1.SEQUENCE IMPEDANCE OF 3-PHASE TRANSFORMER

Aim: To determine Sequence Impedance i.e Positive, Negative and Zero-Sequence Impedance of a 3-Phase Transformer.

Apparatus Required:

S.No	Item	Type	Range	Quantity
1	Transformer	3-Phase	230/230v, 2KVA	1
2	Voltmeter	Digital	(0-600)V	1
3	Ammeter	Digital	(0-10)A	1
4	Variac	3-Phase	(0-440)V	1
5	Connecting Wires			Needed

Theory: The sequence Impedances of an equipment or a component of power system are the positive, negative and zero sequence impedances. They are defined as follows:

- The positive sequence impedance of an equipment is the impedance offered by the equipment to the flow of positive sequence currents.
- The negative or zero sequence impedance of the equipment is the impedance offered by the equipment to the flow of corresponding sequence current.
- For a 3-Phase symmetrical static circuit without internal voltages like transformers and transmission lines, the impedances of the currents of any sequence are the same in the three phases; also the currents of a particular sequence will produce drop of the same sequence or a voltage of a particular sequence will be produce current of the same sequence only, which means there is no, mutual coupling between the sequence networks.
- Since for a static device, the sequence has no significance, the positive and negative sequence impedances are equal; the zero sequence impedance which includes the impedance of the return path through the ground, in the general case, is different from the positive and negative sequence impedance.

Procedure:

(A) Measurement of Positive and Negative Sequence Impedance:

1. Connect the circuit as shown in Circuit Diagram
2. By using 3-Phase variac apply the rated current of the primary and note down the voltage, current and power

Observation:

Voltage(V)(Volts)	Current(I)(Amps)	Power(W)(Watts)

Calculations:

$$Z_1 = Z_2 = \frac{V}{I}=10 \text{ ohms}$$

$$R_1 = \frac{W}{I^2}=4.77 \text{ ohms}$$

$$X_1 = X_2 = \sqrt{Z_1^2 - R_1^2}=8.98 \text{ ohms}$$

(B) Measurement of Zero Sequence Impedance:

1. Connect the circuit as shown in the circuit diagram
2. By using 1-Phase variac apply the rated current to the primary of the transformer and note down the voltage, current and power

Observation:

Voltage(V)(Volts)	Current(I)(Amps)	Power(W)(Watts)

Calculations:

$$Z_0 = \frac{V}{3I}=5.76 \text{ ohms}$$

$$R_0 = \frac{W}{3I^2}=6.36 \text{ ohms}$$

$$X_0 = \sqrt{Z_0^2 - R_0^2} = \text{i}2.69 \text{ ohms}$$

Precautions:

1. Avoid loose and wrong connections
2. Ensure that the auto transformer is at minimum position before powering the circuit.
3. Do not exceed the rated current of transformer while conduction experiment.

Result:

Sl. NO	Impedance	Value (Ω)
1	Positive sequence impedance	
2	Negative sequence impedance	

3	Zero sequence impedance	

Questions For Self Assessment:

1. Define symmetrical components.
2. What is the importance of sequence impedances?
3. The impedances of rotating machines to currents of the three sequences will generally be a) Same for each sequence

   b) Different for each sequence
4. What is the utility of three-phase three-winding transformer?
5. Why is tertiary winding connected in delta?

2.SEQUENCE IMPEDANCE OF 3-PHASE ALTERNATOR

Aim: To determine experimentally Positive, Negative and Zero Sequence Impedances of 3-Phase Alternators.

Apparatus Required:

S. No	Item	Type	Range	Quantity
1	Voltmeter	MI	(0-600)V	1
2	Ammeter	MI	(0-5)A	1
3	Ammeter	MC	(0-2)A	1
4	Rheostats	WW	300Ohms/1.5A	3
5	Variac	1-Phase	(0-270)V	1
6	Tachometer	Digital	(0-9999)RPM	1
7	Connecting Wires			Needed

Theory:

The sequence Impedances of an equipment or a component of power system are the positive, negative and zero sequence impedances. They are defined as follows:

- The positive sequence impedance of an equipment is the impedance offered by the equipment to the flow of positive sequence currents.
- The negative or zero sequence impedance of the equipment is the impedance offered by the equipment to the flow of corresponding sequence current.
- In a symmetrical rotating machines the impedances met by armature currents of a given sequence are equal in the three phases. Since by definition the inductance, which forms a part of impedances, is the flux linkages per ampere, it will depend up on the phase order of the sequence current relative to the direction of rotation of the rotor; positive, negative and zero sequence impedances are unequal in the general case.
- In fact for a rotating machine, the positive sequence impedance varies, having minimum value immediately following the fault and then increases with time until steady state conditions are reached when the positive sequence impedance corresponds to the synchronous impedance.
- The positive sequence impedance depends up on the working of the machine, i.e., whether it is working under sub transient, transient or steady state condition. The impedance under steady state condition is known as the synchronous impedance measured by the well known open circuit and short circuit tests.

$$Z_1 = Z_S = \frac{E_0(Per\ Phase\ Open\ Circuit\ Voltage)}{I_{SC}(Per\ Phase\ Short\ Circuit\ Current)}$$

- For the measurement of Negative sequence impedance, the machine is driven at rated speed and a reduced voltage is applied to circulate approximately the rated current. It is to be noted here that since negative sequence currents flow in this case, there is possibility of hunting which will results in oscillation of the pointer of the ammeter. The mean reading may be taken.

The Negative Sequence Impedance is given by $Z_2 = \frac{V}{\sqrt{3}I}$

- Zero Sequence Impedance is quite variable and depends upon the distribution i.e., the pitch and breadth factors. If the windings were uniformly distributed so that each phase produced a sinusoidal distribution of the mmf then the superposition of the three phases with equal instantaneous currents cancel each other and produce zero filed and consequently zero reactance except for slot and end-connection fluxes. In general zero sequence impedance is much smaller than positive and negative sequence impedances. The machine must, of course, be star connected for otherwise the term zero sequence has no significance as no zero- sequence currents can flow.

