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Civil Services Main Examination Previous Solved Papers : Electrical Engg. (Paper-II)

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Preface

B. Singh (Ex. IES)

Civil Service is considered as the most prestigious job in India and it has become a preferred destination by all engineers. In order to reach this estimable position every aspirant has to take arduous journey of Civil Services Examination (CSE). Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.

I feel extremely glad to launch the revised edition of such a book which will not only make CSE plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years papers of CSE. The book aims to provide complete solution to all previous years questions with accuracy.

On doing a detailed analysis of previous years CSE question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Services and State Services exams. Hence, this book is a one stop shop for all CSE, ESE and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

B. Singh (Ex. IES)

CMD, MADE EASY Group

Previous Years Solved Papers of

Civil Services Main Examination

Electrical Engineering : Paper-II

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1 Control Systems

1. Modelling of a Control System & Transfer Function Approach

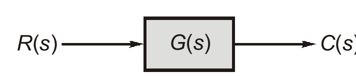
1.1 Show that the feedback reduces the effect of parameter variation on the performance of the control system. Also discuss briefly the effect of feedback on the transient performance of the control system.

[CSE-2002 : 20 marks]

Solution:

Consider an open loop system,

$$T(s) = \frac{C(s)}{R(s)} = G(s)$$

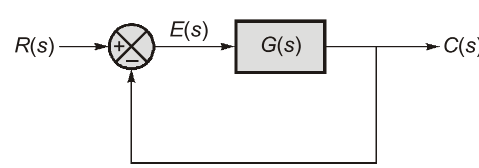


The sensitivity of $T(s)$ with respect to $G(s)$ will be given by

$$S_G^T = \frac{\frac{\partial T}{T}}{\frac{\partial G}{G}} = \frac{\partial T}{\partial G}\cdot\frac{G}{T} = 1$$

Consider a closed loop system,

$$T(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)}$$



$$\therefore \qquad S_G^T = \frac{\partial T}{\partial G}\cdot\frac{G}{T} = \frac{1}{1+G(s)}$$

Hence, feedback reduce the sensitivity of the transfer function to changes in system parameters.

Effect of feedback on transient performance:

1. Feedback reduces the gain of the system.
2. Feedback reduces the system time constant and thus increases response speed.
3. Feedback shifts the pole of the system to left.
4. Feedback introduces the possibility of instability.
5. Feedback increases the bandwidth of the system.

1.2 Explain the effects of negative feedback in control systems on the following :

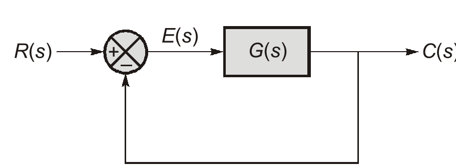
(i) Stability

(ii) External disturbances

[CSE-2003 : 20 marks]

Solution:

For closed-loop system with negative feedback,

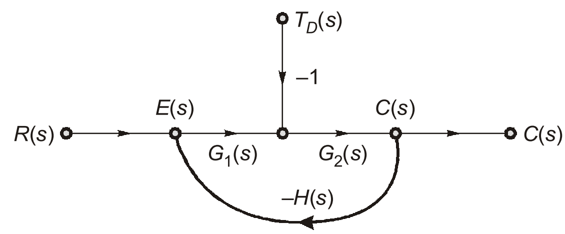


$$\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)}$$

(i) **Stability:** Negative feedback introduces the possibility of instability.

This is because the characteristic equation of $\frac{C(s)}{R(s)}$ may have roots with positive real parts even if $G(s)$ itself is stable.

(ii) **External disturbances:** Negative feedback reduces the effect of external disturbances on output. Consider the closed loop system with disturbances as shown below:



$$\frac{C(s)}{T_D(s)} = \frac{-1}{G_1(s)H(s)} \quad \text{[Considering } R(s) = 0\text{]}$$

Thus, feedback reduces the effect of disturbance on a system.

1.3 **If the roots of characteristic equation of a linear digital control system lie within unity circle in *z*-plane, the system is stable?**

[CSE-2003 : 20 marks]

Solution:

The characteristic equation of *z*-transfer function is

$$1 + GH(z) = 0$$

The stability region in *z*-plane corresponding to *s*-plane is located by mapping from *s*-plane to *z*-plane. *z*-transform is obtained by substituting $z = e^{sT}$ in the corresponding impulse train Laplace transform.

The imaginary axis ($j\omega$) axis in the *s*-plane divides stable and unstable regions and the corresponding regions in *z*-domain can be obtained by putting $s = \pm j\omega$ and plotting the values of '*z*' thus obtained in another complex phase called *z*-plane.

Therefore, $z = e^{\pm j\omega T}$

$z = (\cos \omega T \pm j \sin \omega T)$

Magnitude, $|z| = 1$

Angle, $\angle z = \pm \omega T$

Thus the variation of the dependent variable '*z*' in the *z*-plane as the independent variable 'ω' varied along the imaginary axes in *s*-plane is given by a circle of unit radius central at origin of *z*-plane.

