Voltage AC Transmission Engineering', Wiley Eastern Limited, 1986.
3. Y. Hase, Handbook of Power System Engineering," Wiley India, 2012.
4. J. L. Kirtley, "Electric Power Principles, Sources, Conversion, Distribution and use," Wiley, 2012.

UNIT - I

INTRODUCTION AND SURVEY

INTRODUCTION:

An electrical transient is the outwards (away from a place) manifestations Good condition (evidence) of a sudden change in circuit conditions, as when a switch opens or closes or a fault occurs on a system.

The transient period is usually very short (from few μs to 1 sec). The fraction of their operating time that most circuits spend in the transient condition is in-significant have a little (or) Important compared with the time spent in steady state.

Then these transient periods are extremely important, for it is at such times that the circuit components are subjected to the gratest stresses from excessive currents or voltages.

In extreme very severe case damage results. This may disable (damage) a machine, shut down a plant, or black out a city, depending upon the circuit Involved.

For this reason a clear appreciation importance of events taking place during transient periods is essential for a full understanding of the behavior of electric circuit.

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POWER SYSTEM:

A power system combination of generation, Transmission and Distribution system.

TRANSIENT:

Transient is a condition in which current, voltage, frequency and power will fluctuvate with respect to time.

Transient time:

The time taken for the circuit to change from one steady state to another steady state is called the transient time.

Transient → (momentary) staying in a place for a short time only.

Transient in a power system for a short period from few μsec to 1 sec.

Good condition

Transient is an electrical manifestation of sudden change in circuit conditions:

⇒ switch open or close or fault occuring on a system.

⇒ sudden load rejection (loss of load), Disconnection of Inductive load or connection of capacitive load, unsymmetrical faults.

⇒ Transient occurs in any circuit having R, L, C parameters.

⇒ The degree of the transients will differ from case to case.

⇒ The transient period is very short and is related to the time spent in steady-state operation.

⇒ During transient period there will be a great-stress on circuit components. Excessive voltage or flow q current occurs. which if not prevented will cause damage to the circuit.

SOURCES OF DIFFERENT TYPES OF TRANSIENTS:

Source of Transients:

The transient behaviors q a power system resulting from major disturbance, such as a fault followed by:

(i) switching operations.

(ii) sudden ~~load~~ rejection q load or generation.

(iii) A major disturbance upsets the balance between mechanical input and electrical output q a generator, with the result that some generators may accelerate (to move faster (speed incres)) while others may decelerate ((Speed decrease)).

⇒ faults on transmission lines with subsequent operating q breakers.

⇒ So the rotor angles will undergo wide variations and in this process the synchronism q the system gets affected.

Rotor angle is the position q the rotor relative to the terminal voltage. The relative angle between these two sinusoidally varying quantity has direct relation to the power o/p q the machine.

(iv) sudden change in operating conditions.

(v) uncontrolled loss q large amount q generation or load (or) occurrence q transmission line faults.

TRANSIENT PERIOD AND EFFECTS:

⇒ The transient period is usually very short time from few μSec to 1 Sec.

⇒ The fraction of their operating time that most circuits spend in the transient conditions is insignificant compared with the time spent in the steady state.

⇒ these transient periods are extremely important for it is at such times that the circuit components are subjected to the greatest stress from excessive current or voltage.

⇒ In extreme case damage results

* This may disable a machine
* shut down a plant.

(or)

Black out a city, depending upon the circuit involved.

VARIOUS TYPES OF POWER SYSTEM TRANSIENTS:

(i) switching Transient
  (a) circuit closing transient
  (b) Double frequency transient

(ii) Lightining Transients.

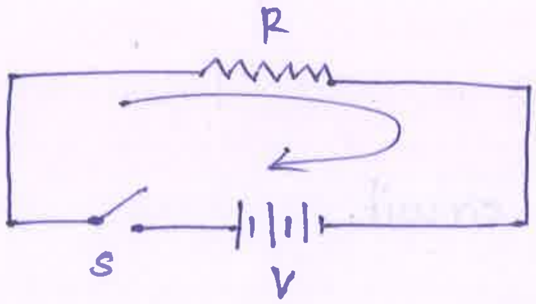
TRANSIENT IN SIMPLE CIRCUIT:

The transients will depends upon the driving source also.

i.e whether it is a D.C source or an A.C source. we will begin with simple problems and then go to some complicated problems.

D.C SOURCE:

(a) Resistance only.

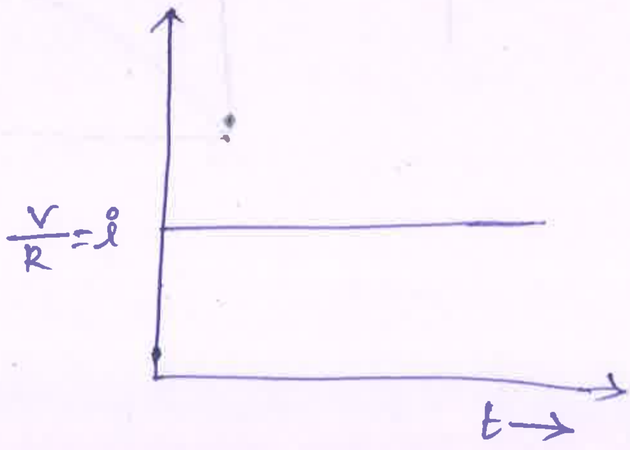


V → voltage
R → Resistance
S → source.

As soon as the switch 'S' is closed the current in the circuit will be determined according to ohms law.

$$I = \frac{V}{R}$$

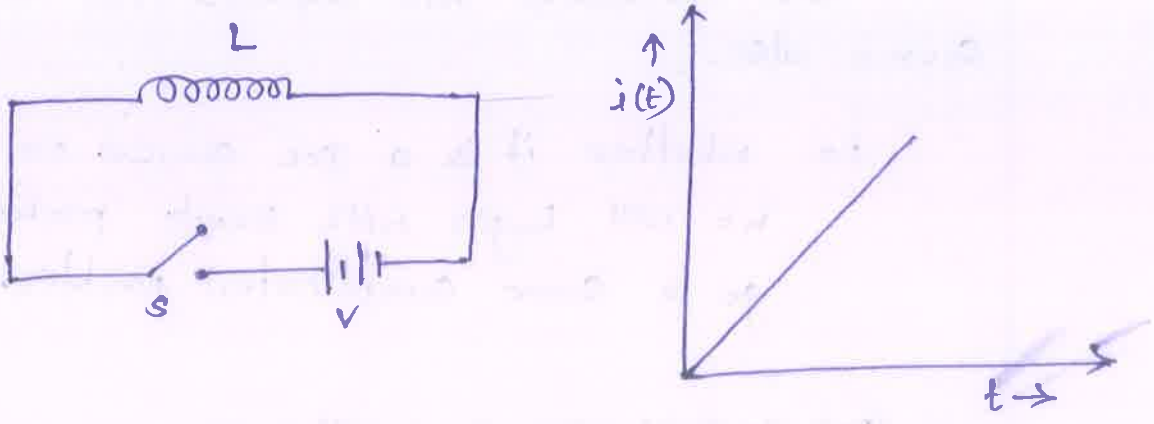
No transient will be there in the circuit.



t → time
i → current

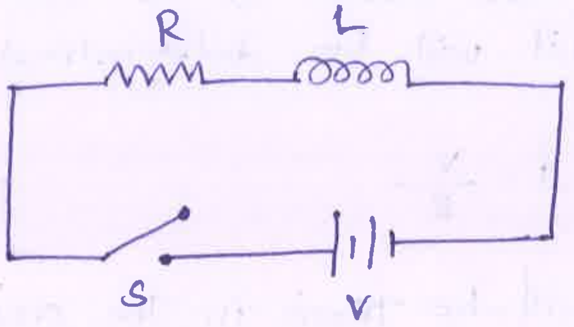
Resistive circuit.

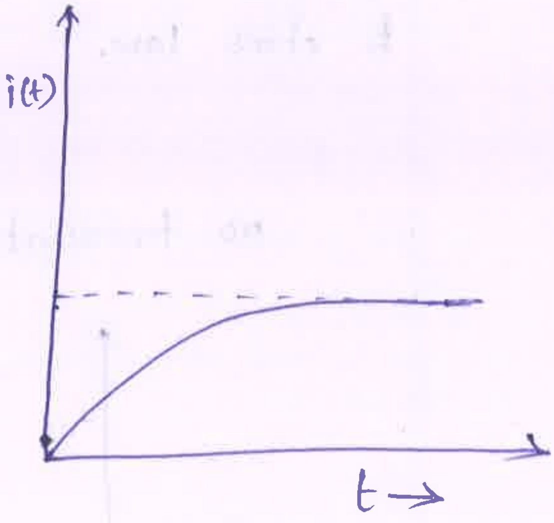
(b) Inductance only:



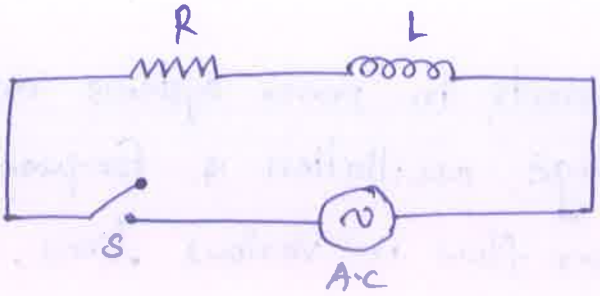
Inductive circuit.

(c) R-L circuit.



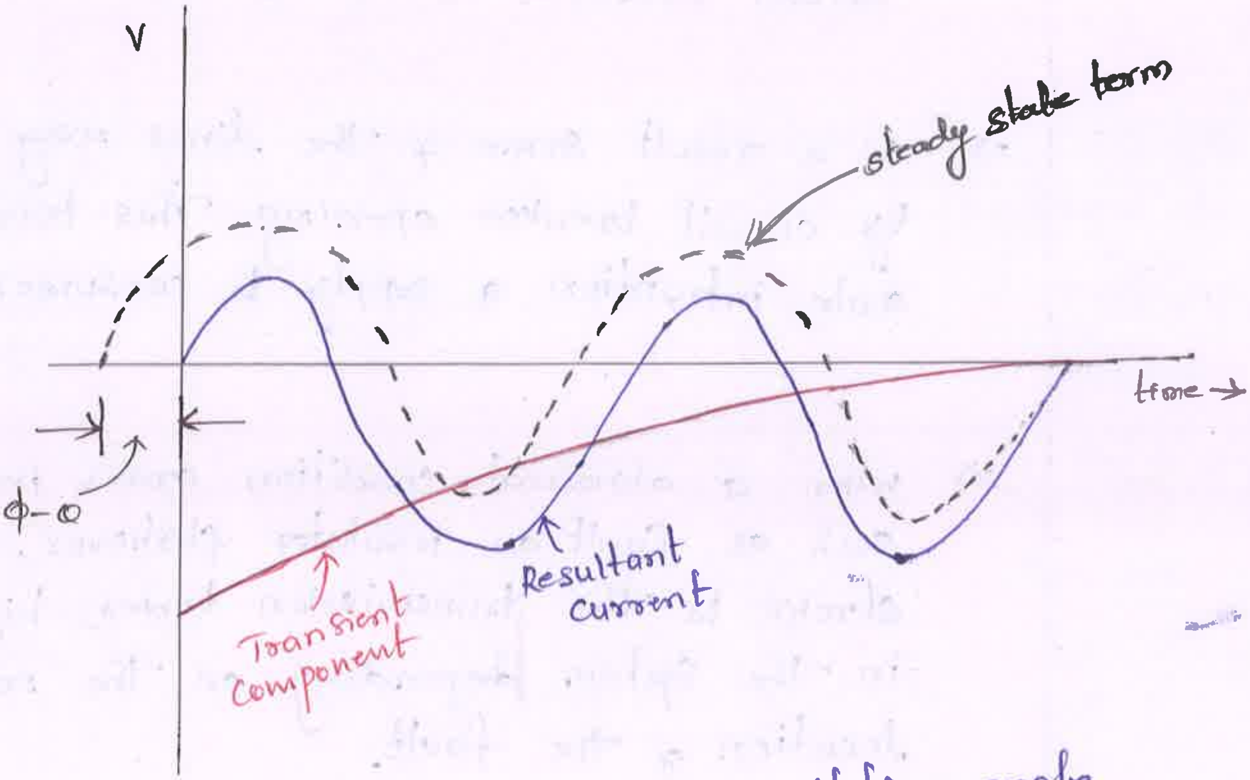


A.C SOURCE:



R.L circuit connected to an A.C source.

The variation of current.



θ → switching angle.

φ → power factor angle.

EFFECT OF TRANSIENTS ON POWER SYSTEMS.

⇒ Transients in power systems causes oscillation of voltage, oscillation of frequency, flucturation in power flow in various lines, Transformers and generators so this is effect of Transient.

⇒ This may lead to series consequences such as power system instability, Insulation damage of Transformers, Generators, Transmissiol lines, circuit breakers, as well as consumer equipment. -

⇒ As a result some of the lines may get isolated by circuit breaker opening. This leads to large scale intruption of supply to consumer.

⇒ when a abnormal condition arises in power system such as fault an insulator flashover, or a lightning stroke to the transmission tower, high current flow in the system depending on the nature and location of the fault.

SWITCHING TRANSIENTS: (Introduction)

⇒ A transient is initiated whenever there is a sudden change of circuit conditions; this most frequently occurs when a switching operation take place.

⇒ The closing of a switch or circuit breaker to energize a load and

↳ The opening of a breaker to clear a fault

⇒ This provides an opportunity to discuss some of the practical details of switching transient.

RL CIRCUIT TRANSIENT WITH SINE WAVE EXCITATION.

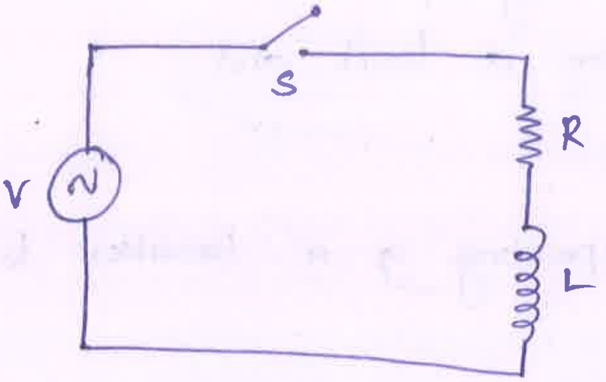
(or)

(RL circuit Transient with sine wave Drive)

(or)

(circuit closing Transient)

The circuit involved in this example is that shown below. It has been reduced to it's barest essential in the intrest of initial simplicity.



RL circuit with a sine wave drive (excitation)

The load is represented by a series combination of Resistance and inductance, which has a steady-state power factor given by.

$$\cos\phi = \frac{R}{|Z|} = \frac{R}{(R^2+\omega^2L^2)^{1/2}} \longrightarrow ①$$

The source is assumed to have negligible impedance compared with the load.

'V" → is source voltage

'ω" → is the supply frequency (indicating a phasor varying at the supply freq)

when the switch 's" is closed, the current is expressed as

$$RI + L\frac{dI}{dt} = V = V_m \sin(\omega t+\theta) \longrightarrow ②$$

The action of containing as a part of whole

The inclusion of the arbitrary phase angle θ permits closing of switch at any instant in the voltage cycle.

our choice

formula used
$(\sin(A+B) = \sin A \cos B + \cos A \sin B)$

eqn ② can be rewritten as

$$RI + L\frac{dI}{dt} = V_m(\sin\omega t \cos\theta + \cos\omega t \sin\theta) \quad \text{③}$$

note:
$L(\sin\omega t) = \frac{\omega}{s^2+\omega^2}$
$L(\cos\omega t) = \frac{s}{s^2+\omega^2}$

Transforming both sides.

$$RI(s) + Ls\,i(s) - LI(0) = V_m\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right) \quad \text{④}$$

sinθ and cosθ are constant once the value of θ has been assigned.

allocation(fixed) switching angle fixed.

In this circuit $I(0) = 0$

$$RI(s) + Ls\,i(s) - 0 = V_m\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right)$$

The operational solution for current is.

$$i(s)(R+Ls) - 0 = V_m\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right)$$

$$i(s) = V_m\left(\frac{1}{R+Ls}\right)\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right)$$

$$i(s) = \frac{V_m}{R+Ls}\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right)$$

$$i(s) = \frac{V_m}{L(s+\frac{R}{L})}\left(\frac{\omega\cos\theta}{s^2+\omega^2} + \frac{s\sin\theta}{s^2+\omega^2}\right)$$

$$i(s) = \frac{1}{s+(\frac{R}{L})}\left(\frac{\frac{V_m}{L}\omega\cos\theta}{s^2+\omega^2} + \frac{\frac{V_m}{L}s\sin\theta}{s^2+\omega^2}\right)$$

where,

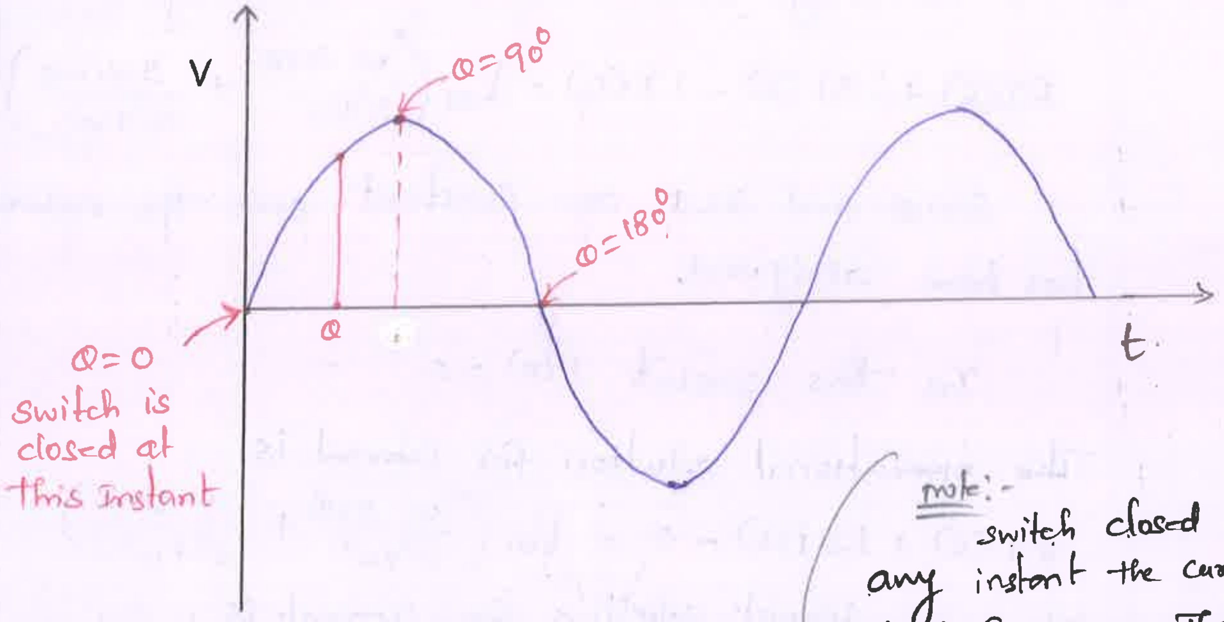
$$A = \frac{V_m}{L}\omega\cos\theta$$

$$B = \frac{V_m}{L}\sin\theta$$

$$\alpha = \frac{R}{L}$$

$$i(s) = \frac{1}{(s+\alpha)}\left(\frac{A}{s^2+\omega^2} + \frac{Bs}{s^2+\omega^2}\right)$$

$$i(s) = \frac{A}{(s+\alpha)(s^2+\omega^2)} + \frac{Bs}{(s+\alpha)(s^2+\omega^2)} \longrightarrow ⑥$$



note:- switch closed at any instant the current start from zero. That is property of electrical circuit.

The invers laplace transform of equation ⑥ and substitute the value of A, B and α

$$I(t) = \frac{V_m}{L(\alpha^2+\omega^2)}\left[\omega\cos\theta\left(e^{-\alpha t} - \cos\omega t + \frac{\alpha}{\omega}\sin\omega t\right) + \sin\theta\left(\alpha\cos\omega t + \omega\sin\omega t - \alpha e^{-\alpha t}\right)\right] \longrightarrow ⑦$$

$$I(t) = \frac{V_m}{L(\alpha^2+\omega^2)}\left[\omega\overset{\checkmark}{\cos\theta} e^{-\alpha t} - \omega\cos\theta \overset{*}{\cos\omega t} + \alpha\cos\theta \overset{\#}{\sin\omega t} + \alpha \overset{*}{\sin\theta}\cos\omega t + \omega \overset{\#}{\sin\theta}\sin\omega t - \alpha \overset{\checkmark}{\sin\theta} e^{-\alpha t}\right]$$

$$I(t) = \frac{V_m}{L(\alpha^2+\omega^2)}\left[(\omega\cos\theta - \alpha\sin\theta)e^{-\alpha t} + (\omega\cos\theta - \alpha\sin\theta)\cos\omega t + (\alpha\cos\theta + \omega\sin\theta)\sin\omega t\right] \longrightarrow ⑧$$

substitute.

Reactance

$$\tan\phi = \frac{\omega L}{R} = \frac{\omega}{\alpha}$$

Resistance

φ, phase angle between V & I

$$\sin\phi = \frac{\omega}{(\alpha^2+\omega^2)^{1/2}} = \frac{\omega L}{|z|}$$

$$\cos\phi = \frac{\alpha}{(\alpha^2+w^2)^{1/2}} = \frac{R}{|z|}$$

$\alpha = \frac{R}{L}, \alpha L = R$

$L = \frac{R}{\alpha}$

$L = R\frac{1}{\alpha}$

$\frac{L}{R} = \frac{1}{\alpha}$

$\frac{WL}{R} = \frac{\omega}{\alpha}$

$$|z| = \sqrt{(WL)^2+R^2}$$

$$\frac{\text{opp side}}{\text{adj side}} = \tan\phi$$

$$\frac{\text{opp side}}{\text{Hyp}} = \sin\phi$$

$$\frac{\text{adj side}}{\text{Hyp}} = \cos\phi$$

eqn ⑧ simplifies further.

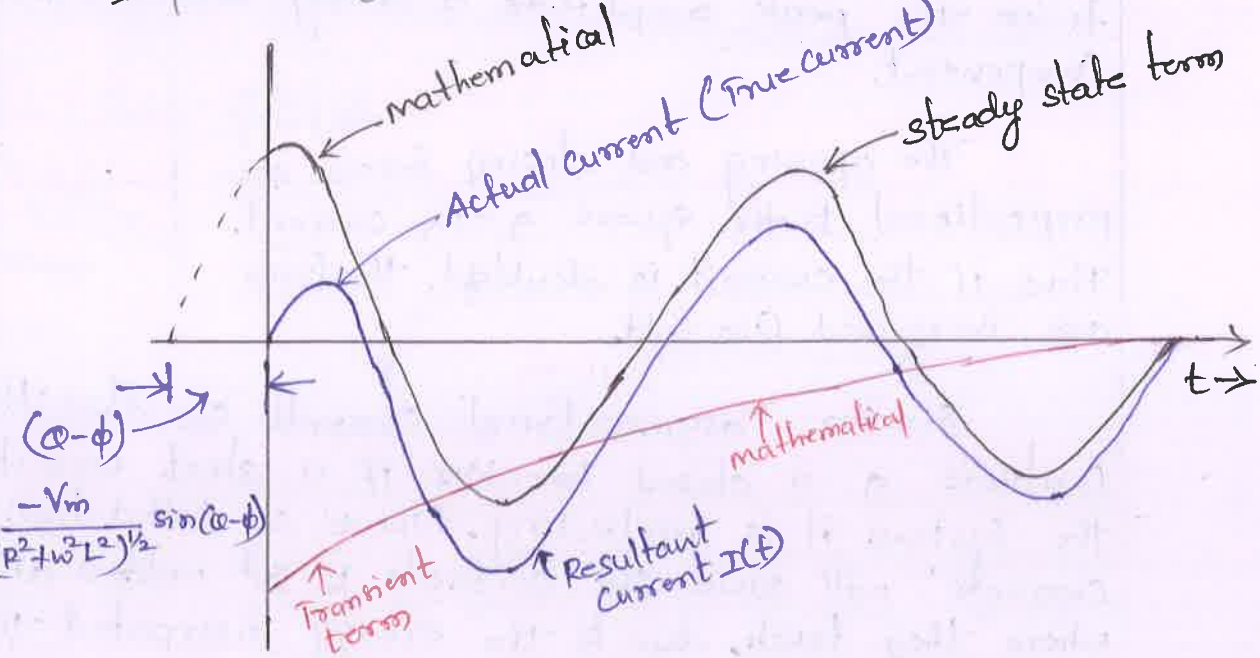
$$I(t) = \frac{V_m}{L(\alpha^2+w^2)^{1/2}}\left[-\sin(\theta-\phi)e^{-\alpha t} + \sin(\omega t+\theta-\phi)\right]$$

peak voltage.

$$\boxed{I(t) = \frac{V_m}{(R^2+w^2L^2)^{1/2}}\left(\underbrace{\sin\omega t+(\theta-\phi)}_{\text{steady state term}} - \underbrace{\sin(\theta-\phi)e^{-\alpha t}}_{\text{Transient term.}}\right)} \rightarrow ⑨$$

circuit Impedance

peak current



In this equation ⑨, the first term is the steady state value. It's amplitude is V_m/Z and it has a phase angle with respect to the voltage.

The second term is the transient term.

case-I

mean immediately after closing the switch.

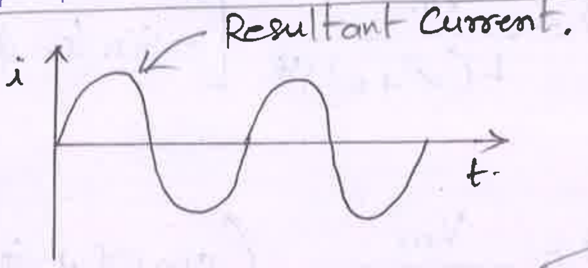
when $t=0$, the transient term is equal and opposite to the steady state term and hence the current start from zero.

case-II

switching angle.

power factor angle of the load.

when the switch closes at $\theta=\phi$, the transient term will be zero and the current wave will be symmetrical



both (magnitude of symmetrical)

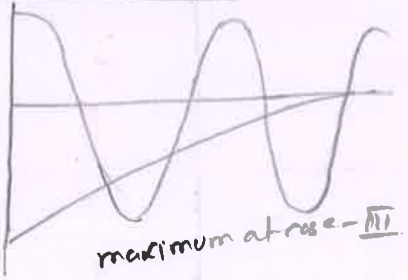
when $\theta=\phi$

$\pm\frac{180}{2}=\pm 90^\circ$

case-III

when the switch closes at $(\theta-\phi)=\pm\frac{\pi}{2}$ The transient term attains it's maximum amplitude and the first peak of resulting composite current wave will approch twice the peak amplitude of steady state sinsoidal Component.

$\theta=\phi\pm\frac{\pi}{2}$



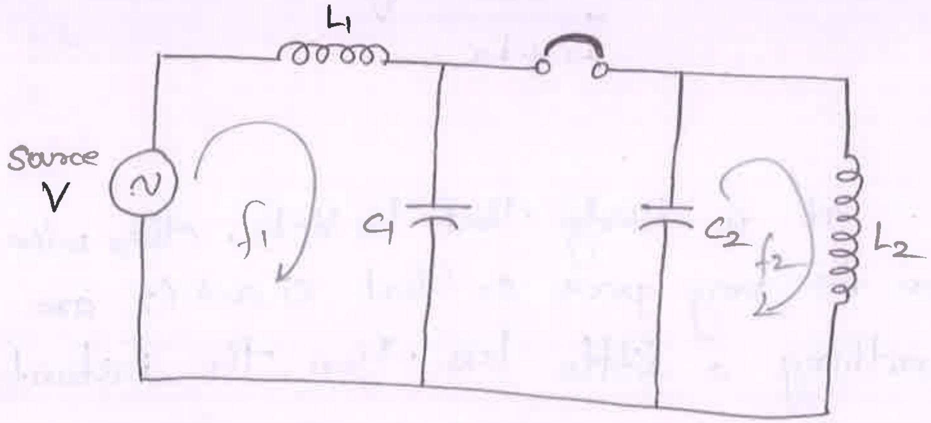
The opening and closing forces are proportional to the square of the current. Thus if the current is doubled, the force are increased four fold.

times

Similar asymmetrical currents can flow through the contacts of a closed breaker if a short circuit occurs on the system it is protecting. "These so calld high "momentary currents" will cause the contacts to get welded at the points where they touch, due to the energy dissipated there in contact resistance.