  The machine is at standstill and a reduced voltage is applied. The zero sequence impedance $Z_0 = \frac{V}{3I}$

Procedure:

(A) Measurement of Positive Sequence Impedance(Z_1):

OC(Open Circuit) Test:

1. Connect the Alternator set as shown in the circuit diagram and start the motor and adjust the speed to the rated value
2. Switch ON the DC supply to the field of the Alternator
3. By increasing the excitation gradually note the field current I_f and generated voltage pf the Alternator.
4. Record the readings and plot the OC Characteristics as shown in the Model Graph.

Tabular Column:

S.No	Field Current(I_f) in Ampere	Open Circuit Voltage(E_0) in Volts

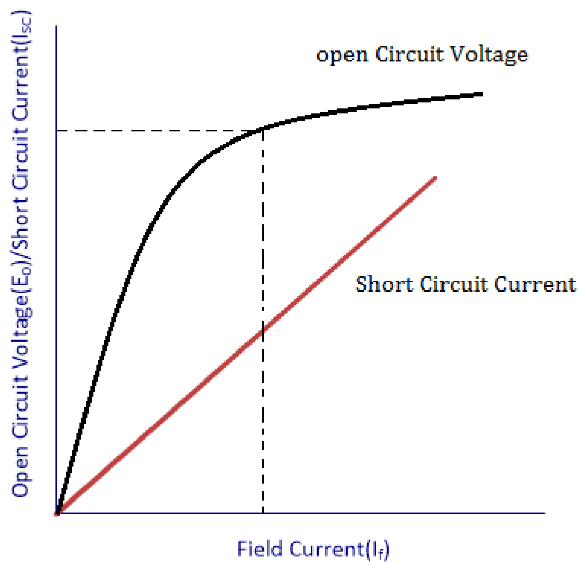
SC(Short Circuit) Test:

1. Keeping the previous connections unchanged replace voltmeter by ammeter and short the other two phase with neutral as shown in the circuit diagram.
2. Run the Alternator set at rated speed and note down the excitation current with respect to short circuit current.
3. Plot the curve filed current versus Short circuit current on the same graph drawn for Open circuit test.

Tabular Column:

S.No	Field Current(I_f) in Ampere	Short Circuit Current(I_{SC}) in Ampere

Model Graph:



Calculations:

Positive Sequence Impedance

$$Z_1 = Z_S = \frac{E_0(Per\ Phase\ Open\ Circuit\ Voltage)}{I_{SC}(Per\ Phase\ Short\ Circuit\ Current)} =$$

Measurement of Negative Sequence Impedance(Z_2):

1. Connect the machine as shown in figure.
2. Run the machine at rated speed.

3. Gradually increase the excitation such that the short circuit does not exceed full load value.
4. Note down the readings of Voltage, Current and Power

Tabular Column:

S.No	Voltage (V)	Current(A)	Power(W)

Calculations:

Negative Sequence Impedance, $Z_2 = \frac{V}{\sqrt{3}I}$=

Wattmeter reading W=VISinθ

⇨ Sinθ=W/VI

Therefore Negative Sequence Impedance $X_2 = Z_2 Sin\theta$

(B) Measurement of Zero Sequence Impedance(Z_0):

1. Connect the armature windings in parallel as shown in the circuit diagram.
2. Short circuit the Alternator field winding.
3. In this case machine need not be in running condition
4. Apply rated current to each phase winding which are connected in parallel through a single phase variac.
5. Take readings of voltage and current.

Tabular Column:

S.No	Voltage (V)	Current(A)

Calculations:

Zero Sequence Impedance $Z_0 = 3V/I$=

Precautions:

1. Avoid loose and wrong connections
2. Ensure that the auto transformer is at minimum position before powering the circuit.
3. Do not exceed the rated current of transformer while conduction experiment.

Results:

Sl. NO	Impedance	Value (Ω)
1	Positive sequence impedance	
2	Negative sequence impedance	
3	Zero sequence impedance	

Questions for self assessment:

1. What are symmetrical components? Why only 3 sets?
2. What is the frequency of Positive, Negative zero sequence component of current, how they affect machine performance?

3.SEQUENCE IMPEDANCE OF 3-PHASE ALTERNATOR BY FAULT ANALYSIS

Aim: To determine the Sequence Impedances of Alternator by creating different faults(without fault impedance).

Apparatus:

S. No	Item	Type	Range	Quantity
1	Voltmeter	MI	(0-600)V	1
2	Ammeter	MI	(0-5)A	1
3	Ammeter	MC	(0-2)A	1
4	Rheostats	WW	300/1.5	3
5	SPST Switch			1
6	Tachometer	Digital	(0-9999)RPM	1
7	Connecting Wires			Needed

Theory: In general the faults can be classified as

(i) Shunt Faults (Short Circuits)

(ii) Series Faults (Open Conductor)

Shunt type faults involves power conductor or conductors-to-ground or short circuit between conductors. When circuits are controlled by fuses or any device which does not open all three phases, one or two phases of the circuit may be opened while the other phases or phase is closed. These are called series type of faults. These faults may also occur with one or two broken conductors. Shunt faults are characterized by increasing in current and fall in voltage and frequency whereas series faults are characterized by increase in voltage and frequency and fall in the faulted phases.

Shunt type of faults are classified as:

(i) Line – to – Ground Fault

(ii) Line – to – Line Fault

(iii) Double Line – to – Ground Fault

(iv) 3 – Phase Fault

Of these, the first three are the unsymmetrical faults as the symmetry is disturbed in one or two phases. The method of symmetrical components will be utilized to analyze the unbalancing in the system. The 3-phase fault is a balanced fault which could also be analyzed using symmetrical components.

The series faults are classified as:

(i) One open conductor, and

(ii) Two open conductors

These faults also disturb the symmetry in one or two phases and are, therefore, unbalanced faults. The method of symmetrical components can be used for analyzing such situations in the system.

Procedure:

1. Connect the circuit as shown in Figure
2. Adjust the speed of the motor to rated speed
3. Vary the excitation of alternator to minimum position and close the Alternator MCB switch
4. Slowly increase the excitation until the fault current is equal to rated current of alternator and note down the line and phase voltages.
5. The above procedure is repeated for different types of faults.