Let, $s = -\alpha \pm j\omega$ [a point in the L.H.S. of *s*-plane]

$z = e^{(-\alpha \pm j\omega)T} = e^{-\alpha T}(\cos \omega T \pm j \sin \omega T)$

$|z| = e^{-\alpha T}$

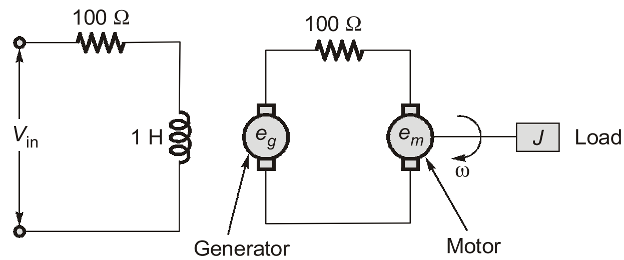
$\angle z = \pm \omega T$

α and T being positive

Therefore, $|z| < 1$ [region represents L.H.S. of s-plane]

Hence if the roots of characteristic equation of a linear control system lie within unit circle in *z*-plane the system is stable.

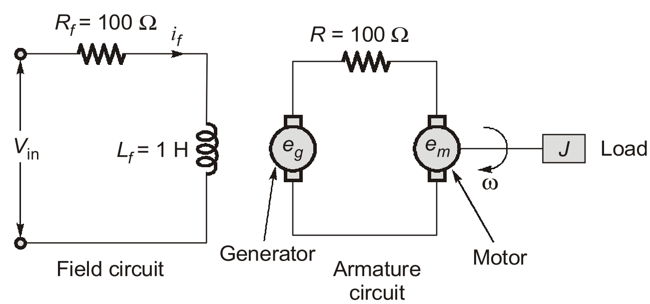
1.4 The diagram of a speed control system is given below :



The generator e.m.f. e_g is 2000 volts per field ampere. The motor e.m.f. e_m is 1.5 volts rad^{-1} sec. The motor torque K_T is 0.5 N-m per armature ampere and the inertia of motor and load is 10^{-4} kg.m^2. Assuming negligible friction, determine the transfer function $\frac{\omega(s)}{V_{in}(s)}$.

[CSE-2011 : 20 marks]

Solution:



Applying KVL in field circuit,
$$V_{in} = R_f i_f + L_f \frac{d i_f}{dt}$$
$$V_{in}(s) = R_f I_f(s) + sL_f I_f(s) \quad ...(1)$$

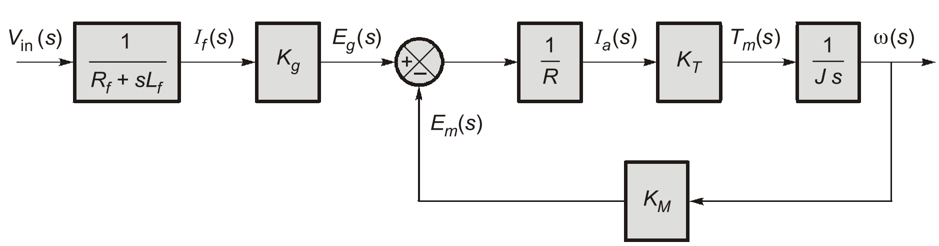
Generated emf,
$$e_g = K_g i_f$$
$$E_g(s) = K_g I_f(s) \quad ...(2)$$

Applying KVL in armature circuit,
$$e_g = R i_a + e_m$$
$$E_g(s) = R I_a(s) + E_m(s) \quad ...(3)$$

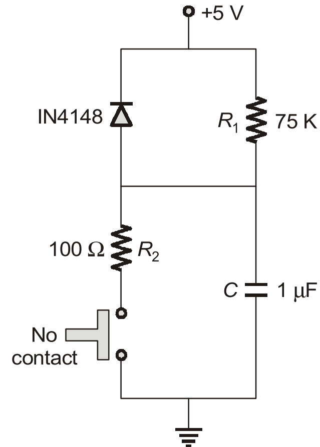
Counter emf of motor,
$$e_m = K_M \omega$$
$$E_m(s) = K_M \omega(s) \quad ...(4)$$

Developed Torque on motor,
$$T_M = K_T i_a$$
$$T_M(s) = K_T I_a(s) \quad ...(5)$$
$$T_M = \frac{J d\omega}{dt} \quad \text{\{Neglecting friction on motor\}}$$
$$T_M(s) = J s \omega(s) \quad ...(6)$$

Block diagram from above equations can be drawn as



On reduction of block diagram we transfer function, The jump-on-reset circuit with typical values of R and C is shown as:



