University of Saskatchewan
Department of Electrical Engineering
EE 442.3 Power System Operation & Control (Term 2)
FINAL EXAMINATION (Take Home)

Dated: April 8, 2020 (9am) **Due Date/Time: April 9, 2020 (12pm)**
Instructor: Dr. Rama Gokaraju **Total Marks: 40**

Instructions:

1) This examination paper consists of 5 questions and 7 pages in total.
2) This is an open-book, open notes, open internet examination.
3) Every student is required to read the attached academic integrity statement and sign. The academic integrity form requires that you provide: the signature of a co-isolating adult confirming that the exam regulations have been followed; OR a declaration that you are isolating without access to another adult who can 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 done in an illegible fashion.
6) Mark allotted for each problem is shown on the right margin.

Student Name: ______________________________ *Student Id:* _____________________

Question 1 (Controller Design for Generator AVR Excitation Systems)
Measurement Attributes: A2 (Problem Analysis), A4 (Design – Excitation Control Stability)

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

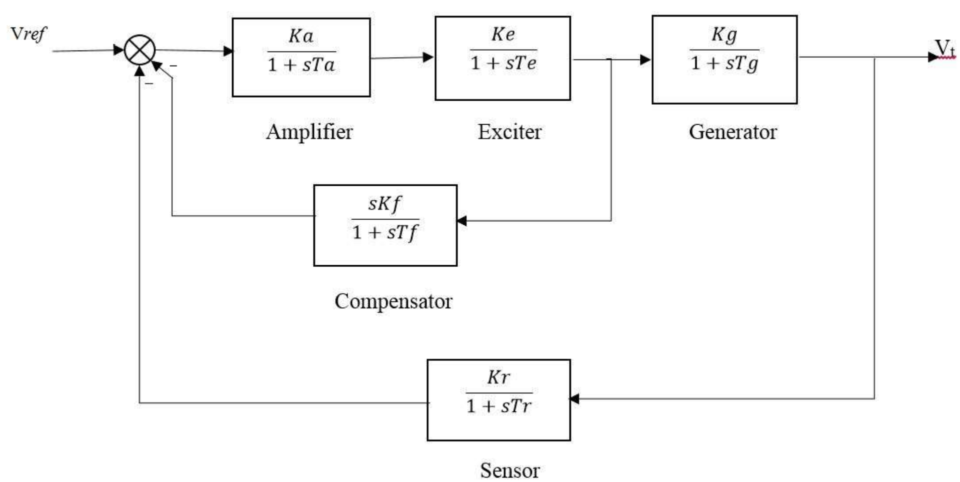

Figure 1: Block diagram of an excitation system with compensator

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*

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?

10 Marks

Question 2 (Coordination of Overcurrent Relays)
Measurement Attributes: A2 (Problem Analysis), A4 (Design)

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.

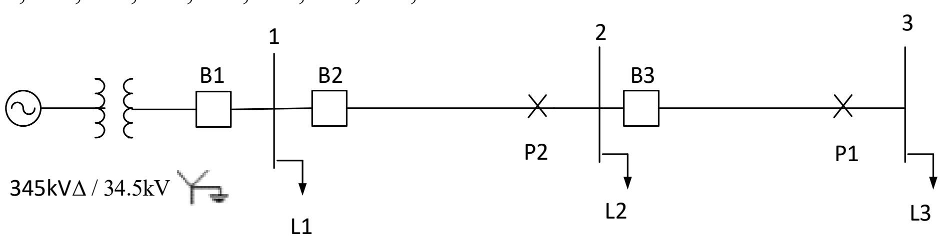

Figure 2: One-line diagram of the radial system.