DOUBLE - FREQUENCY TRANSIENT:

The simplest form of double-frequency transient is the cause (a process or action) to being by opeaning the circuit breaker in the circuit shown below.



circuit with two natural frequencies.

L_1 and C_1 are the inductance and stray capacitance on the source side of the breaker.

L_2 and C_2 might represent an inductive load and its stray capacitance for Example an unloaded transformer.

when the switch operates in such a circuit it
seperat from
completely divorces the load from the supply.

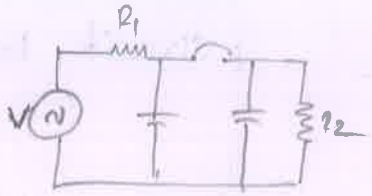
Thereafter the two halves of the circuit behave independently.

It is possible to gather what happens following such a switching operation without any mathematical analysis.

freq (in USA)

The switch opening the 60 cps (cycles per sec) voltage will divide in proportion (part) to the inductances, that is, to a close approximation the voltage q the capacitors will be

$$\frac{L_2}{L_1+L_2}V$$



$$V\frac{R_2}{R_1+R_2} = V_2$$

It is likely that $L_2 \gg L_1$, other wise ~~the~~ Regulation can be very poor, so that C_1 and C_2 are charged to somthing a little less than the instantoneous system voltage

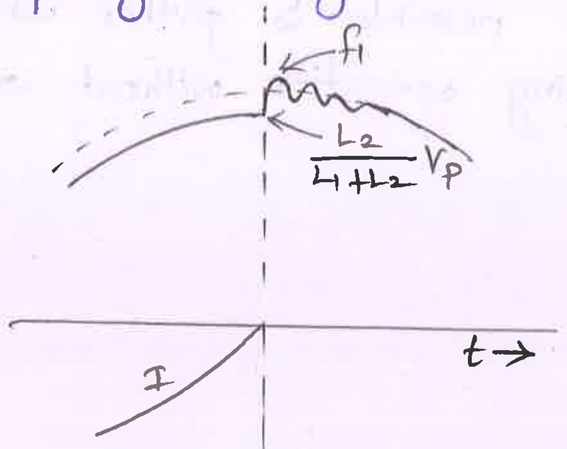
when the current passes through zero, this voltage will be at its peak. following current interruption C_2 will discharge through L_2 with a natural frequency given by

$$f_2 = \frac{1}{2\pi(L_2C_2)^{1/2}}$$

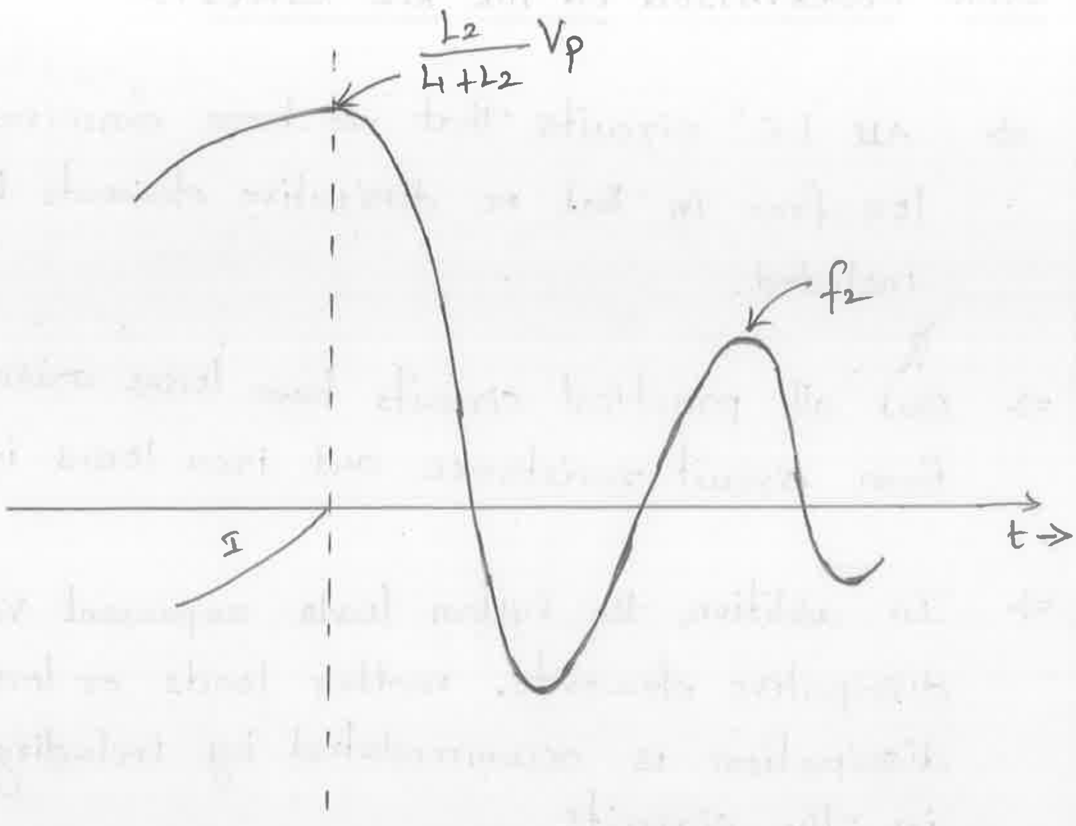
Meanwhile C_1, now free to take up the source potential, will oscillate about that value until the losses q the system damp out the disturbance. The frequency q this oscillation will be

$$f_1 = \frac{1}{2\pi(L_1C_1)^{1/2}}$$

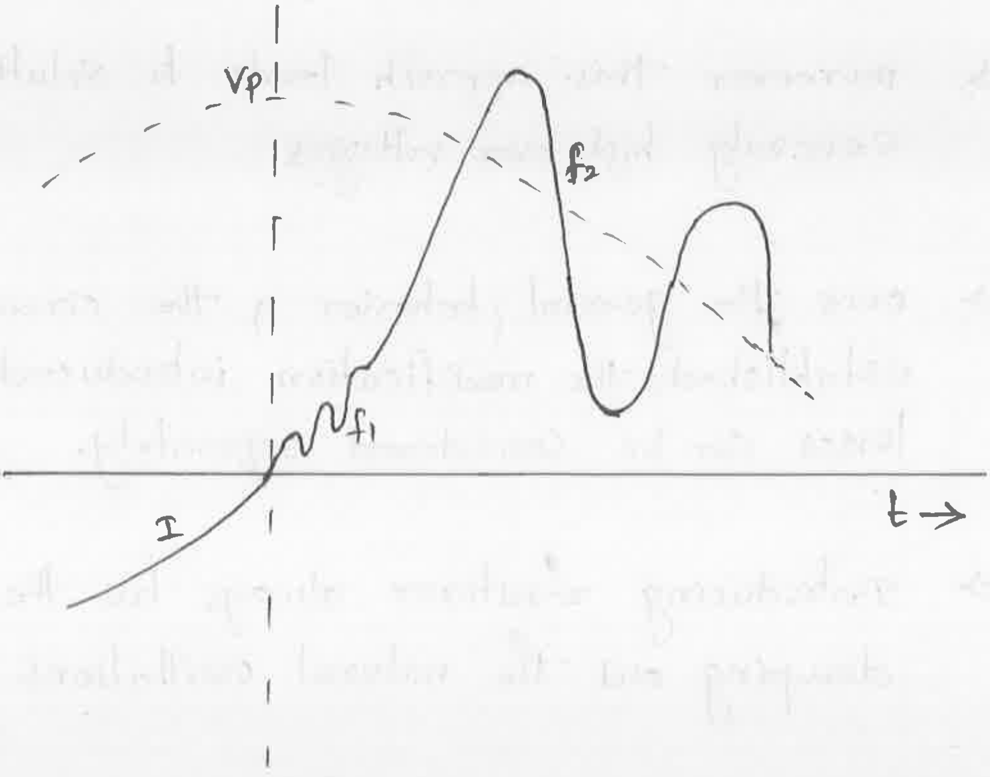
Double frequency recovery transient.



Source side transient.



(b) Load side Transient



(c) Recovery voltage across the switch.

The recovery voltage across the circuit breaker contacts will be the difference between these two as shown in (c).

Some OBSERVATION ON THE RLC CIRCUIT:-

inspect closely to find out the nature (or) condition q

⇒ All 'LC' circuits that we have examined have been loss-free in that no dissipative elements has been included.

resistance

⇒ But all practical circuits have losses arising primarily from circuit resistance and iron losses in equipment.

⇒ In addition, the system loads represent very important dissipative elements. wether loads or losses the dissipation is accommodated by including resistance in the circuits.

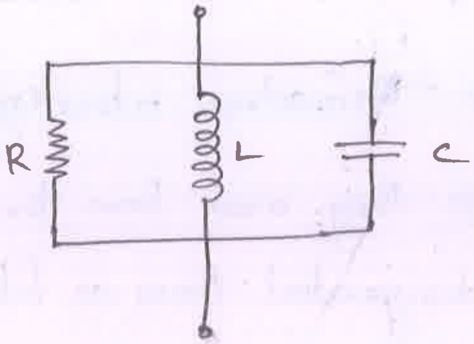
⇒ In making transient analysis, all losses usually are neglected in the first instance, greatly - reducing the complication q the calculation.

⇒ moreover this approch leads to solutions that give severaly high over voltages.

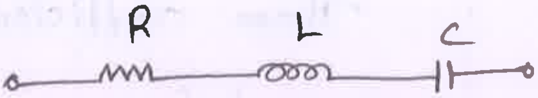
⇒ once the general behavior q the circuit hasbeen established, the modification introduced by the system losses can be considered seperately.

⇒ Introducing resistance always has the effect q damping out the natural oscillations q a circuit.

PARALLEL AND SERIES RLC CIRCUIT:



(a)



(b)

The series and parallel RLC circuit are considered important because the networks involved in many practical transient problems in power systems can be safely reduced to one or the other of these configrations for the purpose of analysis.

The parallel circuit the eqn can be written as

$$\frac{d^2\phi}{dt^2} + \frac{1}{RC}\frac{d\phi}{dt} + \frac{\phi}{LC} = F(t) \longrightarrow ①$$

where ϕ can be the current in any branches or the voltage across the circuit.

The F(t) depends upon the drive.

The series circuit the equation can be written as

$$\frac{d^2\psi}{dt^2} + \frac{R}{L}\frac{d\psi}{dt} + \frac{\psi}{LC} = F(t) \longrightarrow ②$$

where ψ is the voltage across any component or the current through the circuit.

We note that the only difference between eqn ① and ② is the coefficient of their second terms.

These coefficient are ~~themselves~~ interesting. ← preposition

To satisfy eqn ① and ② they must have the dimensions of T^{-1}! Accordingly we designated them as follows:

parallel circuit time constant $= RC = T_P$

Series circuit time constant $= \frac{L}{R} = T_S$

The product of these time constant is the square of the angular period of the undamped circuit is given by

$$T_P T_S = LC = T^2$$

A parameter η as the ratio of the resistance R to the surge impedance, $Z_0 = (L/C)^{1/2}$ that is

$$\overset{\text{eeta}}{\eta} = \frac{R}{Z_0} = R\left(\frac{C}{L}\right)^{1/2}$$

The ratio of the parallel circuit time constant to the series circuit time constant is equated as the square of η.

$$\text{i.e } \frac{T_P}{T_S} = \frac{RC}{\frac{L}{R}} = RC \times \frac{R}{L} = \frac{R^2C}{L}$$

This relationship leads to a duality in the analysis of the series and parallel circuits.

While the basic phenomena in these two circuits are simple, the solutions to the eqn's can be complicated.

To reduce the computational labor once the following steps are followed.

step 1 : Find the laplace transforms that appeare regularly in the operational solutions for problem.

step 2 : Determin their inverse transform.

step 3 : plot the inverse transforms in dimension less curves using η.

step 4 : Extract the solution's from this curves.

BASIC TRANSFORMS OF THE RLC CIRCUIT TRANSIENTS:

(parallel circuit)

⇒ This will help verify some of the assertions that have been made.

a confident and forceful statement.

⇒ consider the solution for the current in the inductor in the parallel circuit, when a switch is closed in the capacitor branch, allowing 'C' to discharge through 'R' and 'L'. Let this current be 'I_L'.

⇒ The current from the capacitor must be equal to the sum of the currents in the other two branches calling the capacitor voltage Vc.

(-ve sign is capacitor is discharge)

$$-C\frac{dV_c}{dt} = I_L + \frac{V_c}{R} \longrightarrow ①$$

$$V_c = L\frac{dI_L}{dt} \longrightarrow ②$$

eliminating Vc from eqn ① and ②

$$-CL\frac{d^2I_L}{dt^2} = I_L + \frac{L}{R}\frac{dI_L}{dt}$$

rewrite the above eqn.

$$\frac{d^2I_L}{dt^2} + \frac{1}{RC}\frac{dI_L}{dt} + \frac{I_L}{LC} = 0 \longrightarrow ③$$

where,

$$T_p = RC$$
$$LC = T^2$$

By taking laplace transform of equation ③ we have

$$\left(s^2 + \frac{s}{T_p} + \frac{1}{T^2}\right) i_L(s) = \left(s + \frac{1}{T_p}\right) I_L(0) + I_L'(0) \longrightarrow ④$$

when $I_L(0) = 0$, $I_L'(0) = \frac{V_c(0)}{L}$

now the eqn ④ becomes

$$i_L(s) = \frac{V_c(0)}{L} \frac{1}{s^2 + \left(\frac{s}{T_p}\right) + \left(\frac{1}{T^2}\right)}$$

The roots of $s^2 + \frac{s}{T_p} + \frac{1}{T^2} = 0$ are given by

$$s_1 = -\frac{1}{2T_p} + \frac{1}{2}\left(\frac{1}{T_p^2} - \frac{-4}{T^2}\right)^{1/2}$$

$$s_2 = -\frac{1}{2T_p} - \frac{1}{2}\left(\frac{1}{T_p^2} - \frac{4}{T^2}\right)^{1/2}$$

Then,

$$i_L(s) = \frac{V_c(0)}{L\left(\frac{1}{T_p^2} - \frac{4}{T^2}\right)^{1/2}} \left[\frac{1}{(s-s_1)} - \frac{1}{(s-s_2)}\right]$$

Take inverse transform.

$$\boxed{I_L(t) = \frac{V_c(0)}{L\left(\frac{1}{T_p^2} - \frac{4}{T^2}\right)^{1/2}} \left(e^{+s_1 t} - e^{s_2 t}\right)}$$

The solution for this circuit depends upon the values of s_1 and s_2. (s_1 and s_2) → are roots.

If $\frac{1}{T_p^2} > \frac{4}{T^2}$ then s_1 and s_2 are real.

If $\frac{1}{T_p^2} < \frac{4}{T^2}$ then s_1 and s_2 are complex.

These conditions can be expressed in terms of parameters η.

where, (is the ratio of the resistance 'R' to the square of the impedance)

$$\eta = \frac{R}{Z_0}$$

If $\frac{1}{T_p^2} = \frac{4}{T^2}$ Then $\eta = \frac{1}{2}$

If $\frac{1}{T_p^2} > \frac{4}{T^2}$ Then $\eta < \frac{1}{2}$

If $\frac{1}{T_p^2} < \frac{4}{T^2}$ Then $\eta > \frac{1}{2}$

when the roots are complex, $\eta > \frac{1}{2}$

$$S_1 = \frac{-1}{2T_p}\left(1 - j\left(4\eta^2 - 1\right)^{1/2}\right)$$

$$S_2 = \frac{-1}{2T_p}\left(1 + j\left(4\eta^2 - 1\right)^{1/2}\right)$$

now

$$I_L(t) = \frac{V_c(0)}{L} \frac{2T_p\, e^{-t/2T_p}}{\left(4\eta^2 - 1\right)^{1/2}} \sin\left(4\eta^2 - 1\right)^{1/2} \frac{t}{2T_p}$$

when the roots are real, $\eta < 1/2$

$$S_1 = \frac{-1}{2T_p}\left(1 - \left(1 - 4\eta^2\right)^{1/2}\right)$$

$$S_2 = \frac{-1}{2T_p}\left(1 + \left(1 - 4\eta^2\right)^{1/2}\right).$$

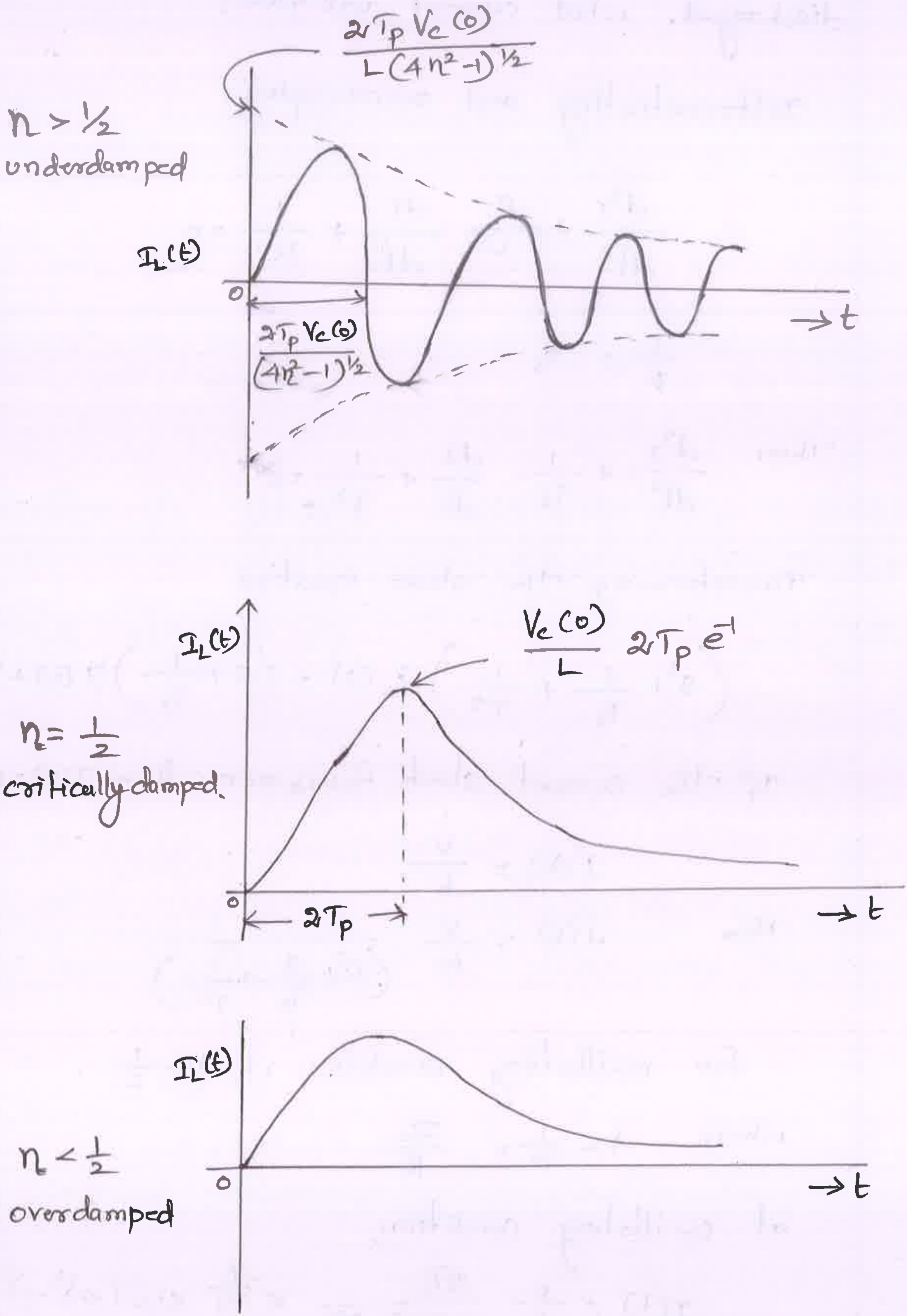
now

$$I_L(t) = \frac{V_c(0)}{L} \frac{2T_p\, e^{-t/2T_p}}{\left(1 - 4\eta^2\right)^{1/2}} \sinh\left(1 - 4\eta^2\right)^{1/2} \frac{t}{2T_p}$$

when $\eta = 1/2$

$$I_L(t) = \frac{V_c(0)}{L}\, t e^{-t/2T_p}$$

for different value of η, the inductor current is plotted, from this curve, we can extract the solution at any instant.



The inductor current in a parallel RLC circuit for different degree of damping.

SERIES CIRCUIT (RLC)

Suppose a battery of voltage is connected to series RLC circuit, in which the capacitor is initially discharged. what current will flow?

Differentiating and rearranging.

$$\frac{d^2I}{dt^2} + \frac{R}{L}\frac{dI}{dt} + \frac{1}{LC} = 0$$

$$\frac{L}{R} = T_s$$

Then $$\frac{d^2I}{dt^2} + \frac{1}{T_s}\frac{dI}{dt} + \frac{1}{T^2} = 0$$

Transforming the above equation.

$$\left(s^2 + \frac{s}{T_s} + \frac{1}{T^2}\right) i_s(s) = \left(s + \frac{1}{T_s}\right) I(0) + I'(0)$$

If the current starts from zero then $I(0)=0$

$$I'(0) = \frac{V}{L}$$

Then $$i(s) = \frac{V}{L}\frac{1}{\left(s^2 + \frac{s}{T_s} + \frac{1}{T^2}\right)}$$

for oscillatory condition if $\lambda > \frac{1}{2}$

where $\lambda = \frac{1}{z} = \frac{Z_0}{R}$

at oscillatory condition,

$$I(t) = \frac{V}{L}\frac{2T_s}{L(4\lambda^2-1)^{1/2}} e^{\frac{-t}{2T_s}} \sin(4\lambda^2-1)\frac{t}{2T_s}$$

when, $\lambda = \frac{1}{2}$ critical damping condition

$$I(t) = \frac{V}{L} t e^{-t/2T_s}$$

when,

$\lambda < \frac{1}{2}$ (i.e) overdamped condition

$$I(t) = \frac{V}{L} \frac{2T_s}{(1-4\lambda^2)^{1/2}} e^{-\frac{1}{2T_s}} \sin (1-4\lambda^2)^{1/2} \frac{t}{2T_s}$$

for this current equations curves are plotted for various values of λ. from this curve 3 the solution can be extracted at any instant.

obtained by a special.

STUDY OF TRANSIENTS IN SYSTEM PLANNING

Transient ⇒ Transient is a condition in which voltage, current, frequency, and power flucturate with respect to time.

Transient time ⇒ The time taken for the circuit to change from one steady state to another steady state is called the transient time.

⇒ Transient (momentary) staying in a place for a short time only.

⇒ Transient in a power system for a short period from few μsec to 1 sec.

Electrical Transient:

away from a place ✓ Good condition evidence

① ⇒ An electrical transient is the outwards manifestations q a sudden change in circuit conditions, as when a switch open or closes or a fault occurs on a system Sudden load rejection (loss q load), disconnection q Inductive load, or connection q capacitive load, unsymmetrical faults.

② ⇒ Transient occurs in any circuit having R,L,C, parameters.

③ ⇒ The degree q the transients will differ from case to case.

⇒ ④ The transient period is usually very short. The fraction q their operating time that most circuits spend in the transient condition is in-significant compared with the time spent in steady state.

⑤ ⇒ Then these transient periods are extremely important, for it is at such times that the circuit components are subjected to the greatest stresses from excessive current or voltages.

⇒ In extreme cases damage results. This may disable (damage) a machine, shut down a plant, or black out a city, depending upon the circuit involved.

⇒ For this reason a clear appreciation of events taking place during transient periods is essential for a full understanding of the behavior of electrical circuit.

Importance of study of Transient.

⇒ studying power system transients is very important because it helps in understanding the behaviour of the system under transient condition.

system planning.

⇒ so that we can take suitable measure during system planning, system design and system operation.

⇒ so as to prevent damage of electrical equipments or Interuption of power supply to the consumer.

UNIT- II

SWITCHING TRANSIENTS

Basic concept of switching transient: (Introduction)

⇒ A transient is initiated whenever there is a sudden change of circuit conditions; this most frequently occurs when a switching operation take place.

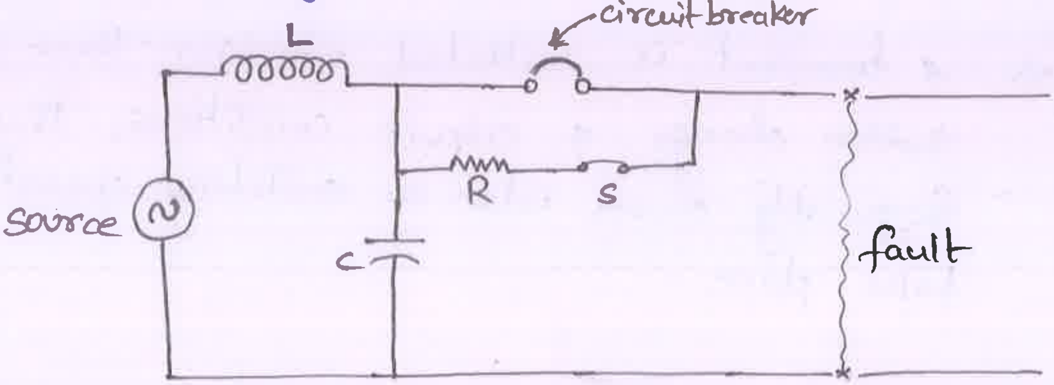
⇒ The closing of a switch or circuit breaker to energize a load

The opening of a breaker to clear a fault.

⇒ This provides an opportunity to discuss some of the practical details of switching transient.

RESISTANCE SWITCHING :

In certain types q circuit breakers the contacts are shunted by resistors.



circuit breaker, with shunt resistor, clearing a fault.

L → System Inductance
C → stray capacitance
R → Resistor used to modify ~~there~~ transient.

⇒ such resistor serve one q two functions. In a multi break circuit breaker they may be used to help to distribute the transient recovery voltage more uniformly across the several breaks.

⇒ Alternatively, their purpose is to reduce the severity q the transients recovery voltage at the time q interruption by introducing damping into the oscillation.

⇒ A resistor q comparatively high ohmic value
sufficient
can suffice for the first q these duties.

⇒ The only requirement can be that it's resistance be low compared with the reactance q the capacitance shunting the breaks at the frequency q the recovery transient.

capacitive Reactive $= \frac{1}{\omega C}$
$\omega = 2\pi f$

⇒ To reduce the transient recovery voltage requires a considerably lower value of resistor.

⇒ when the fault current proper has been switched, a residual current will remain flowing through 'R'.

⇒ This must be interrupted subseqently by opening the auxiliary interrupter 'S'.

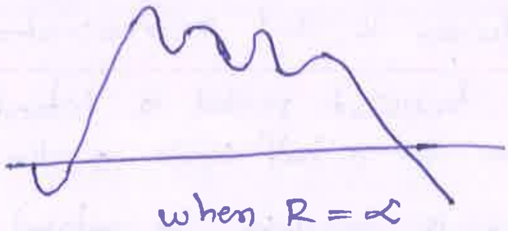
⇒ so how to determine the value of 'R' to achive a desired modification of the transient recovery voltage in a particular situation.