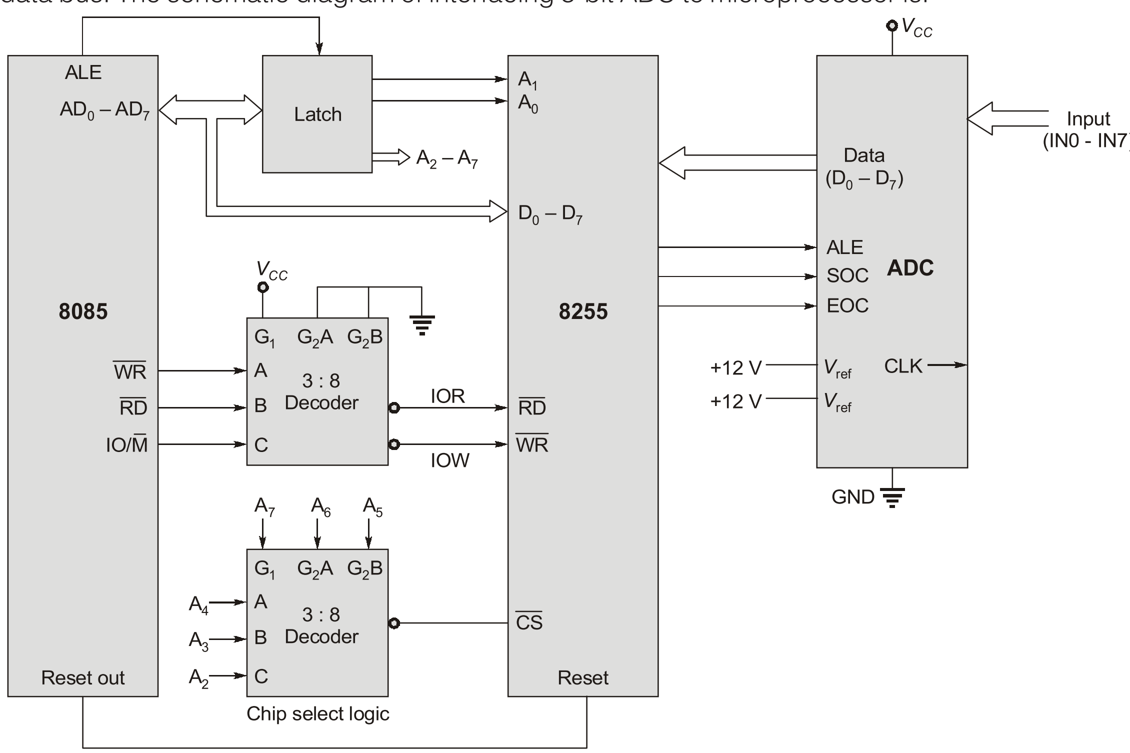
Jump-on-reset circuit

After RESET, 8085 loads 0000 H in PC register and clear the INTE flag.

3.8 Draw the schematic diagram for interfacing an 8-bit analog to digital converter to 8085 microprocessor using 8255 PPI. [CSE-2018 : 10 marks]

Solution:

The ADC 0808 and ADC 0809 are monolithic CMOS devices with an 8-channel multiplexer. These devices are designed to operate from common microprocessor control buses, with tri-state output latches driving the data bus. The schematic diagram of interfacing 8-bit ADC to microprocessor is:



Schematic diagram

3.9 Write an 8085 microprocessor assembly language program to turn ON an LED connected to bit 4 of the 8155 I/O port B. Use address of port B as 22_{16}.

[CSE-2018 : 10 marks]

Solution:

Let starting address be 5000 H.

Address of port B of 8155 is 22 H.

3 Measurement and Instrumentation

1. Measuring Instruments and Error Analysis

1.1 By giving suitable examples explain clearly the difference between accuracy and precision.

[CSE-2009 : 8 marks]

Solution:

Accuracy: It is the closeness with which an instrument reading approaches the true value of a quantity being measured.

Precision: It is a measure of reproducibility of the measurement i.e. it is degree of agreement within a group of measurements.

Consider an ammeter with a problem in zero adjustment. If we measure a current of 10 A (true value) and it shows 12.1 A, 12.1 A, 12.1 A, 12.2 A, 12.1 A. It implies that the ammeter is precise. However due to zero adjustment it is not accurate. So precision doesn't guarantee accuracy.

Let us take another example. Consider the measurement of known voltage of 100 V with a meter. Five readings are taken and indicated value are 104, 103, 105, 103 and 105 V. It is seen that we can not depend on the instrument for an accuracy better than 5% while precision of ±1% is indicated since the maximum deviation from mean reading of 104 V is only 1.0 V. So the instrument can be calibrated so that it can be used to read ±1 V dependably. This illustrates that accuracy can be improved upon but not the precision of the instrument by calibration. Also the readings are close together, they have a small scatter and have high degree of precision but the result is far from accurate.

1.2 A power transformer was tested to determine losses and efficiency. The input power was measured as 3650 W and the delivered output power was 3385 W, with each reading in doubt by ±10 W. Calculate the percentage uncertainty in the losses of the transformer and the percentage uncertainty in the efficiency of the transformer, as determined by the difference in input and output power readings.

[CSE-2009 : 12 marks]

Solution:

Given, $P_i = 3650\text{ W}, \quad P_0 = 3385\text{ W}$

Uncertainties, $W_{Pi} = \pm 10\text{ W}$

$W_{P0} = \pm 10\text{ W}$

Losses in transformer, $P_L = P_i - P_0$

$P_L = 3650 - 3385 = 265\text{ W}$

$$\therefore \quad \frac{\partial P_L}{\partial P_i} = 1, \quad \frac{\partial P_L}{\partial P_0} = -1$$

$$\therefore \quad \text{Uncertainty in loss} = \pm\sqrt{\left(\frac{\partial P_L}{\partial P_i}\right)^2 W_{Pi}^2 + \left(\frac{\partial P_L}{\partial P_0}\right)^2 W_{P0}^2}$$

$$= \pm\sqrt{(1)^2 10^2 + (-1)^2 10^2} = \pm 10\sqrt{2}\text{ W}$$

$$\% \text{ Uncertainty in loss} = \frac{\pm 10\sqrt{2}}{265} \times 100 = \pm 5.34\%$$

