SAULT COLLEGE OF APPLIED ARTS & TECHNOLOGY

SAULT STE. MARIE, ONTARIO

COURSE OUTLINE

Course Title: ELECTRICAL MACHINES II

Code No.: ELR 232-6

Program: ELECTRICAL TECHNOLOGY

Semester: THREE

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New: ________ Revision: XX

APPROVED: L.P. Arozzitto
Chairperson

Date

ELECTRICAL MACHINES II	ELR 232-6
Course Name	Course Number

PHILOSOPHY/GOALS:

To provide a thorough understanding of the characteristics, operation and performance of DC and AC machines and transformers.

METHOD OF ASSESSMENT (GRADING METHOD):

1. Written tests will be conducted at regular intervals.

2. Grading:
   A - 80 - 100%
   B - 66 - 79%
   C - 55 - 65%
   R - less than 55%

3. 70% of course mark is based on theory tests, 30% of the course mark is on laboratory exercises.

TEXTBOOKS:

Rotating Machines and Transformers Technology by Richardson, Reston Publishers

Topics	Periods Theory	Lab	Description
1	2	0	DC Machine Construction a) mechanical b) armature windings c) commutation d) armature reaction e) armature reactance f) magnetic circuit
2	4	3	DC Generator Characteristics a) separately excited b) shunt excited c) series excited d) compound ~~e) paralleling~~
3	4	6	DC Motor Characteristics a) torque and power b) torque, development and measurement c) back emf, armature power, equilibrium motor speed d) shunt motor e) series motor f) compound motor g) motor starting requirements
4	2	3	Efficiency (DC Machines) a) types of losses b) relationship between fixed and variable losses c) loss tests d) temperature effects
5	6	6	DC Motor Control a) starting, stopping, reversing, speed an normal running requirements b) manual starters and controllers c) magnetic starters and controllers d) reversing techniques e) plugging f) dynamic braking g) regenerative braking h) speed control, armature and field contr
6	2	0	DC Machine Selection a) shaft power b) speed rating c) frame size d) speed classifications e) duty cycle f) ambient temperature g) voltage & current ratings h) enclosures

Topic	Periods Theory	Periods Lab	Description
7	8	3	Synchronous Machines a) Physical construction b) windings c) frequency-pole-speed relationship d) voltage, pitch factor, distribution factor e) regulation, lagging, unity and leading power factors f) synchronous impedance g) paralleling and parallel operation
8	8	6	Transformers a) functions and types b) construction c) ideal transformer, transformation ratios d) practical transformer e) equivalent circuits f) primary and secondary phasors g) regulation, unity, lagging and leading power factors h) open and short circuit tests i) efficiency j) single and three-phase winding connectio k) polarity and voltage tests l) autotransformer m) instrument transformers n) parallel operation
9	8	9	Polyphase Induction Motor a) construction, squirrel cage and wound rotor b) polyphase rotating magnetic field c) torque production d) slip e) tests, no-load, blocked rotor f) performance, rotor current and power, torque (maximum, starting and rated) g) NEMA classifications h) wound rotor characteristics i) speed control, pole changing, variable frequency, rotor resistance j) efficiency
10	4	3	Synchronous Motor a) construction b) starting c) power factor control d) Vee curves e) synchronous capacitor f) efficiency
11	4	3	Single Phase Motors a) starting methods

Topic	Periods Theory	Periods Lab	Description
			b) torque c) double revolving field d) rotor cross field e) resistance split-phase motors f) capacitor start g) capacitor start, capacitor run h) permanent split capacitor i) split phase motor characteristics j) efficiency k) shaded pole, synchronous, hysteresis, reluctance and universal motors
12	8	6	<u>AC Motor Control and Application</u> a) across-the-line starters b) reduced voltage starters c) reversing controllers d) wound rotor induction motor starters e) plugging, jogging, braking f) speed control, pole changing, two windings, variable frequency g) shaft power h) speed rating i) frame size j) speed classification k) duty cycle l) temperature m) voltage and current ratings n) enclosures

EVALUATION PROCEDURES

Course: ELR 232-6 Electrical Machines

1. Specific Objectives:

   Specific objectives (S.O.'s) will be assigned.