⇒ The value of resistance 'R' is equal to or less than $\frac{1}{2}\sqrt{L/c}$, the oscillatory nature of transient will not be there and rate of rise of restriking voltage will be within permissible limits of circuit breaker.

For critical damping

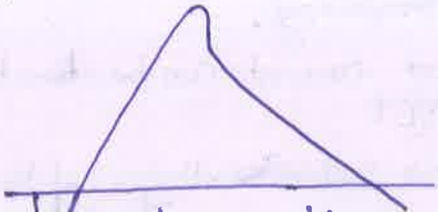
$$R = \frac{1}{2}\sqrt{\frac{L}{c}}$$

For different values of 'R' the oscillations are ~~observed~~ observed.

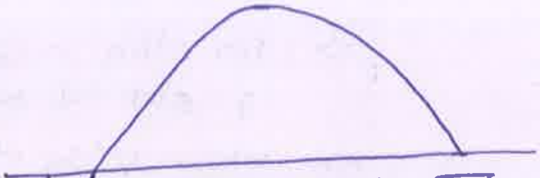


when $R = \infty$
↳ no limit

note:
The principle of superposition can be used to calculate transient recovery voltage.

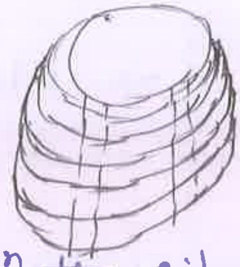


when $R > \frac{1}{2}\sqrt{L/c}$
↳ high



when $R < \frac{1}{2}\sqrt{L/c}$

Low inductance ribbon - wound shunt resistor for an air blast circuit breaker.

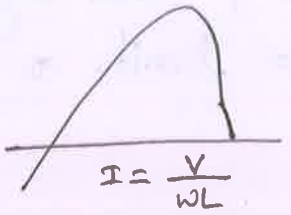


⇒ This type of resistor has a lower ohmic value so that it can effect an even grater reduction in the transient voltage peak in the situation just examined.

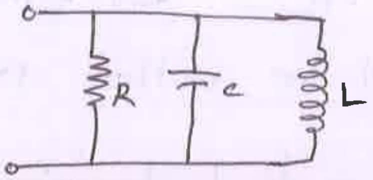
⇒ The resistor is fashioned to reduce its inductance. Any inductance will decrease its effectivenes.

⇒ when the resistor current is subsequently interrupted a second transient will be initiated

EQUIVALENT CIRCUIT FOR THE RESISTANCE SWITCHING PROBLEMS.



⇒



⇒ Viewed from the switch contacts, the circuit elements R, L and c appear in parallel.

⇒ Let us suppose that the fault current being interrupted is symmetrical. It will be given by V/ωL. The problem thus reduces to that represented symbolically.

⇒ The transient period of intrest is usually short compared with the time for a half cycle of the injected current wave.

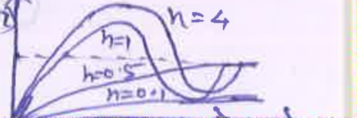
⇒ This is because the natural frequency of the current is usually much higher than the powerfrequency.

⇒ For this reason the injected current can be treated as a ramp, of slop V/L amp/sec or $I = V/L\,t$

⇒ where 'V' is the instantaneous system voltage at the moment of interruption.

$$\therefore V(s) = \frac{1}{s(s^2 + \frac{s}{T_p} + \frac{1}{T^2})} \cdot \frac{I'}{c}$$

* Different values of $\eta = \frac{R}{Z_0}$ for charge in R, the η is modified, hence the



EQUIVALENT CIRCUIT FOR INTERRUPTING the RESISTOR CURRENT

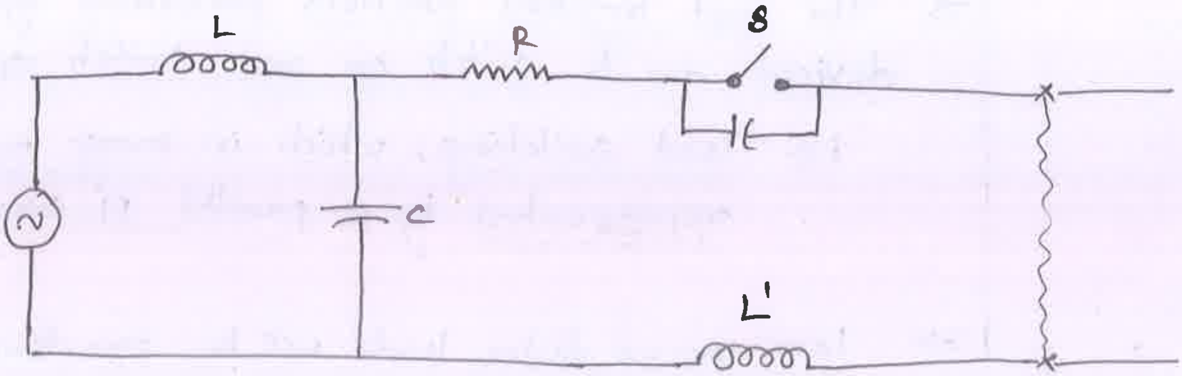


fig: Resistance switching - equivalent circuit for interrupting the resistor current.

⇒ when the resistor current is subsequently interrupted a second transient will be initiated.

⇒ To study this its effect it is necessary to introduce the capacitance 'c' shunting the resistor break and if it is significant, the inductance of the local loop to the fault.

⇒ This appears to be a more complicated circuit than we have analyzed so far, but it can be solved along similar lines.

LOAD SWITCHING:

⇒ The most frequent functions performed by some switching devices are to switch on and switch of loads.

i.e. load switching, which in many instance can be represented by a parallel RL circuit.

⇒ Low power factor loads will be predominantly inductive.

⇒ High power factor loads predominantly resistive.

⇒ when such a (high power factor) load is switched of, the effective capacitance of the load becomes important in determining the form of the transient generated.

EQUIVALENT CIRCUIT: (Transient produced when switching a load)

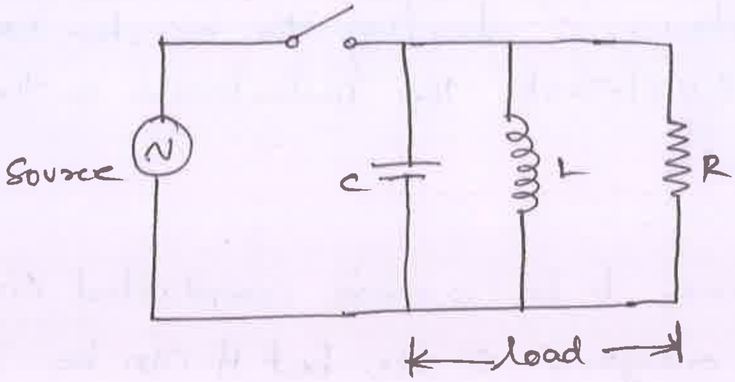


fig: Simple equivalant circuit.

- * The load represented has relatively high power factor.

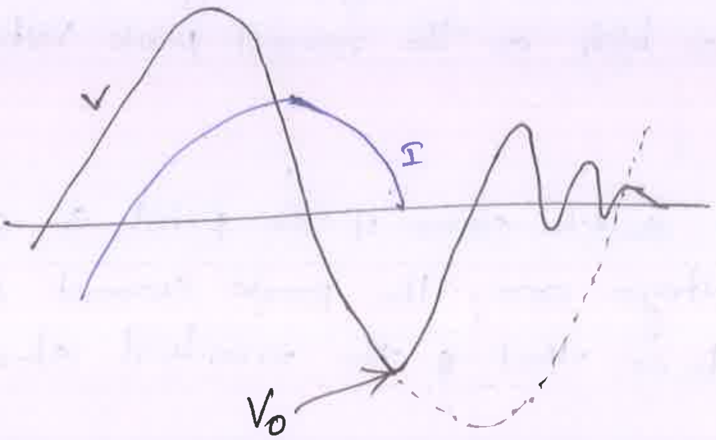
to bring to an end.

- * when the current extinguishes, the instantaneous voltage (and therefore the voltage) across the load, is V_0

- * now 'c' will be charged to this voltage (V_0) and will subsequently discharge through 'L' and 'R'.

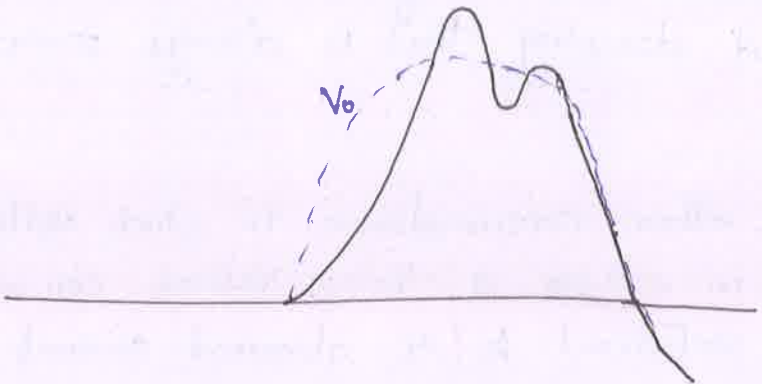
Wave forms for transient voltage across the load switch:

Transient voltage across the load:



In this above fig shown as a damped oscillatory discharge and is in fact a damped cosine wave.

Transient voltage across the switch.



The effect of power factor is interesting to observe. As the power factor improves, the current comes more and more into phase with the voltage, so Vo' decreases. At Vo' voltage is zero when current is zero, so their is no transient at all.

Thus power factor is the major controlling influence in the magnitude of this switching transient.

note: Damping factor reduces the potential peak voltage, but "C" aswell as R and L is important here because all three determined ....

NORMAL AND ABNORMAL SWITCHING TRANSIENTS:

⇒ When a switch opens in a single-phase circuit, it is possible for the recovery voltage to reach a value twice as high as the normal peak voltage of the system.

This phenomeno is called voltage doubling

⇒ When a switch closs if the point of closing occurs at a voltage zero, the peak current can reach a value twice that of the eventual steady-state current

⇒ note: (The above two points are considered normal current and voltage transients)

⇒ But in practical circuits, this theoretical magnitudes of current and voltages are not achived, because of circuit damping that is always present.

note: (The damping is on account of circuit resistance)

⇒ Some other circumstance in which voltage and current far in excess of these values can arise. such transients are referred to as abnormal current and voltage transients.

(eg → for capacitance switching ↓ (an unloaded or lightly loaded Tr. line is switched off by the breaker at the sending end)

⇒ There are several possible ways in which these abnormal disturbances can occure, but they all have one thing in common: They all inlove the traping ← storing of energy somewhere in the circuit and its subsequently release.

(It will cause 4 times 5,6 times the normal voltage)

⇒ This could be due to charge on a capacitor or line and/or current in an inductor. If a circuit is completely quiescent ← initiated (current & voltage) when a transient is initiated, the transient will be a normal transient.

stored Energy } $L = \frac{1}{2} LI^2$

$c = \frac{1}{2} cv^2$

⇒ of course it could be that this transient stores energy in the system so that subsequently when a second transient is initiated, it can be abnormal.

⇒ so abnormal transient have considerable practical significance.

CURRENT CHOPPING

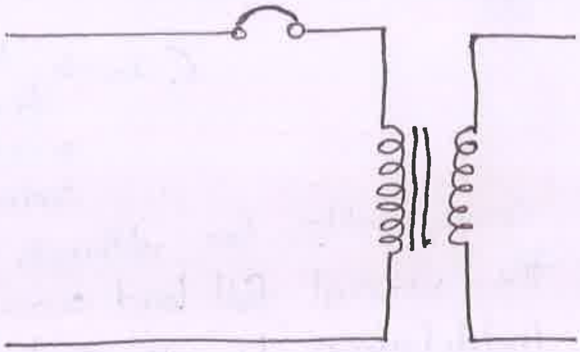
✓ (Although current chopping is a potential hazard, practical considerations of power circuit system remove the danger)

⇒ when a relatively small current is interrupted by a circuit breaker, overzealous action of it's arc suppression devices may cause the current to be brought to zero abruptly and prematurely ahead of the normal zero

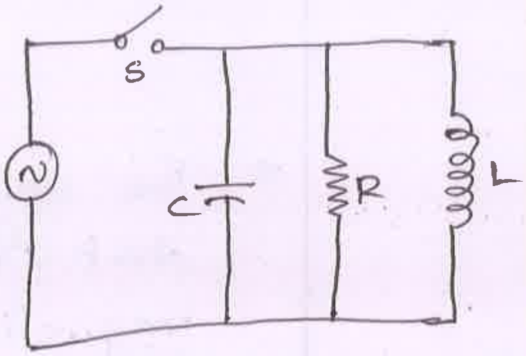
protecting

sudden

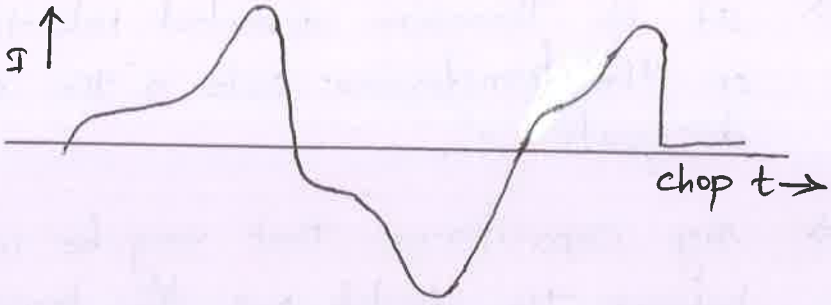
occurring or done before the proper time



(a) The circuit breaker and an unloaded Transformer



(b) The effective equivalent circuit.



(c) The current.

⇒ This is refforred to as "current chopping".

⇒ It can give rise to an abnormal overvoltage by virtue of the magnetic energy associated with the current being trapped (storing) in the circuit.

⇒ This phenomenon often is observed when the no-load or magnetizing current of a transformer is being switched.

⇒ The transformer winding and is associated with a certain amount of magnetic energy, most of which resides in the transformer core:

magnetizing Inductance.

$$Energy = \frac{1}{2} L_m I_0^2$$

(I_0 → suppose that at the time the chop occurs the instantenous current I_0).

⇒ This may be considerable, for although "I" is only about 1% of the normal full load current the magnetizing inductance 'Lm' is quit high.

⇒ The current cannot cease suddenly in such an inductive circuit, yet it has no complete path through the switch.

⇒ It is therefore diverted into the system capacitance on the transformer side of the switch, which is designate 'c'.

⇒ Any capacitance that may be in the connections between the switch and the transformer.

⇒ when the current is diverted into this capacitance the energy of the magnetic field of the transformer is transfered to the electric field of the capacitance.

⇒ If this capacitance is known, it is possible to calculate the voltage to which "c" will be charged:

$$\boxed{\cancel{\tfrac{1}{2}} C V^2 = \cancel{\tfrac{1}{2}} L_m I_0^2} \leftarrow \text{energy balance.}$$

$$V^2 = \frac{L_m}{c} I_0^2$$

$$V = \sqrt{\frac{L_m}{c} \quad I_0^2}$$

$$V = I_0 \sqrt{\frac{L_m}{c}} \quad \text{or} \quad V = I_0 \left(\frac{L_m}{c}\right)^{1/2} \text{———} ①$$

⇒ This state that the peak voltage reached across the capacitor, and therefore across the winding, is given by the product of the instantaneous current chopped and the surge impedance of the transformer.

Example:
A 1000-KVA, 13.8-kV T/f of the kind found in substation of Industrial plants. The magnetizing current is typically 1.5A Thus.

$$L_m = \frac{V}{\omega I_m} = \frac{13,800}{\sqrt{3} \times 377 \times 1.5} = 14\ H$$

note! In 3ϕ system

$$V = \frac{1}{\sqrt{3}}$$ times, to line voltage

per phase voltage

$\omega = 2\pi f$
$\omega = 2\pi$
$\omega =$

The effective capacitance will vary depending on the type of winding and the insulation, wether oil, air but can be in the range 1000-7000 pF

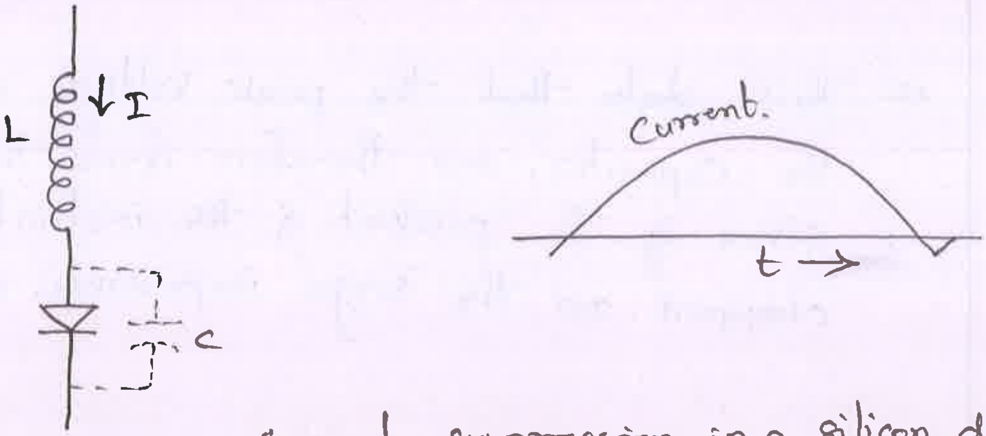
(note! If the current is chopped at the peak and is forced to divert into the capacitance)

⇒ It is worthwhile to examine the current chopping transient more formally because it is a good exercise in the use of the generalized damping curves.

⇒ Consider the circuit (b) suppose the currents in the CRL branch are I_c, I_R and I_L, respectively, and let the value of the chopped be I_0. Immediately after the chop occurs there is no path through the switch, so that thereafter the sum of the currents in the three branches must be zero.

$$I_c + I_R + I_L = 0$$

CURRENT SUPPRESSION:



Current suppression in a silicon diode.

⇒ At the end of a half cycle of conduction in a diode, carriers remaining in the junction region continue to allow current to flow that is, the current momentary reverses.

⇒ But the flow of this reverse current sweeps the carriers from the junction and returns devices to its blocking state.

⇒ This change of Impedance can be very rapid so that this so-called clean-up current collapses very quick.

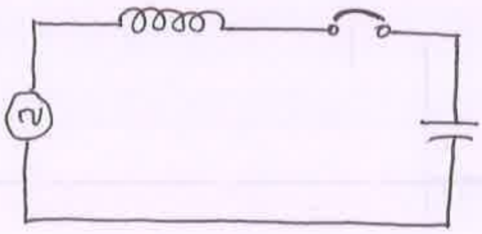
⇒ If the circuit is inductive the stored magnetic energy is transferred to the relatively small capacitance of the diode junction, across. which it develops a considerable voltage.

⇒ To prevent the diode destroying itself a small snubber capacitor can be placed across the device to provide an additional sink for the energy.
drop

CAPACITANCE SWITCHING:

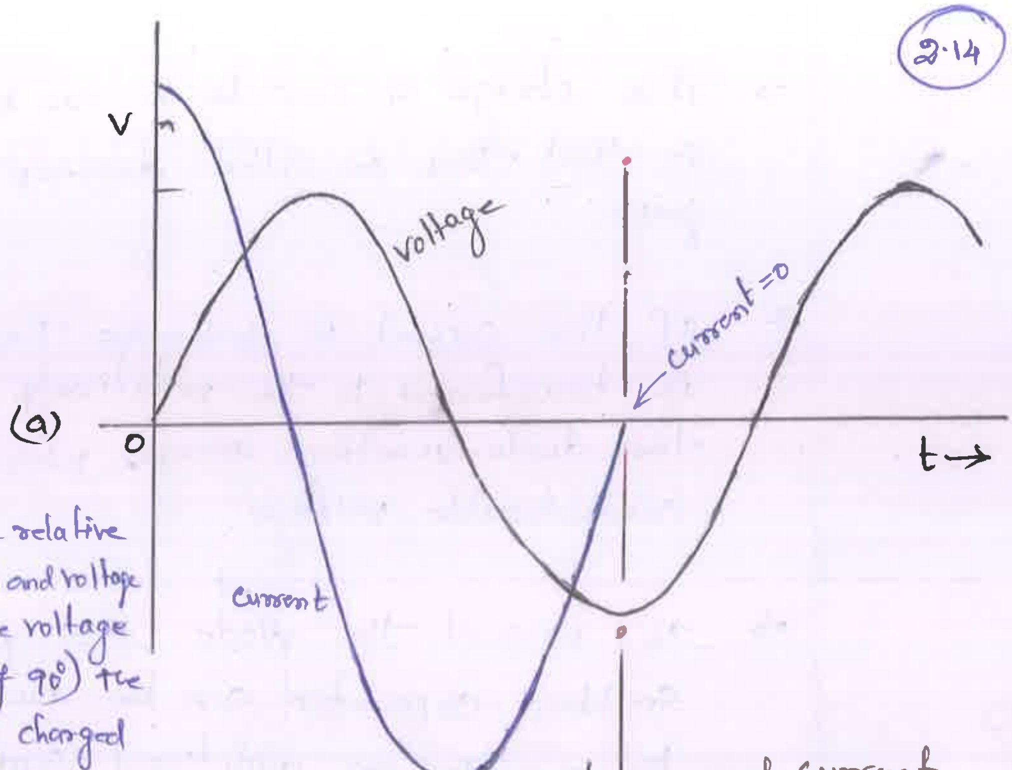
⇒ The switching of capacitance as when a long open
disconnected
circuited line or cable is dropped or when a capacitor bank is disconnected, can present some potentially hazardous conditions.
dangerous

⇒ And has traditionally been a source of considerable
having to do with.
chagrin to the switch gear engineer.
faild



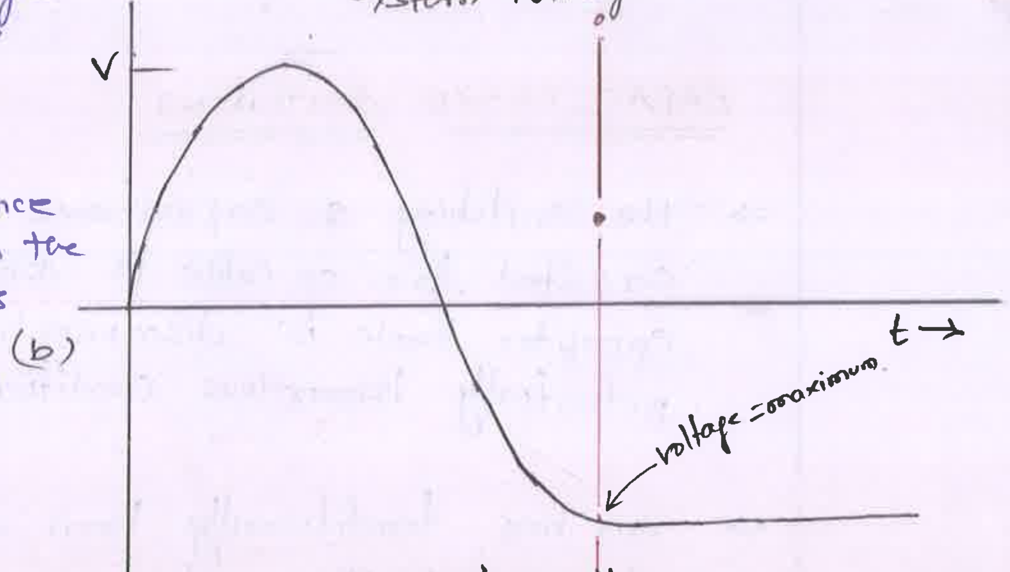
capacitance switching.

⇒ The above diagram depicts events occurring before and
present by drawing
after such a switching operation, which in this case was performed successfully.



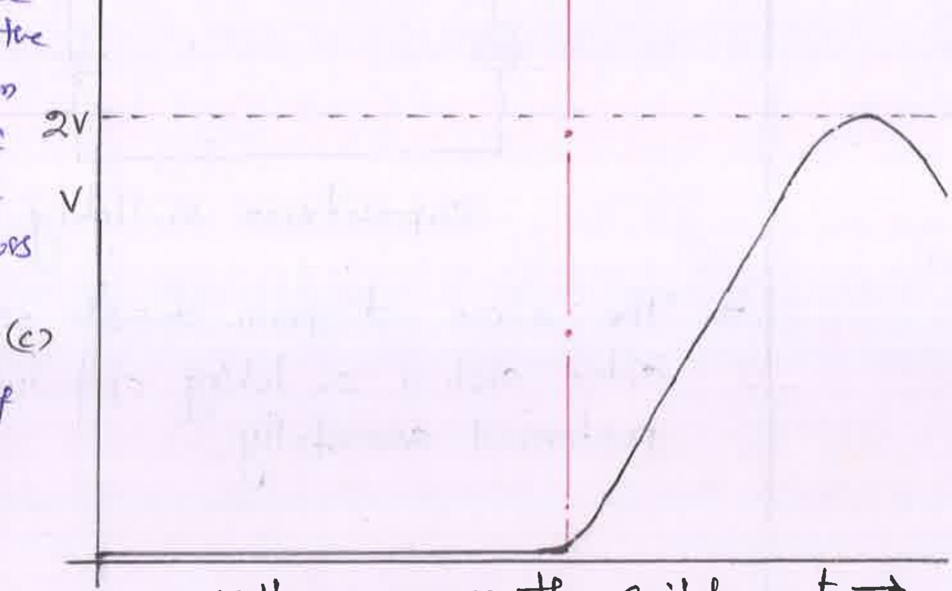
System voltage and current.

⇒ Because of the relative phase of current and voltage (Current leads the voltage by approximately 90°) the capacitor is fully charged to maximum voltage when the switch is Interrupts.



capacitor voltage

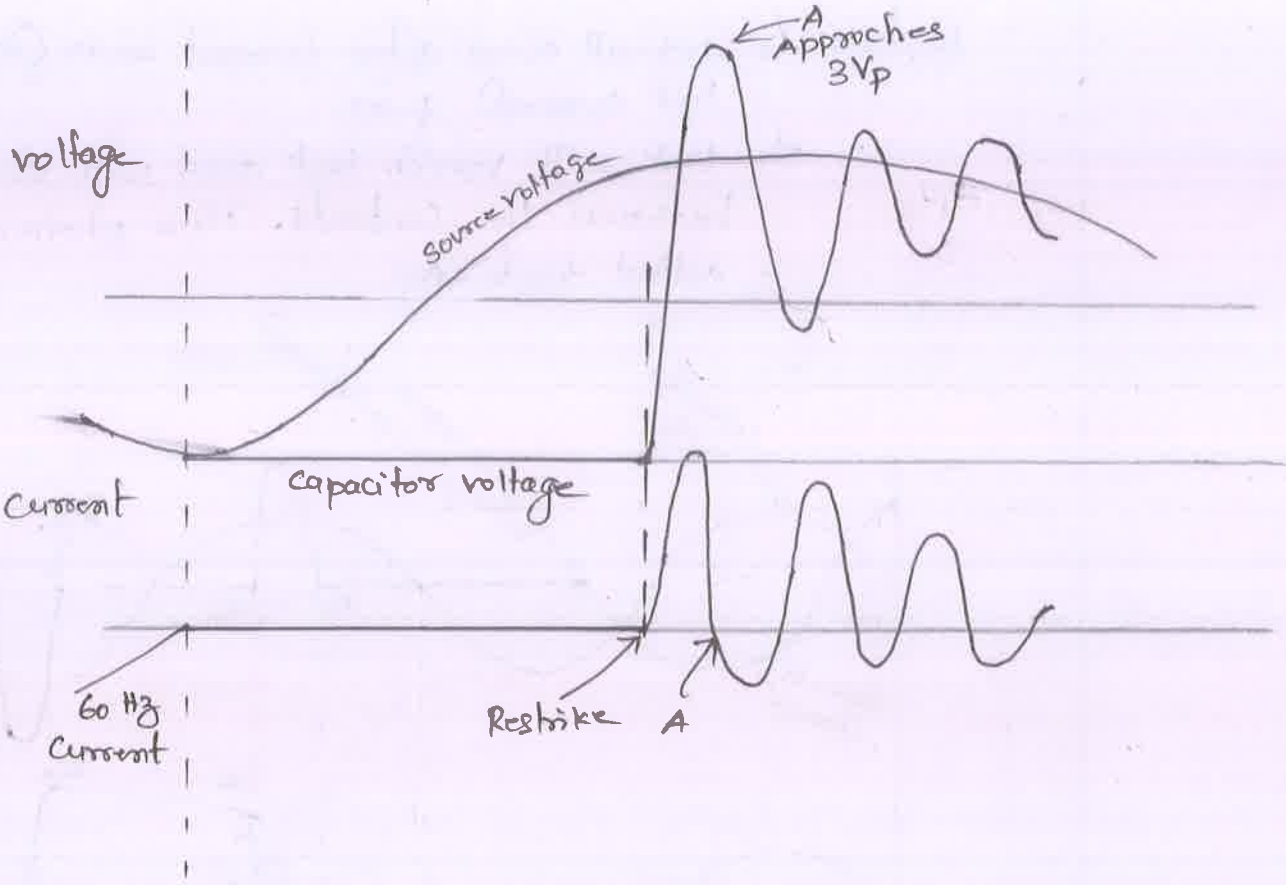
⇒ The capacitance now isolated from the source, retains its charge (as shown in fig b)



Voltage across the switch

⇒ As a consequence of this trapping of the charge (it can be seen from fig c) that half a cycle after current zero the voltage across the switch reaches a peak value of 2V, which is potentially dangerous.

