University of Saskatchewan
Department of Electrical Engineering
EE 442.3 Power System Operation & Control (Term 2)
FINAL EXAMINATION (Room: 2C44)

Dated: April 22, 2016 **Time: 2:00 pm – 5:00 pm**
Instructor: Dr. Rama Gokaraju **Total Marks: 50**

Instructions:

1) This examination paper consists of 8 problems and 6 pages in total.
2) This is a closed-book examination. Four-page formula sheet is allowed. Prepare your formula sheet with pen (photocopied formula sheets are alright). No solved example problems are allowed in the formula sheet.
3) Write the steps of your solution method clearly. There would be penalty marks if your solutions are done in an illegible fashion.
4) Mark allotted for each problem is shown on the right margin.

Student Name: ______________________________ *Student Id:* _____________________

The fuel-cost functions for three thermal plants in *\$/h* are given by

$$F_1(P_1) = 100 + 2P_1 + 0.01P_1^2$$
$$F_2(P_2) = 80 + 2.6P_2 + 0.004P_2^2$$

The inequality constraints for the generators are:

$$25 \le P_1 \le 150MW$$
$$30 \le P_2 \le 200MW$$

Using the Lagrangian method, determine the output of each unit and the total operating cost when P_L = 282 *MW*. Neglect transmission losses.

6 Marks

Question 2 (Single-Area System Control)

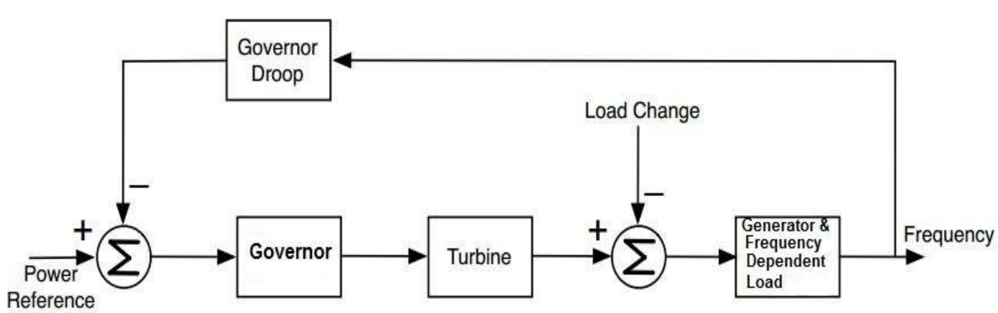

***Figure 1**: LFC for an isolated power system*

An isolated generator has the following parameters:

Turbine time constant = 0.5 *s*
Governor time constant = 0.2 *s*
M of generator = 10 *s*
Governor speed regulation = R *pu*

The load varies by 0.8% for a 1% change in frequency, i.e. D = 0.8. Find a range of R for control system stability.

6 Marks

Question 3 (Automatic Generation Control (AGC) of a Two Area System)

Suppose, you are given two system areas connected by a tie line with the following characteristics:

Area 1	***Area 2***
R = 0.05 pu	R = 0.0625 pu
D = 0.60 pu	D = 0.9 pu
M=10 pu MW/pu frequency/sec	M=8 pu MW/pu frequency/sec
Governor time constant = 0.2 sec	Governor time constant = 0.3 sec
Prime mover time constant = 0.5 sec	Prime mover time constant = 0.6 sec
Base MVA = 750 MVA	**Base MVA = 1,000 MVA**

Where R is equal to *pu* change in frequency divided by *pu* change in unit output (speed droop feedback loop of the governor), D is equal to percentage change in load divided by percent change in frequency. M is the angular momentum of the machine. The tie-line stiffness coefficient is computed from the initial operating conditions and is given to be equal to be 2 *pu*.

Load increases by 200 MW in area 1 of the two-area system. What is the new value of steady-state frequency and what is the change in tie flow? Assume both areas were at nominal frequency (60 Hz) to begin. What are the Area Control Error (*ACE*) values for Area 1 and Area 2.

