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

Dated: April 16, 2019 | **Time: 9:00 am – 12:00 pm**
Instructor: Dr. Rama Gokaraju | **Total Marks: 50**

Instructions:

1) This examination paper consists of 9 questions and 7 pages in total. You are required to do 8 questions: you can do either Question 1 or 2, and rest of the Questions 3-9 are compulsory.
2) This is a closed-book examination. Four-page formula sheet is allowed. **No solved example problems are allowed in the formula sheet.**
3) Programmable calculators are allowed for the examination.
4) Your solution steps and figures should be clear and methodical. There would be penalty marks if your solutions are done in an illegible fashion.
5) Mark allotted for each problem is shown on the right margin.

Student Name: ____________________________ *Student Id:* ____________________

Question 1 (Economic Dispatch taking into account Transmission Losses. Based on Lab 1 material)

An area of a power system has two conventional fuel units. The variable operating costs of these units are given by

$$F_1(P_1) = 10P_1 + 0.008P_1^2 \ \$/h$$
$$F_2(P_2) = 8P_2 + 0.009P_2^2 \ \$/h$$

where P_1, P_2 are in *MW*. $F_i(P_i)$ is in $/h. The total transmission losses for the power system are given by equation:

$$P_L = 1.5 \times 10^{-4} \times P_1^2 + 3 \times 10^{-5} P_1 P_2 + 2 \times 10^{-5} P_2^2 \qquad MW$$

Where P_1 and P_2 are given in megawatts. Determine the output of each unit, total transmission losses, total load demand, and the total operating cost F_T when the system λ=10 $/MWh. What are the penalty factors for each of the units?

6 Marks

Question 2 (Economic Dispatch Using Reduced Gradient Method)

Assume that all three of the thermal units described below are running. Find the economic dispatch schedules for a total demand of 1,000 MW.

Unit Data (MBtu/h)	Minimum (MW)	Maximum (MW)	Fuel Cost ($/MBtu)
$H_1 = 225 + 8.4P_1 + 0.0025P_1^2$	45	350	0.80
$H_2 = 729 + 6.3P_2 + 0.0081P_2^2$	45	350	1.02
$H_3 = 400 + 7.5P_3 + 0.0025P_3^2$	47.5	450	0.90

Use the gradient method to find the economic schedule for the three units given for a total demand of 1,000 MW.

Assume the initial conditions (i.e. loadings) on the three units are

$P_1 = 300$ MW, $P_2 = 300\ MW$, and $P_3 = 400\ MW$

<u>Do one step of the iteration only (two steps if there is a limit violation at the end of iteration one).</u> Give the individual unit loadings and the cost per hour, as well as total cost per hour.

6 Marks

<u>Question 3 (Unit Commitment - Spinning Reserve)</u>

Suppose a power system consists of two small microgrids. Five Independent Power Producers (IPPs) with Distributed Generator (DG) sets are located in the two microgrids as shown in Figure 2. The five IPPs have committed to supply 30 MW. The maximum DG capacities and their outputs are shown in Table 1. The two regions are separated by transmission tie lines that can transfer 4 MWs in either direction.

Fill in the numbers ('?'s) in Table 1 below. Analyze whether the loss of DG Unit 4 on this system can be covered by the spinning reserve on the remaining units (show sample calculations briefly for Unit 4).

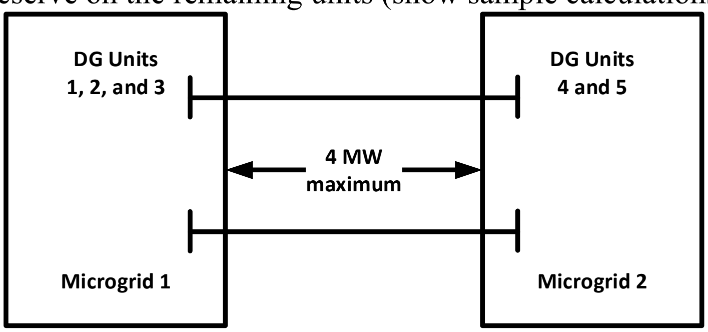

Figure 1: Two microgrid system.

Region	Unit	Unit Capacity (MW)	Unit Output (MW)	Regional Generation (MW)	Spinning Reserve	Regional Load (MW)	Power Interchange (MW)
	1	10	9		?		
Western	2	8	4	?	?	20	?
	3	8	4		?		
Eastern	4	12	10	?	?	10	?
	5	5	3		?		
Total	1-5	43	30	30	?	30	

Table 1: Data for the system shown in Figure 1.

6 Marks

<u>Question 4 (Automatic Generation Control (AGC) of a Two Area System)</u>

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
Turbine time constant = 0.4 sec	Turbine time constant = 0.5 sec
Base MVA = 1,000 MVA	**Base MVA = 750 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*.