CAPACITANCE SWITCHING WITH A RESTRIKE



capacitance switching with a restrike at peak voltage.

⇒ The initial clearing, the traping of the charge on the capacitor, and the subsequent restrike (are shown above fig)

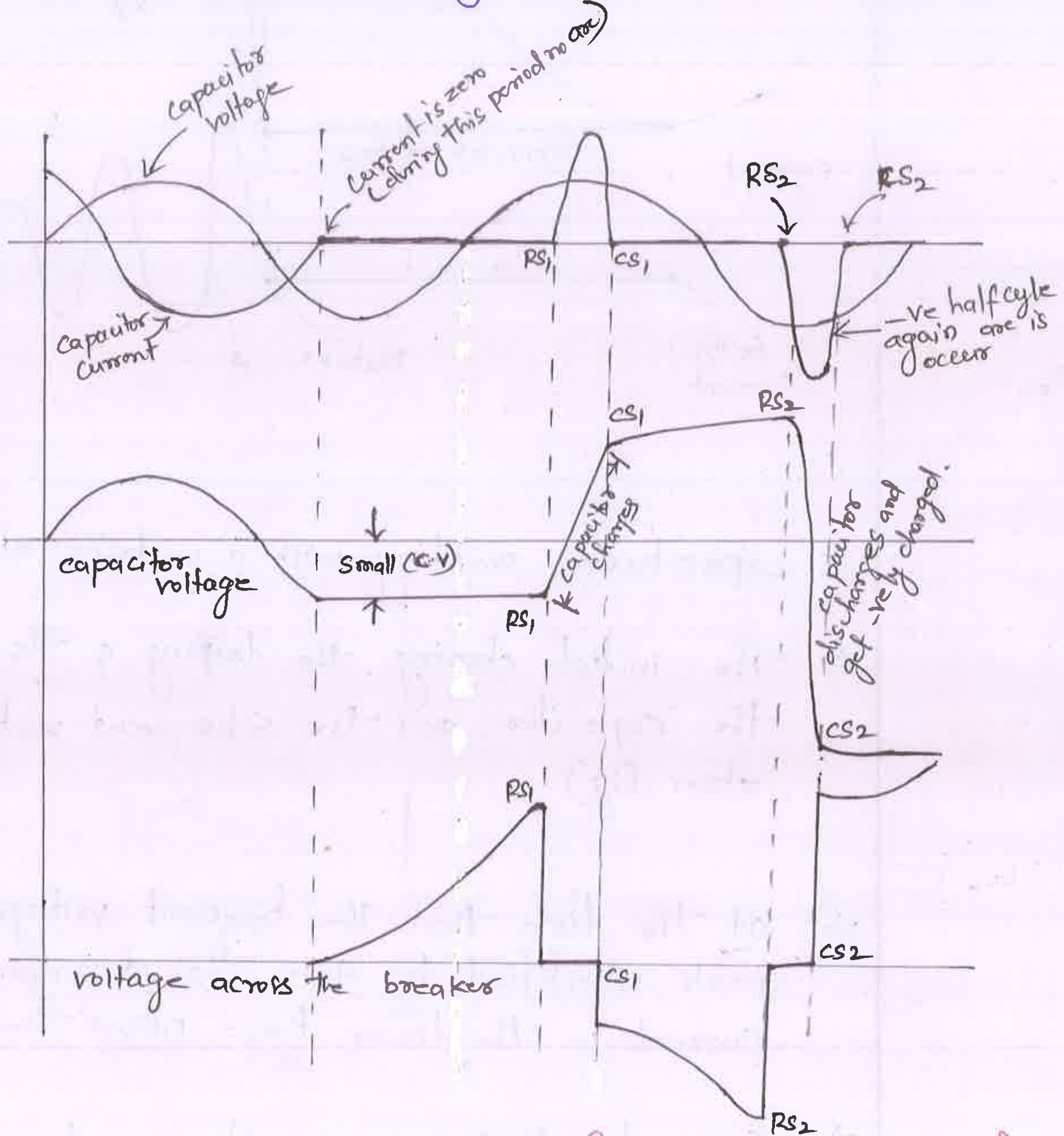
⇒ At the time that the transient voltage reaches its peak identified by A in the diagram, the transient current in the lower trace passes through zero.

⇒ Some breakers are capable of interrupting at such a current zero. If it is happens the high voltage is left trapped on the Capacitor. and many times

CAPACITANCE SWITCHING WITH MULTIPLE RESTRIKES

Restrikes ⇒ Arck will occur after current zero (arck is nothing but current) I → 0

⇒ Arck will vanish but arck will strik again between the contacts. This phenomenon is called restriking.



CV ⇒ capacitor voltage

note! Current is +ve mean it charge is flowing into the capacitor

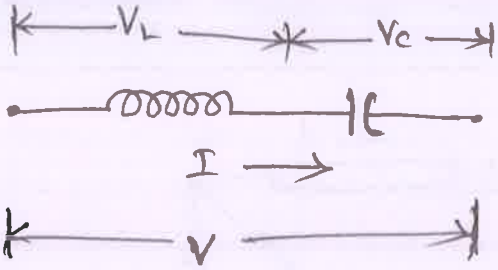
⇒ In the sequence drawn in wave form the RS represent sequential restrikes and the CS subsequent clearings.

FERRO RESONANCE:

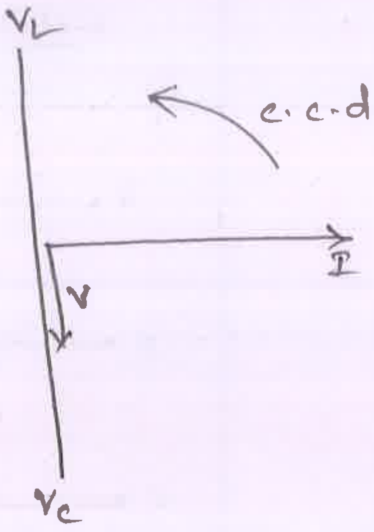
highly sensitive

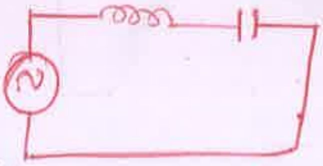
⇒ In this phenomenon of series resonance, a very high voltage can appear across the element of a series LC circuit when it is excited at or near it's natural frequency.

supply current.



(a)

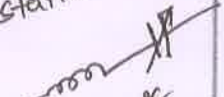




simple series Resonance.

(b)

Eg: In Radio when you are tuning the Radio at one stage we will get the particular radio station at the time the circuit is sensitive to the particular station frequency.



tank capacitor.

f_s ⇒ supply frequency

supply frequency matches the natural frequency the system will be under resonance

$f_s = f_n$ resonance condition.

$$f_{natural} = \frac{1}{2\pi\sqrt{LC}}$$

If the frequency of the current passing through the circuit is same as its natural frequency Then their will be resonance

Eg:

resonance.

$f_r = f_n$.

under resonance condition get a clear signals due to frequency matches.

⇒ The above diagram (a) it is evident that the voltages V_L and V_C add to give the applied voltage V.

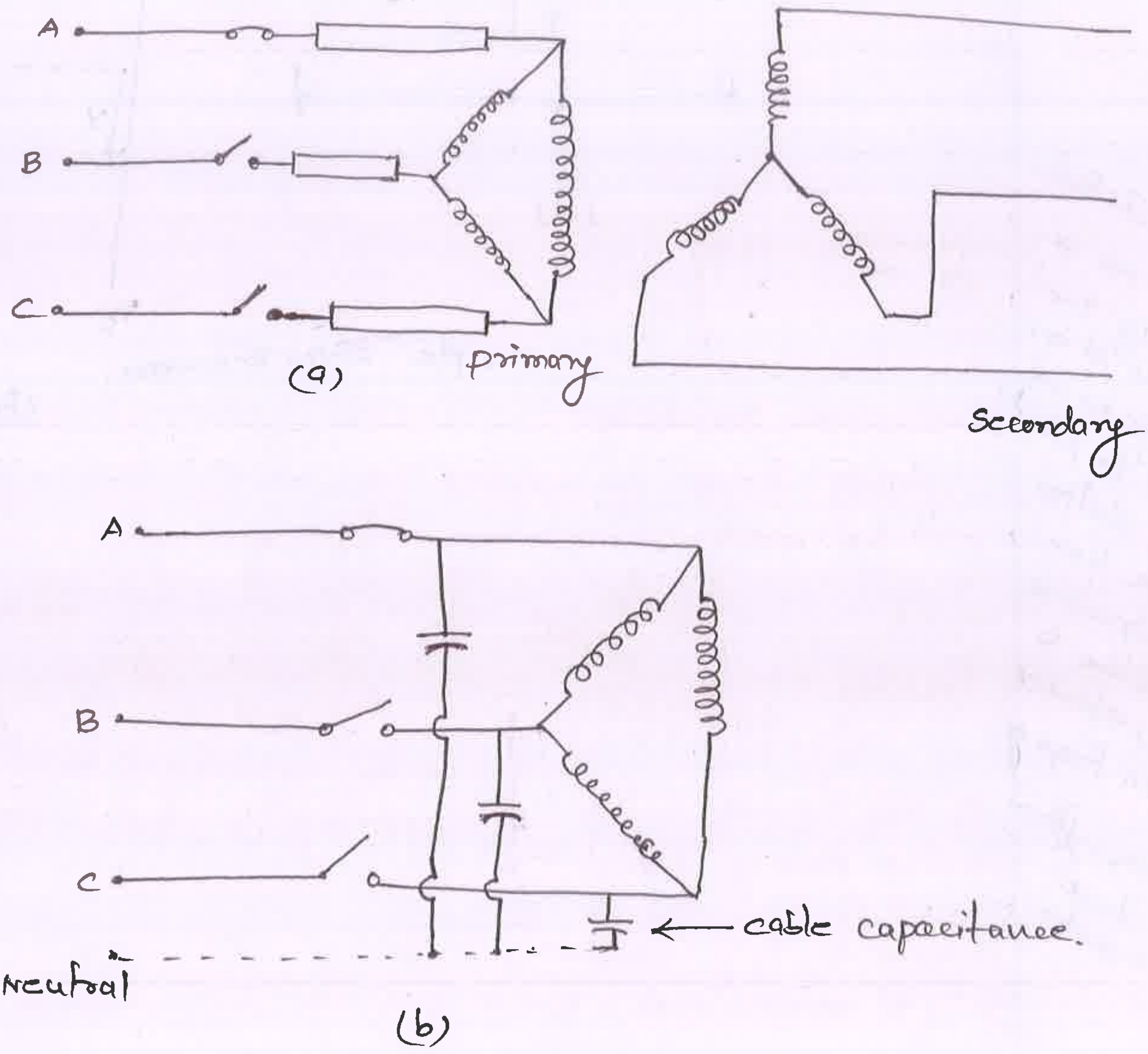
⇒ But because the voltage across the inductor leads the current in phase by 90° and the capacitor voltage lags the current by the same amount.

⇒ It is seen that both V_L and V_c can far exceed V_s voltage conditions of this kind can be sustained and are therefor more properly called dynamic over voltages, rather than transients.

← to some extent, fairly.

← don't call them transient.

CIRCUMSTANCE IN which FERRORESONANCE CAN OCCUR



Circumstance in which ferroresonance can occur.

⇒ The phenomenon is referred to as ferroresonance, since the inductance involved is usually iron cored, and more often than not a transformer. the nonlinear character of an iron-clad inductance also introduces some peculiar effects.

note: The iron is involved so this is called ferroresonace.

Example will be described to Explain how the phenomenon may arise:

⇒ A switch used to energize and de-energize the primary of a transformer. The two are interconnected by a length of cable, a common practice in distribution systems, where the switching device may be mounted at the top of a pole and the transformer on a nearby pad at ground level.

⇒ The switch is shown with only one pole closed. this condition will prevail momentarily on as the first pole completes it's circuit.

⇒ Some circuits of this kind use a fuse in series with the switch to interrupt fault current.

⇒ The condition (in fig 'a') can be sustained, therefore if two of the fuses had blown.

⇒ It might appear at first that with only one pole of the switch closed the transformer is not energized.

⇒ In a way this is true. There nevertheless remains a path for current through two of the phase winding and the cable capacitance.

⇒ It is this current that can produce resonance and impress excessive voltages across the transformer and the cables on the unenergized phases.

⇒ It can, for instance, cause lightning arresters connected at the 'B' and 'C' bushings of the transformer to operate.

⇒ If the condition is sustained, repeated operation can destroy the arrestors.

UNIT-III

LIGHTNING TRANSIENTS.

LIGHTNING TRANSIENTS:

Lightning ⇒ The occurrence of a high-voltage electrical discharge between a cloud and the ground or with in a cloud accompanied by a bright flash.

Transient ⇒ That electrical transients are the outward manifestation of a sudden change in circuit condition due to the physical phenomenon of lightning.

The IEEE - EEI committee report issued outages on EHV Lines.

⇒ In it we find the statement that lightning is the gratest ~~signal~~ single cause (Responsable) of outages accounting (T.lines) for about 26% of the outages on 230-kV circuits and about 65% of the outages on 345 kV.

(Discharge is physical phenomenon.)

⇒ This conclusion was reached after analyzing data obtained over a 14 year period from some 42 operating companies in the united states and Canada.

⇒ The data were gathered from 386 high-voltages circuits (T.o. circuits.), representing 25,499 miles of transmission line.

⇒ Also over a 14-Years period over 50,000 fault reports were analyzed on circuit up to and including 33 kV. It was found that 47% of all these incident, including those of unknown origin, were caused by lightning.

⇒ The chief causes of overvoltage in electrical systems, namely lightning overvoltages. Lightning overvoltages is a natural phenomenon.

⇒ The magnitude of lightning voltages appearing on transmission lines does not depend on line design and hence lightning performance tends to improve with increasing insulation level, that is with system voltage.

⇒ Lightning overvoltages have to be considered while (mean time) for ultra high voltages (>400kV), the chief condition for design considerations.

(NATURAL) CAUSES FOR OVERVOLTAGES :- LIGHTNING PHENOMENON

Responsable

Is beyond our control

⇒ Lightning phenomenon is a peak discharge in which charge accumulated in the clouds discharges into a neighbouring cloud or to the ground.

⇒ The electrode seperation i.e. cloud - to - cloud or cloud - to - ground is very large, perhaps 10km or more.

⇒ The mechanism of charge formation in the clouds and their discharge is quite a complicated and uncertain process.

THEORIES OF CLOUD FORMATION
(or)
CHARGE FORMATION IN THE CLOUDS:-

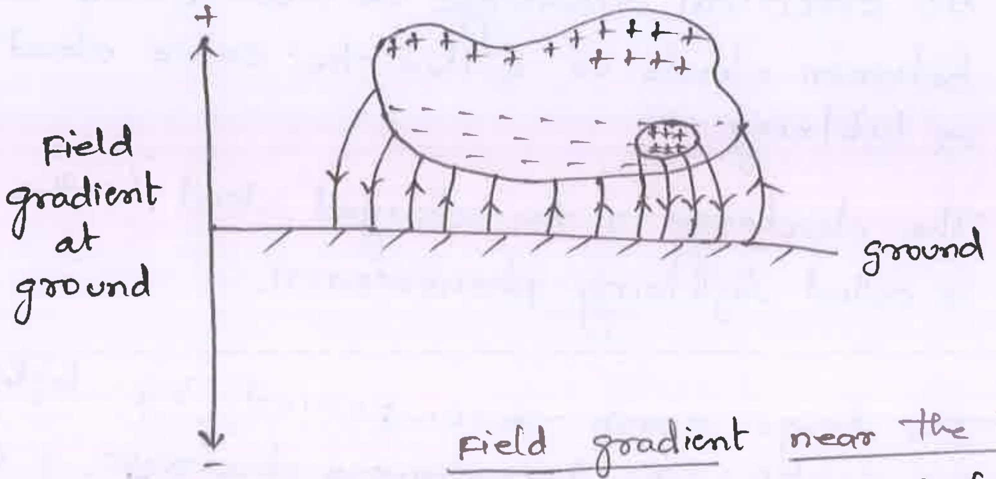
⇒ The formation or accumulation of charge in the clouds are too many and uncertain. But during thunderstorms, positive and negative charges becomes seperated by the heavy air currents with ice crystals in the upper part and rain in the lower parts of the cloud.

⇒ This charge seperation depends on the height of the cloud's, which range from 200 to 10,000 m, with their charge centres probably at a distance of about 300 to 200 m.

⇒ The volume of the clouds that participate in lightning flashover are uncertain, but the charge inside the cloud may be as high as 1 to 100 C. clouds may have a potential as high as 10^7 to 10^8 V with field gradients ranging from 100V/cm with in the cloud to as high as 10 KV/cm at the initial discharge point.

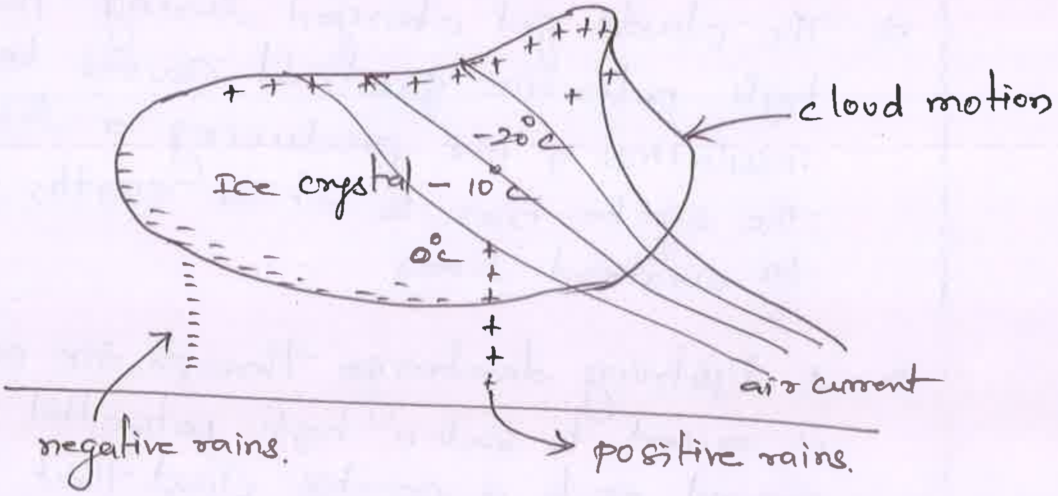
⇒ The energy associated with the cloud discharges can be as high as 250 kWh.

A probable charge distribution model is given below with the



Field gradient near the ground corresponding to the probable charge distribution in a cloud.

According to Simpson Theory:



- ⇒ Air currents travel above 600 cm/s
- ⇒ The temperature is 0°c at about 4km from the ground and may reach -50°c at about 12 km heigh.
- ⇒ But water droplets do not freeze as soon as the temperature is 0°c
- ⇒ They freeze below -40°c only as the solid particles on which crystalline ice pattern develop and grown.

⇒ According to the Reynold's theory which is based on experimental results the hail packets get -ve charged when impinged upon by hamer ice crystal.

MECHANISM OF LIGHTNING DISCHARGES.

⇒ An electrical discharge between cloud and earth, between clouds or within the same cloud is known as lightning.

⇒ The discharge q the charged cloud to the ground is called lightning phenomenon.

⇒ The large spark accompanied by light produced by an abrupt, discontinuous discharge q electricity through the air, from the clouds generally under turbulent conditions q atmosphere is called lightning

⇒ The clouds get charged during thunder-storms, the high potential gradient causes breakdown q insulation q air producing a lightning stroke. the stroke tries to hit the earth. It is attracted by overhead lines.

⇒ A lightning discharge through air occurs when a cloud is raised to such a high potential with respect to the ground or to a nearby cloud that the air breakdown and insulating property q the surrounding air is destroyed. This raising q potential is caused by factional effects due to thunder storms or atmospheric disturbance acting on the particles forming the cloud.

⇒ The cloud and the ground form two plates q a gigantic capacitor whose dielectric medium is air. During thunder storms, positive and negative charges are seperated by the movement q air currents forming ice crystals in the upper layer q cloud and rain in the lower part.

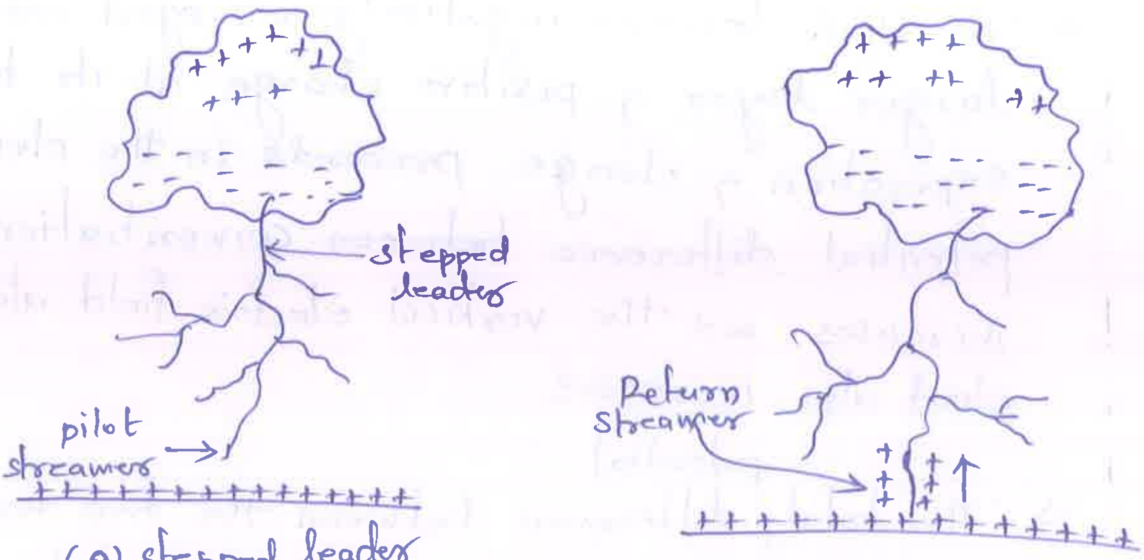
⇒ The cloud becomes negatively charged and has a larger layer of positive charge at its top. As the seperation of charge proceeds in the cloud, the potential difference between concentrations of charges increases and the vertical electric field along the cloud also increases.

⇒ The total potential difference between the two main charge center's may vary from 100 to 1000 MV. only a part of the total charge is released to the ground by lightning, and the rest is consumed in inter cloud discharges.

⇒ As the lower part of the cloud is negatively charged, the ground gets positively charged by induction. Lightning discharge requires breakdown of the dielectric medium, i.e., air between the negatively charged cloud and the positively charged ground.

Mechanism:

⇒ when a charged cloud passes over the earth, it induces equal and opposite change on the earth below. As depicted in the figure (a) (b) the charge acquired by the cloud increases, the potential between cloud and earth increases and therefore, gradient in the air increases. when the potential gradient is sufficient to breakdown the surrounding air, the lightning stroke starts.



(a) stepped leader (b) Return streamer.

fig: Lightning mechanism.

⇒ At this, instant, a streamer called a 'pilot streamer' starts from the cloud towards the ground which is not visible. The current and velocity associated with the streamer is about 100 amperes and 0.15 m/μs (i.e. 0.05) percent of the velocity of the light). Depending upon the air surrounding the pilot streamer is branched into several paths, forms a stepped leader as depicted in fig (a)

⇒ This process continues until one of the leaders strikes the ground. when one of the stepped leaders strike the ground, an extremely bright return steamer propagates upward from the ground to the cloud following the same path as the main channel of the downward leader as shown in fig(b).

⇒ The conventional directions of the current in the stepped leader and return streamer are the same. The current varies between 1KA and 200KA and the velocity of propagation of the streamer is about 10% of the light.

3.6.c

⇒ It is here that the negative charge of the cloud is being neutralised by the positive induced charge on the ground. It is instant which rise to the lightning flash which is visible with our naked eye.

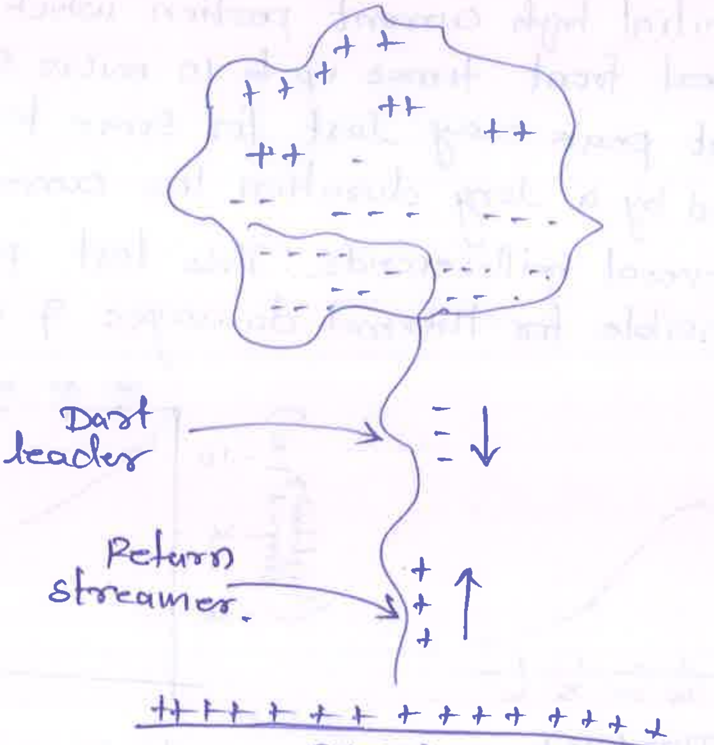


Fig (c)

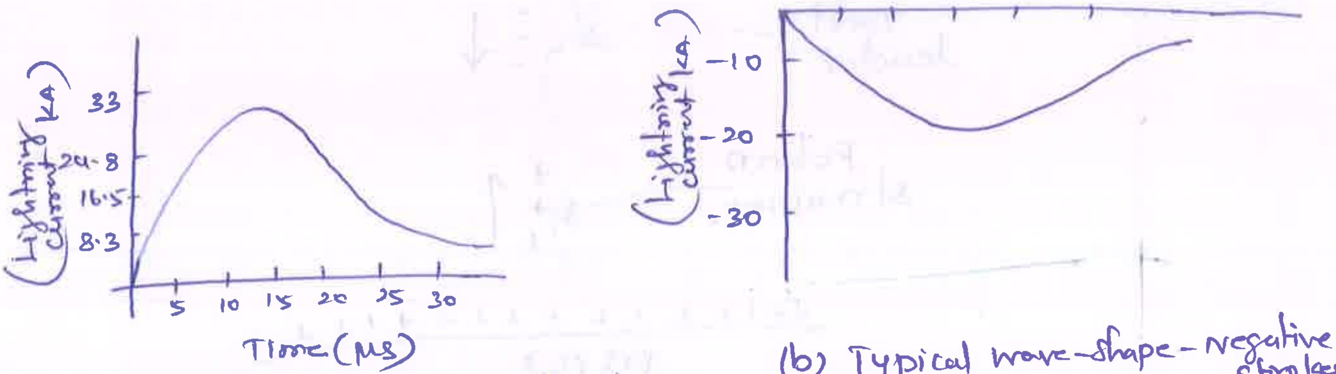
⇒ After the neutralization of the most of the negative charge on the cloud any further discharge from the cloud may have to originate from another charge centre within the cloud near the already neutralized charge centre. This streamer of discharge is called a dart leader as show in fig(c)

⇒ The velocity of this streamer is about 3% that of light. Though the discharge current in the return streamer is relatively large but since it continues only for a few microseconds, it contains less energy and hence this streamer is called a cold lightning stroke. The dart leader is called a hot lightning stroke because even though the current in this leader is relatively smaller, it contains relatively more energy since it continues for some milliseconds.