6 Marks

Problem 4 (Design Problem – Overcurrent Protection)

Data for a 60 Hz radial system shown in Figure 2 are given in Table I and II. Select current tap settings and time-multiplier settings (TMSs) to protect the system from faults using IEC standard inverse current relays to provide protection for line-ground/line-line faults and three-phase faults. The tap settings are as follows: 1.0, 1.2, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 12.0 A. Use a 0.3 second coordination time interval.

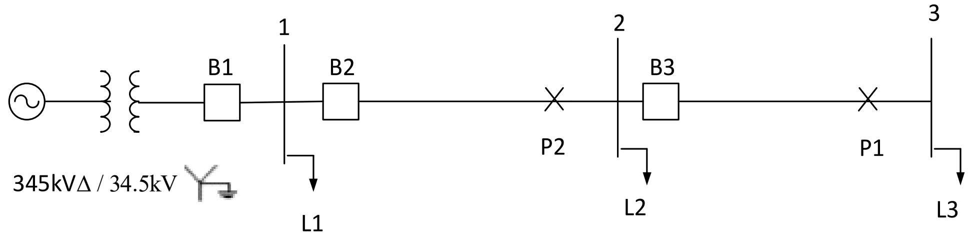

Figure 2: One-line diagram of the radial system.

Table I: Maximum and Minimum Fault Currents

Bus	Maximum Fault Current (Bolted Three-Phase) A	Minimum Fault Current (L-G or L-L) A
1	3000	2200
2	2000	1500
3	1000	700

Table II: Standard CT ratios

Current ratio	**Current ratio**	**Current ratio**
50:5	300:5	800:5
100:5	400:5	900:5
150:5	450:5	1000:5
200:5	500:5	1200:5
250:5	600:5	