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	

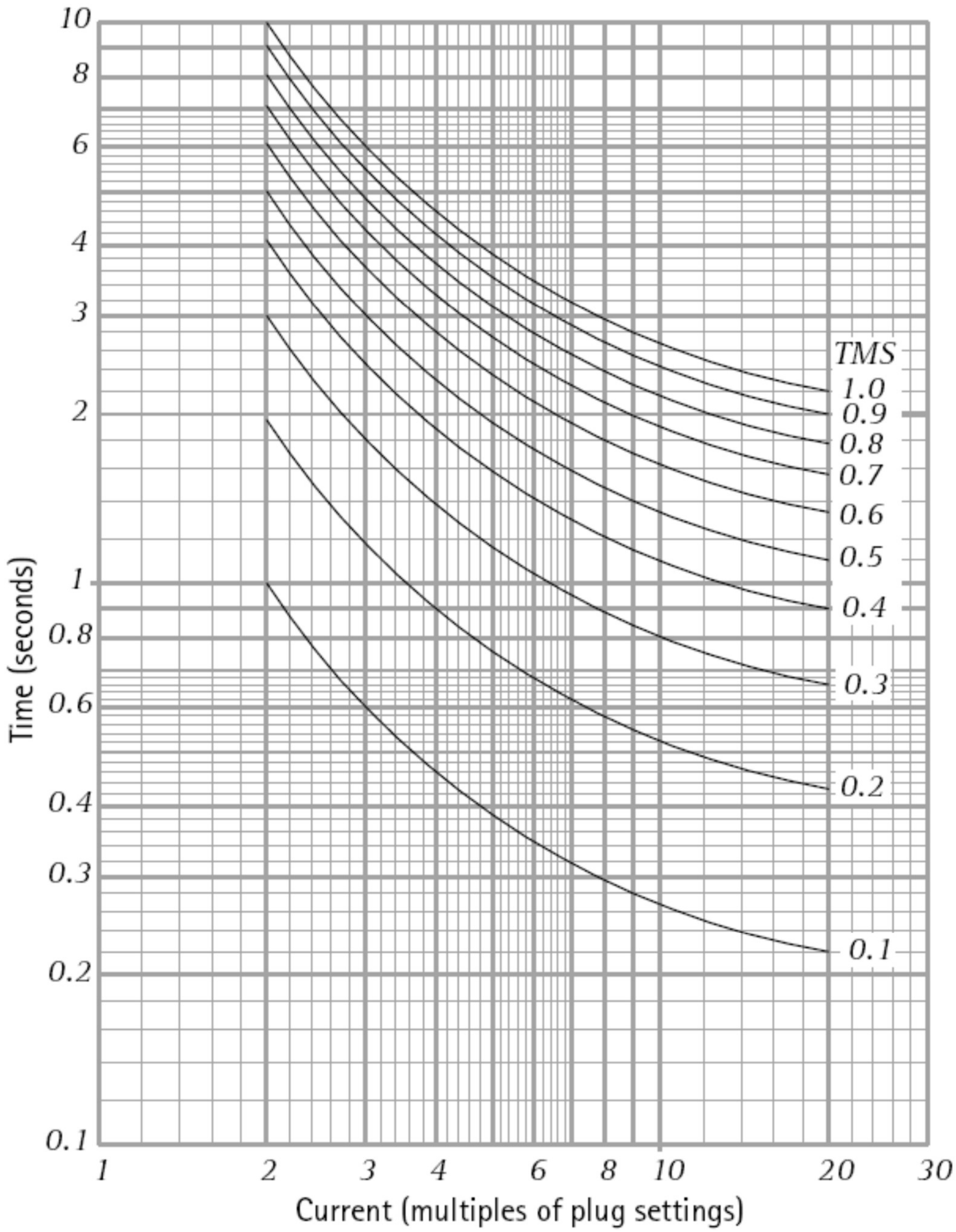

Figure 3: Characteristic curves of type IEC standard inverse overcurrent relays.

10 Marks

Question 3 (Transmission Protection – Develop a Distance Protection Methodology When There Is Infeed Currents)
Measurement Attributes: A2 (Problem Analysis), A4 (Design)

Consider the multi-terminal line in the system shown in Figure 3 (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 A (ie relay located at right side of Bus A - R_A).