Efficiency,
$$\eta = \frac{P_0}{P_i}$$

$$\frac{\partial \eta}{\partial P_i} = -\frac{P_0}{P_i^2} = -\frac{3385}{(3650)^2} = -2.54 \times 10^{-4}$$

$$\frac{\partial \eta}{\partial P_0} = \frac{1}{P_i} = 2.74 \times 10^{-4}$$

$$\text{Uncertainty in } \eta = \pm\sqrt{\left(\frac{\partial \eta}{\partial P_i}\right)^2 W_{Pi}^2 + \left(\frac{\partial \eta}{\partial P_0}\right)^2 W_{P0}^2}$$

$$= \pm\sqrt{(2.54 \times 10^{-4})^2 (10)^2 + (2.74 \times 10^{-4})^2 (10)^2}$$

$$= \pm\sqrt{645.2 \times 10^{-8} + 750.8 \times 10^{-8}} = \pm 37.36 \times 10^{-4}$$

$$\eta = \frac{P_0}{P_i} = \frac{3385}{3650} = 0.927$$

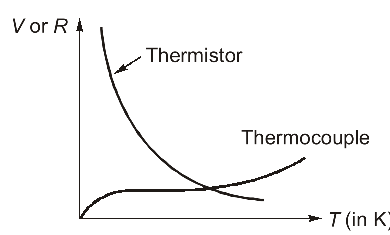
$$\% \text{ Uncertainty in efficiency} = \pm\frac{37.36 \times 10^{-4}}{0.927} \times 100\% = \pm 40.30 \times 10^{-2}\ \%$$

$$\% \text{ Uncertainty in efficiency} = \pm 0.4030\%$$

1.3 Comment upon 'Linearity' and 'Sensitivity' of thermistors in comparison to thermocouples.

[CSE-2012 : 2 marks]

Solution:



Resistance : Temperature characteristic of thermistor
Emf: Temperature characteristic of thermocouple

- Thermistor are more sensitive than thermocouple. Temperature coefficient of thermistor can be 5% – 6% for 1°C variation whereas for thermocouple sensitivity is quite low.
- However thermistors are extremely non-linear whereas thermocouples are relatively linear.

1.4 Why is 'lead wire compensation' not required for thermistors?

[CSE-2012 : 1 mark]

Solution:

Lead wire compensation is required in temperature measuring devices like RTD but not required in thermistor. The connecting lead to the devices has some resistance and it may inadvertently creep into reading by device. So compensation for resistance of lead wire is required. However the high resistance of thermistor offer an advantage e.g. common thermistor value is 5000 Ω at 25°C. Lead resistance of about 100 Ω produces an about 0.05°C error at a sensitivity of 4%/°C.

1.5 **Giving classification of errors in measurement, explain these errors giving suitable examples. Explain how systematic errors can be minimised.**

[CSE-2013 : 5 marks]

Solution:

Types of error:

1. Gross errors
2. Systematic errors
3. Random errors

1. **Gross error:** Mainly due to human error in reading instruments, recording and calculating measurement results e.g. reading current of 31.1 A as 37.1 A.
2. **Systematic error:** This error is subdivided as follows:
   - (a) **Instrumental errors:** It arises due to 3 reason: (i) Inherent shortcoming of instrument, (ii) Misuse of instruments, (iii) Loading effect of instruments
     - (i) May be due to construction, calibration or ageing of instrument e.g. if spring of an instrument becomes weak.
     - (ii) A good instrument used in unintelligent way may give erroneous results e.g. failure to adjust zero, use load of high resistance etc.
     - (iii) Use of voltmeter for measuring voltage across a high resistance circuit.
   - (b) **Environmental error:** Error due to conditions external to device e.g. temperature, humidity, pressure, dust.
   - (c) **Observational error:** eg. parallex error,
3. **Random error:** Error due to multitude of factors which change or fluctuate from one measurement to another. **Example:** error due to noise

   Ways to minimise systematic errors:
   1. Calibration of instruments against standard.
   2. Correction factor should be applied after determining the error.
   3. The error due to loading effect should be considered and corrections for these effects should be made e.g. when measuring a low resistance by ammeter-voltmeter method, voltmeter with high resistance should be made.
   4. Conditions for measurement should be kept same.
   5. Using of equipment immune to these effects. e.g. variation of resistance with temperature could be minimised by using resistive material with low temperature coefficient of resistance.
   6. Electrostatic and magnetic shield may be provided.
   7. Parallex error can be eliminated by having a pointer and scale in same plane.

1.6 **A circuit consists of two branches in parallel. The current in one branch is I_1 = 10 ± 0.2 A, and in other is I_2 = 20 ± 0.5 A. Determine the value of the total current $I = I_1 + I_2$,**
(a) consider the errors in I_1 and I_2 as limiting errors.
(b) considering the errors as standard deviations.
Comment on the result.