CHARACTERISTICS OF LIGHTNING STROKES.

Typical lightning current characteristics.

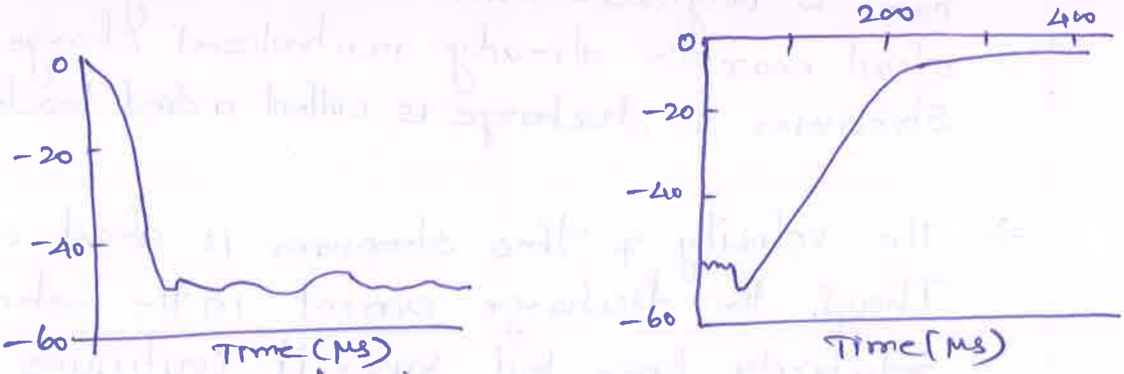
⇒ In fig(1), the lightning current characteristics indicate and initial high current portion which is characterised by short front times up to 10 micro seconds. the high current peak may lost for some tens of micro seconds followed by a long duration low current portion lasting for several milliseconds. This lost portion is normally responsible for thermal damages of equipments connected.



(a) Typical waveshape-positive stroke

(b) Typical wave-shape-negative strokes.

Fig(1) Typical Lightning waveshapes.



(a) Long duration low current event

(b) Long duration high current portion.

Fig(2) Lightning wave shape on transmission line.

⇒ Fig(2) illustrate the characteristics of lightning occurs on a transmission line. Fig 2(a) indicates the long duration low current portion and Fig 2(b) indicates the long duration high current portion.

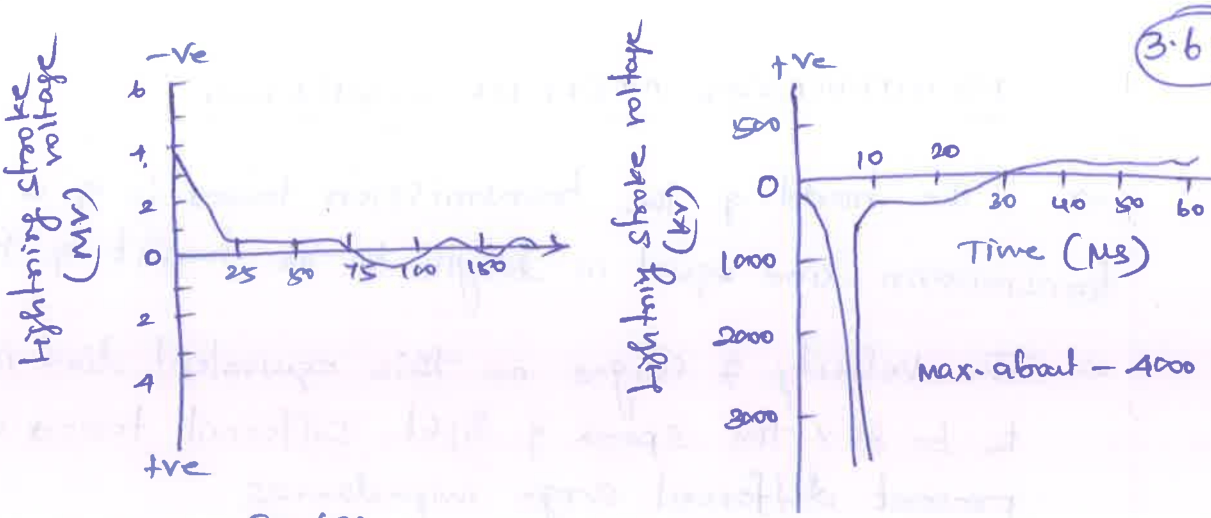


Fig (a)

Fig (b)

Fig (3) Typical lightning stroke voltage on transmission line without ground.

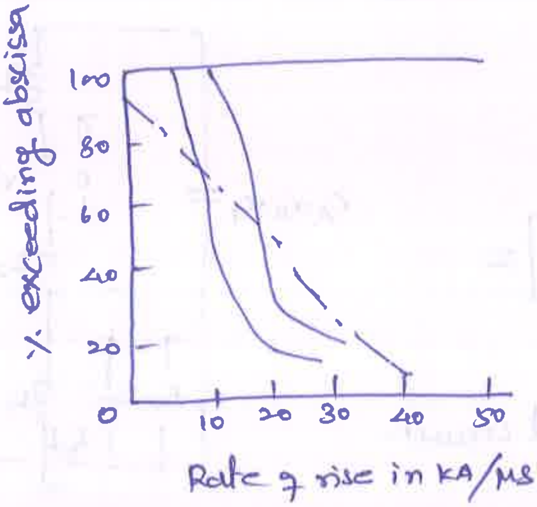


Fig (4) Rate of rise of current of lightning strokes

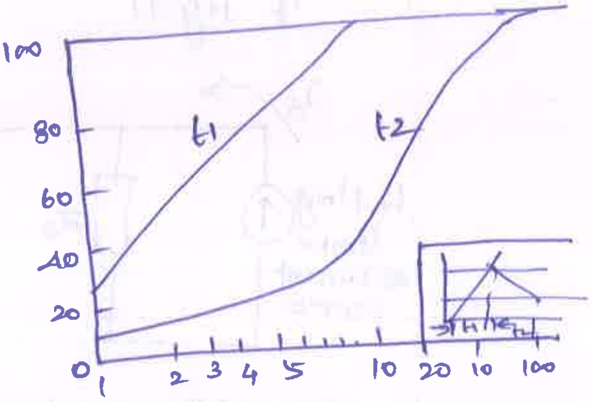
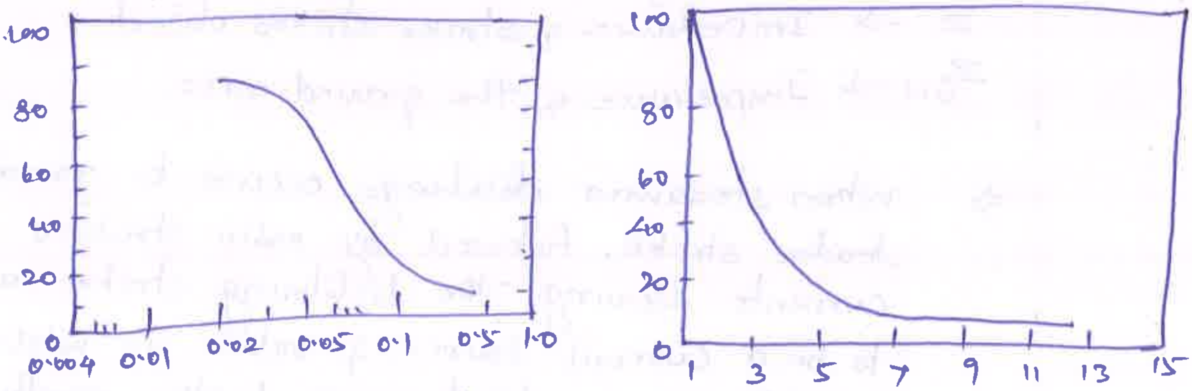


Fig (5) Lightning strokes - wave front and wave tail times.



(a) Time interval between successive strokes

(b) Number of strokes in lightning discharge

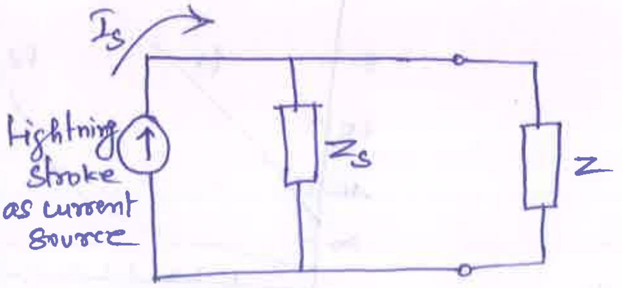
Fig (5) Average curves - case study.

MATHEMATICAL MODEL FOR LIGHTNING

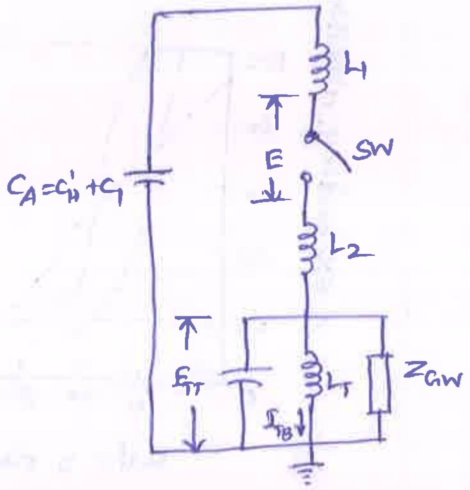
⇒ The model of the transmission tower is of a vertical transmission line equal in length to the height of the tower.

⇒ The velocity of surges on this equivalent line is assumed to be 85% the speed of light. Different towers designs present different surge impedances.

⇒ A useful way to compute the voltage generated by a lightning stroke is to consider the lightning stroke as a current source, which arrangement is a simple variation of fig(1)



Fig(2) Thevenin's equivalent circuit - Lightning surge.



fig(1) Lumped parameter equivalent

Z_s → Impedance of lightning channel

I_s → Lightning stroke.

Z → Impedance of stroke strikes object

Z_{GW} → Impedance of the ground wire.

⇒ When streamer discharge occurs to ground by first a leader stroke, followed by main strokes with considerable currents flowing, the lightning stroke may be thought to be a current source of value I_s with a source impedance Z_s discharging to the earth.

⇒ The Thevenin equivalent current generator shown in fig(2)

⇒ If the lightning stroke strikes an object of impedance Z, the voltage built across.

⇒ The magnitude of surge voltage is of

$$V = I Z \quad \text{———} ①$$

$$V = I_s \frac{Z Z_s}{Z + Z_s} \quad \text{———} ②$$

In other terms,

$$V = I_s \frac{Z}{1 + \left[\frac{Z}{Z_s}\right]} \; ③ \Rightarrow I_s \frac{Z}{\frac{Z_s + Z}{Z_s}} = I_s \frac{Z Z_s}{Z + Z_s}$$

⇒ In case of the stricken object is combination of the tower and ground wire, the surge impedance.

$$Z = \frac{1}{2} Z_{GW}$$

$$\therefore \; Z = \frac{Z_{GW}}{2} \longrightarrow ④$$

substitute the z in eqn ③

$$V = \frac{I_s Z_{GW}}{2} \times \frac{1}{1 + \left[\frac{Z_{GW}/2}{Z}\right]}$$

$$V = \frac{I_s Z_{GW}}{2} \times \frac{1}{1 + \left[\frac{Z_{GW}}{2} \cdot \frac{1}{Z_s}\right]}$$

$$V = \frac{I_s Z_{GW}}{2} \times \frac{1}{1 + [Z_{GW}/2 Z_s]}$$

$$\boxed{V = \frac{I_s Z_{GW}}{2 \times 1 + [Z_{GW}/2 Z_s]}}$$

⇒ If a lightning stroke current as low as 10,000 A strikes a line of 400 Ω surge impedance, it may cause an over-voltage of 4000 kV. This is a heavy over-voltage and causes immediate flashover of the line conductor through its insulator strings.

Iso Keraunic Level:

The incidence of lightning strokes on transmission lines and sub-station is related to the degree of thunderstorm activity.

It is based on the level of "Thunderstrom days" (TD) known as "Isokeraunic Level" defined as the number of days in a year when thunder is heard or recorded in a particular location.

FACTORS CONTRIBUTING TO GOOD LINE DESIGN:

⇒ In order to reduce the hazard that lightning poses to power system, certain factors that determine the line performance. (must be understood)

* The objective of good line design is to reduce the number of outages caused by lightning

* First we try to keep the incidence of strokes to the system to a minimum.

* Then we try to minimize the effects of those strokes that do not terminate on the system.

* Lightning problems can be eliminated it all transmission was through tunnels atlest 20 feet under the ground.

a passage that is built under ground.

* Tall towers are more vulnerable than low goal-post-like structures. In order to prevent the lightning, some adequate clearance must be provided.

at risk (exposed to being attack or harme)

* High ground impedance or tower footing resistance are to be avoid.

* High surge impedance in ground wires, tower structures are to be avoided.

PROTECTION USING GROUND WIRES:

Protection offered by ground wires:-

Ground wire ⇒ It is a conductor run parallel to the main conductor of the transmission line supported on the same tower and earthed at every equally and regularly spaced towers.

⇒ It is run above the main conductor of the line.

⇒ The ground wire shield's the transmission line conductor from induced charges from clouds as well as from a lightning discharge.

Function of Ground wires:

⇒ Ground wire system can dramatically reduce the number of outages.

sudden and striking.

⇒ The first function of ground wires is to shield the phase conductors.

a broad piece of armour held for protection against

⇒ Then to serve in lieu of those conductors as the termination of the lightning stroke.

PROTECTION OFFERED BY GROUND RODS:

⇒ If the surge impedance of the tower is reduced the surge voltage developed is also reduced considerably.

highly skilled

⇒ This is accomplished by providing driven ground rods and counter poise wires connected to tower legs at the tower foundation.

Ground Rods:

⇒ They ara a number of rods about 15mm diameter and 2.5 to 3m long, driven into the ground.

operated

⇒ They are usually made of galvanized iron or copper bearing steel.

coated with a protective layer of zinc

⇒ The spacing of the rod, the number of rods, and the depth to which they are driven depend on the desired tower footing resistance. with 10 rods of 4m long and spaced 5m apart, connected to the legs of the tower, the dynamic or effective resistance may be reduced to 10Ω

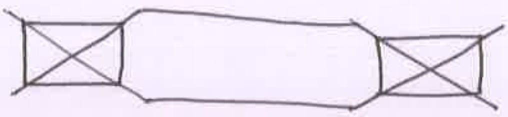
zinc → (a silvery white metallic chemical element which is used to making brass and for coating iron and steel as a protected against corrosion

COUNTER – POISE WIRES:

(i)

single parallel continuous.

(ii)



Double parallel continuous.

(iii)

Radial

⇒ These are wires buried in the ground at a depth of 0.5 to 1.0 m running parallel to the transmission line conductors and connected to the tower legs.

⇒ These wires are 50 to 100m long and are effective than driven rods. the surge impedance of the tower may be reduced to as low as 25Ω

⇒ The depth does not affect the resistance.

OTHER PROTECTIVE DEVICES:

- * Expulsion gap - on the line itself
- * protector tubes - on the line itself
- * surge arresters - At the line terminations, Junction of lines, substation etc.
- * Rod Gaps, - At the line terminations, Junction of lines, substation etc.

TOWER - FOOTING RESISTANCE

(Resistance experinced by the current entering ~~by~~ the ground through the tower)

⇒ Tower footing resistance is the resistance offered by tower footing to the dissipation of current.

abnormal current

⇒ The effect of a ground wire depends to a large extend on the tower footing resistance. The tower top potential depends on this resistance.

Impostance.

SIGNIFICANCE OF TOWER FOOTING RESISTANCE

⇒ A low value of tower footing resistance results in less voltages stress across line insulation.

⇒ A tower footing resistance of 20Ω for EHV lines and 10Ω for HV lines provides sufficient lightning protection. (based on practical experiences)

cost effect (low still better but it will deficult)

(Depends on Insulation on EHV line)

⇒ Tower footing resistance depends on

(i) Types of electrode configuration employed

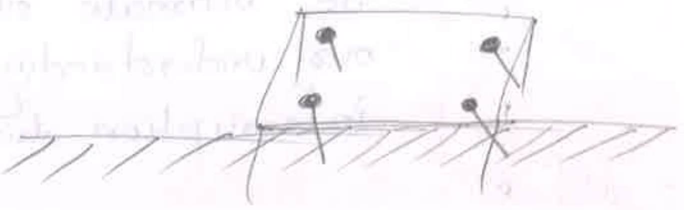
(ii) Solid resistivity. (Electrical property)

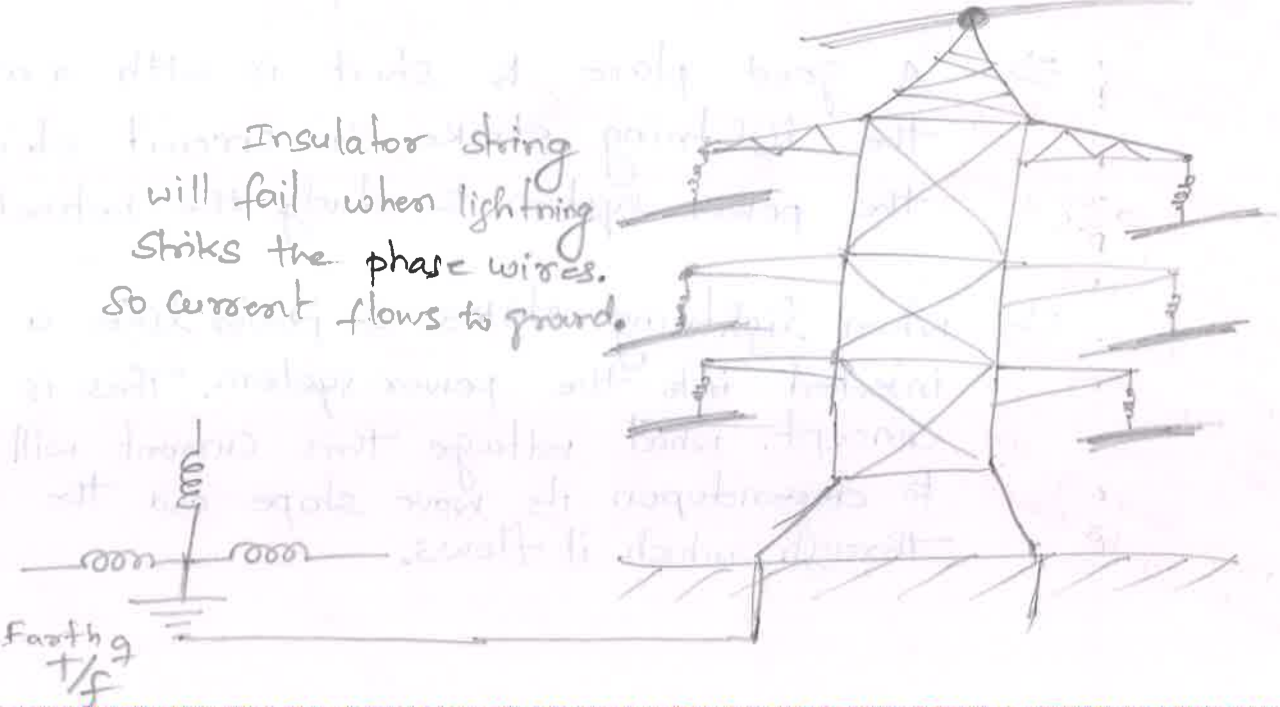
$R = \rho \frac{l}{a}$

ρ → (Resestivity of soil)

l = (length of ground path)

(a = area of cross section of ground)





Insulator string will fail when lightning striks the phase wires. So current flows to ground.

what is the link between lighting & power system for Designing Purpose.

INTRACTION BETWEEN LIGHTNING AND POWER SYSTEM

⇒ The occurance of a high-voltage electrical discharge between a cloud and the ground or with in a cloud accompaind by bright flash.

(so concerned for most part with lightning phenomaon relation to power system)

⇒ we have been concerned for the most part with lightning ~~bye bad~~ as a phenomenon and we will consider it in relaction to the power system.

discharge is physical phenomenon.

Collecting Data statistices and making measurement and efficacy reduce of the outages of lightning

⇒ Some have been concerned simply with collecting ~~statically~~(statistics) some with making measurements, still others with evaluating the efficasy of the various means that have been employed to reduce the outages due to lightning, and others have tried to probe more deeply in to the physical nature of the problem.

Investicated

Reduce the system outages & Reducing the chance of Insulation flash over.

⇒ The ultimate objective in all cases has been improve our understanding, so that the incidence of service interruption due to lightning will be reduced.

ultimate objective to improve our understanding and incidence of service intruption due to lightning reduced.

⇒ ~~when lightning strikes a power line a current is injected into the power system.~~

In this intraction a good place start ~~for~~ the model for lightning

⇒ A good place to start is with a model for the lightning stroke, in circuit elements of the power system to study the Intraction.

~~I~~ Lightning strike power lines a current injected to P-S is very useful concept. what voltage this current will give rise.

⇒ when lightning strikes a power line a current is injected into the power system. This is very useful concept. what voltage this current will give rise to dependupon its wave shape and the impedance through which it flows.

Impedance of the power will be concern.

for example:

If it is a tower that is struck, the impedances of the tower will be of concern.

The voltage drop down the tower will appear across the line insulation.

If this is excessive flashover of the insulation will occur and a fault will be placed on the system.

attempt to Avoid the flash over

Ground wires its serve several purpuse

In an attempt to avoid this one or more ground wires are often strung on the towers above the line conductors. These serve several purposes.

They shield the phase conductors that is frequently they are themselves struk instead of the phase conductors.
past and post part (of strike)
inplace

⇒ In the event of a stroke to a tower the tower impedance is paralleled by the surge impedance of the ground wires, which extend away in both directions, so that the total impedance is reduced and the tower top potential is correspondingly less.

⇒ Finaly, there is considerable electric and magnetic coupling between the ground wires and the power line properly, which tends to limit the voltage that can be established between them, there by reducing the chance of Insulation flashover in the manner described.

⇒ It is a small concern if the top of the distance tower flies up to a high potential if the line conductors do like wise.

⇒ It is true that these disturbance travel as waves along the line and must ultimately reach a terminal where they will be impressed across the equipment at that point.

⇒ So that damage to terminal equipment becomes likely only when the lightning strikes close to the terminal.

⇒ The tower current must of couse flow in the ground . . .

UNIT- IV

TRAVELING WAVES ON TRANSMISSION LINE COMPUTATION OF TRANSIENTS

Travelling waves:

⇒ An electrical transmission line, the voltages, current, power and energy flow from the source to a load at a located distance, propagating as electromagnetic waves with a finite velocity.

produce

limited

⇒ Hence it takes a short time for the load to receive the power.

⇒ The current flow is governed mainly by the load Impedance, the line charging current at power frequency and voltage.

⇒ If the load impedance is not matched with the line impedance, some of the energy transmitted by the source is not obserbed by the load and it is reflected back to the source.

⇒ At every point on the line, there are two waves present and the resulting voltage or current is equal to the sum of the transmitted and reflected quantities. These waves are called travelling waves.

note: Reflection coefficient $\alpha = \frac{V_{ri} \text{ (Reflected component)}}{V_i \text{ (Incident component)}}$

⇒ exactly matched no reflection.

what do you mean by travelling waves?

⇒ Any disturbance on a transmission line (or) system such as sudden opening or closing of line, a short circuit or a fault result in the development of overvoltage or over current at that point

Eg: 1 − 0.3

transmitted = 0.7 ⇒ 70 %

30 % is Reflected.

produce

⇒ This disturbance propagates as a travelling wave to the ends of the line (or) to a termination, such as a substation.

⇒ usually these travelling waves and high frequency disturbance and travel as waves.

⇒ They may be reflect, transmitted attenuated or distorted during propagation until the energy is absorbed.

Damages caused by travelling waves.

1. High peak (or) crest voltage q the surge may cause flashover in the internal winding (so spoil the winding insulation)

   sharp

2. The steep wave front q the surge may cause internal flashover between interns q Transformer 1/4)

3. High peak voltages q the surge may cause external flashover, between the terminals q the electrical equipment, which may result in damage to insulators.

4. The steep wave front resulting into resonance and high voltages may cause internal or external flashover q an unpredicable nature causing doubling up q the oscillation in the electrical apparatus.

Note: The load impedance and line impedance exactly matched no reflection wave.

Reflection coefficient for voltage} $\alpha = \frac{Z_2 - Z_1}{Z_1 + Z_2}$

$Z_1 \rightarrow$ surge impedance on source side,
$Z_2 \rightarrow$ surge impedance on load side.

Eg: 1 - 0·3
transmitted = 0·7 ⇒ 70% wave transmitted, 30% is reflected

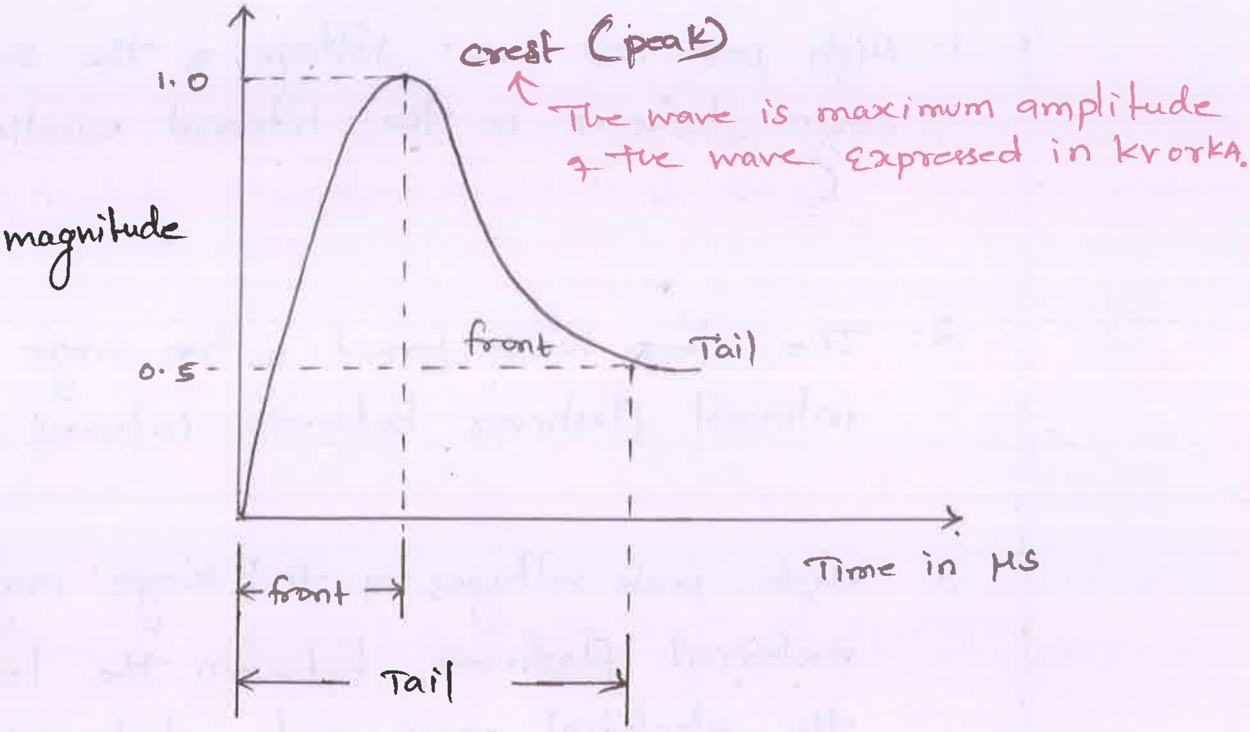
Reflection coefficient $\alpha = \frac{V_{r}}{V_{i}}$ ← reflected component / ← incident component.