The areas are initially operating in steady state with each area supplying 1,000 MW. 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.

<u>A sudden load change of 187.5 MW occurs in Area 2.</u> 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.

6 Marks

<u>Question 5 (Excitation Control Systems – Closed Loop Transfer Function Analysis. Based on Lab 5)</u>

Figure 2 shows a block diagram of a typical excitation system. The data pertaining to this system are given below.

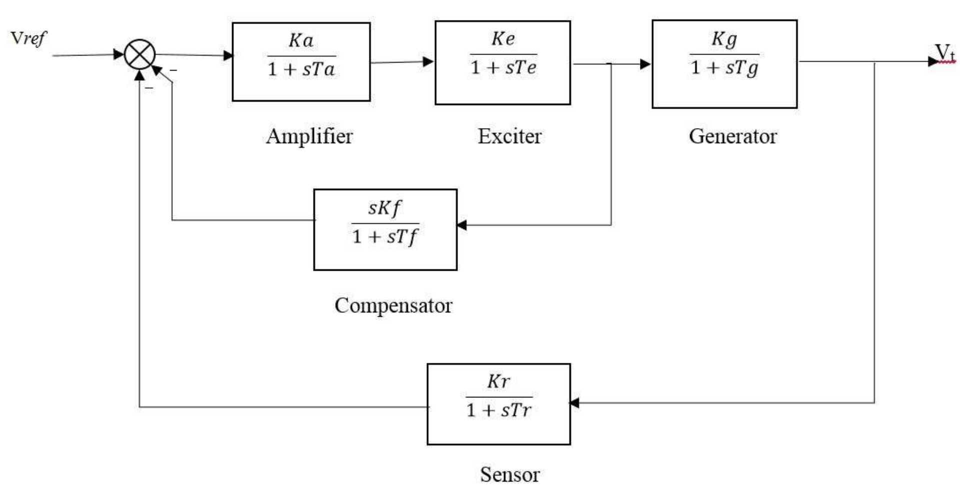

Figure 2: Block diagram of an excitation system with compensator

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*

Find the gain K_a so that the steady state error is less than *1%*.

5 Marks

Question 6 (Design Problem – Overcurrent Protection)

Data for a 60 Hz radial system shown in Figure 3 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.

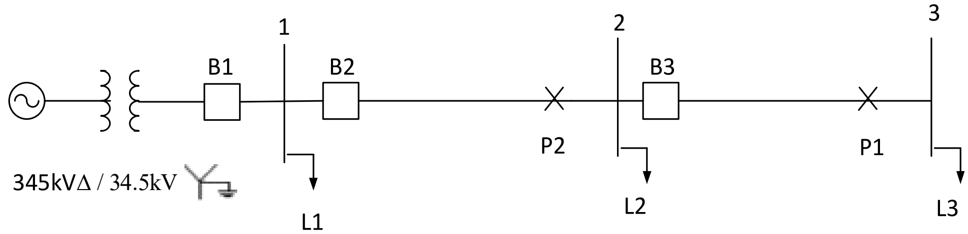

Figure 3: One-line diagram of the radial system.

