University of Saskatchewan
Department of Electrical Engineering
EE 442.3 Power System Operation & Control (Term 1)
FINAL EXAMINATION (Online/ @Home Exam)

Dated: Dec 9, 2020 (9 am-12 pm) **Due Date/Time: Dec 9, 2020 (12:30 pm)**
Instructor: Dr. Rama Gokaraju **Total Marks: 50**

Instructions:

1) **This examination paper is for the EE 442 undergraduate students only. The examination paper consists of 7 questions and 7 pages in total.**
2) This is an open-book, open notes. Formula sheets are also permitted.
3) You are not permitted to take assistance of others to solve exam questions. You would severely penalized, if your solutions point to this. Every student is required to read the attached academic integrity statement and sign.
4) Programmable calculators, any other softwares such as MATLAB, Excel etc are allowed for doing the examination.
5) Your solution steps and figures should be clear and methodical. There would be penalty marks, if your solutions are presented in an illegible fashion.
6) Mark allotted for each problem is shown on the right margin.

Student Name: ______________________________ *Student Id:* ______________________

Question 1 (Economic Dispatch Using the Lagrangian Optimization Method)

The fuel-cost functions for two thermal plants are given in *$/h*

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

where P_1 and P_2 are in *MW*. Determine the economically optimum division of generation for a total load equal to 282 *MW* using the Lagrangian optimization method. Neglect transmission losses. The generator limits are as follows:

$$25 \leq P_1 \leq 150\ MW$$

$$30 \leq P_2 \leq 200\ MW$$

5 Marks

Question 2 (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 100 MW in Area 1 and decreases by 200 MW in Area 2 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.

7.5 Marks

Question 3 (Controller Design for Generator AVR Excitation Systems)

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

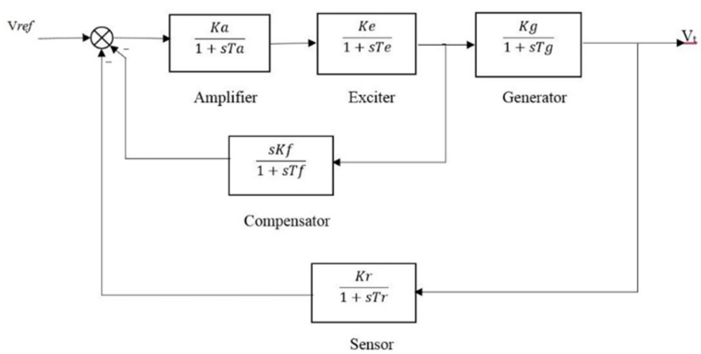

Figure 1: Block diagram of an excitation system with compensator

	Gain	Time Constant
Amplifier	K_a	*0.05 sec*
Exciter	$K_e=1$	*0.5 sec*
Generator	$K_g=1$	*1.0 sec*
Sensor	$K_r=1$	*1 sec*

Compensator K_f *0.1 sec*

1. Analysis of the Uncompensated System (ie without the compensator): Find the gain K_a so that the steady state error is less than *1%*. Where are the poles of the system (you can use rlocus function in MATLAB to plot root locus diagram). Plot the step response and comment on the stability of the system.
2. Design the Compensated System (ie with the compensator): The excitation system is made stable for large values of Ka (say equal to 100) and achieve desired time domain performance requirements by adding a derivative feedback as shown in Fig. 1. Set K_f = 15. Determine the time domain performance of the system. Plot the step response of the closed loop system of the compensated system. Comment on the stability of the system with the compensator?

7.5 Marks

Question 4 (Coordination of Overcurrent Relays)

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.

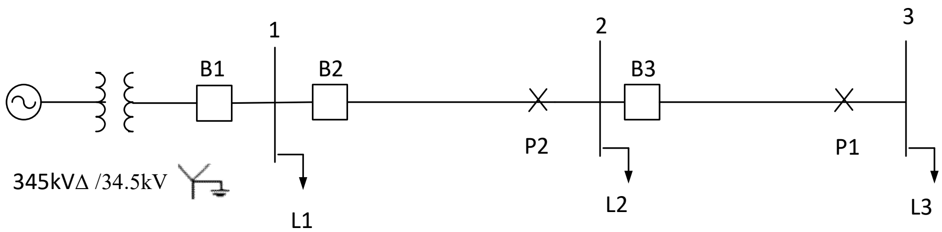

Figure 2: One-line diagram of the radial system.