2. Tests:

   Approximately four (4) 1 hour tests will be given during the semester. Students will be advised at least one week in advance of a test. Quizzes may be given without notice.

3. Laboratory:

   Students will be subject to continuous evaluation in the laboratory, with emphasis on skill in the use of tools and test equipment, work habits, safety practices and co-operation.

   Each student shall maintain a laboratory logbook which will be available for marking weekly. Correct use of the English language and neatness will also be evaluated.

4. Grading:

   Grades will be assigned as follows:

A	80 - 100%
B	66 - 79%
C	55 - 65%

   The grading will be distributed as follows : 70% for theory, 30% for laboratory. To achieve an overall grade a passing grade in theory and laboratory must be achieved.

   Students with a final grade between 50 and 55% may at the discretion of the instructor sit a final three (3) hour examination covering the whole course, the maximum mark that can be achieved is 55%.

   Students with a grade less than 50% will be assigned an R.

ELECTRICAL MACHINES II

ELR 232-6

SPECIFIC OBJECTIVES

BLOCK I: DC Machine Construction

At the end of this block the student shall be able to:

1. recall and apply:

   a) Faraday's Law of Induction
   b) Fleming's Relationships
   c) Lenz's Law
   d) The generated voltage equation: $E = \frac{\Phi ZSP}{60a} \times 10^{-8}$ volts (E) or

   $$E = \frac{\phi ZwP}{2\pi a} \text{ volts (SI)}$$

   e) The force acting on a conductor is: $F = \frac{BIL}{1.13} \times 10^{-7}$ lbs. (E) or

   $$F = BI\ell \text{ newtons (SI)}$$

2. Recall and explain:

   a) the construction and function of the parts of a dc machine.

   b) the application and configurations of lap, wave and frog-log windings.

   c) the purpose of multielement and multiplex armature coils.

   d) Commutation, brush neutral.

   e) armature reaction and reduction methods.

   f) armature reactance and reduction methods.

   g) the requirements of the magnetic circuit.

BLOCK II: DC Generator Characteristics

At the end of this block the student shall be able to:

1. Recall and explain with the aid of schematics and/or graphs:

   a) the open circuit magnetization curve of a generator.
   b) the four factors affecting the build-up of voltage by a self excited generator.
   c) the connections of a shunt generator, and recall and be able to apply:

   $$I_a = I_f + I_\ell \quad \text{and} \quad V_a = V_f = V_t = E_g - I_aR_a$$

$$\text{Percent regulation} = \frac{E_g - V_t}{V_t} \times 100$$

d) The external characteristics of a shunt generator.
e) the connections of a series generator, and recall and be able to apply:

$$I_a = I_{SE} = I_\ell \quad \text{and}$$

$$V_t = E_g - I_a (R_a + R_{SE})$$

f) the external characteristic of a series generator.
g) the connections of a sompound generator, short and long shunt
h) the effects of cumulative, flat and differential compounding.
i) the external characteristic of compound generator configurations.
j) $I_{SE} = I_a + I_f = I_\ell$ (Short Shunt)

$I_{SE} = I_a = I_\ell + I_f$ (Long Shunt)

k) the need for parallel operation.
l) the requirements for paralleling.

BLOCK III: DC Motors

At the end of this block the student shall be able to:

1. Recall, explain and utilize as appropriate:

a) the relationship between torque and power and be able to apply:

$$hp = \frac{2\ FDS}{33{,}000} = \frac{TS}{5252.1} \quad (E)$$

or

$$kW = fdw \times 10^{-3} = tw \times 10^{-3} \quad (SI)$$

b) the torque produced by the armature is:

$$T = \frac{BI_a LZ(\%\ cov)D \times 10^{-7}}{1.13\ a} \quad \text{ft-lbs} \quad (E)$$

or

$$t = \frac{BI_a \ell Z(\%\ cov)d}{a} \quad \text{N-m} \quad (SI)$$

c) the prony brake method of torque measurement.
d) the production and effects of back emf and that:

$$V_a - E_c = I_a R_a \quad \text{and} \quad E_c I_a = V_a I_a - I_a^2 R_a$$

e) that the developed armature power is:

$$E_c I_a = P_d$$

f) that

$$E_c = K\Phi S \quad (E)$$

$$E_c = k\phi w \quad (SI)$$

$$S = \frac{V_a - I_aR_a}{K\Phi} \qquad (E)$$

or

$$w = \frac{V_a - I_aR_a}{k\phi}$$

f) the connections, speed and torque versus output characteristics of a shunt motor, and:

$$T = C\Phi I_a \qquad (E)$$

or

$$t - c\phi I_a \qquad (SI)$$

and percent speed regulation is:

$$\frac{S_{n\ell} - S_{f\ell}}{S_{f\ell}} \times 100 \qquad (E)$$

or

$$\frac{w_{n\ell} - w_{f\ell}}{w_{f\ell}} \times 100 \qquad (SI)$$

g) the connections, speed and torque versus output characteristics of a series motor, and:

$$S = \frac{V_a - I_a\ (R_a + R_{SE})}{KK^1I_a} \qquad (E)$$

or

$$w = \frac{V_a - I_a\ (R_a + R_{SE})}{kk^1I_a} \qquad (SI)$$

and

$$T = C\Phi I_a = CC^1I_a{}^2 \qquad (E)$$

$$t = c\phi I_a = cc^1I_a{}^2 \qquad (SI)$$

h) the connections, speed and torque versus output characteristics of cumulatively and differentially compounded motors, and:

$$S = \frac{V_a - I_a\ (R_a + R_{SE})}{K\Phi_{sh} \pm KK^1I_a} \qquad (E)$$

($\pm$ cumulative differential)

or

$$w = \frac{V_a - I_a\ (R_a + R_{SE})}{k\phi_{sh} \pm kk^1I_a} \qquad (SI)$$

and $$T = C\phi_{sh} I_a \pm CC^1 I_a^2 \quad \text{(E)}$$

$$t = c\phi_{sh} I_a \pm cc^1 I_a^2 \begin{cases} + \text{ cumulative} \\ - \text{ differential} \end{cases} \quad \text{(SI)}$$

i) the requirements and reasons for reduced voltage starting and be able to calculate required starting resistances.

j) the requirements and methods of reversing dc motors.

BLOCK IV: Efficiency of DC Machines

At the end of this block the student shall be able to:

1. Recall, explain and utilize as appropriate:

   a) the basic efficiency relationships:

$$\eta = \frac{\text{output}}{\text{input}} \times 100\%$$

$$= \frac{\text{input} - \Sigma \text{ losses}}{\text{input}} \times 100\%$$

$$= \frac{\text{output}}{\text{output} + \Sigma \text{ losses}} \times 100\%$$

   b) the distribution of losses in dc generators and motors and calculate efficiencies from observed data.

BLOCK V: DC Motor Control

At the end of this block the student shall be able to:

1. Recall, explain, connect and trouble-shoot with the aid of schematic diagrams, as appropriate.

   a) the starting, stopping, reversing, normal running, speed control, and safety requirements of dc motors.

   b) three-point and four-point namual faceplate starters.

   c) the comparative advantages and disadvantages of automatic versus manual starters.

   d) definite time acceleration starters, with:
      1) time-delay relays
      2) time-delay contactors
      3) timed to open relays
      4) mechanical timing

   e) current limit acceleration starters, with:
      1) counter emf relays
      2) holding coil relays
      3) series relays
      4) holding coil and voltage drop starters

f) reversing control, plugging reverse control.
g) retardation, dynamic and regènerative braking
h) stopping, electric brakes
i) jogging
j) the four methods of dc motor speed control:
   1) field control
   2) armature resistance control
   3) series and shunt armature resistance control
   4) armature voltage control