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	

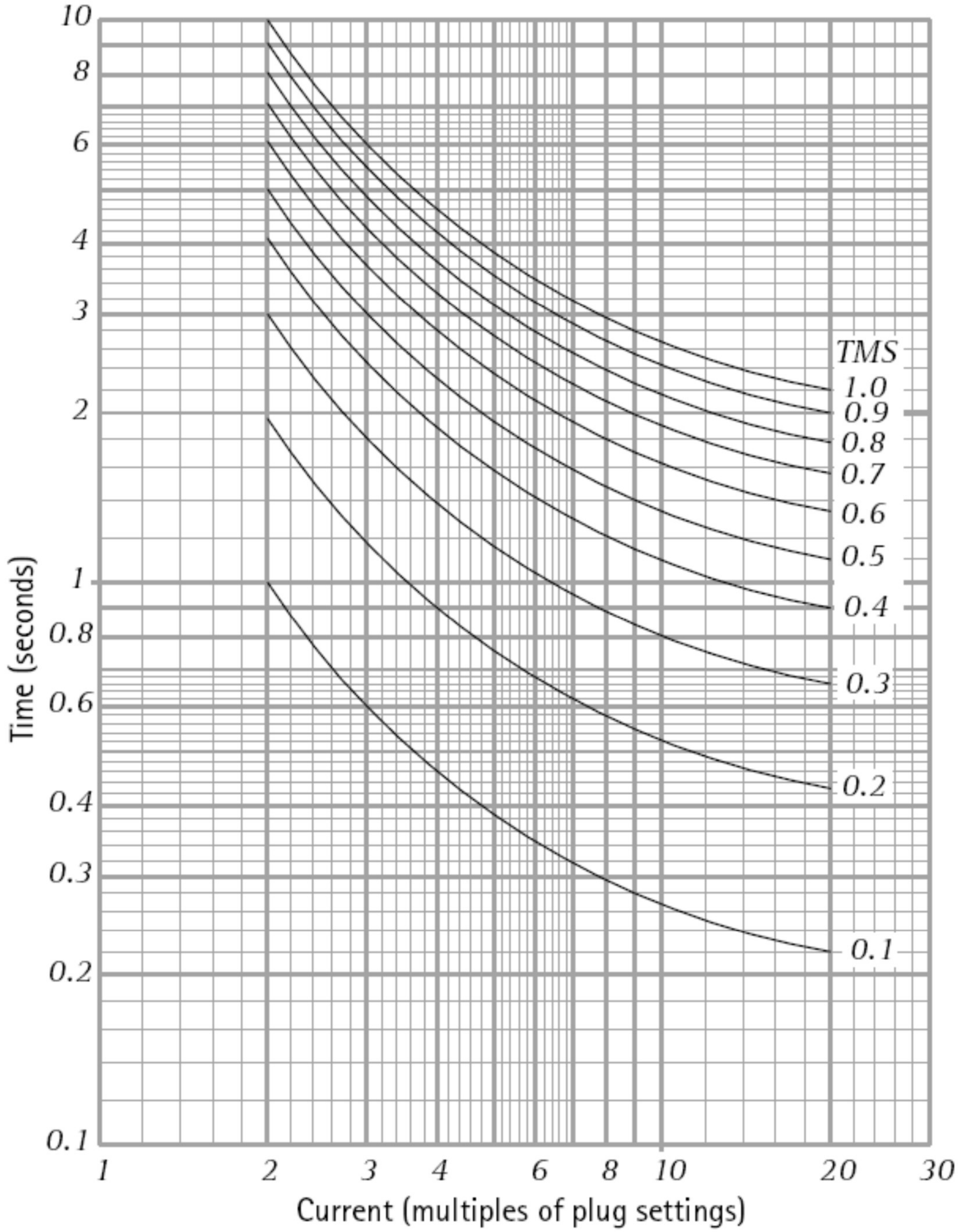

Figure 4: Characteristic curves of type IEC standard inverse overcurrent relays.

8 Marks

Question 7 (Effect of Infeed on Distance Protection)

Line impedances for the power system shown in Figure 5 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 (without the infeed current).

If $|I_{32}/I_{12}| > 0.25$, does the B12 relay see the fault at bus 4?

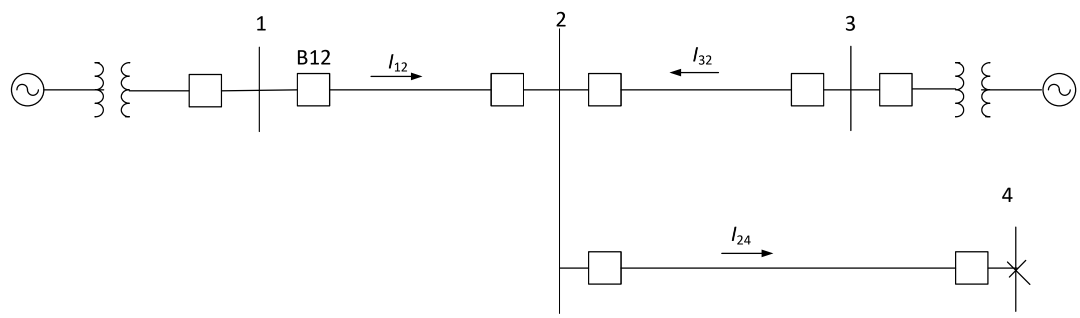

Figure 5: Transmission Line Distance Protection

6 Marks

Question 8 (DFT filter to estimate current phasor)

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, and harmonic components. The current waveform also contains a decaying dc and a small measurement noise. The quantized values for 13 samples are listed below:

Sample No	**Quantized Value**
1	315
2	202
3	889
4	2,065
5	3,491
6	4,655
7	5,246
8	5,128
9	4,200
10	2746
11	1058
12	-332
13	-1,094

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 13. Show the detailed calculations for the 13^{th} sample number and give the estimated magnitude and phase angle of the current at the end of sample number 13. Plot (as a rough sketch) the current phasor in a complex plane at the end of sample number 13.

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

Question 9 (Transformer Protection - Design Question)

A three-phase, 500 MVA (top MVA), 345 kV Δ/500 kV Y transformer is protected by current differential relay.

Design a differential protection for the above transformer either using relay taps (just like a GE BDD relay) or auxiliary CT. The available relay tap settings for GE BDD are 5, 5.5, 6.6, 7.3, 8, 9, and 10.

The relay minimum pick up current is set to 30%. Draw a rough sketch of the percentage differential characteristics. Give a High Set value. Also, give a recommended value for the slope of the percentage differential relay.

6 Marks

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