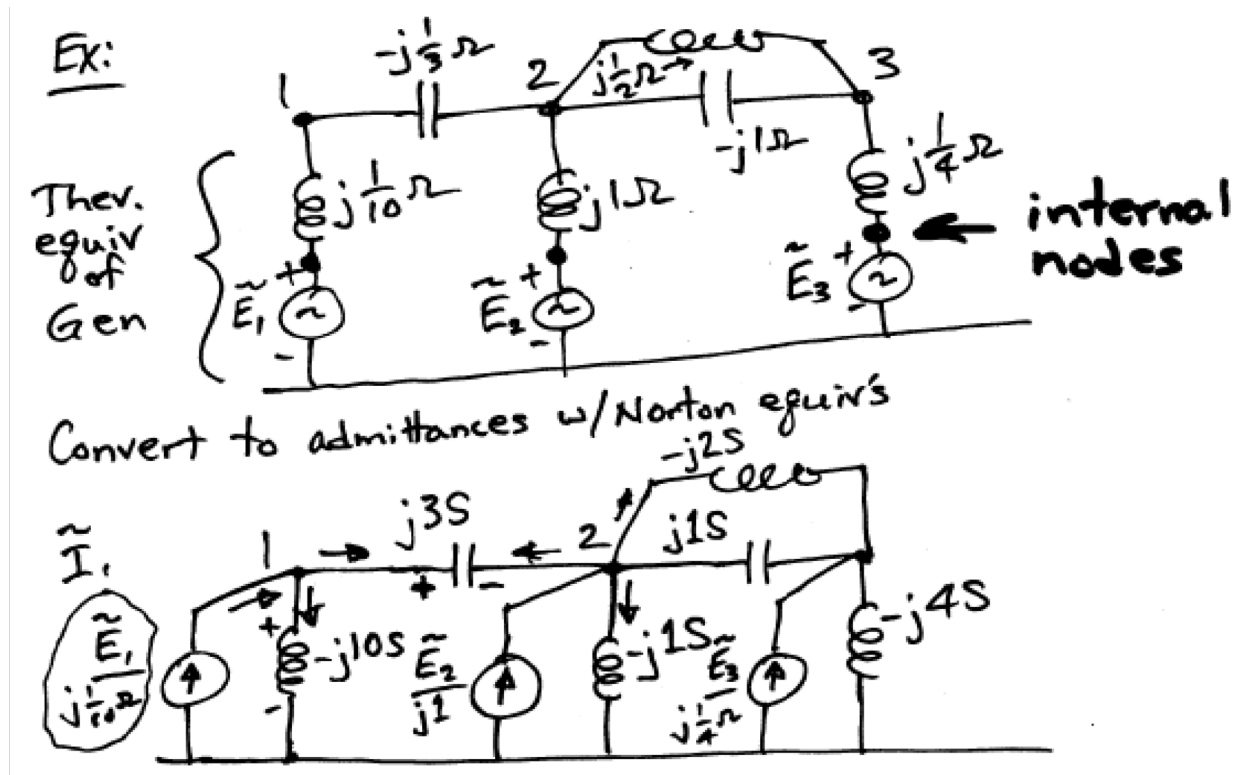


Objectives: Familiarization with most basic MatLab usage: entering complex numbers, matrix operations used to solve node equations, admittance and impedance matrices, plotting a simple waveform, etc.

Getting started: If you have not already, go thru the Matlab video tutorials posted on the EE5200 web page. From inside the Matlab program, you can also access tutorials by pressing F1 for Help, and then clicking on "Getting Started." Do this assignment with the goal of developing basic skills and making useful notes that you yourself will continue to refer back to. Hint to save a lot of time: make generous use of the e-mail forum to ask for and share ideas on even the most basic issue.

- 1) Referring to the circuit below, assume $E_1 = 120/0^\circ$ V, $E_2 = 100/-20^\circ$ V, and $E_3 = 120/30^\circ$ V.
 - a) form $[Y]$ and enter the matrix into matlab (entries are complex numbers!),
 - b) use MatLab to solve the matrix equation $[Y][V] = [I_{in}]$ for the 3 node voltages.
 - c) confirm your solution is correct - confirm KCL at node 2.
 - d) invert $[Y_{bus}]$ to get $[Z_{bus}]$.



- 2) A graphing (use Matlab "plot" function) exercise. In this case, save and execute your program as an .m file. Let's investigate the well-known L-L fault current which includes a dc offset due to X/R ratio and fault inception angle. Given the pos and neg sequence impedances and pre-fault voltage, calculate the induced force (as a function of time) between the 2 bus bars at a spacing of d meters and with span length L between supporting station post insulators. [Refer to IEEE Std. 605-2008, Section 11.3.1, for short circuit forces.]