Tabulation:

Type of Fault	**I_a**	**I_b**	**Field Current(I_f)**	**Prefault Voltage(E_a)**
LG				
LLG				
LL				

Model Calculations:

From LLG Fault:

$$I_a = \frac{E_a}{Z_1 + \left(\frac{1}{Z2} + \frac{1}{Z0}\right)}$$

$$Z_1 + \left(\frac{1}{Z2} + \frac{1}{Z0}\right) = E_a/I_a =$$

From LL Fault:

$$I_{a1} = \frac{E_a}{Z_1 + Z_2} \; and \; I_{a1} = \frac{1}{3}(\lambda - \lambda^2) I_b$$

$$\boldsymbol{\lambda} - \lambda^2 = -j\sqrt{3} \qquad \therefore I_{a1} = \frac{I_b}{\sqrt{3}}$$

$\boldsymbol{Z_1 + Z_2 = \frac{E_a \times \sqrt{3}}{I_b}}$= **--------------------(1)**

From LG Fault:

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0}$$

$$I_a = I_{a1} + I_{a2} + I_{a0} \quad But \; I_{a1} = I_{a2} = I_{a0}$$

$$\therefore \; I_{a1} = \frac{I_a}{3}$$

$$Z_1 + Z_2 + Z_0 = \frac{E_a}{I_{a1}} = \frac{E_a \times 3}{I_a}$$

$Z_1 + Z_2 + Z_0 = \frac{3E_a}{I_a}$=

100+Z_0=58.57, Z_0 =

Z_1*Z_0+Z_1Z_2+Z_2Z_0=6.67*(Z_2+Z_0)-------------------------(2)

From equation 1 &2,

Z_2=

Z_1=Precautions:

1. Pre fault voltage should be low.
2. Do the connections properly at fault analyzer

Result: Various faults have been created in an unloaded Alternator and Sequence Impedances can be determined.

Sl. NO	Impedance	Value (Ω)
1	Positive sequence impedance	
2	Negative sequence impedance	
3	Zero sequence impedance	

Questions For Self Assessment:

1. What are different types of faults? Give classification
2. Which one is severe fault?
3. What are symmetrical components? Why only 3 sets?
4. How do you recognize a type of fault from given sequence component?
5. What is the frequency of Positive, Negative zero sequence component of current, how they affect machine performan

4.Determination of A,B,C,D constants of short, medium and long lines.

Aim:
To determine A,B,C,D constants of transmission lines for R=4 OHMS, L=80mH, C=0.44 µf.

Apparatus:

1. Digital Ammeter, 20A, AC - 02 Nos.
2. Digital Voltmeter, 0-600V, AC – 02 Nos.
3. Connecting Wires
4. ABCD Parameters of Transmission line kit

Procedure:

Short transmission line:

Open circuit test:

- Make connections as per circuit diagram.
- Switch ON the trainer.
- Set the input voltage as 40 volts by adjusting Variac
- Note down the readings of VS, VR and IS in the digital meters.

short circuit test:

- Now short the output terminals of the transmission line.
- Switch ON the trainer.
- Set the input voltage as 10 volts by adjusting Variac
- Note down the readings of VS, IS and IR in the digital meters.

THEORITICAL CALCULATIONS:

SHORT TRANSMISSION LINE

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

So A=1 and B=Z

C=0 and D=1

Z=R+Jx

R=Transmission line resistance + internal resistance of Inductor

R=

AC equivalent resistance=

$Z=[R^2+(\omega L)^2]^{1/2}$

B=

$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$= $\begin{bmatrix} 1 & 47.68 \\ 0 & 1 \end{bmatrix}$

MIDIUM TRANSIMISSION LINE

$I=I_R+I_{C1}$

$I_S=I+I_{C2}$

$V_S=V_R+I_Z$

$=V_R+(I_{Z+}I_{C1)}Z$

$=V_{R+}I_RZ+V_R(Y/2)Z$

$V_S=V_R(1+ZY/2)+I_RZ$

A=1+ZY/2 and B=Z

Z=

$Y=2\pi FC$=

Y=

A=1+((44.11)(1.38*10^-4)/2)=

A=D=1+(ZY/2)=

B=

$I_S=I+I_{C2}$

$I_S=I_R+I_{C1}+I_{C2}$

$I_S=I_R+V_R(Y/2)+V_S(Y/2)$

$I_S=I_R+(V_SY/2)+(V_RY(1+(YZ/2))+(I_RZ))Y/2$

$I_S=I_R(1+(YZ/2))+V_RY(1+(YZ/4)$

SO C=Y(1+(ZY/4))

=1.38*10^-4(1+((44.11)(1.38*10^-4)/4))

=

$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$=

AS 2 CIRCUITS ARE CASCADED

$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$=$\begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} A & B \\ C & D \end{bmatrix}$

$A = V_S/V_R \mid I_R=0$

$B = V_S/I_R \mid V_R=0$

$C = I_S/V_R \mid I_R=0$

$D = I_S/I_R \mid V_R=0$

Observation:

OC test on short transmission line

Sl. No	**Vs (V)**	**Vr (V)**	**Is (A)**	**A**	**C**

SC test on short transmission line

Sl. No	**Vs (V)**	**Is (A)**	**Ir (A)**	**B**	**D**

OC test on Medium transmission line

Sl. No	**Vs (V)**	**Vr (V)**	**Is (A)**	**A**	**C**

SC test on Medium transmission line

Sl. No	**Vs (V)**	**Is (A)**	**Ir (A)**	**B**	**D**

Now repeat the above procedure (i.e conducting OC test and SC test) for medium distance transmission line and long distance transmission line.

RESULT:

Sl. No	Parameter	Transmission line type		
			Medium	Short
1	A			
2	B			
3	C			
4	D			

5. DIELECTRIC STRENGTH OF TRANSFORMER OIL

Aim:

To learn the measurement of the dielectric strength of the oil using HT testing kit.

Apparatus required:

Sl. No.	Name of the apparatus	Type	Range	Quantity
1	HT testing kit, Input : 240 V,50 HZ, Output :0-80 kV (2 kv/sec)	---	---	1
2	Measuring scale	---	2 mm	1

Theory:

The oil transformer kit is used to determine the dielectric strength of oil these are generally used in transformers. It contains two electrodes of a small gap between there when ever break down voltage occurs there will be a spark is observed at the high voltage side of the transformer. For calibration the gap in between the two electrodes is 4 mm. the voltage that is obtained when flash over occurs is rapidly applied voltage.