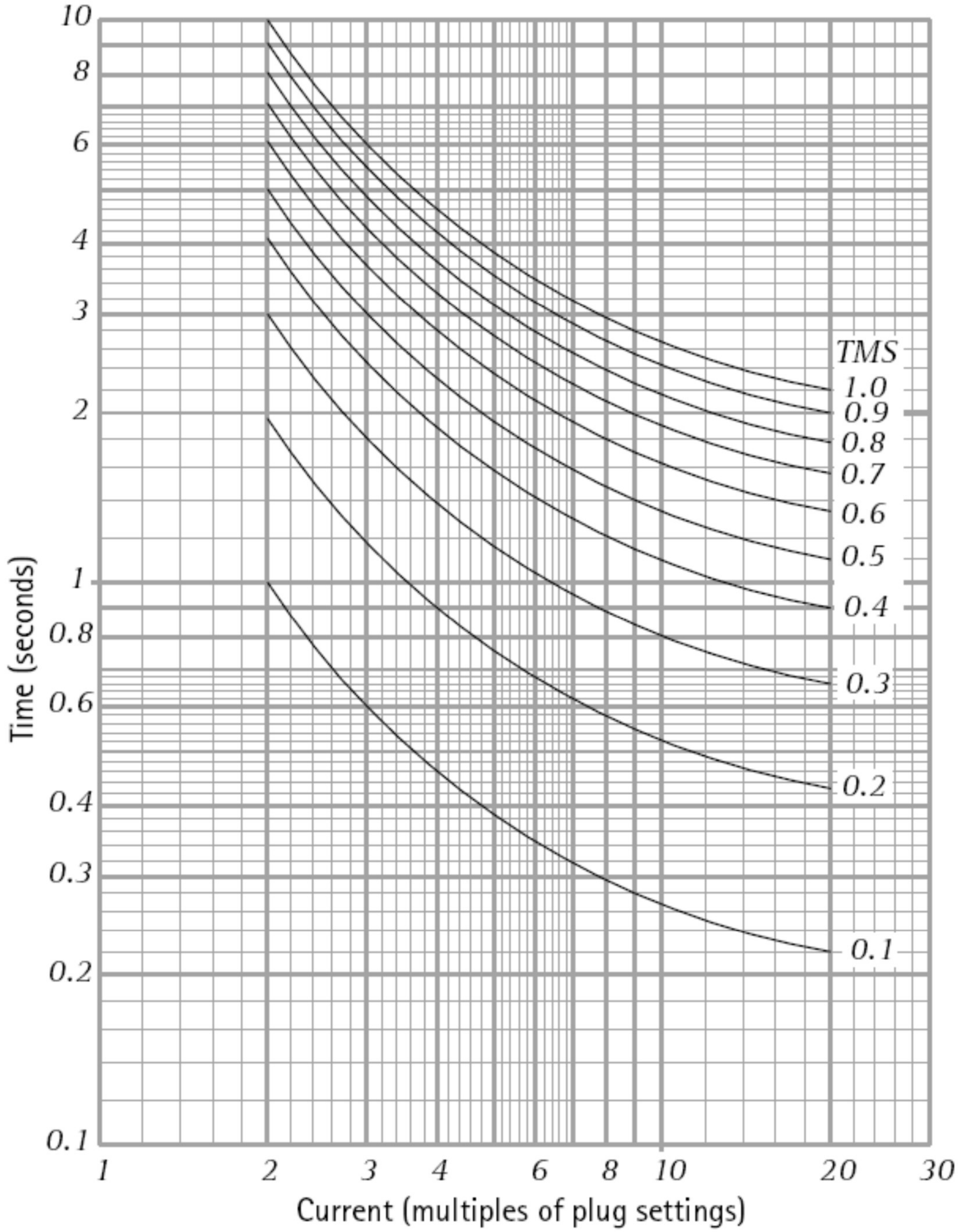

Figure 3: Characteristic curves of type IEC standard inverse overcurrent relays.

6 Marks

Question 5 (Bus Differential Protection)

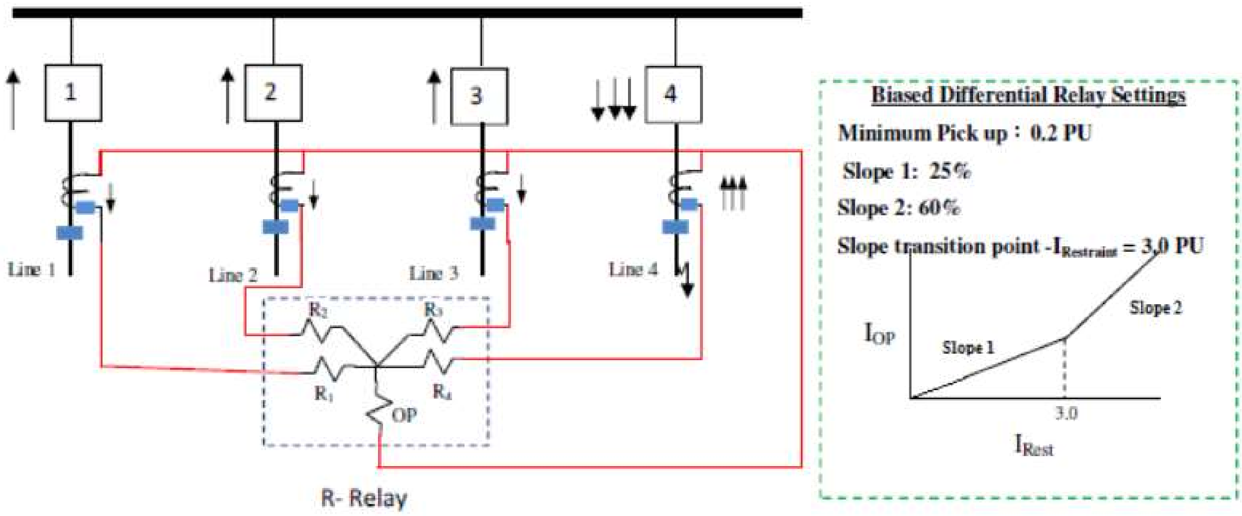

Figure 4: *Percentage Biased Differential Relay Connections*

Percentage biased differential relay is connected to protect a bus as shown in Figure 4. The figure also shows currents in the relay for external fault on line 4.

