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

Dated: April 22, 2017 **Time: 2:00 pm – 5:00 pm**
Instructor: Dr. Rama Gokaraju **Total Marks: 50**

Instructions:

1) This examination paper consists of 9 questions and 7 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:* _____________________

Question 1 (Economic Dispatch - Lagrangian Method. No transmission losses)

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

$$F_1(P_1) = 500 + 5.3P_1 + 0.004P_1^2$$
$$F_2(P_2) = 400 + 5.5P_2 + 0.006P_2^2$$
$$F_3(P_3) = 200 + 5.8P_3 + 0.009P_3^2$$

where P_1, P_2 and P_3 are in MW. The generator limits are as follows: $200\ MW \leq P_1 \leq 350\ MW$, $150\ MW \leq P_2 \leq 350\ MW$, $100\ MW \leq P_3 \leq 225\ MW$.

Using the Lagrangian method, determine the output of each unit, when $P_L = 800MW$. Neglect transmission losses.

5 Marks

Question 2 (Economic Dispatch - Penality Factor Calculations)

The fuel-cost curves of two generators in *\$/h* are given by

$$F_1(P_1) = 500 + 10P_1 + 0.05P_1^2$$
$$F_2(P_2) = 600 + 20P_2 + 0.04P_2^2$$

where P_1, P_2 are in MW. The penalty factor for the first generator is equal to one. For the second generator the partial derivative of the losses with respect to P_2 is

$$\frac{\partial P_{losses}}{\partial P_2} = 0.05.$$

Calculate the optimal dispatch values of P_1, P_2 for load plus losses of 1,000 MW.

5 Marks

Question 3 (Single-Area Load Frequency Control)

You are given a single-area power system consisting of three generators. Following are the data for the three generators,

$M_1 = 3.0\,pu$	$D_1 = 1.10$	$R_1 = 0.01$	Unit Rating = 100 MVA
$M_2 = 4.0\,pu$	$D_2 = 1.20$	$R_2 = 0.015$	Unit Rating = 500 MVA
$M_3 = 4.5\,pu$	$D_3 = 1.25$	$R_3 = 0.015$	Unit Rating = 500 MVA

Refer all quantities refer to a 500 MVA base. Calculate the final frequency for load-step change of 0.15 *pu*. Assume that the frequency was at the nominal value (60 Hz) initially.

5 Marks

Question 4 (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 = 0.50 pu	D = 0.9 pu
M=9 pu MW/pu frequency/sec	M=8 pu MW/pu frequency/sec
Governor time constant = 0.2 sec	Governor time constant = 0.3 sec
Turbine time constant = 0.4 sec	Turbine time constant = 0.5 sec
Base MVA = 1,000 MVA	**Base MVA = 1,250 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*.

A positive load change of 200 MW and a negative load change of 150 MW occur simultaneously in areas 1 and 2 of the two-area system. What is the new value of steady-state frequency and what is the change in tie flow? What are the Area Control Error (*ACE*) values for Area 1 and Area 2. Assume both areas were at nominal frequency (60 *Hz*) to begin.

Show the Automatic Generation Control (AGC) system for the above system and clearly identify the different blocks. Briefly comment on the purpose of the various control blocks used in the figure.

5 Marks

Question 5 (Excitation Control Systems – Closed Loop Transfer Function Analysis)

Figure 1 shows a block diagram of a typical excitation system. The data pertaining to this system are given below.