Write a for-loop which fills 3 storage vectors with the values of current $I(1..3334)$ and the corresponding time values $t(1..3334)$ for $\Delta t = 100\mu s$, for plotting of 20 cycles at 60-Hz. Plot the waveforms. Investigate the sensitivities by producing several cases with varying values of X, R, and inception angles.

Prob 2
(Hmwk#3)

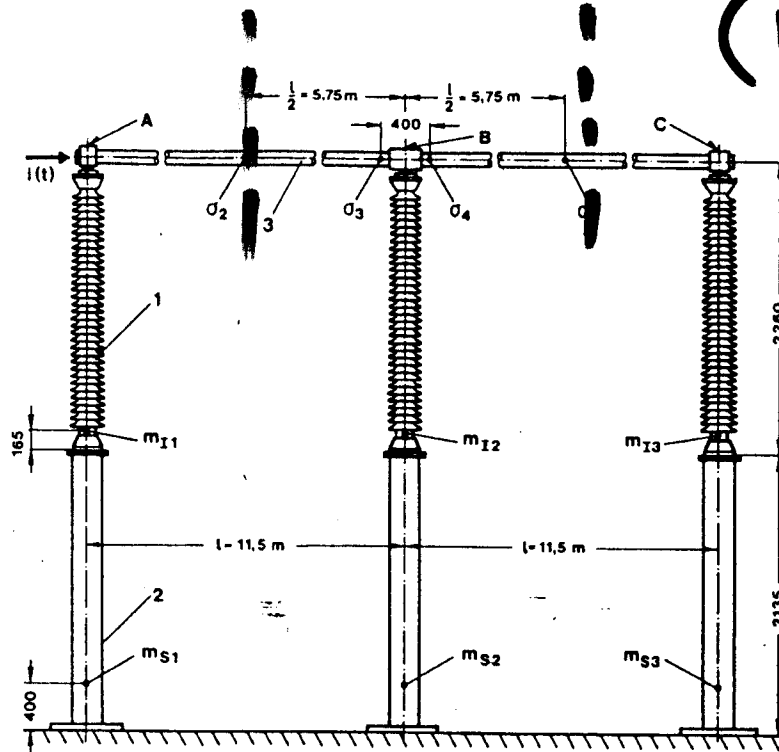


Figure F.1—CIGRE structure D (from Hosemann and Tsanakas [B14])

The structural data used in calculations is presented in Table F.1. The fault parameters are presented in Table F.2.

Table F.1—Structural data

Characteristic	Conductor	Insulator	Support
Length L	span of 11.5 m (including portion in conductor clamps)	2.10 m	2.135 m
Material	Aluminum	Porcelain	Steel
Young's modulus E	70 GPa	30.6 GPa	206 GPa
Area A	2.238E-3 m ²	36.14E-3 m ²	4.714E-3 m ²
Moment of inertia I	3.704E-6 m ⁴	76.08E-6 m ⁴	26.83E-6 m ⁴
Mass	6.04 kg/m	180 kg	36.8 kg/m

NOTE 1—In the finite-element model, the insulator length was extended to 2.26 m in order to reach the midconductor position.

NOTE 2—For the insulator and support, the moment of inertia used was obtained from measurements on equivalent spring stiffness ($3EI/L^3$) as provided in Hosemann and Tsanakas [B14]; this is why in Table F.1 the values given do not necessarily correspond to the actual dimensions.

NOTE 3—The bending stiffness for the insulator is assumed constant along its length to correspond to an equivalent beam of constant section although its shape is conical.

NOTE 4—In the finite-element model, lumped masses of 13.8 kg, 18.2 kg, and 13.8 kg have been added at the top of columns 1, 2, and 3, respectively, to account for actual clamp masses. Lumped masses of 36.8 kg have been added to the top of each steel support to account for mass of top plate.

NOTE 5—Conductor is assumed to be pinned at top of columns 1 and 3 and fixed at top of column 2.

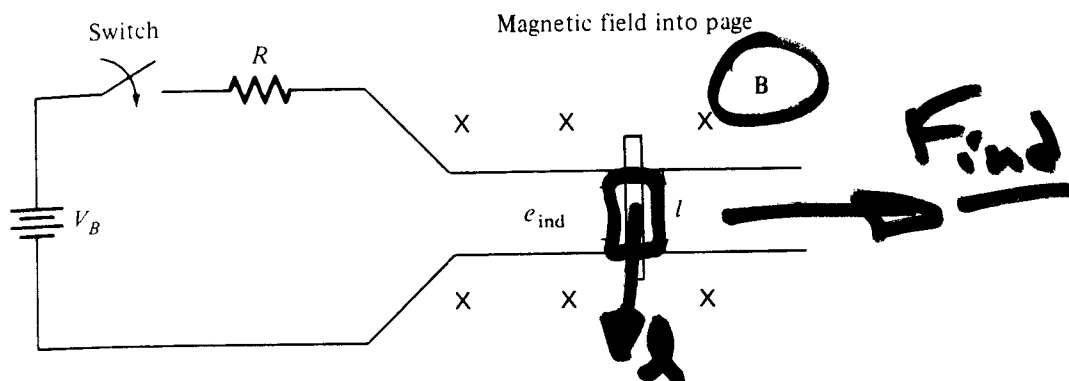


FIGURE 4-1

A linear dc machine. The magnetic field points into the page.