Oil test set is basically consists of a double wound high voltage transformer with the H.T. end brought out and terminated on an epoxy insulation. The lower end of the H.T winding is at earth potential and is also brought out. The intermediate circuitry included in series with the primary of H.T transformer, if the current through the test coil exceeds a predetermined value.

The low voltage winding of the main transformer is rated for 230 V or as specified .It is energized by means of an auto transformer through a fuse link and an intermediate contactor /relay, the provision of an auto transformer enables gradual application of high voltage to the oil under test.

A voltmeter is provided on the panel to indicate the applied high voltage. The voltmeter is connected on the low voltage side of the main transformer but it is calibrated to read H.T voltage directly .When the failure of the test oil occurs, the supply to the voltmeter is maintained although the supply to the H.V transformer is instantly cut off. The voltmeter therefore indicates the voltage at which the oil under test has failed.

The test method consists of subjecting the oil contained in a special apparatus to an AC electric field with continuously increasing voltage till the oil breaks down. The electrodes are made of brass-bronze or stainless steel. The brass is an alloy of copper and zinc and the bronze is an alloy of copper and nickel. The polished electrodes are spherical (12.5 - 13 mm dia meter). The electrodes are mounted 2.5 cm apart with an accuracy of 0.1 mm.

Procedure:

1. This test consists of applying to the electrodes an increasing ac voltage of frequency 40-60 Hz, the rate of increase of voltage being uniform and equal to 2kv/sec, starting from zero up to the value producing breakdown.
2. The test shall be carried out six times on the same cell filling.
3. The first application of voltage is made as quickly as possible after the cell has been filled, provided there are no longer air bubbles and the oil and at the latest 10 min after filling, after each break down.
4. The oil is gently stirred between the electrodes by means of a clean, dry glasses avoiding as far as possible production of air bubbles for the subsequent flue tests the voltage is re applied one minute after the disappearance of air bubbles that may have been formed if the observation of the disappearance of air bubbles.

Parts:

1. Main switch
2. Fuse
3. Main pilot lamp L1
4. HT off push button
5. Motor control switch
6. HT on pilot lamp
7. Kilo voltmeter
8. L & N reserve pilot lamp
9. Earth open pilot lamp

Observation:

Table-6.2: Dielectric strength of transformer oil

Sl. No	Dielectric strength (kV/mm)	
	Manual mode (voltage)	Distance between electrodes

Average=
Dielectric strength=

Precautions:

1. In motoring mode, the coupling between motor and autotransformer should be properly done.
2. In manual mode, motor and autotransformer should be recouped.

Result:

Hence the dielectric strength of oil is tested using HT testing kit in manual mode.
Dielectric strength=

Questions for self assessment:

1. What are the different types of insulating materials?
2. What do you mean by dielectric strength?
3. What is difference between insulator and dielectric?
4. What is difference between breakdown voltage and dielectric strength?
5. What are the different types of insulating oils?
6. What is the dielectric strength of ideal oil?

6. TONG TESTER CALIBRATION

Objective:

To Calibrate the tong tester and determine the Percentage of error

Apparatus required:

Sl. No.	Name of the apparatus	Type	Range	Quantity
1	Auto transformer	1-Φ	230V/(0-270)V, 8A	1
2	Current transformer	---	Precision- 10/5 , 10/1	1
3	Voltmeter	DMM	(0-600) V	1
4	Ammeter	DMM	(0-20A)	1
5	TongTester	DMM	(0-400A)	1

<u>THEORY:</u>

In Power system it is often necessary to measure the high currents in current carrying bus bars (or) feeders to know the temperature, heating effect and loading permitted.

In many cases, however, it is difficult to find a suitable location where a practical circuit can be conveniently broken for measuring current and, of course, a 'live' circuit will need to be de-energised before we can break the circuit to insert the ammeter. This requires the load to be temporarily taken out of service while the ammeter is inserted, which might not be convenient or practical.

For alternating current, these difficulties can be overcome by using an instrument called a clamp-on ammeter or clamp-on multimeter (sometimes known as 'tong testers'). The accuracy of a current reading taken with a clamp-on ammeter will not be as accurate as a conventional ammeter but, usually, a great degree of accuracy is unnecessary for those applications where such an ammeter is used. A clamp-on ammeter can, of course, only measure alternating current flowing in an individual conductor (e.g the line or the neutral conductor); it cannot measure the currents flowing in a multicore cable, because the magnetic fields set up by currents flowing in opposite directions in, say, the line and neutral conductors act to cancel each other! Similarly, the phasor-sum of identical line currents in a three-phase cable is zero.

<u>PROCEDURE:</u>

1. Connect the circuit as shown in the Figure 7.2.
2. Apply 1-phase 230 V, 50Hz AC supply to variac.
3. Now connect the tong tester (Clamp on meter).
4. Now by using the variac apply different voltages and note down the corresponding tong tester and ammeter reading.
5. Calculate the percentage error.

Observation:

Sl. No	Applied current (A)	Voltmeter reading (V)	Tong tester reading (A)	Error(%)	Calibration
1					
2					

Calibration = Tong tester current – Applied current.

Error: (Tong tester current – Applied current)/(Applied current)

Result:

Calibration and % error are calculated for given tong tester.

QUESTIONS FOR SELF ASSESSMENT:

1.What is the difference between multimeter and Tong tester?

2.What is a clamp on ammeter?

3. What are the advantages of Tong Tester?

7. TRANSIENT STABILITY OF SINGLE MACHINE CONNECTED TO INFINITE BUS BY POINT BY POINT METHOD

Aim**:** To determine transient stability of single machine connected to infinite bus by point by point method

Apparatus: MATLAB software with PC compatibility

THEORY:

Stability of power system is its ability to return to normal or stable operating conditions after having been subjected to some form of disturbance. Increase in load is a kind of disturbance. Causes for disturbances are

- Change in load
- Loss of excitation
- Switching operation
- Fault conditions

PROBLEM:

A 20 MVA ,50 HZ generator delivers 18MW over a double circuit line to an infinite bus. The generator has kinetic energy of 2.52MJ/MVA at rated speed. The generator transient reactance is $X^1{}_d$ =0.35PV. Each transmission circuit has R=0 and reactance of 0.2Pu on a 20MVA base. $|E^1|$=1.1Pu and infinite bus voltage(v)= $1.0<0^0$. A 3-ø short circuit occurs at midpoint of one of transmission lines. Plot swing curve for 0.25cycles.