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	2,200	1,500
3	1,000	600

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	

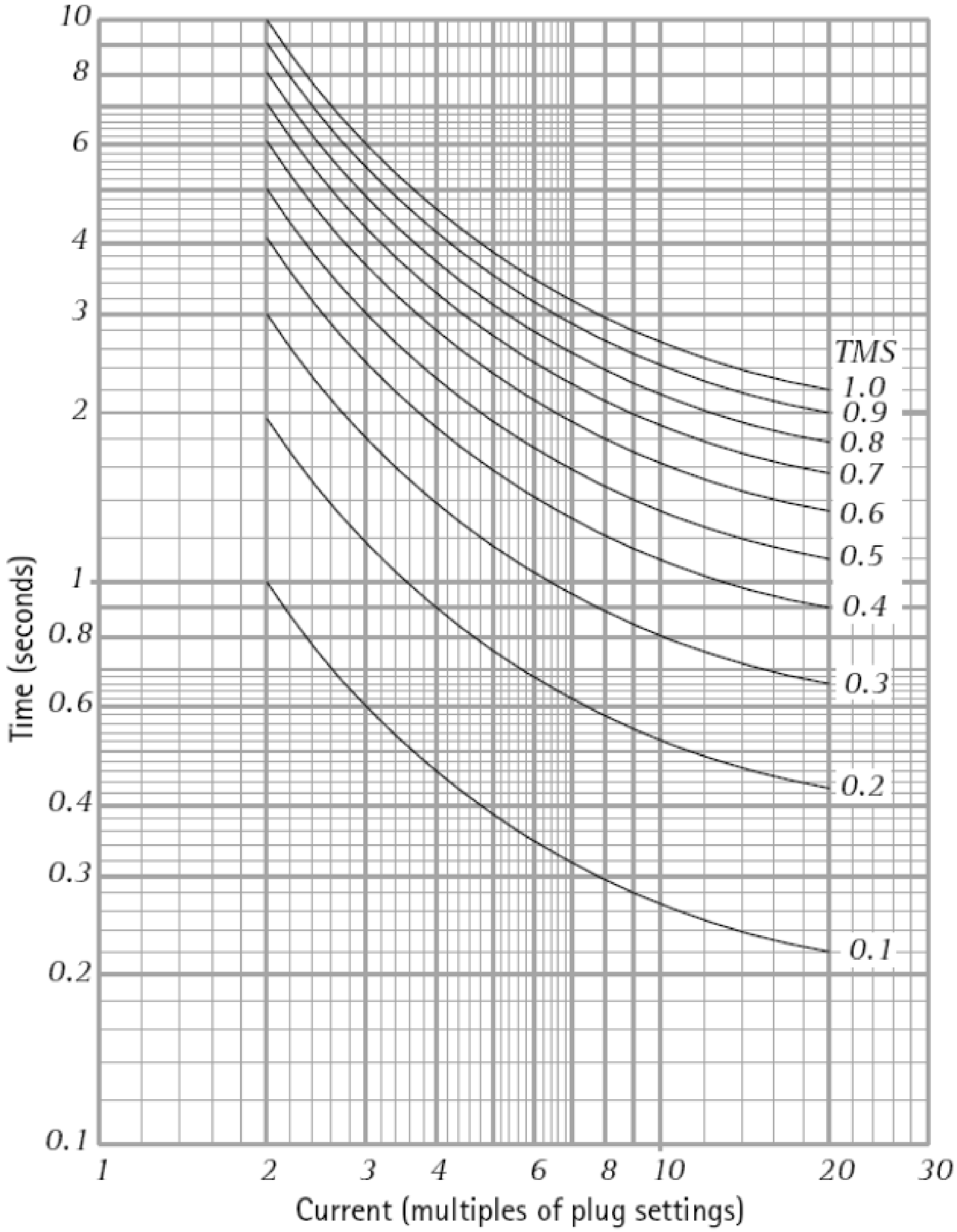

Figure 3: Characteristic curves of type IEC standard inverse overcurrent relays.

10 Marks

Question 5 (Transmission Line Distance Protection)

Consider the multi-terminal line in the system shown in Figure 4 (impedances are given in Ω). Each of the buses C, D, G, H and J has a source of power behind it. For a three-phase fault on Bus B, the contributions from each of the sources are as follows:

Source	Current, I (Amperes)
J	600
C	200
D	300
G	800
H	400

You may assume that the fault current contributions from each of these sources remain unchanged as the fault is moved around throughout the system shown. Determine the zones 1, 2 and 3 settings for the distance relays at Bus J (ie relay located at right side of Bus J – R_J).