[CSE-2013 : 5 marks]

Solution:

(a)
$$I = I_1 + I_2$$

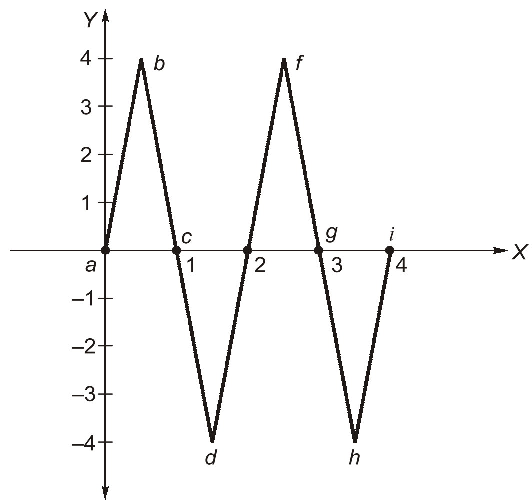
Fractional error in I,
$$\frac{\delta I}{I} = \pm\left(\frac{I_1}{I}\frac{\delta I_1}{I_1} + \frac{I_2}{I}\frac{\delta I_2}{I_2}\right)$$

$$\frac{\delta I_1}{I_1} = \frac{0.2}{10} = 0.02$$

Similarly deflections can be calculated for all other points as below:

	Deflection	
$a(0, 0)$ ⇒	$(0, 0)$	$b(6.25, 40) \Rightarrow (0.5, 4)$
$c(12.5, 0)$ ⇒	$(1, 0)$	$d(18.15, -40) \Rightarrow (1.5, -4)$
$e(25, 0)$ ⇒	$(2, 0)$	$f(31.25, 40) \Rightarrow (2.5, 4)$
$g(37.5, 0)$ ⇒	$(3, 0)$	$h(43.75, -40) \Rightarrow (3.5, -4)$
$i((50, 0)$ ⇒	$(4, 0)$	

The points obtained as deflections (in cm) will be seen on CRO's screen as below.



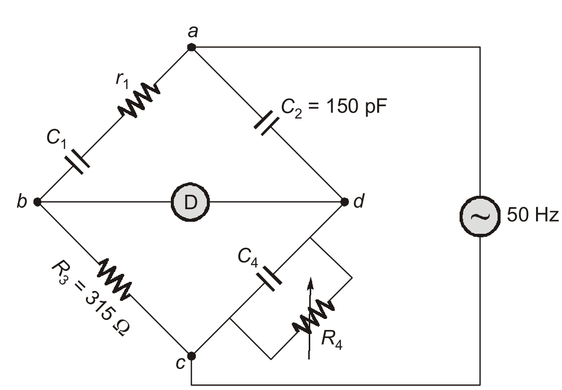
3.11 A schering bridge, used to test a specimen has the following bridge arms: arm *ab* contains the unknown capacitance (C_1) whose loss part is represented by a series resistance (r_1), arm *bc* contains a non-inductive resistance (R_3) of 315 Ω, arm *cd* contains a variable capacitor (C_4) in parallel with a variable non-inductive resistance (R_4) and arm *da* contains a standard capacitor (C_2) of 150 pF. The supply is connected between *a* and *c* and the detector is connected between *b* and *d*. The specimen is tested at a frequency of 50 Hz, it is having a thickness of 6.3 mm and it is tested between electrodes each having dimension of 0.15 m × 0.18 m. At balance, C_4 = 0.375 μF and R_4 = 423 Ω. Find the capacitance, dissipation factor and relative permittivity of the specimen. Given: Permittivity of free space = 8.854×10^{-12} F/m.

[CSE-2017 : 15 marks]

Solution:

The bridge is being used to test a specimen (C_4).

At balance:



$$\Rightarrow \quad \left(r_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{R_3}{j\omega C_2}$$

$$\Rightarrow \quad \frac{(1 + j\omega C_1 r_1)}{j\omega C_1}\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{R_3}{j\omega C_2}$$

$$\Rightarrow \quad (1 + j\omega C_1 r_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{R_3 C_1}{C_2}$$

$$\Rightarrow \quad (1 + j\omega C_1 r_1)(R_4) = \frac{R_3 C_1}{C_2}(1 + j\omega C_4 R_4)$$

Equating imaginary and real parts of above equation,

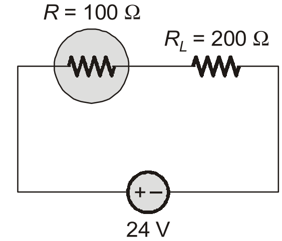
Advantages of LVDT :
1. Linearity
2. Infinite resolution
3. High output
4. High sensitivity

Disadvantages of LVDT :
1. Large displacements are required for appreciable differential output.
2. Limited dynamic response.
3. Temperature affects on the performance of the transducer.

5.29 A resistance strain gauge having a resistance of 100 Ω and gauge factor of 2 is connected in series to a load resistance of 200 Ω across 24 volts. The modulus of elasticity is 200 GN/m^2. Calculate the change in output voltage due to the applied stress of 120 MN/m^2.