Conclusion: (i) Thus any sudden clossing q switch will cause a voltage surge as well as current surge to produce (propogate) along the line at the speed q the light.

(ii) After few sec steady state condition will be reached and the entier line acquir constant voltage.

(iii) If the load is their the load current will attain steady state.

SPECIFICATION OF TRAVELLING WAVES:



1. crest q wave

2. Front q a wave.
   ⇒ The front q the wave is the portion q the wave before crest and is expressed intime from beginning q the wave to the crest value in ms or μs.

3. Tail q the wave.
   ⇒ Tail q the wave is portion beyond the crest. Expressed in time (μs) from beginning q the wave to the point where (The wave has reduced to 50 % q its value at crest)

4. polarity.
   ⇒ It is polarity q crest voltage or current.
   A positive wave q 500 kv crest, 1 μs front time and 25 μs tail time (will be represented as +500/1.0/25.0)

Reaction (qualatative treatment only) 4.5

TRANSIENT RESPONCE OF SYSTEM WITH SERIES AND SHUNT LUMPED PARAMETER'S

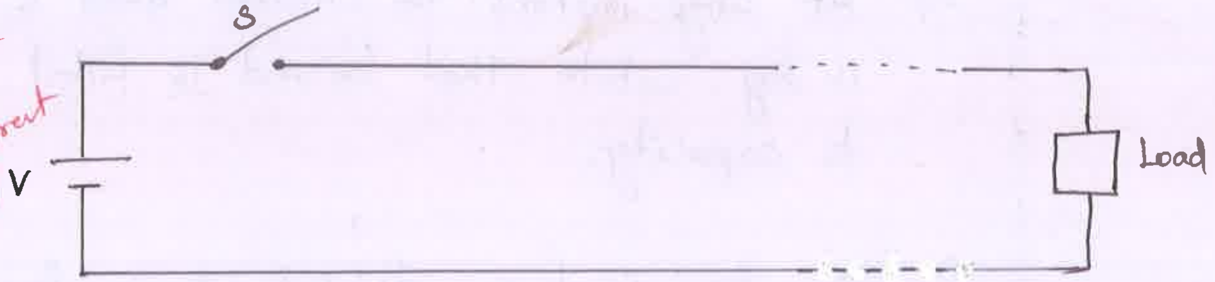
(Concentrated in one place)

⇒ On an electrical transmission line the voltage, current, power and energy flow from the source to a load located at a distance "L" producing electromagnetic waves with finit velocity.

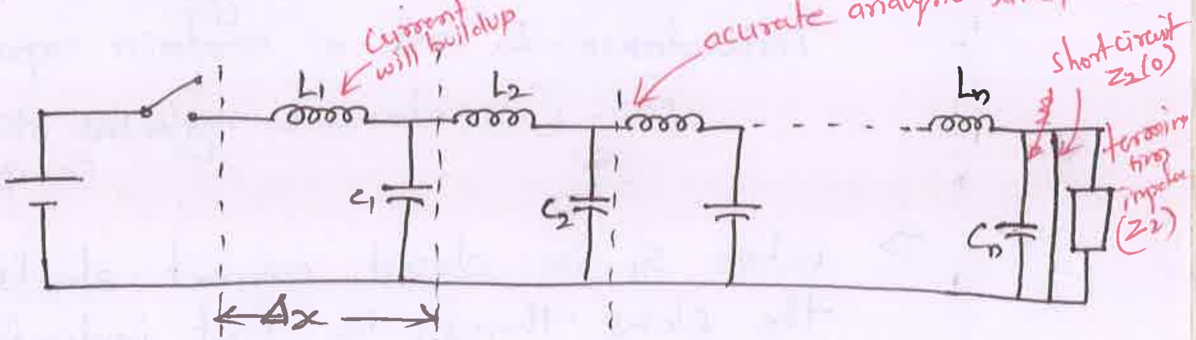
⇒ Hence it takes a short time for the load to receive the power.

(property of Inductance ↓ will not allow current increse rapidly)

speed of the wave 3×10^8 meter/sec (or) 186 thousand miles/sec



(a) Two - wire Transmission line.



(b) Lumpy - representation.

↑ full of

section of Transmission line

Δx → tends to zero but not zero.

very small value

⇒ Consider the two-wire circuit fig (a) by closing the switch "S", the transmission line is connected to a source of voltage "V".

note: Surge Impedance of the line $Z_n = \sqrt{L/C}$

L & C per unit length.

Inductance property ↑ current does not increase suddenly.

(Eg) The action q closing the switch can be compared to opening a valve at the end q a channel or pipe there by admitting water to the pipe or channel from some reservoir behind.

Capacitor property ↑ voltage can not increase suddenly.

⇒ when the valve is opened, the channel does not instantly fill with water. what we observe instead is a wave q water advancing (moving) down the channel.

⇒ At any instant the channel ahed q the wave front is dry, while that behind is filled with watter to capacity.

⇒ The line is here divided into a large number q section, each section being associated with a certain inductance L_1 and a certain capacitance C_1.

note: (Resistance is neglected otherwise Analysis is complicated)

⇒ when S_1 is closed, current starts from zero and the flows through the first inductance to charge the first capacitance.

⇒ But, as soon as this capacitor has acquired (Received) any charge whatsoever, there is a voltage across the next section q the line and current commences to flow through the second 'L_2' to charge the second C_2 and soon.

⇒ Thus, with a lumped circuit some disturbance (it is an electrical disturbance) on the line when S_1 is closed.

⇒ The disturbance created by closing s (switch) on the smooth line travels with a finite velocity and is felt at remote points, after a finit interval of time which is determined by the speed of the propagation of electromagnetic waves in the medium surrounding the line.

past and past past.

TRAVELLING WAVE CONCEPT – STEP RESPONSE

Consider a two wire transmission line along with the distributed elements r, l, g, c

The travelling wave equation is

$$\frac{d^2 v}{dx^2} = z \cdot y \cdot V_x = p^2 V \qquad ①$$

$$\frac{d^2 I}{dx^2} = z \, y . \, I_x = p^2 I \qquad ②$$

where

$p \rightarrow$ propagation constant

$p \rightarrow \sqrt{zy} = jw\sqrt{lc} = \frac{jw}{v} = j2\frac{\pi}{\lambda}$

$\lambda \rightarrow$ wavelength

$v \rightarrow$ velocity of propagation

$$V(x) = \frac{\cosh px + \left[\frac{z_o}{z_t}\right] \sinh px}{\cosh pL + \left[\frac{z_o}{z_t}\right] \sinh pL} \qquad ③$$

$$I(x) = \frac{1}{z}\frac{\partial v}{\partial x} = \sqrt{\frac{y}{z}} \; E(s) \; \frac{\sinh px + \left(\frac{z_o}{z_t}\right] \cosh px}{\cosh pL + \left[\frac{z_o}{z_t}\right] \sinh pL} \longrightarrow ④$$

voltage at open - End is given by

$$Z_t = \infty$$ ← infinity

$$V(0,s) = E(s)/\cosh pL = 2E(s)/(e^{pL}+e^{-pL})$$

$$V(0,s) = 2E(s)\left[e^{pL} - e^{-3pL} + e^{-5pL} \ldots\right] \quad ⑤$$

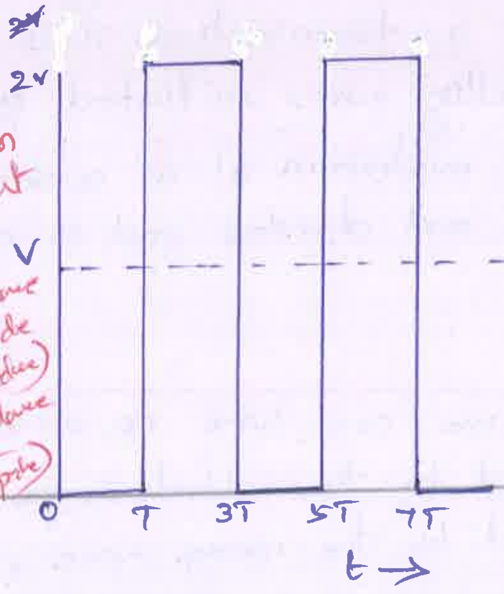
The response of the Travelling waves ~~[illegible]~~

STEP RESPONCE

⇒ voltage change suddenly (in zero time) from one value to another value this is called step change or step responce.

step response of Transmission line

Impedance of Ideal Source =0

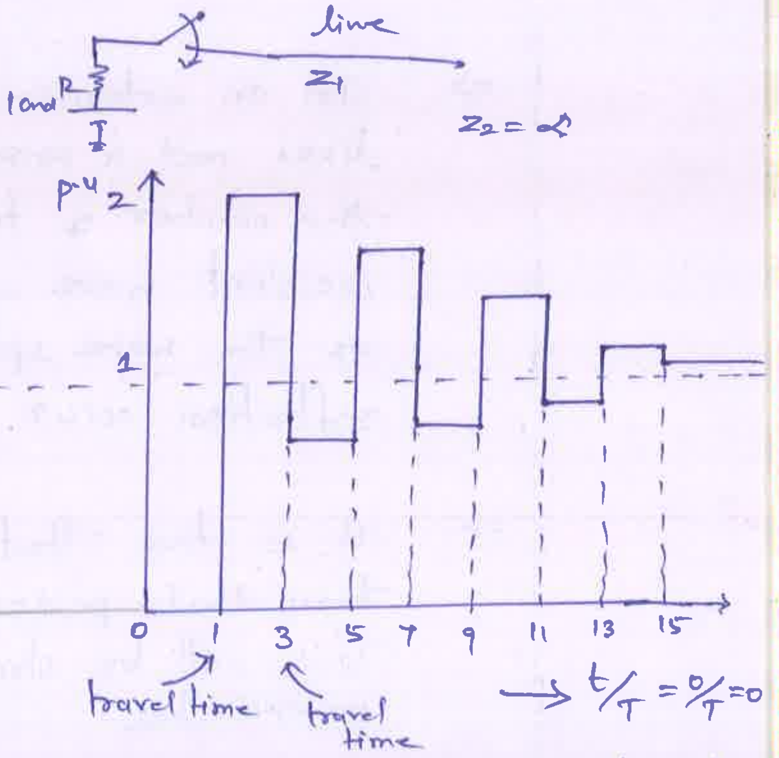


→ is a reflection coefficient

Z_1 → surge impedance of source side (line impedance)

Z_2 → surge impedance on load side (load impedance)

(a) losses neglected



$$\rightarrow t/T = 0/T = 0$$

$$t = 1 = \frac{1}{T}$$

(b) losses and attenuation included.

damped out ↑ but it will take lot of time $t = \infty$

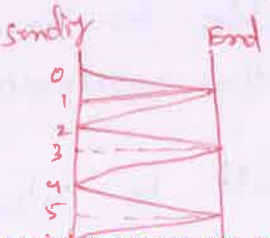
$$\alpha_1 = \frac{0 - Z_1}{0 + Z_2} = -1$$

Reflection coefficient of sending end

$$\alpha_2 = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

Reflection coefficient of receiving end

$$= \frac{\infty - Z_1}{\infty + Z} = 1$$



Time space diagram

BEWLEY's LATTICE DIAGRAM:

(A digital computers Bewley proposed a scheme of time space diagram, called lattice diagram)

⇒ Bewley has given the lattice (or) time-space diagrams from which the motion of reflected and transmitted waves ③ and their position at every instant the motion of reflected and transmitted waves and their position at every instant can be obtained

⇒ ~~Ide is~~ In an extensive network with many interconnected lines and variety of ~~transmi~~ ① terminations or line trapped at intervales, that the number of travelling waves encounter sucessive reflections at the transition point.

② ⇒ It is difficult to calculate the multiplicity of these reflections.

⇒ In an extensive network with many interconnected lines and a variety of terminations it is clear that the number of travelling waves initiated by a single incident wave will mushroom ←increasing at a considerable rate as the wave splits and divides and as multiple reflection occur.

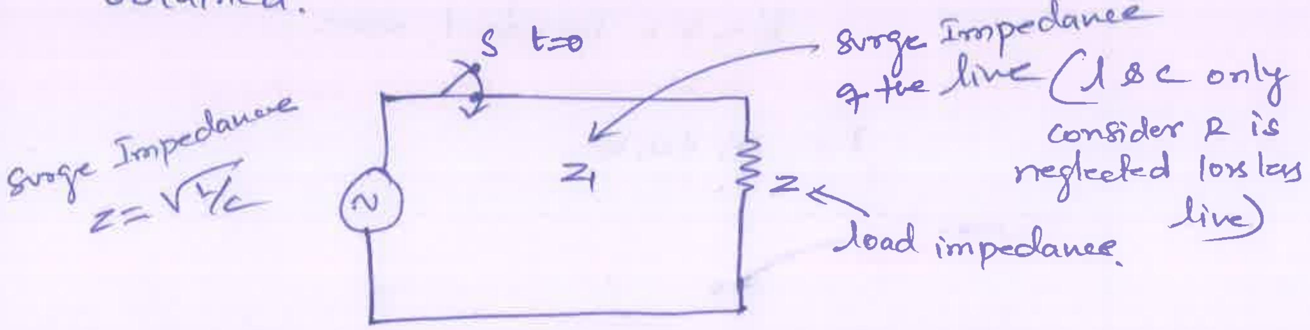
⇒ It is true that we can have no more energy than that possessed by the initial surge and that this will be shared by the many wave give rise to nevertheless.

⇒ It is possible for the voltage to build up a certain points by the reinforcing action of several waves.

strength increases.

⇒ It is difficult to calculate the multiplicity of these reflections

⇒ Bewley has give the lattice or time space diagrams from which the motion of reflected and transmitted waves and their position at every instant can be obtained.



⇒ To introduce the lattice diagram we will consider a single line terminating clong circuit. at the remote end in an impedance 'z' and having itself a surge impedance Z_1.

⇒ let us suppose that at the near end, line can be connected to a bus whose surge impedance is so low to be consider a short circuit. The connection is made through a circuit breaker.

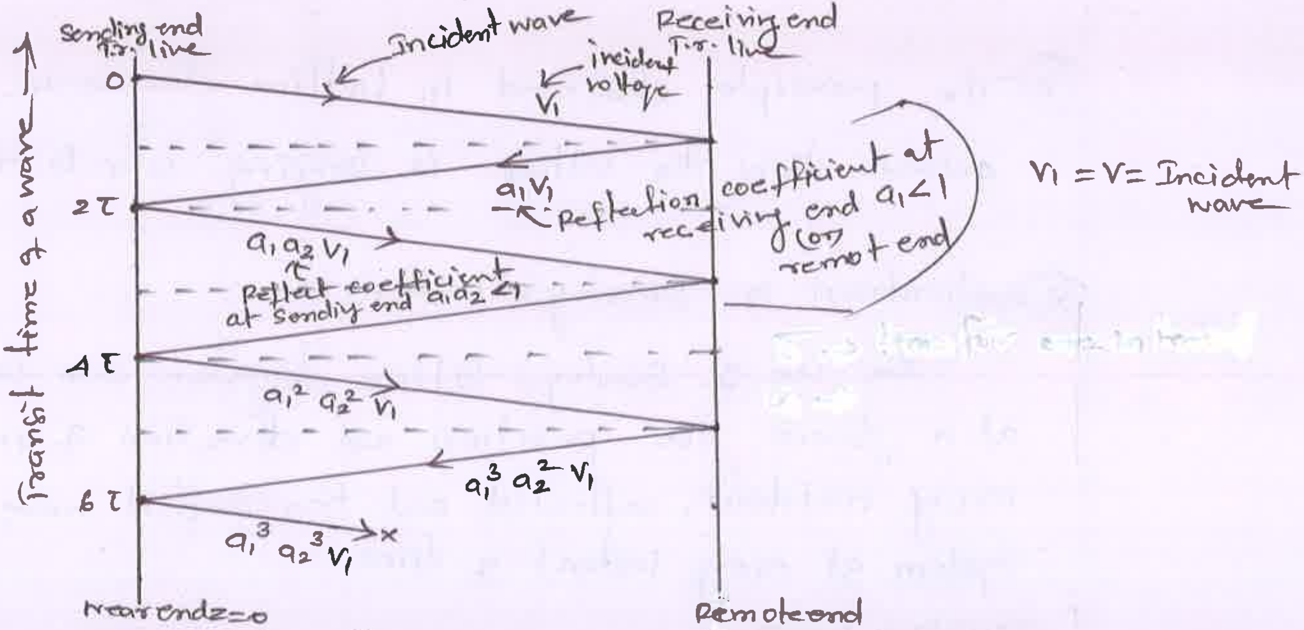


fig → lattic diagram for a single transmission line terminated in an Impedance -z

$T \rightarrow$ time for one interval

$a_1 \rightarrow$ reflection coefficient at receiving end (or) remot end.

$a_2 \rightarrow$ reflection coefficient at sending end (or) near end.

$$V_1 = V = \text{Incident wave}$$

Time required for one travel

$$T = V_1 + a_1V_1$$

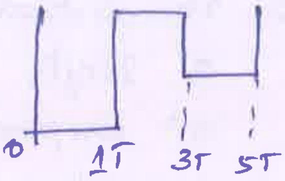
time at voltage

$$3T = V_1 + a_1V_1 + a_1a_2V_1 + a_1^2a_2V_1$$

(Reflection coefficient of receiving end)

$$a_1 = \frac{z - z_1}{\boxed{z + z_1}}$$

$a<1$



* So the remot termination the voltage fluctuation occur.

(Reflection coefficient of sending end)

$$a_2 = \frac{0 - z_1}{0 + z_1}$$

$0 \rightarrow$ Generator Impedance.

(*) The principle observed in Lattice diagrams.

Answer: How the voltage is varying w.r.to time.

(*) Application of Bewley's lattice?

The use of Bewley's lattice diagram one can know at a glance the position and direction of motion of every incident, reflected and transmitted wave on the system at every instant of time.

STANDING WAVES:

A standing wave, also known as stationary wave, is a wave that remains in a constant position. This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference between two waves travelling in opposite directions.

NATURAL FREQUENCY:

The natural frequency is the frequency at which a system oscillates when it is disturbed. systems have inertial and elastic characteristics, which make them

Transmitted wave

REFLECTION AND REFRACTION OF TRAVELLING WAVES.

⇒ whenever their is an abrupt change in the parameters of a transmission line, such as an open circuit or a termination, the travelling waves undergoes transition, part of the wave is reflected or sent back and only a portion is transmitted forward.

⇒ At the transition point (or) junction, the voltage or current wave may attain a value vary from zero to twice its initial value.

⇒ The incomming wave is called the incident wave and the other waves are called reflected and transmitted (refracted waves at the transition (Junction point) point)

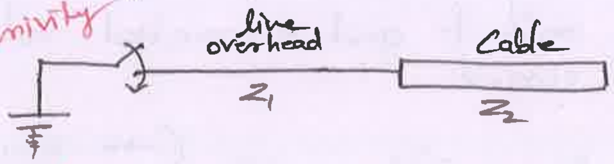
⇒ The amplitudes of the reflected and refracted waves are such that the voltage to current proportionality (characteristic impedance Z_0 of the line) are preserved for each, as demanded by the characteristices impedance of the lines on which they are travelling; current and voltage at the line discontinuity are themselves continuous, and energy is conserved.

⇒ consider the junction between the lines of characteristic impedance Z_A and Z_B

⇒ Let us suppose $Z_A > Z_B$.

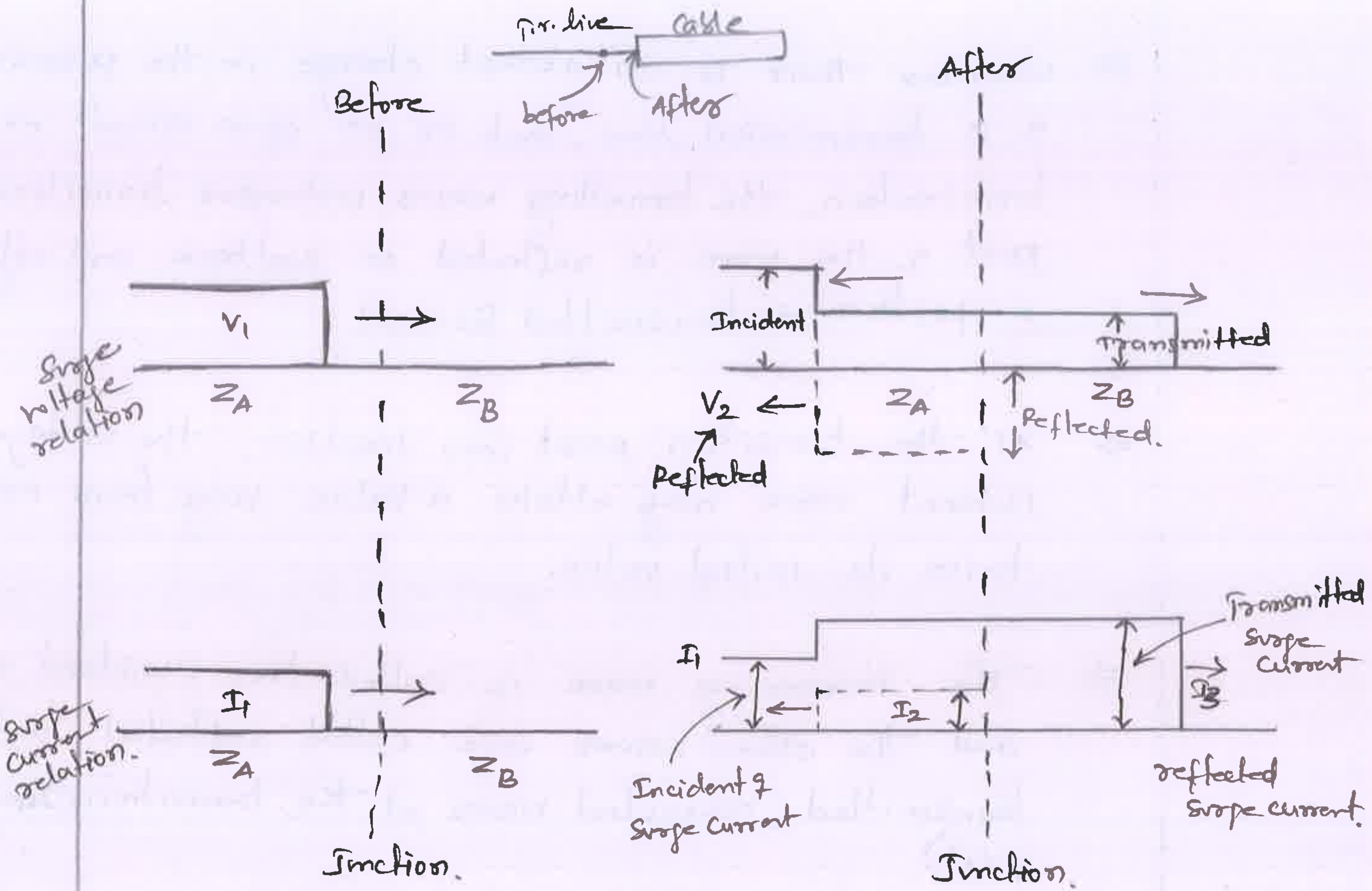
Consider the function between an overhead line and cable.

$Z_1 \neq Z_2$ discontinuity



$Z_2 \rightarrow$ will decrease the transmitted component of V & I.

Conservation of energy principle → Incident energy = Reflected Energy + Transmitted energy.



voltage and current waves reflected and refracted at the junction between two lines.

$V_1 \rightarrow$ Incident voltage wave
$V_2 \rightarrow$ Reflected voltage wave
$V_3 \rightarrow$ Refracted voltage wave
$I_1 \rightarrow$ Incident current wave
$I_2 \rightarrow$ Reflected current wave
$I_3 \rightarrow$ Refracted current wave.

note: $I = \frac{V}{R}$
$V = I \times R$

$$I_1 = \frac{V_1}{Z_A} \longrightarrow ①$$

The reflect and refracted voltage waves be V_2 and V_3 and their current.

$$I_2 = \frac{-V_2}{Z_A} \longrightarrow ②$$

(-ve sign indicates that I_2 is travelling in the direction of minus x and has a sign opposite to V_2)

$$I_3 = \frac{V_3}{Z_B} \longrightarrow ③$$

If the voltage and current are to be continuous at the function.

$$\overset{\text{Incident}}{V_1} + \overset{\text{Reflected}}{V_2} = \overset{\text{Transmitted}}{V_3} \longrightarrow ④$$

Components point of view ← voltage component or current component

(Transmitted = reflected + Incident)

$$I_1 + I_2 = I_3 \longrightarrow ⑤$$

$$\frac{V_1}{Z_A} - \frac{V_2}{Z_A} = \frac{V_3}{Z_B} \longrightarrow ⑥$$

$$V_2\left[\frac{Z_B + Z_A}{Z_B \cdot Z_A}\right] = V_1\left[\frac{Z_B - Z_A}{Z_A \cdot Z_B}\right]$$

$$V_2 = \left[\frac{Z_B - Z_A}{Z_B + Z_A}\right] V_1 \longrightarrow ⑦$$

$[(Z_B - Z_A)/(Z_B + Z_A)]$ is called reflection coefficient is designated 'a'.

$$a = \left[\frac{Z_B - Z_A}{Z_B + Z_A}\right]$$

The refracted wave is obtained by eliminating V_2 between

$$V_1 + V_2 = V_3 \quad \& \quad \frac{V_1}{Z_A} - \frac{V_2}{Z_A} = \frac{V_3}{Z_B}$$

$$V_3\left[\frac{Z_B + Z_A}{Z_B Z_A}\right] = \frac{2V_1}{Z_A}$$

$$V_3 = \boxed{\left[\frac{2Z_B}{Z_B + Z_A}\right]} V_1 \longrightarrow ⑧$$

is called the refraction coefficient is designated 'b'.

$$b = \frac{2Z_B}{Z_B + Z_A}$$

The marked reduction of the incident wave as it penetrates the cable is some time utilized in power system to protect terminal equipments from surge approaching down connected lines. (A cable is inserted between the overhead line and the terminal

UNIT-V

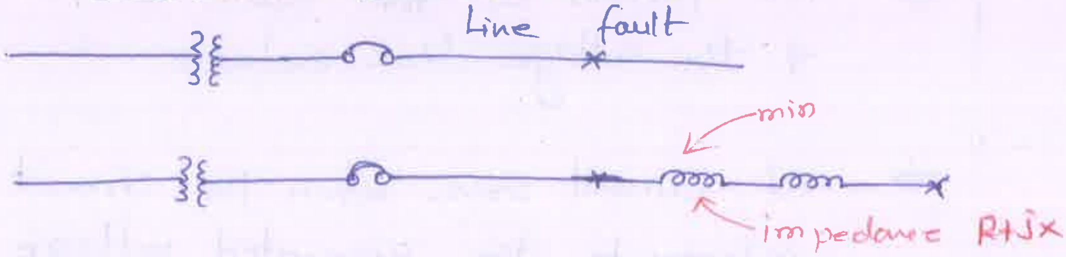
TRANSIENTS IN INTEGRATED POWER SYSTEM

SHORT LINE ~~AND~~ or KILOMETRIC FAULT:

short-circuit faults occuring on a transmission line length between 0.5 to 5km are termed as short line faults or kilometric falults.