CALCULATION:

Base MVA =

Inertia constant M(Pu) = H/180f = /elec.degree

Pre fault:

X_L=

$Pe_{1`}=p_{max1}\sin\delta$

=

Pre fault power transfer=

Initial power angle is given by

δ_0 =

During fault:

X_{11} =

$Pe_{11} = p_{max11} \sin \delta$

=

Past fault:

X_{111} = $Pe_{111} = p_{max111} \sin \delta$

=

Let us choose $\Delta t = 0.05S$

$P_a\,(n-1) = P_m - P_{max} \sin \delta\,(n-1)$

$\Delta\delta_n = \Delta\delta_{n-1} + (\Delta t)^2/m\ P_a\,(n-1)$

$\delta_n = \delta_{n-1} + \Delta\delta_n$

P_a for first interval

$P_a(O) = \Delta P_u$ and $P_a\,(o_+)$ =

$P_a(o_{avg})$ =

PROGRAM:

% Point by Point method

```
clear
t=0
tf=0
tfinal=0.5
tc=0.125
tstep=0.05
m=2.52/(180*50)
i=2
delta=21.64*pi/180
ddelta=0
time(1)=0
ang(1)=21.64
pm=0.9
pmaxbf=2.44
pmaxdf=0.88
pmaxaf=2.00
while t<tfinal,
if(t==tf)
    paminus=0.9-Pmaxbf*sin(delta)
    paplus=0.9-pmaxaf*sin(delta)
```

```
    paav=(paminus+pa)/2
    pa=paav
end
if(t==tc)
    paminus=0.9-pmaxdf*sin(delta)
    paplus=0.9-pmaxaf*sin(delta)
    paav=(paminus+paplus)/2
    pa=paav
end
if(t>tf&t<tc),
    pa=pm-pmaxdf*sin(delta)
end
if(t>tc)
    pa=pm-pmaxaf*sin(delta)
end
t,pa
ddelta=ddelta+(tstep*tstep*pa/m)
delta=(delta*180/pi+ddelta)*pi/180
deltadeg=delta*180/pi
t=t+tstep
pause
time(i)=t
ang(i)=deltadeg
i=i+1
end
axis=([0.06 0 160])
plot(time,ang,'ko-')
```

APPLICATIONS:

- Stability of power system is done by some sessions. So, these sessions need this sort of analysis for fast operation.
- Torque (or) load angle adjustment (or) control uses these in stability (or) transient analysis of the power system.

TABULAR FORM:

t(sec)	P_{max}(pu)	sinδ	$P_e= P_m\sin\delta$(Pu)	P_a=0.9-P_e (Pu)	$(\Delta t)^2$/m P_a	Δδ (deg)	Δ (deg)

RESULT:

Swing curve for the given problem is observed using MATLAB software program

Swing equation, $M\, d^2\delta/dt = P_a$

8. LOAD FREQUENCY CONTROL WITHOUT CONTROL

OBJECTIVE:

To find frequency deviation for a single area case without control.

OUTCOME:

After doing this experiment student will be able to student will be able to determine dynamic response of frequency for a step change in load

Software used: MATLAB/SIMULINK

THEORY:

Let us consider the problem of controlling the power output of the generators of a closely knit electric areas o as to maintain the scheduled frequency. All the generators in such an area constitute a coherent group so that all the generators speed up and slow down together maintaining their relative power angles. Such an area is defined as coherent area.

The boundaries of a control area will generally coincide with that of an individual Electricity Board Company.

To understand the load frequency control problem, let us consider a single turbo-generator system supplying an isolated load.

Model of speed governing system: Block diagram of speed governing system is given below in the Figure 8.1.

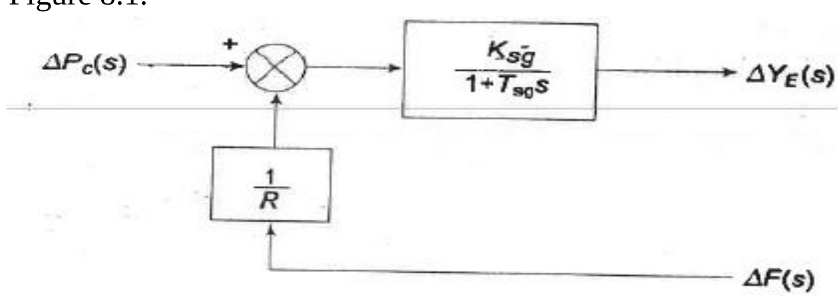


Fig: 8.1 Block diagram representation of speed governor system

Where, $\Delta P_C(s)$ – Laplace transform of commanded increase in power (pu MW),

Ksg – Gain of speed governor,

Tsg – Time constant of speed governor (Second),

R – Speed regulation of governor (Hz/pu MW),

ΔY_E – Change in steam valve setting,

ΔF – Change in frequency

Turbine Model: Block diagram of turbine model is given in the figure 3.2

Where,

$\Delta P_t(s)$ – Laplace transform of change in turbine power (pu MW),
Kt – Gain of turbine,
Tt – Time constant of turbine (Second),
ΔY_E – Change in steam valve setting.

Generator and Load model: Block diagram of Generator – Load model is given below in the Figure 3.3.

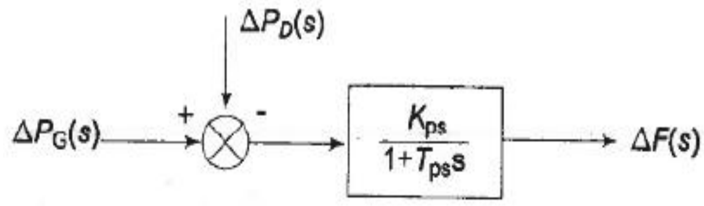


Fig: 8.3. Block diagram representation of generator-load model

Where,
$\Delta P_G(s)$ – Laplace transform of incremental generator output (pu MW),

$\Delta P_D(s)$ – Laplace transform of load incremental (pu MW),

Kps – Power system gain,

Tps – Power system time constant (Second),

ΔF – Change in frequency.