The restraint current in this relay is defined as $I_{REST} = [|I_1| + |I_2| + |I_3| + |I_4|]$. 1 pu current is equal to 5 A (rated nominal secondary current of a CT). The relay setting and the slope characteristic is as shown in the box. If the restraint currents are 10 A and 20 A, what would be the differential currents required for relay operation?

6 Marks

Question 6 (Transformer Protection)

A three-phase, 500 MVA, 345 kV Δ/500 kV Y transformer is protected by differential relays with taps. The available relay tap settings are 5:5, 5:5.5, 5:6.6, 5:7.3, 5:8, 5:9, and 5:10. Select CT ratios, CT connections, and relay tap settings (**<u>no need to draw the CT connection and relay diagram)</u>**. Determine the currents in the transformer and in the CTs at rated conditions. Determine the tap setting, which gives the minimum percentage mismatch. Also give a recommended value for the slope of the percentage differential relay.

6 Marks

Question 7 (Effect of Infeed on Distance Protection)

Line impedances for the power system shown in Figure 5 are $Z_{12} = Z_{23} = 3 + j40\ \Omega$, and $Z_{24} = 6 + j80\ \Omega$. Reach for the zone 3 of the B12 impedance relays is set for 100% of line 1-2 plus 120% of line 2-4. Find the settings for Zone 1, Zone 2 and Zone 3 distance settings.

If $|I_{32}/I_{12}| > 0.20$, does the B12 relay see the fault at bus 4?

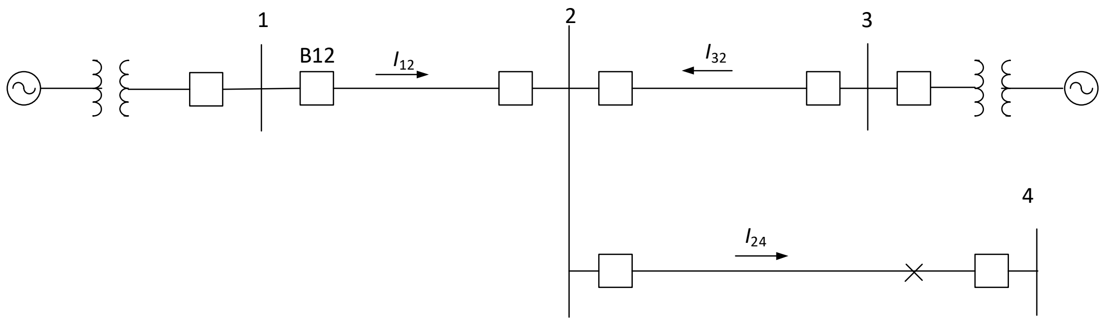

Figure 5: Transmission Line Distance Protection

6 Marks

Question 8 (DFT calculations: Estimating the magnitude and phase angle of the fault current)

Following are the sampled values of the fault current recorded by a digital fault recorder in a substation. The current signal is sampled at 720 Hz. Doing a FFT of the signal, it could be found that the current waveform is composed of an *ac* component of 60 Hz fundamental frequency component, a 30 Hz sub-harmonic component. The current waveform also contains a decaying dc and a small measurement noise. The quantized values for 12 samples (1 cycle) are listed below:

Sample No	Quantized Value
1	4,044
2	2,543
3	1,172
4	315
5	202
6	889
7	2,065
8	3,491
9	4,655
10	5,246
11	5,128
12	4,200

Use Discrete Fourier Transform (DFT) technique to estimate the magnitude and phase angle of the fundamental value of the current signal at the end of sample number 12. Show the detailed calculations for the 12^{th} sample number and give the estimated magnitude and phase angle of the current at the end of sample number 12. Plot (as a rough sketch) the current phasor in a complex plane at the end of sample number 12.

Discuss briefly the suitability of the DFT technique, i.e., effect of noise, sub-harmonic and harmonic frequencies, decaying dc component on estimation of the fundamental value of the current signal.

8 Marks

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