BLOCK VI: DC Machine Selection

At the end of this block the student shall be able to:

1. Recall and explain the following factors used in motor application:

   a) shaft power in or out in hp or kW
   b) driven load characteristics
   c) speed rating
   d) frame size
   e) speed classifications
   f) duty cycle and compute rms hp
   g) ambient temperature effects
   h) allowable temperature vise
   i) voltage and current ratings
   j) enclosure types
   k) maintenance factors

BLOCK VII: Synchronous Generators

At the end of this block the student shall be able to:

1. Recall and explain with the aid of sketches as appropriate:

   a) the reasons for and the physical construction of salient pole and cylindrical rotor attenuators.

   b) attenuator windings, chording, coil group connections and winding distributior

   c) the pole-speed-frequency relations:

$$f = \frac{PS}{120} \text{ Hz} \qquad \text{(E)}$$

$$f = \frac{Pw}{4\pi} \text{ Hz} \qquad \text{(SI)}$$

   d) the basic generated voltage is:

$$E_{AV/PP} = 4\Phi Nnf \times 10^{-8} \text{ volts} \qquad \text{(E)}$$

$$= 4\phi Nnf \text{ volts} \qquad \text{(SI)}$$

   e) the pitch factor is kp - sin (p/2) and the distribution factor is:

$$k_d = \frac{\sin(n\alpha/2)}{n \sin(\alpha/2)}$$

   and that the complete pole-phase group voltage is:

$$Egpp = 4.44\Phi Nnf \text{ kp kd} \times 10^{-8} \text{volts} \qquad \text{(E)}$$
$$= 4.44\phi Nnf \text{ kp kd volts} \qquad \text{(SI)}$$

f) the effects of load power factor upon the terminal voltage.

g) the percent voltage regulation is:

$$\frac{E_{gp} - V_p}{V_p} \times 100$$

where
$$E_{gp} = \sqrt{(V_p + I_aR_a)^2 + (I_aX_s)^2}$$
$$= (V_p + I_aR_a) + {}_fI_aX_s$$
V.P.F.

$$= \sqrt{(V_p \cos\theta + I_aR_a)^2 + (V_p \sin\theta + I_aX_s)^2}$$
$$= (V_p \cos\theta + I_aR_a) + {}_f(V_p \sin\theta + I_aX_s)$$
Lagging P.F.

$$= \sqrt{(V_p \cos\theta + I_aR_a)^2 + (V_p \sin\theta - I_aX_s)^2}$$
$$= (V_p \cos\theta + I_aR_a) + {}_f(V_p \sin\theta - I_aX_s)$$
Leading P.F.

h) how to measure per phase resistance and synchronous impedance.

i) the reasons and advantages of paralleling attenuators.

j) the requirements for parallel operation and synchronizing procedures.

k) Phase sequence matching by:
1) dark lamp method
2) bright lamp method
3) two bright, one dark method
4) synchroscope

BLOCK VIII: Transformers

At the end of this block the student shall be able to:

1. Recall, explain and utilize as appropriate:

a) the physical construction of power and distribution transformers and discuss the relative merits of core and shell type transformers.

b) with the aid of phasor diagrams the principle of operation of the ideal transformer.

c) calculations involving the transformation ratio: $\alpha = \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$

d) the general voltage equation of the ideal transformer is:

$$E = 4.44\ f\ \Phi\sin\ N \times 10^{-8}\text{volts} \qquad (E)$$

$$= 4.44\ f\ \phi\sin\ N\ \text{volts} \qquad (SI)$$

e) with the aid of phasors, describe the operation of a loaded transformer and carry out the necessary calculati[illegible]s.

f) use reflected impedances and equivalent circuits to calculate performance under varying power factor load conditions.

g) the procedures for open and short circuit testing and use the observed data to determine losses, voltage drops, regulation and efficiency.

h) typical distribution transformer connections.

i) how to identify coils and carry out polarity and voltage tests.