Complete block diagram representation of Load – Frequency control of a single area system: A complete block diagram representation of a single area system comprising turbine, generator, governor and load is easily obtained by combining the individual components i.e. by combining Figs. 8.1, 8.2, 8.3. The complete block diagram with feedback is shown below in the Figure 8.4.

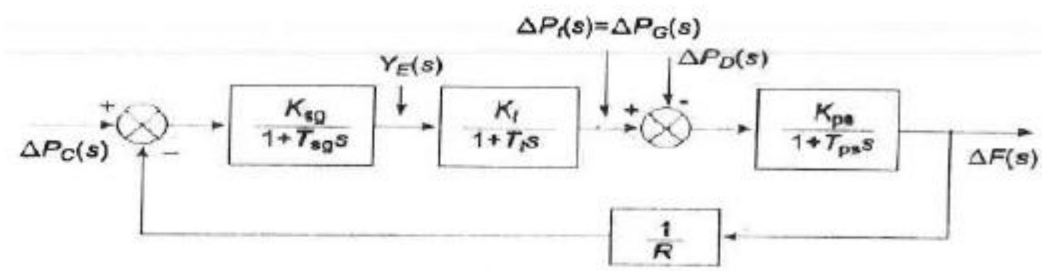


Fig: 8.4. Block diagram model of load frequency control (isolated powers system)

Dynamic response: To obtain the dynamic response giving the change in frequency as function of the time for a step change in load, we must obtain the Laplace inverse of $\Delta F(s)$. The characteristic equation being of third order, dynamic response can only be obtained for a specific numeric case. However the characteristic equation can be approximated for first order by examining the relative magnitudes of time constants involved. Typical values of the time constants of load frequency control system are related as, Typically Tg = 0.4 Sec, Tt = 0.5 Sec and Tps = 20 Sec, $K_{t=}$0.1.

First order approximation block diagram: Letting Tsg = Tt = 0 Sec and Ksg*Kt = 1, complete block diagram of single area system reduces to the Figure 8.5.

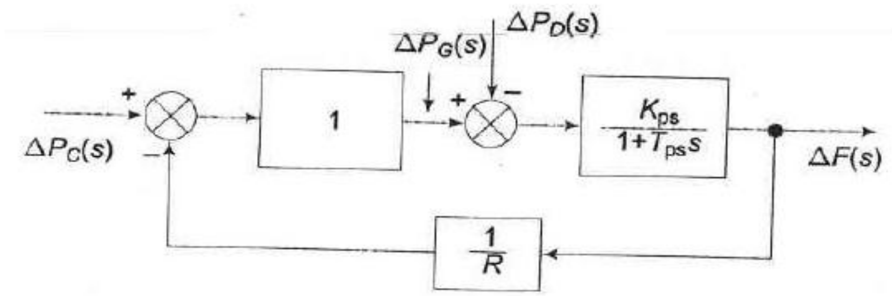


Fig: 8.5. First order approximate block diagram of load frequency control of an isolated area

Dynamic response of change in frequency for a step change in load with ΔP_D = 0.01 pu, Tg = 0.4 Sec, Tt = 0.5 Sec, Tps = 20 Sec, Kps = 100 and R = 3, $K_{g=}$10 is given in the Figure 3.6.

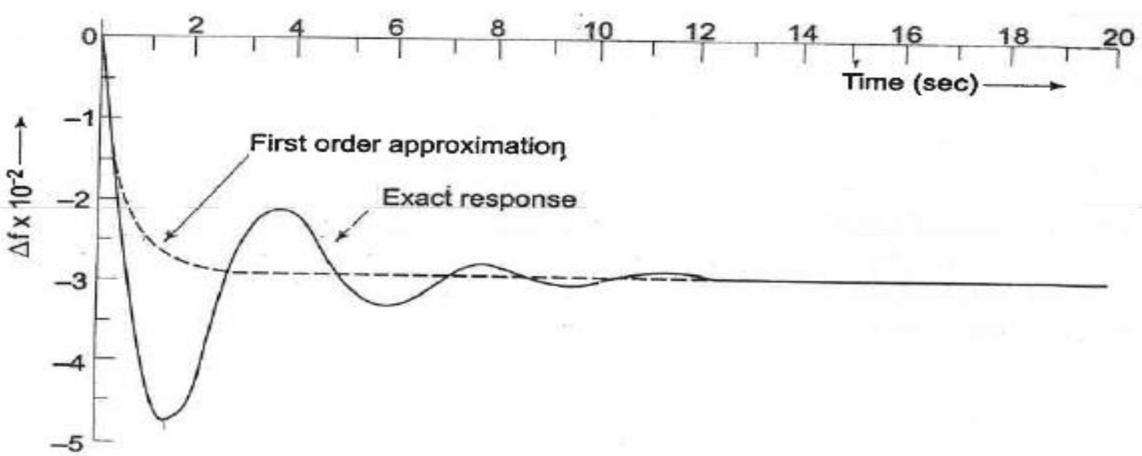


Fig: 8.6. Dynamic response of change in frequency

Sample Problem: The parameters for load frequency control of a single area are:

Sl. No	Parameter	Value
1	Speed governor gain	Ksg=10
2	Time constant of speed governor	Tsg=0.4
3	Speed regulation of speed governor	R=3
4	Gain of turbine	Kt=0.1
5	Time constant of turbine	Tt=0.5
6	Gain of power system	Kps=100
7	Time constant of power system	Tps=20
8	Changes in the load	ΔPD=0.01 pu

PROCEDURE:

1. Open Matlab-->Simulink--> File ---> New---> Model.
2. Open Simulink Library and browse the components.
3. Connect the components as per circuit diagram.
4. Set the desired voltage and required frequency.
5. Simulate the circuit using MATLAB.
6. Plot the waveforms.

Theoretical calculations:

$\Delta f \big|$ steady state $\Delta P_{c=0} = \lim_{s\to 0} S*\Delta F(s) = -(R*K_{PS} /(R+K_{PS*}\ K_{t*}\ K_g))*\Delta P_D$

$\Delta f\ (t)=[-R*K_{PS} /(R+K_{PS})]*[1-\exp(-t/T_{ps}(R/(R+K_{ps})))]*\ \Delta P$

Steady state frequency drop is =

QUESTIONS FOR SELF ASSESSMENT:

1. Define regulation?
2. What is steady state error?
3. What is dynamic response?
4. Why steady state error is not zero in single area system without control?