[CSE-2022 : 10 marks]

Solution:



$$Y = 200 \times 10^9 \text{ N/m}^2$$

$$E = 120 \times 10^6 \text{ N/m}^2$$

$$\in = \text{Longitudinal strain} = \frac{E}{Y}$$

$$\in = \frac{120 \times 10^6}{200 \times 10^9} = 6 \times 10^{-4}$$

$$\text{Gauge factor} = 2 = \frac{\frac{\Delta R}{R}}{\in}$$

Change in resistance, $\Delta R = 2 \times \in \times R = 2 \times 6 \times 10^{-4} \times 100$

$$\Delta R = 0.72\ \Omega$$

Change in output voltage, $\Delta V_o = \dfrac{24 \times 0.72}{0.72 + 100 + 200}$

$$\Delta V_o = 0.0575 \text{ Volts}$$

5.30 A resistive strain gauge, with a gauge factor 2.2, is cemented on a rectangular steel bar with the elastic modulus, $E = 205 \times 10^6$ kN/m^2. The width and thickness of the steel bar is 3.5 cm and 0.55 cm respectively. An axial force of 12 kN is applied. If the nominal resistance of the strain gauge is 100 Ω, determine the change in resistance of the strain gauge.

[CSE-2023 : 10 marks]

Solution:

Given : Axial force, $F = 12$ kN

$$E = 205 \times 10^6 \text{ N/m}^2$$

$$\text{Area, } A = 3.5 \times 10^{-2} \times 0.55 \times 10^{-2} = 1.925 \times 10^{-4} \text{ m}^2$$

$$\text{Strain, } \varepsilon = \frac{F}{A \times E} = \frac{12 \times 10^3}{1.925 \times 10^{-4} \times 205 \times 10^6}$$

$$\varepsilon = 0.304$$

$$\frac{\frac{\Delta R}{R}}{\varepsilon} = \text{G.F.}$$

$$\Delta R = \text{G.F.} \times \varepsilon \times R = 2.2 \times 0.304 \times 100$$

$$\Delta R = 66.9\ \Omega$$

■■■■

4 Power Systems

1. Performance of Transmission Lines, Line Parameters and Corona

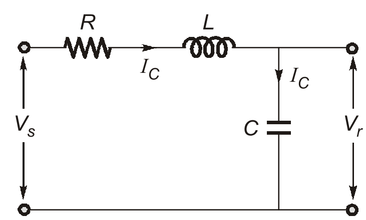
1.1 Explain the following connection with power systems Ferranti effect, infinite line, Peterson coil, load bus.

[CSE-2001 : 20 marks]

Solution:

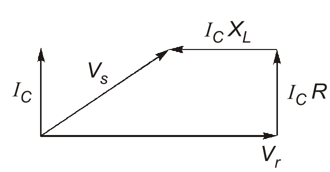
Ferranti Effect: When a long line is operating at no load or lightly loaded condition, the receiving end voltage is greater than the receiving end. This is called Ferranti effect.

Consider an approximate lumped parameter for a long line as below:



Lumped network representation

Usually capacitive reactance of line is quite large as compared to inductive reactance under no load or lightly loaded conditions the line current is of leading power factor. The phasor diagram of the condition is as below:

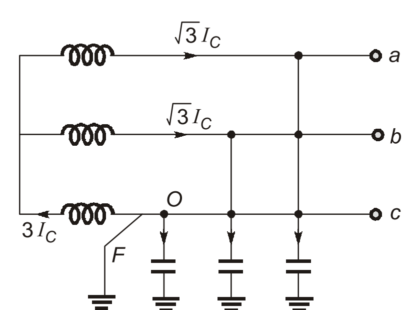


Phasor diagram

(Since $X_C >> X_{L,}$ I_S is dominating capacitance current I_C).

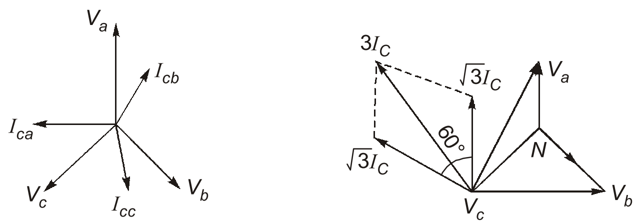
From above it is clear that $V_r > V_s$ for no load conditions.

Infinite line: The characteristic impedance of a uniform transmission line is the ratio of the amplitudes of voltage and current of a single wave propagating along the line, i.e. a wave travelling in one direction in the absence of reflections in other direction. A transmission line of finite length that is terminated at one end with an impedance equal to characteristic impedance produces no reflections to a wave and is called infinite line.



Peterson coil: In an ungrounded balanced 3-phase system potential of neutral is held at ground potential. The diagram of balanced system is shown figure.

The phasor diagram for balanced and faulted system is as under:



The voltage of healthy phase rises to $\sqrt{3}\,V_{p_n}$. The presence of inductance and capacitance in the system leads to Arcing Grounds and voltage of system rises to dangerously high value.

These voltage can be eliminated by connecting an inductance of suitable value between neutral and ground. If value of inductance is such that the fault current balances exactly the charging current, then the ground is known as resonant grounding or Peterson coil.

Load Bus: At this Bus the real and reactive components of power are specified. It is desired to find out the voltage magnitude and phase angle through the load flow solution. A pure load bus (no generating facility at the bus i.e. $P_{Gi} = Q_{Gi} = 0$)is a *PQ* bus. *PQ* buses or load buses are the most common, comprising almost 80% of all the bus in a given power system.