$I = V/R$

$= I \cdot Z$

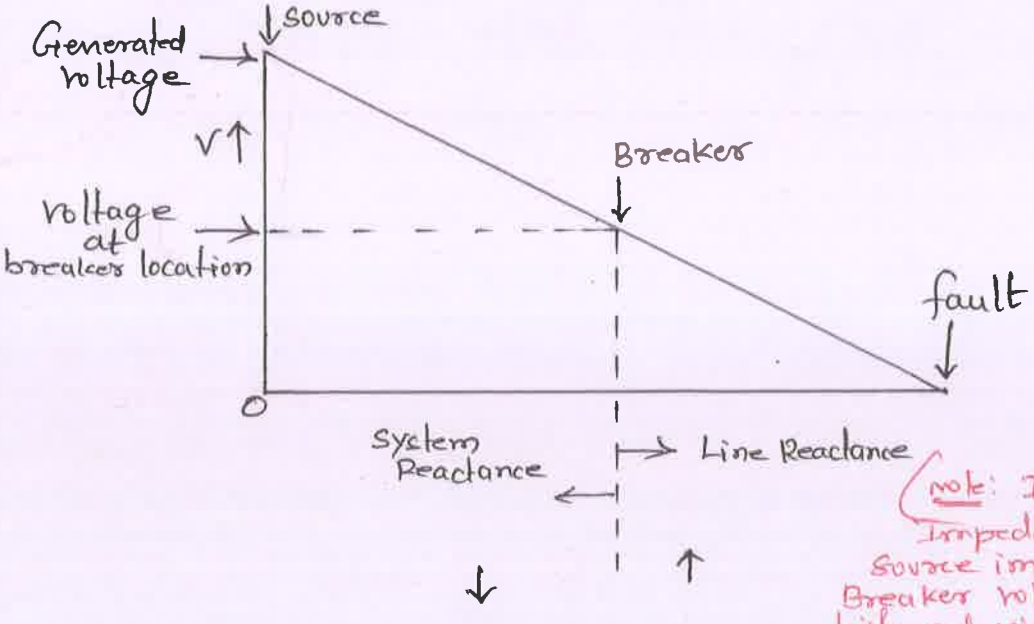


⇒ certain circuit breaker had less difficulty interrupting current to a fault located close to their terminals, rather than the current to a similar fault some distance out along a transmission line, where because of the added impedance of the line, the current should have been appreciably less

opening

important enough to be noticed.

⇒ The significant difference between the fault close to the breaker and the fault some distance out along the line is that the line impedance not only limits the current in some measure but, as a consequence, support some of the system voltage.



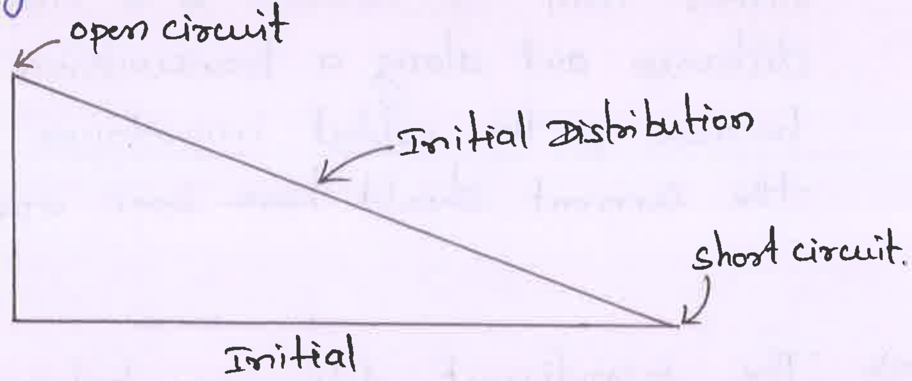
(note: If the line Impedance is more than Source impedance the Breaker voltage will be high and wise versa.)

⇒ The generated voltage is divided on either side of the breaker in proportion to the impedance of the source and the line.

⇒ The further out ~~that~~ fault is the grater fraction of the voltage line sustains.

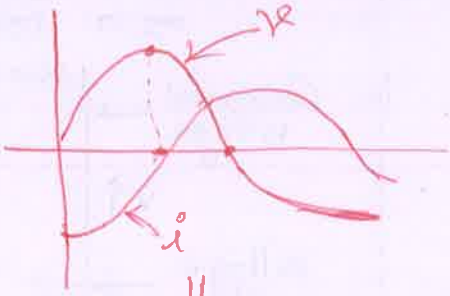
⇒ At current zero, when the circuit breaker interrupts the generated voltage will be near its peak.

Voltage Distribution on a short fault.



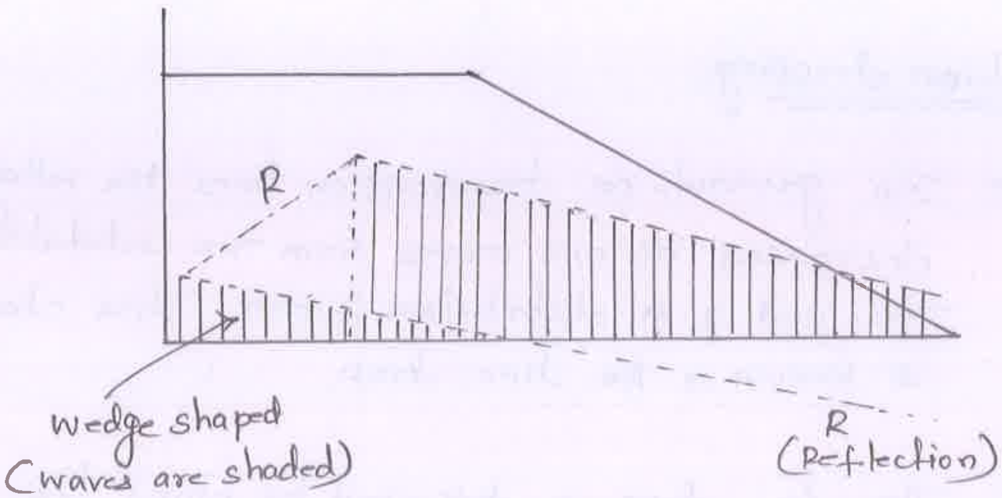
note: The initial voltage distribution on the line "L" is here the Source inductance and L1 the line inductance to the fault : E is the instantaneous value of the emf driving the fault current peak amplitude

$\frac{1}{2} \frac{L_1}{L+L_1}$,



⇓

(Current is lagging behind the voltage 90° So I is 0, V is peak.)



voltage distribution.

⇒ The initial wedge-shaped waves are shaded; their reflections are unshaded and identified by "R" (Reflection)

⇒ The two reflected waves will themselves suffer reflection as they reach the opposite terminations and so the phenomenon will proceed, subjected to the effect of the loss of the line.

Lion Dropping and Load Rejection:

Lion dropping:

=> In general, on transmission lines the voltage simply decreases as one moves from the substation out forward the end q a distribution feeder. This charge in voltage is known as the line drop.

=> The line drop is described by ohm's law, V= IZ. ohm's law also shows us that the line drop depends on the connected load, since a greater power demand implies a greater current. while the line impedance stays the same, the voltage drop varies in proportion to the load.

=> In practice, the voltage drops in distribution systems are quite significant, especially for long transmission feeders.

=> Recognizing that it is physically impossible to maintain a perfectly flat profile, operating guidelines generally prescribe a tolerance q ± 5% q the nominal voltage. This range applies throught transmission and distribution systems.

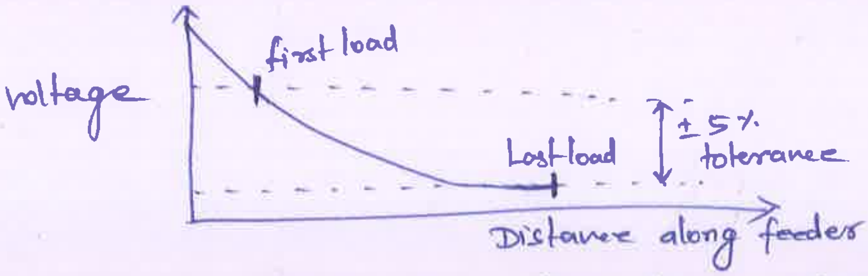


fig: voltage drop along a distribution feeder.

=> The above fig(or)illustrate the problem q voltage drop along the feeder. If the feeder is very long, the voltage drop may exceed the window q tolerance. In order to maintain a permissible voltage level along the entire length q a feeder. it may therefore be necessary to interrvene and boost the voltage somewhere along the way.

Controlling voltage drop:

The two methods for controlling or supporting voltage in the transmission and distribution system are transformer taps and reactive power injection usually capacitance.

(i) Transformer taps providede for a variable turns ratio, and thus a variable amount of voltage change.

(ii) capacitors, static VAR compensators or synchronous condensers, all of these devises provide capacitive reactance, meaning that they inject reactive power into the system in order to boost the local voltage level.

Load Rejection:

=> Load rejection is when there is a fault on the transmission line which is sensed by the protection system and trip the circuit breaker concern, during that's time the load connected with the feeder and lines are suddenly dropped i-e, load throw If (or) load rejection occurs.

=> sudden load rejection on integrated power system causes the over speeding up of prime movers of generators. The speed governors and automatic voltage regulators will interrvene to restore the normal conditions. The approximate voltage raise due to load rejection may be

$$V = \frac{F}{F_0} E' \left[\left(1 - \frac{F}{F_0}\right) \frac{X_s}{X_c} \right]$$

where

F_0 → is the normal frequency

F → is the instantaneous increased frequency.

E' → is voltage generated before over speeding and load rejection.

X_s → is the reactance of the source or generator.

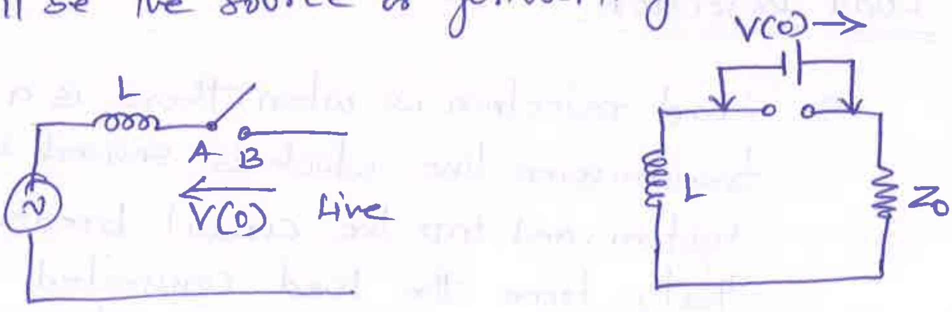
X_c → is the capacitive reactance of line at open.

VOLTAGE TRANSIENTS ON CLOSING AND RECLOSING LINES.

⇒ when closing a switch on transmission line with simple source

⇒ when a switch closes, that voltage across it is destroyed at the instants of closing, only to appear again immediately, impressed across the impedances on either side of the switch.

⇒ one side will be a transmission line and the other side will be the source or generating station.



(a) Transmission line

(b) current flows through the switch.

fig:(1) switching operations in a transmission line closing of switch.

⇒ fig(1) illustrate the concepts of transmission line while closing the switch. The transmission line or cable can be represented by resistor equal to its surge impedance for a wave to travel to the remote end of the line and back again to source.

=> Referring fig (1)(a), the current that flows through the switch is given by

$$I = \frac{V_0}{s} \frac{1}{Ls + Z_0}$$

The voltage impressed at the line will be

$$\frac{V(0)}{s} \frac{Z_0}{Ls + Z_0}$$

while considering the source side inductance.

$$\frac{V(0)}{s} \frac{Ls}{Ls + Z_0}$$

Battery source in fig 1(b), indicating that the source voltage remains unchanged at V(0). Thus the travelling wave can be described by

$$V(0)\ (1 - \varepsilon^{-Z_0 t/L})$$

which start at zero and rises asymptotically to V(0) with a time constant L/Z_0.

OVER VOLTAGES INDUCED BY FAULTS:

⇒ when the lightning strikes one conductor line, then the waves will be developed.

⇒ There are two pair q waves in either direction on both lines. Due to these waves, the current injected into the line by lightning stroke get dispersed. The surges on the adjacent conductor were induced by electromagnetic coupling.

⇒ over voltages due to ground fault.

⇒ The over voltages are induced when a ground fault occurs on one q the conductor. Due to the occurrence q ground fault, instead q a current being injected, a voltage is suddenly applied. The voltage due to fault is equal and opposite to that q existing voltage on the conductor at that time.

⇒ For the protection q circuits from overvoltages caused by faults, the circuit breakers must be carfully designed.

⇒ A line to ground fault can produced an overvoltage on an unfaulted phase as high as 2.1 times the normal line to neutral voltage on a three phase line. The below fig. shows the oscillogram q line-to-ground voltages obtained on TNA (Transient network Analyses) at midpoint q 180 mile, three-phase line for single line-to-ground fault at that print.

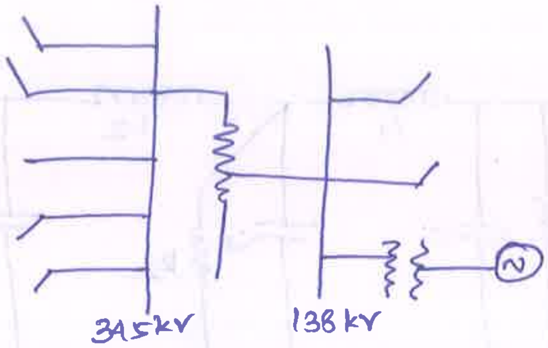
oscillogram q line - to - ground voltage

SWITCHING SURGES ON AN INTEGRATED SYSTEM:

⇒ The disturbance produced by the switching operation in a system spreads through~~out~~ the ~~line~~ Integrated line system by setting up travelling waves.

⇒ They travel along the connected lines and reflect to and fro as discontinuities are encountered.

consider the following system in the below fig (1)

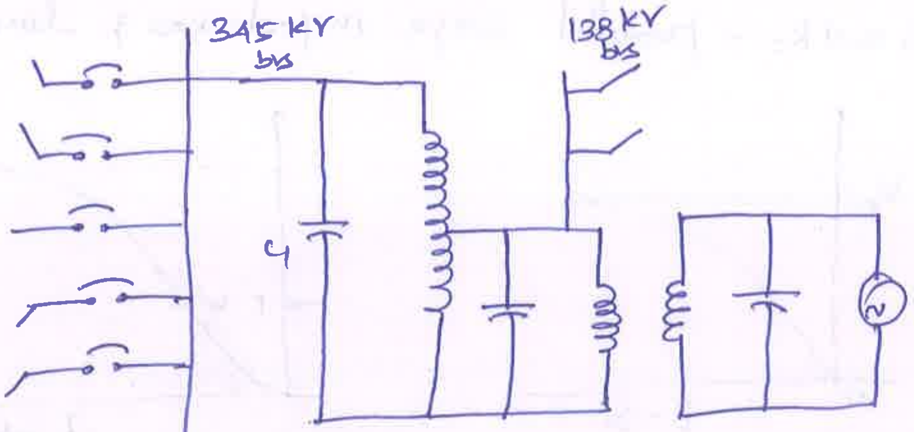


fig(1)

⇒ There are buses at 138 kV and 345 kV interconnected by auto transformer. The 138 kV bus is fed through the generator transformer. There are lines and/or ties connected to both buses.

⇒ The circuit in fig(1) can be redrawn using a single phase representation and the significant capacitances are included as in fig(2).

⇒



Fig(2)

5.9

⇒ If one of the CB, in 345 kV is opened to clear a fault on its line, the switching operation will evoke a response from both the line and the system.

⇒ If the impedance are reduced to a common voltage base, Then the circuit becomes as in fig ③. In this circuit the lines are represented by the resistor R_1 and R_2.

⇒ The Resistance R_1 effectively suppressed all oscillations.

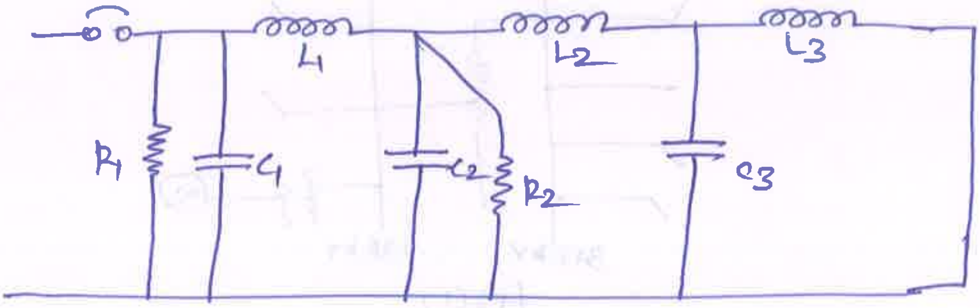
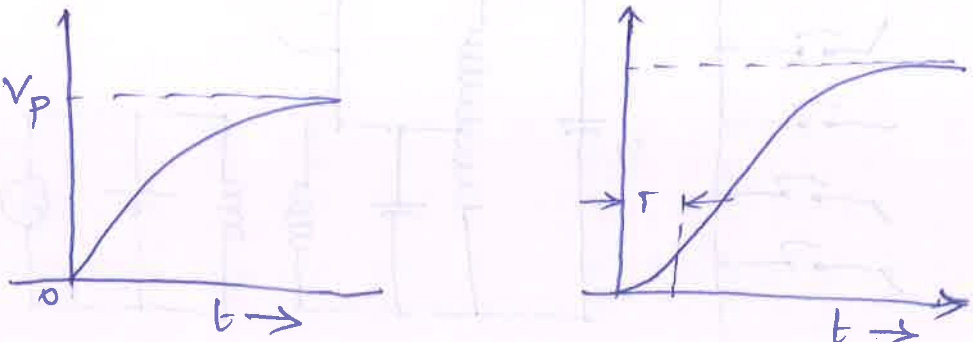


Fig ③

C_1 = Capacitance of 345 kV bus
C_2 = capacitance of 138 kV bus
C_3 = capacitance of generator bus
L_1 = Inductance of auto transformer
L_2 = Inductance of generator transformer
L_3 = Generator inductance
R_1 and R_2 = parallel surge impedences of line



(a) capacitance neglected (b) capacitance included

Fig (4) approximate response of the integrated circuit to

QUALITATIVE APPLICATION OF EMTP FOR TRANSIENT COMPUTATION

⇒ EMTP is a comprehensive computer program designed to solve electrical transient problems in lumpy circuits, distributed circuits.

⇒ This program is capable of solving steady-state circuit problems.

⇒ Transient analysis can be carried out in circuits with any arbitrary configuration of lumped parameters (R, L and C). Transmission lines with distributed parameters, transposed (or) untransposed, can be included in the network.

⇒ In order to perform transient analysis, it is often a good idea to obtain a steady-state solution first to check on the validity of the network representation and also obtain initial conditions for the transient study.

Formulation and method of solution for the EMTP

Lossless line:

The wave equation of a single phase line

$$\frac{\partial^2 V}{\partial x^2} = LC \frac{\partial^2 V}{\partial t^2}$$

and

$$\frac{\partial^2 I}{\partial x^2} = LC \frac{\partial^2 I}{\partial t^2}$$

The solution of the above equation is given in the form of,

$$I(x,t) = f_1(x-vt) + f_2(x+vt)$$

$$V(x,t) = z_0 f_1(x-vt) + z_0 f_2(x+vt)$$

The solution of equation (1) and (2) are given as

$$V(x,t) + Z_0 I(x,t) = 2Z_0 f_1(x-vt)$$

The expression $v + z_0 i$ can be written as,

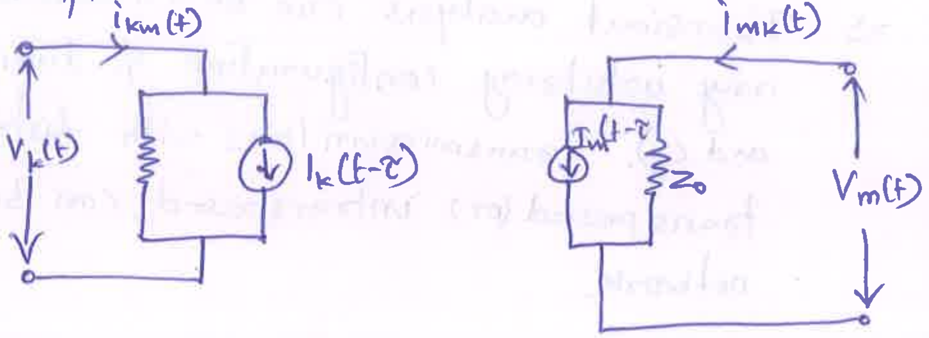
$$V_m(t-\tau) + z_0 i_{mk}(t-\tau) = V_k(t) + z_0(-i_{k,m}(t))$$

where τ is the travelling time of the wave in a transmission line and $\tau = \frac{d}{v} = d(LC)^{1/2}$

where d is the line length

The wave leaves node m at time $t-\tau$, and the wave arrives at node k at time t.

A simple lossless line can be represented as shown in fig.



This follows the equation.

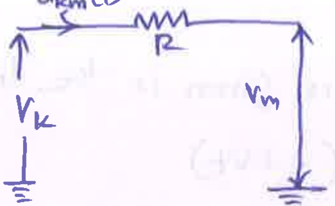
$$i_{k,m}(t) = (1/z_0)\, V_k(t) + I_k(t-\tau)$$
$$i_{m,k}(t) = (1/z_0)\, V_m(t) + I_m(t-\tau)$$

Thus a transmission line can be modelled and the conditions at one terminal with respect ~~to the~~ other can be seen indirectly and with a time delay τ through the equivalent source I

A similar approach can be used t model the lumped parameters L, C and R.

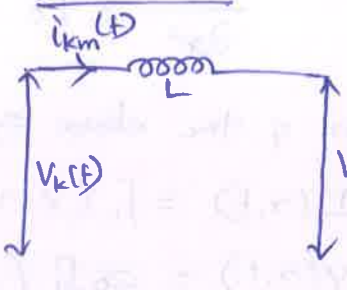
These are the EMTP works proceedd by Dommel.

Resistance:



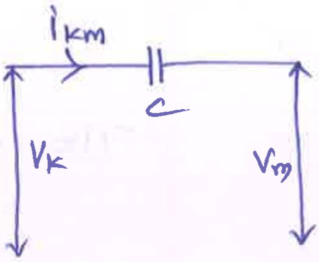
$$i_{km}(t) = \frac{V_k(t) - V_m(t)}{R}$$

Inductance:



$V_k(t) - V_m(t)$

$R_{ef} = \frac{2L}{\Delta t}$



$R_{eff} = \frac{\Delta t}{2C}$

UNIT-I (Two Marks)

(INTRODUCTION AND SURVEY)

① what is called transient in power system? (April/may 2010)

POWER SYSTEM: A power system combination of generation Transmission and distribution & load.

Transient: Tranient is a condition in which current, voltage, frequency and power will fluctuvate with respect to time.

② what are the source of transients? (April/may 2008)

(i) Switching operations.

(ii) sudden ~~load~~ rejection of load or generation.

(iii) The major disturbance upsets the balance between mechanical input and electrical output of a generator, with the result that some generators may accelerate while others may decelerate.

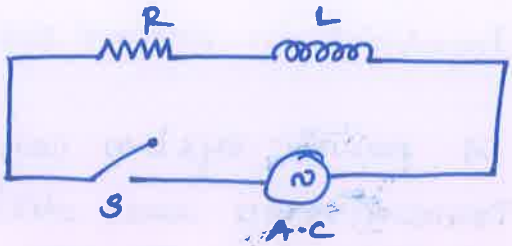
③ state the importance of transient study in planning. (Nov/Dec 2008)

Studying power system transients is very important because it helps in understanding the behaviour of the system under transient condition.

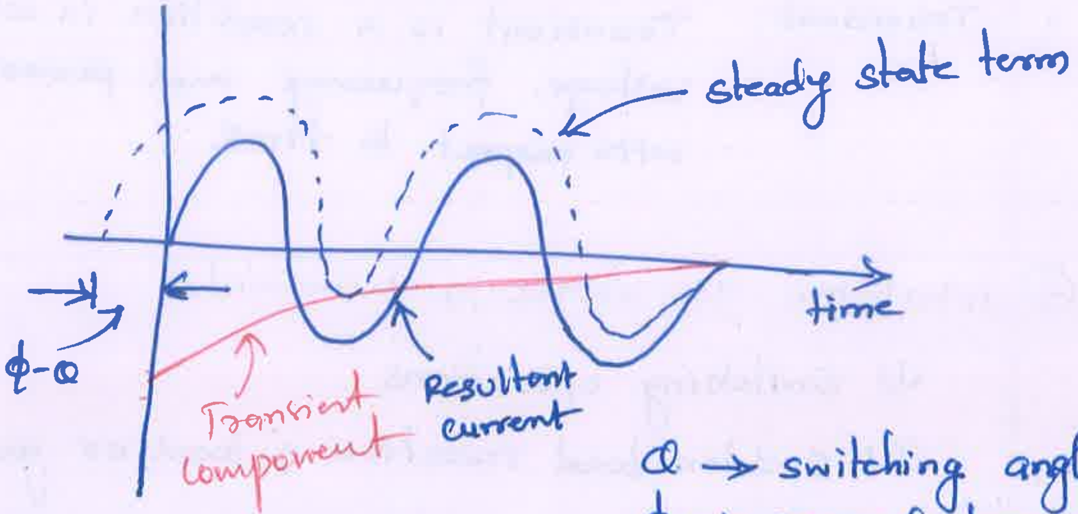
So that we can take suitable measure during system planning, system design and system operation.

So as to prevent damage of electrical equipments or Intruption of power supply to the consumer.

④ Draw a simple circuit which can produce transients. (Jun/July 2008)



RL circuit connected to an A.C source.



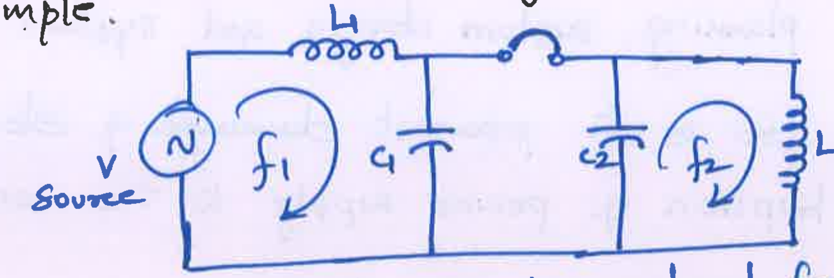
θ → switching angle
φ → power factor angle

⑤ What are the causes of transients in a power system? (Nov/Dec 2008)

Transients in power systems causes oscillation of voltage, oscillation of frequency, fluctuation in powerflow in various lines, transformers and generators.

This may lead to series consequences such as power system instability, Insulation damage of Transformers, Generators.

⑥ Draw the double frequency transients circuits with an example.



$$f_1 = \frac{1}{2\pi(L_1 C_1)^{1/2}}$$

$$f_2 = \frac{1}{2\pi(L_2 C_2)^{1/2}}$$

Circuit with two natural frequency

⇒ L_1 and C_1 are inductance and stray capacitance on the source side of the breaker.