9. LOAD FREQUENCY CONTROL WITH CONTROL

OBJECTIVE:

To find frequency deviation for a single area case with control.

OUTCOME:

After doing this experiment student will be able to determine dynamic response of frequency for a step change in load with integral controller.

Software used: MATLAB/SIMULINK

THEORY:

Control Area Concept: It is possible to divide an extended power system (say, national grid) into subareas (may be, State Electricity Boards) in which the generators are tightly coupled together so as to form a coherent group, i.e. all the generators respond in unison to changes in load or speed changer settings. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions. For purposes of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo-generator and load system. All the control strategies discussed so far are, therefore, applicable to an independent control area.

Proportional plus integral control: It is seen that with the speed governing system installed on each machine, the steady load frequency characteristics for a given speed changer setting has considerable droop. System frequency specifications are rather stringent and, therefore, so much change in frequency cannot be tolerated. In fact, it is expected that the steady change in frequency will be zero. While steady state frequency can be brought back to the scheduled value by adjusting speed changer setting, the system could undergo intolerable dynamic frequency changes with changes in load. It leads to the natural suggestion that the speed changer setting be adjusted automatically by monitoring the frequency changes. For this purpose, a signal from Δf is fed through an integrator to the speed changer resulting in block diagram configuration shown in the Figure 9.1. The system now modifies to a proportional plus integral controller, which, as is well known from control theory, gives zero steady state error, i.e. $\Delta f|$ steady state = 0.

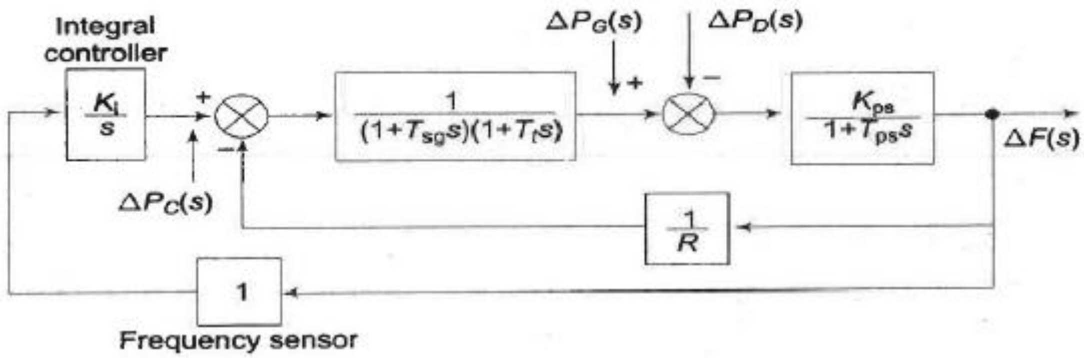


Fig: 9.1. Proportional plus integral load frequency control

Where Ki – Gain of integral controller.

The signal ΔPc(s) generated by the integral control must be of opposites sign to ΔF(s) which accounts for negative sign in the block for integral controller.

Now, Obviously, $\Delta f|_{\text{steady state}} = 0$.

We find that the steady state change in frequency has been reduced to zero by the addition of the integral controller. This can be argued out physically as well. Δf reaches steady state (a constant value) only when $\Delta P_c = \Delta P_D$ = Constant. Because of integrating action of the controller, this only possible if $\Delta f=0$.

The dynamics of the proportional plus integral controller can be studied numerically only, the system being of fourth order the order of the system has increased by one with the addition of the integral loop. The dynamic response of the proportional plus integral controller with Ki = 0.09 for a step load disturbance of 0.01 pu obtained through digital computer. For the sake of comparison the dynamic response without integral control action is also represented on the same figure.

Dynamic response of change in frequency for a step change in load with ΔP_D = 0.01 pu, Tsg = 0.4 Sec, Tt = 0.5 Sec, Tps = 20 Sec, Kps = 100, R = 3 and Ki = 0.09 is given in the Figure 4.2.

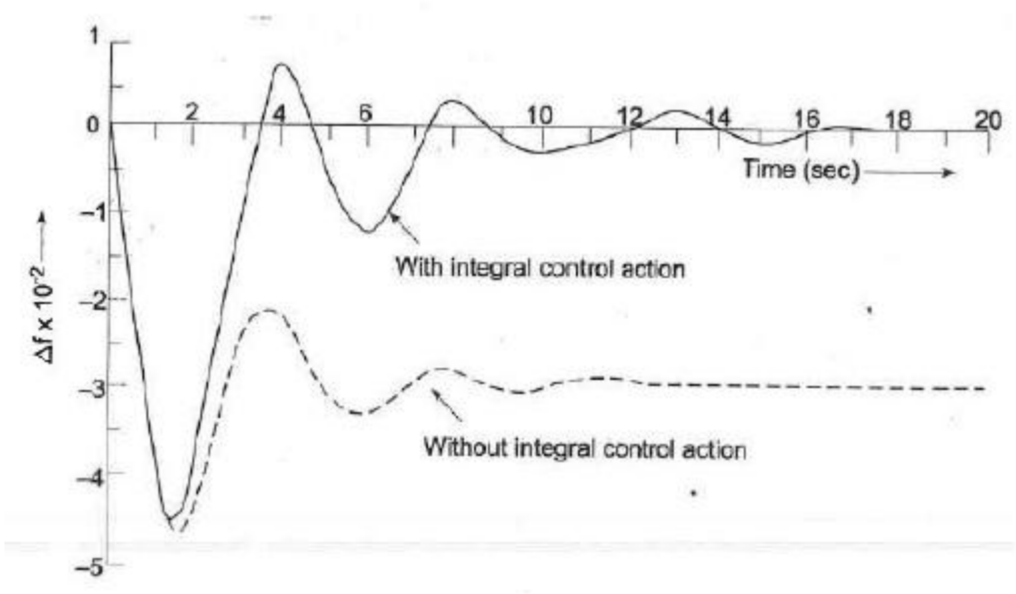


Fig: 9.2. Dynamic response of change in frequency

Exercise: The parameters for load frequency control of a single area are:

Sl. No	Parameter	Value
1	Speed governor gain	Ksg=10
2	Time constant of speed governor	Tsg=0.4
3	Speed regulation of speed governor	R=3
4	Gain of turbine	Kt=0.1
5	Time constant of turbine	Tt=0.5
6	Gain of power system	Kps=100
7	Time constant of power system	Tps=20
8	Changes in the load	ΔPD=0.01 pu
9	Gain of integral controller	Ki = 0.09

PROCEDURE:

1. Open Matlab-->Simulink--> File ---> New---> Model.
2. Open Simulink Library and browse the components.
3. Connect the components as per circuit diagram.
4. Set the desired voltage and required frequency.
5. Simulate the circuit using MATLAB.
6. Plot the waveforms.