1.2 **In order to increase the distance between poles, carrying long distance transmission line, aluminium conductors should be strengthened by strain-hardening?**

[CSE-2001 : 20 marks]

Solution:

The statement is correct.

Operating transmission lines for high current rating causes significant conductor heating. Heating of conductor can cause significant conductor sag, which will either limit the length of the span or require taller support structure. Conventional conductors of aluminium may also be limited by their own maximum operating temperature, above which they will physically degrade.

One way to increase line capacity and consequently span length is to use stronger conductors. In order to provide adequate strength, the aluminium strands are 'strain-hardened' or 'work-hardened' or 'cold worked'. It is done to enhance their physical strength. This increase in strength is due to dislocations in the crystal structure of the material which makes it difficult for layers of atoms to slip past one another. These dislocations also slightly increase the electrical resistance of the conductor.

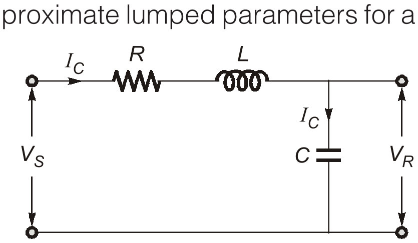
Heating a strain-hardened conductor above design temperature will cause conductor to anneal. When material anneals, the strength of material may reduce. This is basis of operating temperature of most conductors.

1.3 **In a long transmission line, the sending end voltage is always greater than the receiving end voltage and this effect is known as Ferranti effect?**

[CSE-2005 : 20 marks]

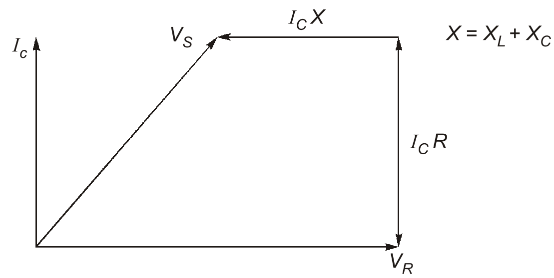
Solution:

The statement is not correct. The correct statement is when a long line is operating under no load or lightly loaded condition, the receiving end voltage is greater than the sanding end voltage. This is known as Ferranti effect. Consider an approximate lumped parameters for a long line as given below:



Lumped line representation

Usually capacitive reactance of line is quite large as compared to inductive reactance, under no load or lightly loaded conditions the line current is of leading pf. The phasor diagram for this condition is as under:



Phasor diagram

The charging current produces drop in the reactance of the line which is in phase opposition to receiving end voltage and hence sending end voltage become smaller then the receiving end voltage.

1.4 **'For overhead transmission lines, shunt admittance is mainly capacitive susceptance ($j\omega LC$)'. Comment.**

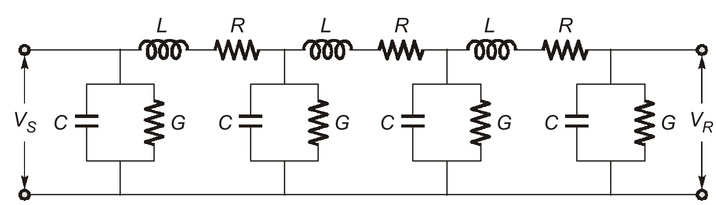
[CSE-2006 : 20 marks]

Solution:

The performance of a transmission line depends upon its parameters. These are mainly four parameters:

1. Resistance
2. Inductance
3. Capacitance
4. Shunt conductance

These parameters are uniformly distributed along line as shown below:



The inductance and resistance form series impedance whereas the capacitance and conductance form the shunt admittance.

Line capacitance: In transmission line air acts as a dielectric medium. This dielectric medium constitutes the capacitor between conductors which stores the electrical energy. The capacitance of conductor is defined as charge per unit of potential difference. The admittance of line capacitance = $j\omega C$.

Shunt conductance: Air, though a dielectric medium allows some current to flow through it due to dielectric imperfections. Such current is called leakage current. Leakage current depends upon the atmosphere conditions and pollution like moisture and surface deposits. However for an overhead transmission line it has been found to be negligible small and can be safely neglected.

In view of this the shunt branch of transmission line is composed of the capacitive impedance only which has a capacitive susceptance of $j\omega C$.

1.5 **In a 3-phase system, show that for a given conductor current density, the power loss/unit length for transporting certain power at certain power factor is inversely proportional to the line voltage.**

[CSE-2008 : 10 marks]

Solution:

Power, $P = \sqrt{3} VI \cos\theta$

V = line voltage

$\cos\theta$ = power factor

Line current, $I = \frac{P}{\sqrt{3} V \cos\theta}$

Current density, $\delta = \frac{I}{A}$

$A \rightarrow$ Area of cross-section

$$A = \frac{I}{\delta} = \frac{P}{\sqrt{3} V \delta \cos\theta}$$

Resistance, $R = \frac{\rho l}{A}$ $\quad \rho \rightarrow$ resistivity

Resistance of unit length, $R = \frac{\rho}{A} = \frac{\sqrt{3} V \delta \rho \cos\theta}{P}$