⇒ L_2 and C_2 might represent an inductive load and its stray

⑦ List the various types of power system transients.

(i) switching transient
  (a) circuit closing transient
  (b) Double frequency transient

(ii) Lightning Transient

⑧ Name the effects to transients on power system.

* The transient period is usualy very short time from few μ sec to 1 sec, the time spent in the steady state.

* These transient period are extremely important for it is at such times that the circuit components are subjected to the greatest stress from excessive current or voltage.

* In extreme case damage results.
  ⇒ This may disable a machine
  ⇒ shut down a plant
  or
  Black out a city, depending upon the circuit involved.

⑨ How are the transients produced in power system?

An electrical transient is the outwards manifestations of a sudden change in circuit conditions, as when a switch open or closes or a fault occurs on a system, sudden load rejection (loss of load), disconnection of inductive load or connection of capacitive load.

⑩ What are the three cases in the RL circuit transient with sine wave excitation?

mean immediately after closing the switch.

Case-I

When $t=0$, the transient term is equal and opposite to the steady state term and hence the current start from zero.

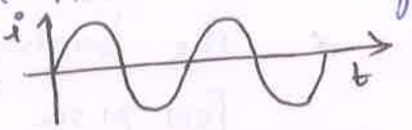
switching angle

power factor angle of the load.

Case-II

When the switch closes at $\theta = \phi$, the transient term will be zero and the current wave will be symmetrical

magnitude of both (symmetrical)

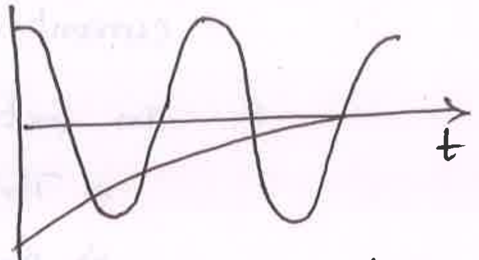


when $\theta = \phi$

Case-III

When the switch closes at $(\theta - \phi) = \pm \frac{\pi}{2}$ the transient term attains it's maximum amplitude and the first peak of resulting composite current wave will approach twice the peak amplitude of steady state sinsoidal component.

$\theta = \phi \pm \frac{\pi}{2}$



maximum at case-III

Unit-II (SWITCHING TRANSIENTS)

(Two Marks)

① Define switching transients.

A transient is initiated whenever there is a sudden change of circuit conditions; this most frequently occurs when a switching operation take place.

The closing of a switch or circuit breaker to energize a load, the opening of a breaker to clear a fault, transient is initiated its called switching transient.

② what is current chopping?

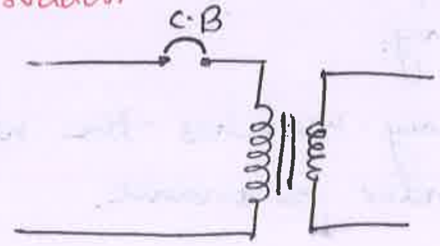
(All though current chopping is a potential hazard, practical consideration of power circuit often remove the danger (transient).)

when a relatively small current is interrupted by a circuit breaker, overzealous action of its arc supression devices may cause the current to be brought to zero abruptly and prematurely ahead of the normal zero.

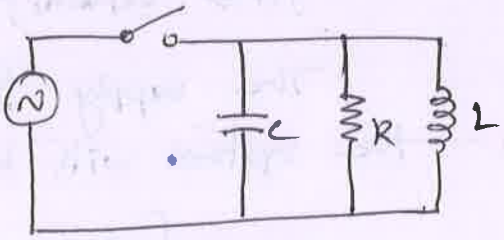
protecting

sudden

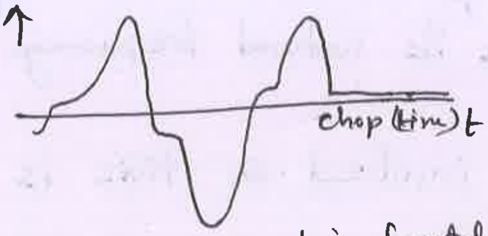
occurring or done before the proper time.



(a) The circuit breaker and an unloaded Transformer



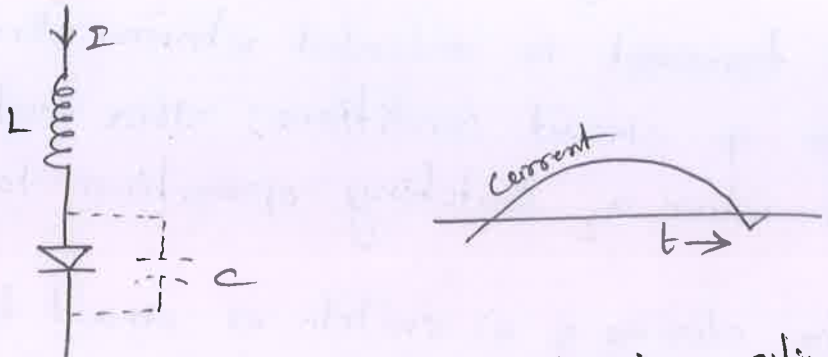
(b) The effective equivalent circuit.



(c) The current is clopped

* The instantaneous current chopped.

③ Define current suppression

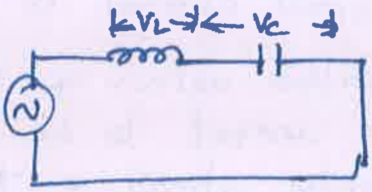


Current suppression in a silicon diode

* At the end q a half cycle q conduction in a diode, carriers remaining in the junction region continue to allow current to flow that is, the current momentarily reverses.

* But the flow q this reverse current sweeps ~~that~~ the carriers from the junction and returns devices to its blocking state.

④ Define ferro resonance.



$\Rightarrow f_s = f_n.$

$f_s \Rightarrow$ supply frequency
$f_n \Rightarrow$ natural frequency.

The supply frequency matches the natural frequency the system will be under resonance.

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

If frequency q the current passing through the circuit is same as its natural frequency then their will be resonance.

The iron is involved so this is called ferroresonance

⑤ List out the advantage of low inductance ribbon-wound shunt resistor.

⇒ The ribbon-wound shunt resistor has a lower ohmic value so that it can effect an even grater reduction in the transient voltage peak in the situation just examined.

⇒ The resistor is fashioned to reduce its inductance. Any inductance will decrease its effectivenes.

⑥ Define load switching

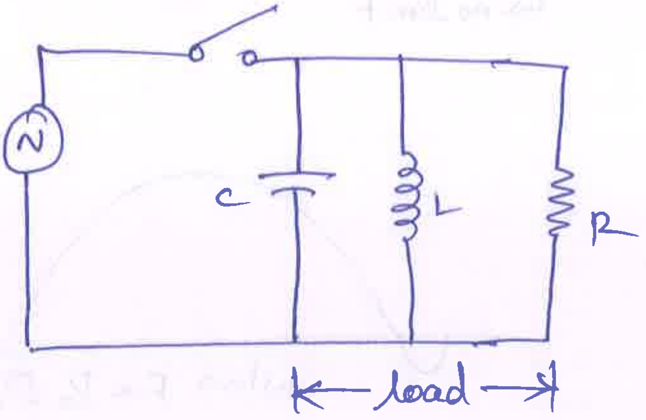
⇒ The most frequent functions performed by some switching devices are to switch on and switch off loads.

i.e load switching, which in many instance can be represented by a parallel RL circuit.

⇒ Low power factor loads will be predominantly inductive.

⇒ High power factor loads predominantly resistive.

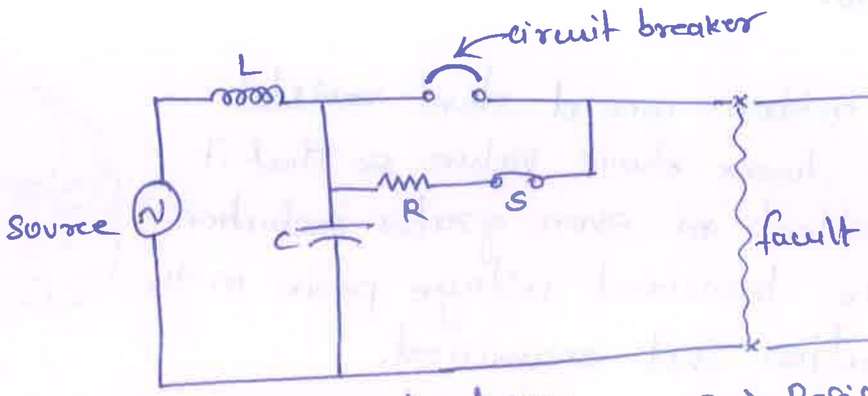
⇒ when such a (high power factor) load is switched off, the effective capacitance of the load becomes important in determining the form of the transient generated.



Note: (Transient produced when switching a load)

fig: Simple equivalant circuit.

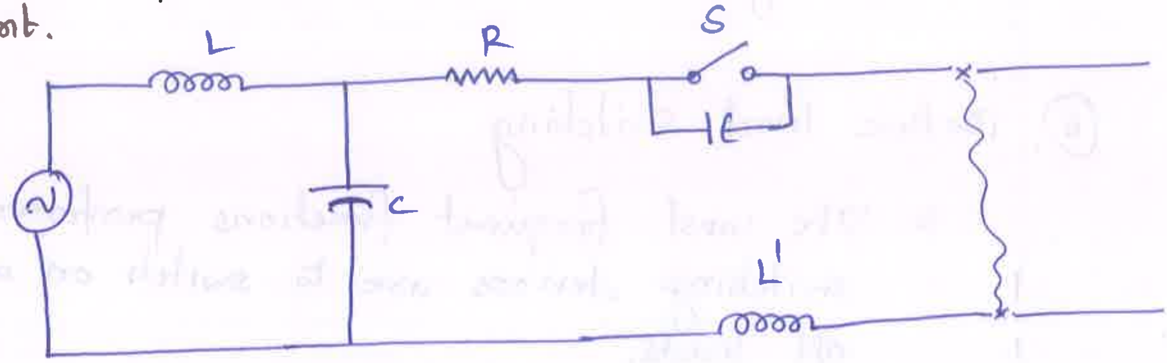
⑦ Draw a Resistance switching.



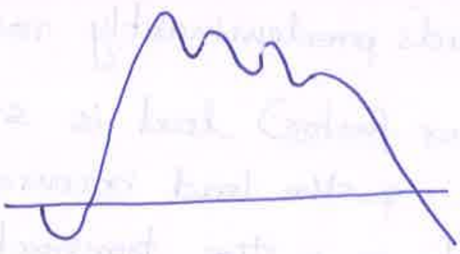
L → system Inductance.
C → stray capacitance.

R → Resistor used to modify these transient.

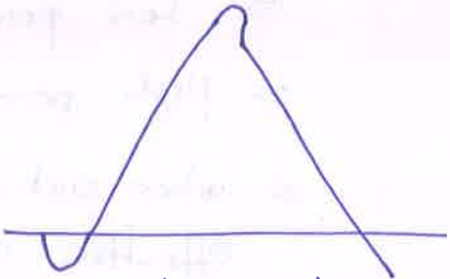
⑧ Draw the equivalent circuit for interrupting the resistor current.



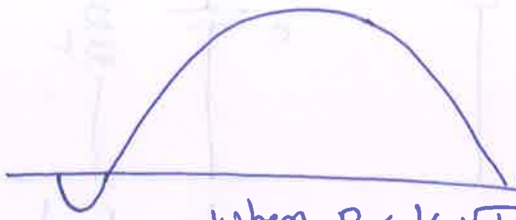
⑨ What are the different values of 'R' the oscillation are observed.



when R = ∝
↳ no limit



when $R > \frac{1}{2}\sqrt{L/C}$
↳ high.



when $R < \frac{1}{2}\sqrt{L/C}$

UNIT-III (Two marks)

LIGHTNING TRANSIENTS

1. what are the causes of over voltage? (April/may 2010)

over voltages on power systems are do various causes. The voltage stresses due to over voltages can be so high that they may become dangerous to both the lines as well as the connected equipment and may causes damages unless some protective measures against these voltages are taken.

2. Define Lightning.(or) what do you mean by lightning? (may/Jun 2009)

Lightning → The occurrence of a high-voltage electrical discharge between a cloud and the ground or with in a cloud accompanied by a bright flash.

3. Define Lightning transients.

That electrical transients are the outward manifestation of a sudden change in circuit condition due to the physical phenomenon of lightning.

4. Give the factors contributing to good line design. (may/Jun 2009)

1. Reduce the number of outages caused by lightning
2. keep the incidence of strokes to a minimum
3. Try to minimize the effects of stokes.
4. High footing resistance are to be avoided.
5. High ground impedance is to be avoided.
6. High surge impedance is to be avoided.

5. what is the use of ground wire?

* Ground wire it is a conductor run parallel to the main conductor of the transmission line supported on the same tower and earthed at every equally and regularly spaced towers.

* It is run above the main conductors of the line.

* The ground wire shield's the transmission line conductor from induced charges from clouds as well as from a lightning discharge.

6. List out the fenction of ground wires.

sudden and striking

(i) Ground wires system can dramatically reduce the number of outages.

(ii) The first fenction of ground wires is to shield the phase conductors.

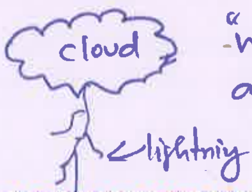
a broad piece of armour held for protection against.

(iii) Then to serve in lieu of those conductors as the termination of the lightning stroke.

7. what is back flashover?

when a direct lightning stroke occurs on a tower, the tower has to carry huge impulse currents. If the tower footing resistance is considerable, the potential of the tower rises to a large value, steeply with respect to the line and consequently a flashover may take place along the insulator strings. This is known as back flashover.

8. Define stepped leader.



"when the lightning stroke is occurs and towards to the ground to reach the ground in first wave called stepped leader.

⑨ Explain the significance of tower footing resistance.

(Resistance experienced by the current entering the ground through the tower)

⇒ Tower footing resistance is the resistance offered by tower footing to the dissipation of current. (abnormal current.)

⇒ A low value of tower footing resistance results in less voltages stress across line insulation.

cost effect (10Ω still better but it will dificult)

⇒ A tower footing resistance of 20Ω for EHV lines and 10Ω for H.V lines provides sufficient lightning protection. (based on practical experiences)

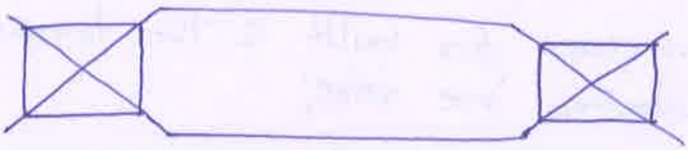
10. Define counter-poise wires.

⇒ These are wires buried in the ground at a depth of 0.5 to 1.0 m running parallel to the transmission line conductors and connected to the tower legs.

(i)

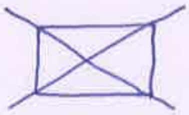
Single parallel continuous.

(ii)



Double parallel continuous

(iii)



Radial.

⑪ Mention the different theories of charge formation.

(i) Simpson's theory
(ii) Reynold's theory
(iii) Mason's theory.

⑫ state Mason's theory of lightning.

According to this theory, the thunder clouds are developed at heights 1 to 2 km above the ground level. They may go to up 14 km above the ground. For the charge formation air currents in the clouds, moisture and specific temperature range are required.

⑬ List the characteristic features of lightning stroke.

(i) Amplitude of the current
(ii) Rate of rise
(iii) probability distribution of the above
(iv) wave shapes of the lightning and current.

⑭ Explain direct lighting stroke.

When the thundercloud directly discharges onto a transmission line tower or line wire it is called a direct stroke. This is the most sever form of the stroke.

However for bulk of the transmission systems the direct strokes are rare.

UNIT-IV (Two Marks)

TRAVELING WAVES ON TRANSMISSION LINE
COMPUTATION OF TRANSIENTS

1. what do you mean by travelling waves?

Any disturbance on a transmission line or system such as sudden opening or closing of line, a short circuit or a fault result in the development of overvoltage or over current at that point.

This disturbance propagates as a travelling wave to the ends of the line (or) to a termination such as a substation.

usually these travelling waves and high frequency disturbance and travel as waves.

2. write the condition for no reflection wave.

The load impedance and line impedance exactly matched no reflection wave.

$$\text{Reflection coefficient } \alpha = \frac{V_{r1} \text{ (Reflected component)}}{V_i \text{ (Incident component)}}$$

3. what are the damages caused by the travelling waves?

(i) High peak or crest voltage of the surge may cause flashover in the internal winding.
(So spoil the winding insulation)

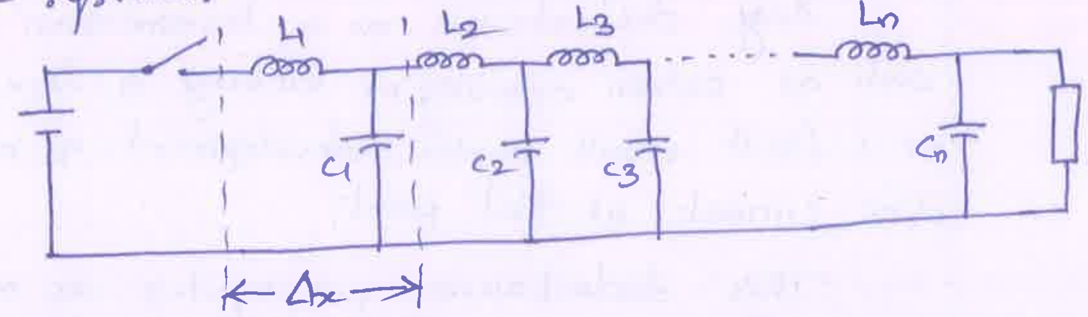
(ii) The steep wave front of the surge may cause internal flashover between interns of transformer (T/F).

(iii) High peak voltage of the surge may cause external flashover, between the terminals of the electrical equipment, which may result in damage to insulators.

④ Define lumped parameters. (April/may 2010)

(concentrated in one place)

The lumped parameters system is that in which the distrubance orginating at one point of the system is propagated instantaneously to every other point in the system.



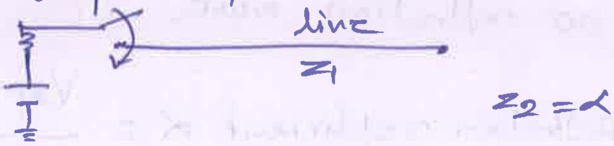
Lumpy -representation.

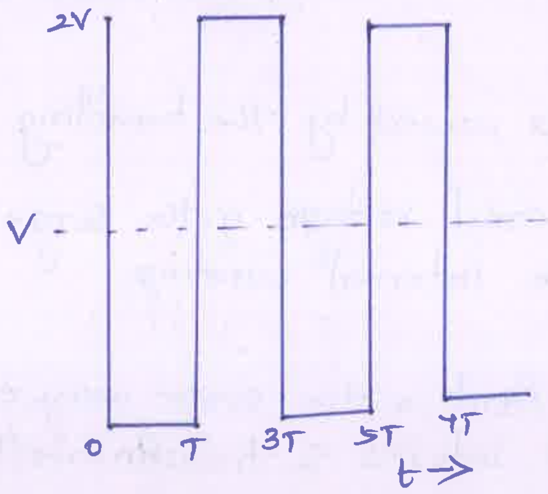
These lumped systems can be modeled by ordinary differential equations.

⑤ Define step responce.

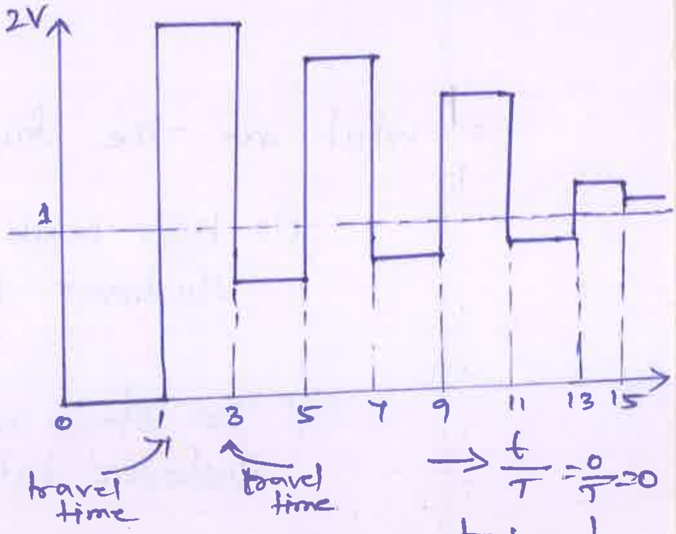
voltage change suddenly (in zero time) from one value to another value that is called step change or stepresponce.

step response of transmission line.





(a) losses neglected



$\rightarrow \frac{t}{T} = \frac{0}{T} = 0$

$t = 1 = \frac{1}{T}$

(b) losses and attenuation included.

damped out

but it will face

⑥ Define Bewley's Lattice diagram.

~~It's called~~ Bewley has given the lattice (or) time-space diagrams from which the motion of reflection and transmitted waves and their position at every instant the motion of reflected and transmitted waves and their position at every instant can be obtained.

⑦ ~~Ag~~ what is the application of Bewley's lattice diagram?

The use of Bewley's lattice diagram one can know at a glance the position and direction of motion of every incident, reflected and transmitted wave on the system at every instant of time.

The principle observed in lattice diagram, how the voltage is varying w.r.to time.

⑧ Define standing wave.

A standing wave, also known as stationary wave, is a wave that remains in a constant position.

This phenomenon can occur because the medium is moving in the opposite direction to the wave, or it can arise in a stationary medium as a result of interference between two waves travelling in opposite directions.

⑨ Define natural frequency.

The natural frequency is the frequency at which a system oscillates when it is disturbed. System have internal and elastic characteristics which make them want to oscillate or vibrate at certain frequencies. These specific frequency are called natural frequency.

⑩ what is meant by reflection and refraction q travelling waves?

The travelling wave undergoes a transition, the incoming wave is called the incident wave and other waves are called reflected and refracted waves are transmitted at transition point.

⑪ write the expression for reflection coefficient and refraction coefficient.

Reflection coefficient is designated 'a'

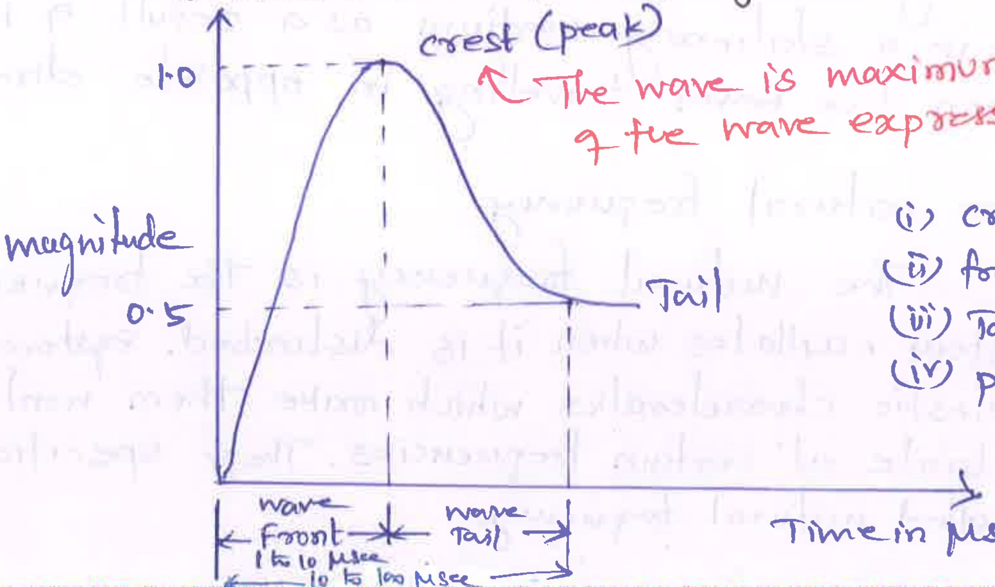
$$a = \left[\frac{Z_B - Z_A}{Z_B + Z_A}\right]$$

Refraction coefficient is designated 'b'

$$b = \left[\frac{2Z_B}{Z_B + Z_A}\right]$$

where, Z_A, Z_B are the characteristic impedance q the line.

⑫ what are the specifications q travelling wave?
(or)
Generalised waveshape q lighting stroke.



The wave is maximum amplitude q the wave expressed in kV or kA.

(i) crest q a wave
(ii) front q a wave
(iii) Tail q a wave
(iv) polarity.

UNIT - V (Two marks)

TRANSIENT IN INTEGRATED POWER SYSTEM.

1. what is meant by kilometric fault? (April/may 2008)

Kilometric fault is the fault located beyond the terminals and thus the current can be easily interrupted due to the added impedance of the line. This added impedance not only limits the current but also supports some of the system voltage.

2. what is meant by switching surges? (April/may 2010)

The disturbance produced by the switching operation in a system which sets up travelling waves which travel along the connected lines to and from. These disturbances are called as switching surges.

3. calculate the surge impedance of the line with inductance is 110 mH and capacitance is 2·5 μF.

$$\text{Surge impedance } Z_0 = \left(\frac{L_1}{C_1}\right)^{1/2} = \left[\frac{0{\cdot}11}{2{\cdot}5\times10^{-6}}\right]^{1/2} = 2100\,\Omega$$

4. what are the applications of EMTP? (May/Jun 2009)

(i) EMTP is a comprehensive computer program designed to solve electrical transient problems in lumpy circuits, distributed circuits.

(ii) This program is capable of solving steady-state circuit problems.

(iii) Transient analysis can be carried out in circuits with any arbitrary configuration of lumped parameters (R, L and C).

5. Define Load Rejection.

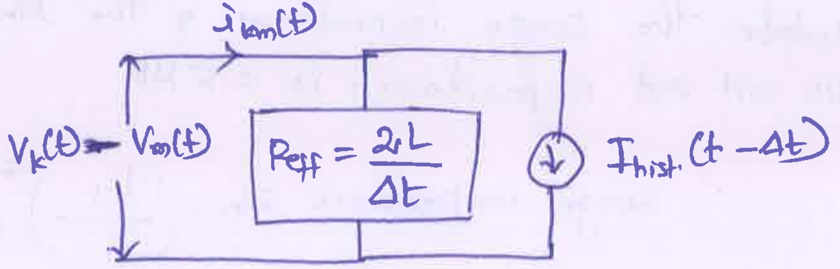
⇒ Load rejection is when there is a fault on the transmission line which is sensed by the protection system and trip the circuit breaker concern, during that's time the load connected with the feeder and lines are suddenly droped i.e, load throw off (or) load rejection occurs.

6. what are the effects (causes) of load rejection in power system?

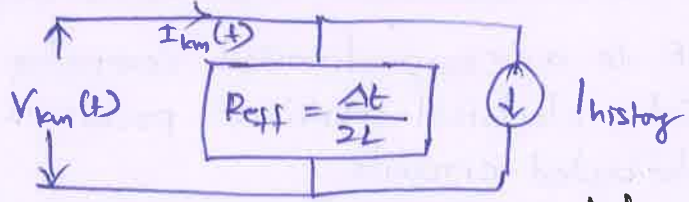
Sudden load rejection on large power systems causes the speeding up of generator prime movers.

The speed governors and automatic voltage regulates will intervene to restore the normal conditions. Initially both the frequency and voltage increases.

7. Draw the norton's equivalent circuit to model a inductor in a network for EMTP calculation.



⑧ Draw the norton's equivalent circuit to model a capacitor in a network for EMTP calculation.



⑨ write the network equation to model a transmission network for EMTP calculation.

$$[G]\,[V(t)] = i(t) - [I]$$

Where,

$[G]$ → is the modal conductance matrix

$[V(t)]$ → is the n node voltages

$[i(t)]$ → is the vector of current sources

$[I]$ → is the vector of past history terms.