Theoretical calculations:

$\Delta F(S) = [-S*K_{PS*}R*(1+S*\tau_{sg})(1+S*\tau_t)/(s*(1+S*\tau_{ps})(1+S*\tau_{sg})*(1+S*\tau_t)R+K_{PS*})(S+R*K_t))]*\Delta P_D/S$

$\Delta f\,\big|\,\text{steady state} = \lim_{s\to 0} S*\Delta F(s) = 0$

QUESTIONS FOR SELF ASSESSMENT:

1. What is area control error?

2. Why negative feedback is given for integral controller?

3. How can we improve the dynamic response of a single area system with controller in terms of speed of response?

10.ECONOMIC LOAD DISPATCH WITHOUT LOSSES

OBJECTIVE:

To find economic dispatch of generation of the given set of generators for the given power demand using Lambda iteration method without considering transmission line loss.

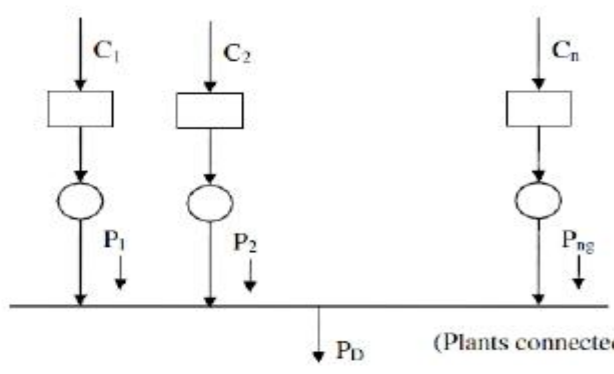
OUTCOME:

Student will be able to determine economic dispatch of generation of the given set of generators for the given power demand using Lambda iteration method without considering transmission line loss.

Software used: MATLAB/SIMULINK

THEORY:

Power is allowed to vary within certain limits so as to meet a particular load demand with minimum fuel cost. This is called the optimal power flow (OPF) problem. The OPF is used to optimize the power flow solution of large scale power system. This is done by minimizing selected the same distance from the Centre of loads and their fuel costs are different. Also under normal operating conditions, the generation capacity is more than the total load demand and losses. Thus, there objective functions while maintaining an acceptable system performance in terms of generator capability limits and the output of the compensating devices. The simplest economic dispatch problem is the case when transmission line losses are neglected. This is the problem model does not consider system configuration and line impedances. In essence, the model assumes that the system is only one bus with all generation and loads connected to it as shown in figure below



(Plants connected to a common bus)

Since transmission losses are neglected, the total demand P_D is the sum of all generation.
A cost function C_i is assumed to be known for each plant. The problem is to find the realpower generation for each plant such that the objective function as defined by the equation,

$$C_t = \sum_{i=1}^{ng} C_i = \sum_{i=1}^{n} \alpha_i + \beta_i P_i + v_i P_i^2$$

is minimum, subject to the constraint,

$$\sum_{i=1}^{ng} P_i = P_D$$

Where, C_t is the total production cost, C_i is the production cost of i_{th} plant, P_i is generation of the i_{th} plant, P_D is the total demand and ng is the total number of despicable generating plants.

A rapid solution is obtained by the use of the gradient method (Lambda iteration).

Let f(2) = P_D

Expanding the left hand side of the above equation in Taylor's series about an operating point 2_k and neglecting the higher-order terms result in,

$$f(\lambda)^k + \left[\frac{df(\lambda)}{d\lambda}\right]^k \cdot \Delta\lambda^k = P_D$$

$$\Delta\lambda^k = \frac{\Delta P^k}{\left[\frac{df(\lambda)}{d\lambda}\right]^k} = \frac{\Delta P^k}{\sum\left(\frac{dP_i}{d\lambda}\right)^k} \ (or)\ \Delta\lambda^k = \frac{\Delta P^k}{\sum \frac{1}{2v_i}}$$

$$\text{and therefore, } \Delta\lambda^{k+1} = \lambda^k + \Delta\lambda^k$$

$$\text{where, } \Delta P^k = P_D - \sum_{i=1}^{ng} P_i^k$$

Algorithm:

1. Start the program.
2. Read the input data values
3. Start the iteration counter.
4. Check the test for convergence.
5. iter=iter+1
6. Calculate P,delp, J, deltambda and lambda.
7. Display the above values.
8. To find the total cost = sum(alpha+beta.*P+gamma.*P.Δ2
9. Print the value of total cost.
10. Stop the program

PROCEDURE:

1. Enter into the command window of MATLAB software.
2. Create a new M-file by selecting 'File -> New -> Blank M-File'.
3. Type the program code in the editor window and save program with extension '.m'.
4. Execute the program by clicking 'Run' icon or press the function key 'F5' in the editor window or by typing file name without '.m' extension at the command prompt

and pressing ‘Enter’ key.

5. View the results displayed in the command window.

<u>Exercise:</u>

The fuel cost fuctions for three thermal plants is $/h are given by,

Point of comparison/Result	Generator no	Theoretical	Simulated
Output (MW) of generator	1		
	2		
	3		
Total			
Cost of generation (Rs/Hr)	1		
	2		
	3		
Total			
Incremental fuel cost (Rs/MWHr)			

Result analysis:

Questions for self assessment:

1. What is economic load dispatch?
2. What is incremental production cost
3. How incremental production cost affects the economic dispatch?
4. Write the Lagrangian equation for economic load dispatch without considering transmission line loss.
5. What could be the optimum value of incremental production cost for optimal scheduling of generators?