Power loss, $3I^2R = 3\left(\frac{P}{\sqrt{3} V \cos\theta}\right)^2 \cdot \frac{\sqrt{3} V \delta \rho \cos\theta}{P}$

$$= \frac{\sqrt{3} P(\delta\rho)}{V \cos\theta}$$ P, δ, ρ, $\cos\theta$ are given as constant

So power loss, $P_L = \frac{K}{V}$

$$P_L \propto \frac{1}{V}$$

1.6 A three-phase, 132 kV transmission line delivers 50 MVA at 132 kV and p.f. 0.8 lagging at its receiving end. The line constants are: $A = 0.98\angle 3°$ and $B = 110\angle 75°$ ohms/phase.
Compute:
(i) sending-end voltage and power angle,
(ii) sending-end active and reactive powers,
(iii) line losses and the 'VARS' absorbed by the line,
(iv) unity p.f. load that can be supplied at the receiving end with 132 kV as the line voltage at both the ends.

[CSE-2008 : 20 marks]

Solution:

$$V_r = \frac{132}{\sqrt{3}} = 76.21 \text{ kV}, A = 0.98\angle 3°, B = 110\angle 75\text{ °ohms/phase}$$

$$\text{p.f.} = \cos\phi = 0.8, \qquad \sin\phi = 0.6$$

(i) $V_S = AV_r + BI_r$

$$|I_r| = \frac{50 \times 10^6}{(\sqrt{3})(132 \times 10^3)} = 218.69 \text{ A}$$

$$I_r = 218.69\angle -\cos^{-1}(0.8) = 218.69\angle -36.86° \text{ A}$$

$$V_S = (0.98)(76.21 \times 10^3)\angle 3° + (110\angle 75)(218.69)\angle -36.86°$$

$$= 93.50 \times 10^3 + j\,18765.31$$

$$= 95.36 \times 10^3 \angle 11.35° \text{ V}$$

$$V_{S(l-l)} = 165.18\angle 11.35° \text{ kV}$$

$$|V_{S(l-l)}| = 165.18 \text{ kV}, \qquad \delta = 11.35°$$

(ii) For ABCD parameters $\begin{vmatrix} A & B \\ C & D \end{vmatrix} = 1$

$$\Rightarrow \quad AD - BC = 1$$

$$A = D$$

$$\Rightarrow \quad C = \frac{A^2 - 1}{B} = \frac{(0.98)^2 \angle 6° - 1}{110\angle 75°}$$

$$C = \frac{-0.045 + j0.1}{110\angle 75°} = \frac{0.1096\angle 114.16°}{110\angle 75°} = 9.96 \times 10^{-4} \angle 39.16° \text{ S}$$

$$I_S = CV_r + DI_r$$

$$= (9.96 \times 10^{-4} \angle 39.16°)\left(\frac{132}{\sqrt{3}}\right) \times 10^3 + (0.98 \angle 3°)(218.69 \angle -36.86°)$$

$$I_S = 247.27 \angle -16.78°$$

$$P_S = 3V_S I_S \cos(11.35 + 16.78) = (3)(95.36 \times 10^3)(247.27) \cos 28.13°$$

$$= 62.83 \text{ MW}$$

$$Q_S = 3V_S I_S \sin(28.13)° = (3)(95.36 \times 10^3)(247.27) \sin 28.13°$$

$$= 33.35 \text{ MVAR}$$

(iii)

$$\text{Line loss} = P_S - P_R$$

$$P_S = 62.83 \text{ MW}$$

$$P_R = 50 \times 0.8 = 40 \text{ MW}$$

$$\text{Line losses} = 62.83 - 40 = 22.83 \text{ MW}$$

$$\text{VAR absorbed} = Q_S - Q_R$$

$$Q_S = 33.35 \text{ MVAR}$$

$$Q_R = (50)(0.6) = 30 \text{ MVAR}$$

$$\text{VAR absorbed} = Q_S - Q_R = 3.35 \text{ MVAR}$$

(iv) For upf load, $Q_R = 0$

$$V_S = V_S = 132 \times 10^3 \text{ V}$$

$$Q_R(\text{for upf}) = 0$$

$$= \frac{|V_S||V_R|}{|B|}\sin(\beta - \delta) - \left|\frac{A}{B}\right||V_R|^2 \sin(\beta - \alpha)$$

$$= \frac{(132 \times 10^3)(132 \times 10^3)}{110}\sin(75° - \delta) - \left|\frac{0.98}{110}\right|(132 \times 10^3)^2 \sin(75° - 3)$$

$$= \sin(75 - \delta) - 0.98 \sin 72°$$

$$\sin(75 - \delta) = (0.98)(0.951)$$

$$\delta = 6.25°$$

$$P_R = \frac{|V_S||V_R|}{|B|}\cos(\beta - \delta) - \left|\frac{A}{B}\right||V_R|^2 \cos(\beta - \alpha)$$

$$= \frac{(132 \times 10^3)}{110}\cos(75 - 6.25°) - \left(\frac{0.98}{110}\right)(132 \times 10^3)^2 \cos 72°$$

$$= (57.41 \times 10^{-6}) - (47.97 \times 10^6)$$

$$P_R = 9.44 \text{ MW for upf}$$