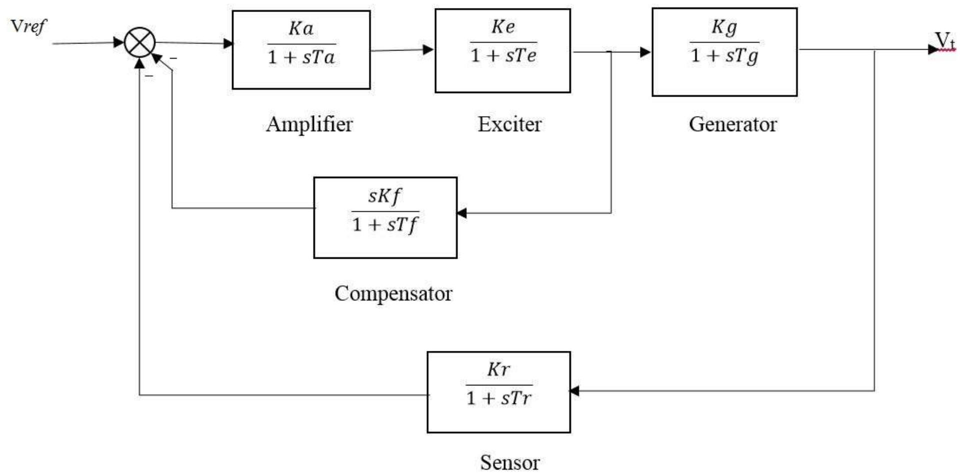

Figure 1: Block diagram of an excitation system with compensator

Gain	Time Constant	
Amplifier	K_a	*0.1 sec*
Exciter	$K_e=1$	*0.5 sec*
Generator	$K_g=1$	*6.0 sec*
Sensor	$K_r=1$	*0.05 sec*
Compensator	K_f	*0.1 sec*

Determine the transfer function analytically first for the uncompensated excitation and find the gain K_a so that the steady state error is less than *1%.*

Set $K_f=1$ for the compensator and find the limiting value of K_a for which the system is still stable.

5 Marks

Question 6 (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.

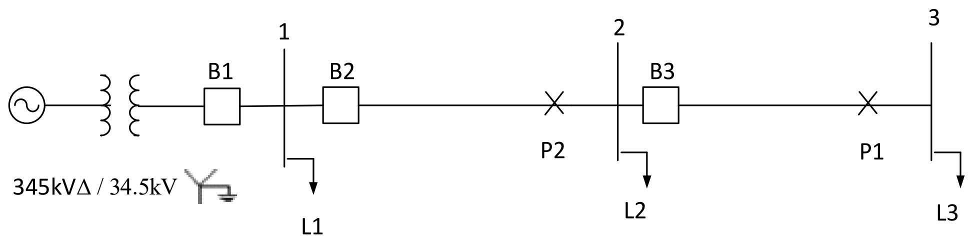

Figure 2: One-line diagram of the radial system.

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	3,000	2,000
2	2,000	1,500
3	1,000	500