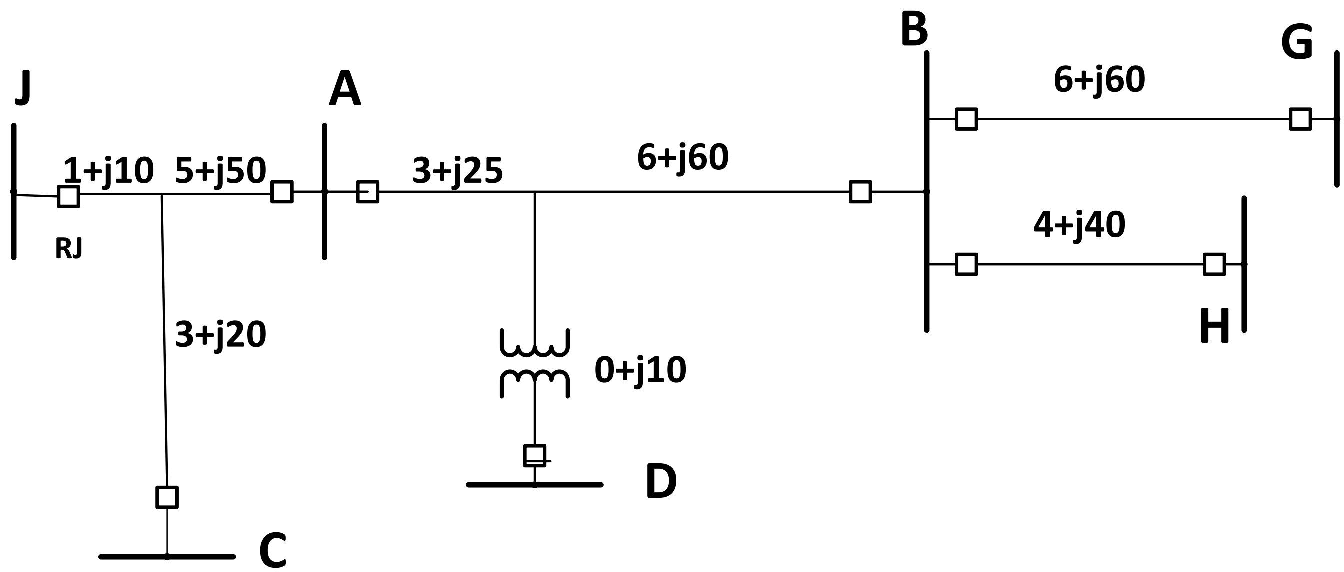

Figure 4: Transmission Line Diagram

5 Marks

Question 6 (Digital Protection Analysis: DFT filter to estimate fault 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 are listed below:

Sample No	**Quantized Value**	**Sample No**	**Quantized Value**
1	6,034	13	5,246
2	6,104	14	5,128
3	5,363	15	4,200
4	2,543	16	2,747
5	1,172	17	1,058
6	315	18	-333
7	202	19	-1,094
8	889	20	-1,081
9	2,065	21	-255
10	3,491	22	1,143
11	4,655	23	2,779
12	5,246	24	4,232

Use Discrete Fourier Transform (DFT) technique to estimate the magnitude and phase angle of the fundamental value from the digital values of the fault current signal for sample number 1-24. Show the detailed calculations for one sample number. Plot the magnitude & phase angle vs. the sample number.

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

7.5 Marks

Question 7 (Microgrid Protection)

With conventional sources and long transmission lines and for a forward fault, what is the phase angle relationship between the positive sequence current to positive sequence voltage?
What is the phase angle relationship between the negative sequence current to the negative sequence voltage?
What is the phase angle relationship between the zero-sequence current to the zero-sequence voltage?

What are the three issues that arise while considering the Y-side grounding or no-grounding of the Distribution Resource Side's interconnecting transformer? Explain briefly.

From the two fault current waveforms shown in Fig. 5, can you identify what type of fault has occurred? Identify which one would correspond to the fault current characteristics for a conventional (synchronous generator) source & which one would correspond to a renewable energy type source/ with an inverter.

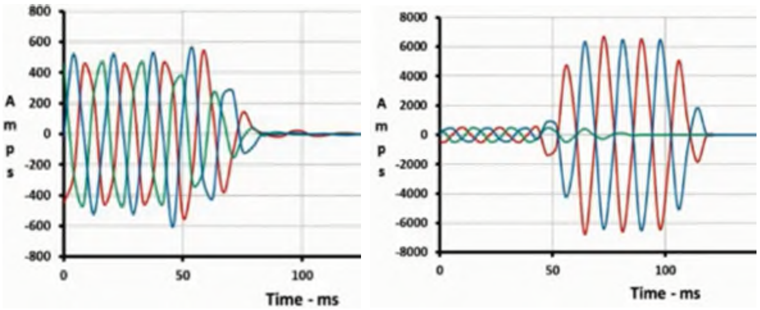

Fig 5 60 Hz Fault Current Waveforms with Conventional & RES/ with inverter

7.5 Marks

College of Engineering Academic Integrity Statement

This is a formal statement of commitment to academic integrity for assessment in **EE 442-Power System Operation & Control**. Students should read this statement carefully and must sign this document indicating that they understand and have followed the requirements for academic integrity.

The exam is to be completed individually. Specifically, you are not to discuss the exam with others or cooperate on the completion of the exam with others, including other students in this course, in any manner. Please report any concerns to the instructor for follow up.

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1. I, ___________________________________, ID#____________(First Name Last Name, U of S Student Number) do solemnly swear that I have not and will not communicate about this final examination with anyone, especially other students in the course, until after the deadline for submission of exam solutions.

2. I fully understand that disciplinary action may be taken against me if I am discovered to have communicated with anyone about the content or solution of this final examination.

__________________________/ID#_____________/________________________/_____________

student name student number signature date

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