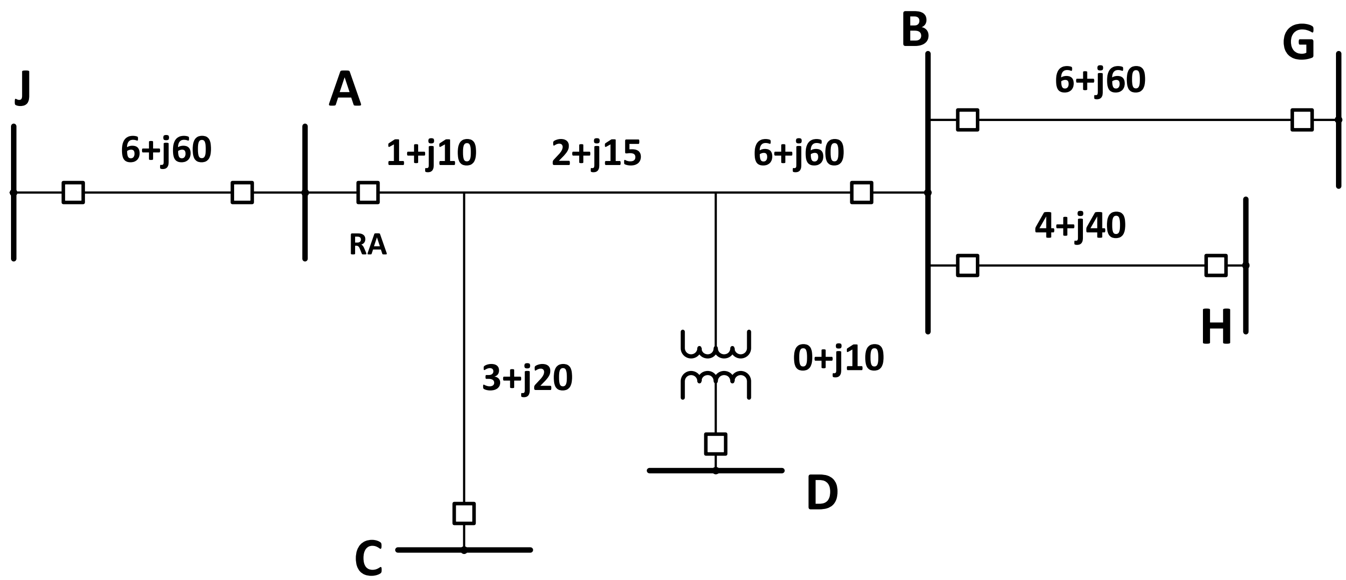

Figure 3: Transmission Line Diagram

10 Marks

<u>Question 4 (DFT filter to estimate fault current phasor – Digital Protection Analysis Method)</u>
Measurement Attributes: A2 (Problem Analysis)

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 from the digital values of the fault 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 fundamental frequency 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.

5 Marks

<u>Question 5 (Transformer Protection Using one Manufacturer's Practice)</u>
Measurement Attributes: A2 (Problem Analysis), A4 (Design)

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

Develop a differential protection for the above transformer either using relay taps (example -- GE BDD relay). The available relay tap settings 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.

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.

High standards of professional integrity are expected of engineers, and of engineering students. These commitments are part of our Hard Hat Ceremony Statement of Ethics (attached), and we rely on you to live up to this commitment, especially in these challenging times.

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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.

3. I (am/am not) living with students currently enrolled in an engineering program. Their names are provided below:

____(name/program/university)
____(name/program/university)

4. I solemnly swear that while observing Covid-19 isolation requirements, I am:
   - ☐ Isolating without another adult (in this case no countersignature is available) **OR**
   - ☐ Co-isolating with at least one other adult. (In this case, a co-isolating adult is asked to sign the declaration below)

________________________**/ID#**____________/______________________/____________
student name **student number** **signature** **date**

By countersigning, I state that to the best of my knowledge, ________________________(name) has completed the exam for ________(course title and number) individually.

________________________/ ______________________/____________
counter signer name **signature** **date**

Hard Hat Ceremony Statement of Ethics

1. I will hold paramount the safety, health and welfare of the public and the protection of the environment and will promote health and safety where I study, work and live.
2. I will keep myself informed in order to maintain my competence and I will strive to advance the body of knowledge that I practice within.
3. **I will conduct myself with integrity, fairness, courtesy and good faith towards others and give credit where it is due.**
4. I will be aware of, and make others aware of, the societal and environmental consequences of engineering actions or projects and I will endeavour to interpret engineering issues objectively and truthfully.
5. **I will conduct myself in an honourable and ethical manner and uphold and enhance the honour and dignity of the engineering profession.**

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