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	

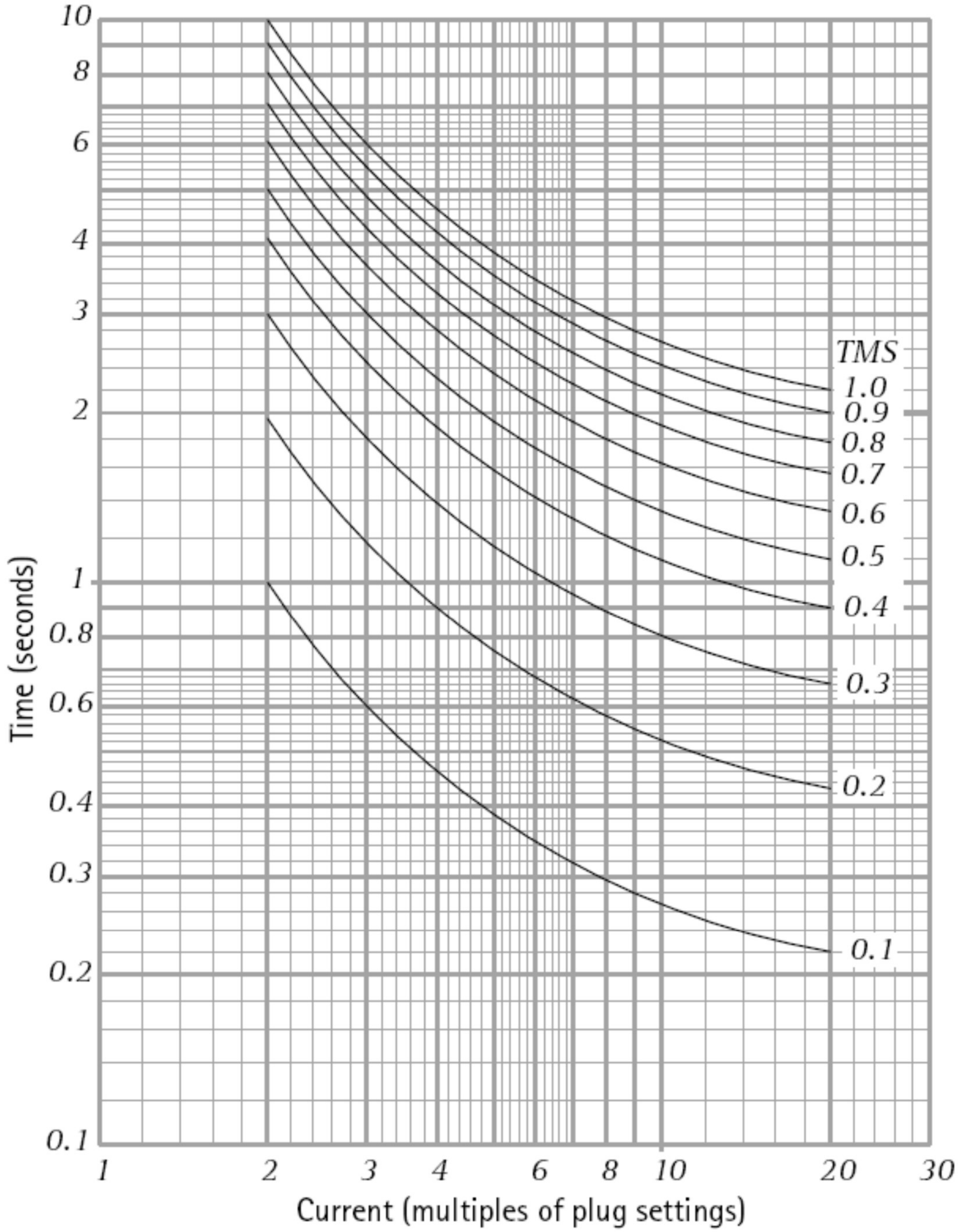

Figure 3: Characteristic curves of type IEC standard inverse overcurrent relays.

8 Marks

Question 7 (Design Problem - Effect of Infeed on Distance Protection)

Line impedances for the power system shown in Figure 4 are $Z_{12} = Z_{23} = 2 + j50\ \Omega$, and $Z_{24} = 5 + j80\ \Omega$. 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 $|I_{32}/I_{12}| > 0.25$, does the B12 relay see the fault at bus 4?

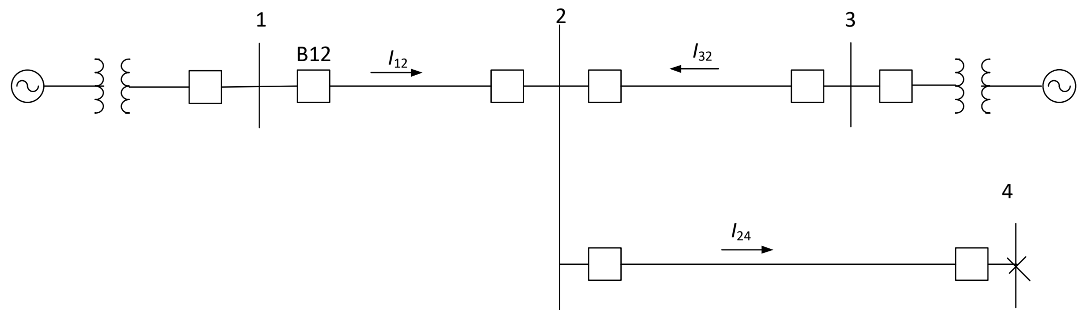

Figure 4: Transmission Line Distance Protection

5 Marks

Question 8 (Design Question - Transformer Protection)

A three-phase, 500 MVA, 345 kV Δ/500 kV Y transformer is protected by differential relays with taps. The short-term emergency rating is 600 MVA. The available relay tap settings are 5:5, 5:5.5, 5:6.6, 5:7.3, 5:8, 5:9, and 5:10.

Design a differential protection for the above transformer. Select CT ratios, CT connections, and auxiliary CT ratios (a simple 1 phase-relay diagram would be sufficient for connection diagram - **no need to draw a 3-phase connection diagram)**. Draw a rough sketch of the percentage differential characteristics showing various errors, mismatches that could happen. Also give a recommended value for the slope of the percentage differential relay.

5 Marks

<u>Question 9 (Design Problem – Designing a DFT filter to estimate current phasor)</u>

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.

7 Marks

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