j) the three principle types of autotransformers and that the power transferred is:

$$P_{tr} = P_1(1 - \frac{1}{\alpha})$$

and $$P_{con} = P_2 - P_{tr}$$

and the applications and disadvantages of autotransformers.

k) the function and precautions that must be exercised in using instrument transformers.

l) the requirements for parallel operation of transformers.

m) the relative advantages and requirements of using single-phase transformers in 3-phase applications.

n) the standard three-phase transformer connections, namely:
1) Wye-Wye
2) Delta-Delta
3) Wye-Delta
4) Delta-Wye
5) Open delta
6) Scott Tee

BLOCK IX: Polyphase Induction Motors

At the end of this block the student shall be able to:

1. Recall, explain and utilize as appropriate:

a) the physical construction of the squirrel cage induction motor (scim) and the wound rotor induction motor (wrim).

b) the production of a rotating magnetic field.

c) the production of torque and be able to apply:

$$S = \frac{20f}{P} \text{ rpm} \qquad \text{(E)}$$

or $$w = \frac{4\pi f}{P} \text{ rads/sec.} \qquad \text{(SI)}$$

$$o = \frac{\text{synchronous speed - rotor speed}}{\text{synchronous speed}}$$

$$= \frac{S-S_r}{S} \times 100\% \qquad \text{(E)}$$

or $$= \frac{w-w_r}{w} \times 100\% \qquad \text{(SI)}$$

and $$S_r = S(1-s) = (\frac{120f}{P})(1-s) \qquad \text{(E)}$$

or $$w_r = w(1-s) = (\frac{4\pi f}{P})(1-s) \qquad \text{(SI)}$$

and $$fr = of$$

d) to be able to carry out on wrims and scims, no-load. blocked rotor, stator resistance and load tests and use the results to determine the machine performance in terms of starting torque, maximum torque and efficiency.

e) NEMA speed-torque characteristics of scims and their application to varying load requirements.

f) the four major advantages of a wrim using external rotor resistance.

g) the three principle methods of speed control of scims.

BLOCK X: Synchronous Motor

At the end of this block the student shall be able to:

1. Recall, explain and utilize as appropriate:

a) the construction of synchronous motors
b) the production of torque
c) the methods of starting synchronous motors.
d) the use of a synchronous motor as a variable power factor source.
e) the relationships between armature current and power factor versus field current
f) how to obtain V-curves and determine motor efficiency by testing and carry out calculations involving these results.
g) the operating characteristic curves.

BLOCK XI: Single Phase Motors

At the end of this block the student shall be able to:

1. Recall and explain with the aid of schematics and phasors as approp[illegible]:

a) the reasons why single-phase induction motors are not self-starting.
b) the production of starting torque and running torque in terms of the double revolving field and rotor cross field theories.
c) the operating principles, connections, characteristics and reversing connectio[illegible] of the following single-phase induction motors
   1) resistance split-phase motor[illegible]
   2) capacitor start motors
   3) capacitor start, capacitor r[illegible] motors
   4) permanent split capacitor mo[illegible]
d) the testing methods to determine single-phase motor efficiencies.
e) the operating principles, connections, characteristics and reversing connections of the following single-phase motors:
   1) shaded pole
   2) reluctance-start
   3) reluctance synchronous
   4) hysteresis synchronous
   5) subsynchronous
   6) universal

BLOCK XII: AC Motor Starting and Control

At the end of this block the student shall be able to:

1. Recall, explain and trouble-shoot with the aid of schematics the following types of polyphase motor controls:

a) reversing and non-reversing full voltage starters.

b) reversing and non-reversing reduced voltage starter types: 1) line resistance
2) line reactance
3) auto transformer
4) Wye-Delta
5) wound rotor

c) the use of plugging, jogging, retarding and stopping techniques.

d) speed control methods: 1) consequent pole (constant torque, constant horse power and variable torque)
2) two winding stators
3) variable frequency

e) the factors affecting ac motor selection: 1) shaft power
2) speed rating
3) frame size
4) speed classification
5) duty cycle
6) temperature effects
7) voltage and current ratings
8) enclosures