1. The equation for the force on a wire in the presence of a magnetic field:

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B})$$

(1-43)

where \mathbf{F} = force on wire

i = current flowing in wire

\mathbf{l} = length of wire, with direction of \mathbf{l} in the direction of current flow

\mathbf{B} = magnetic flux density vector

2. The equation for the voltage induced in a wire moving in a magnetic field:

$$e_{\text{ind}} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l}$$

(1-45)

where e_{ind} = voltage induced in wire

\mathbf{v} = velocity of wire

\mathbf{B} = magnetic flux density vector

\mathbf{l} = length of conductor in magnetic field

3. Kirchhoff's voltage law for this machine. From Fig. 4-1 this law gives

$$V_B - iR - e_{\text{ind}} = 0$$

$$V_B = e_{\text{ind}} + iR$$

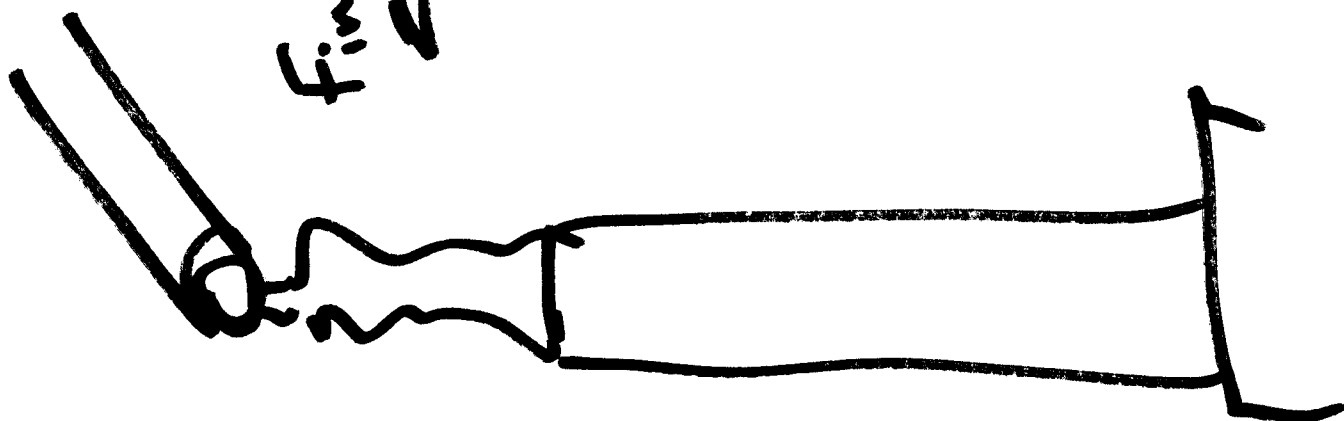
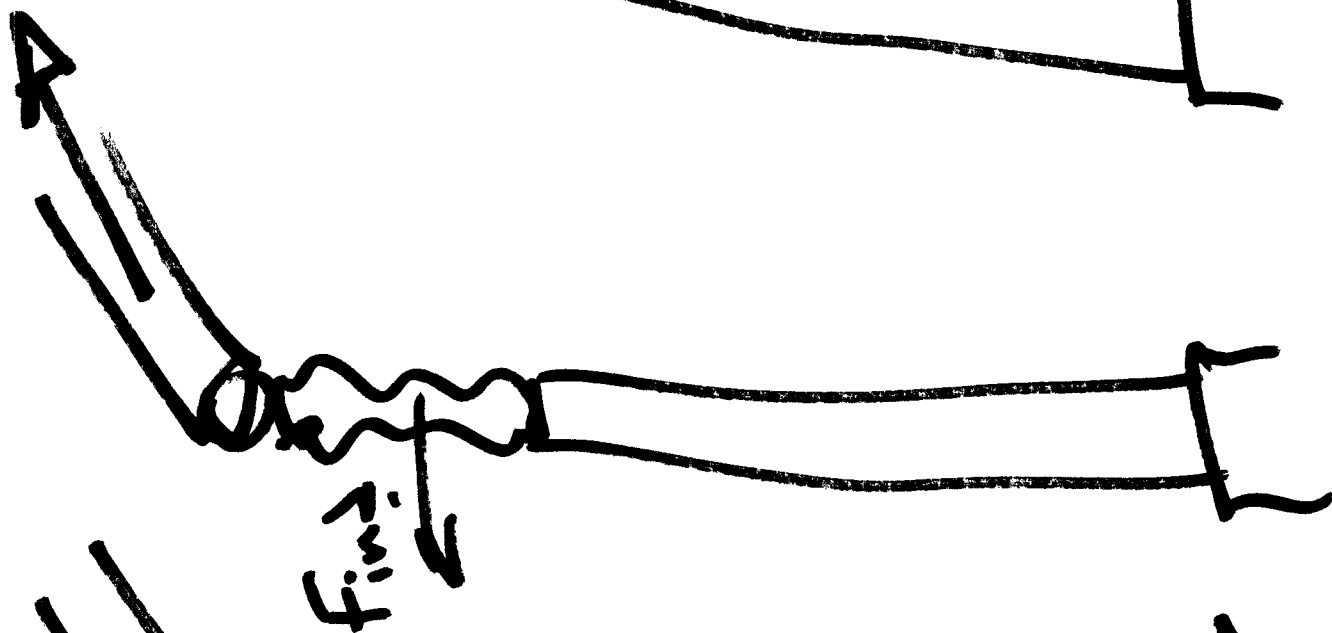
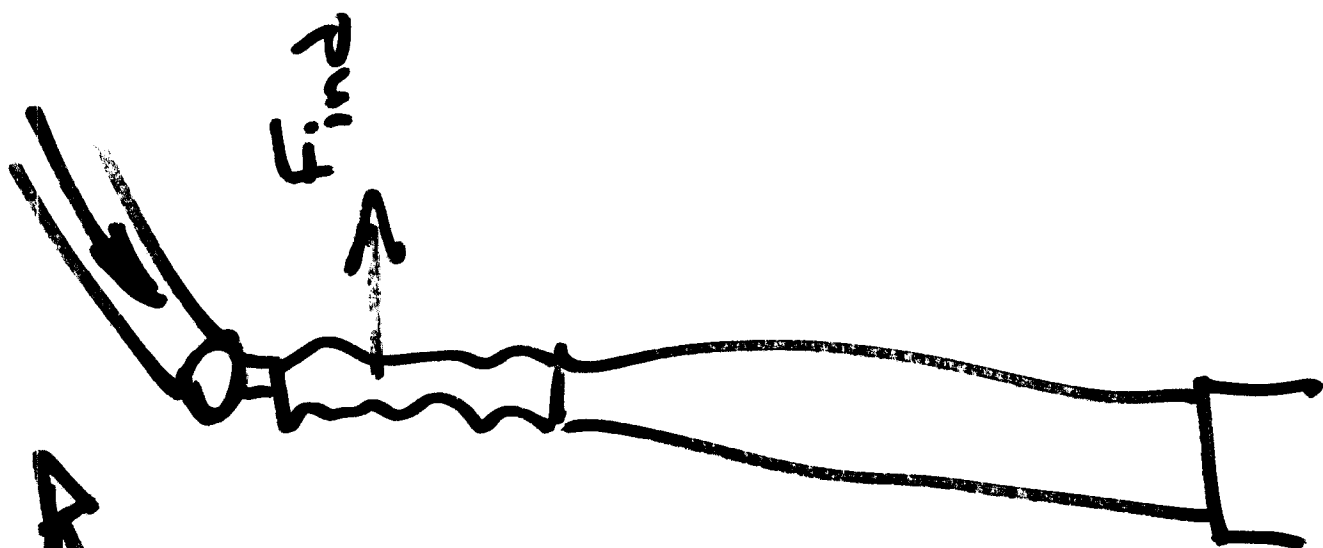
(4-1)

4. Newton's law for the bar across the tracks:

$$F_{\text{net}} = ma$$

(1-7)

The fundamental behavior of this simple dc machine will now be explored by using these four equations as tools.



The flow of high levels of current generates forces on the current carrying conductors. The basic physical law is expressed with the *Biot-Savart* equation as below, which is explained with the aid of Figure 19. The figure shows two segments of conductors of lengths d_1 and d_2 , respectively and carrying electric current i_1 and i_2 , respectively. The force that will act on each one of these two segments is as follows:

$$F(t) = \frac{\mu}{4\pi r^2} i_1(t) i_2(t) [d_1 \otimes (u_r \otimes d_2)] \quad (13)$$

where

μ	is the magnetic permeability equal to $4\pi \times 10^{-7}$ V-s/(A-m)
r	is the distance between the two conductor segments
u_r	is the unit directional vector in the direction r
d_1	is a vector of length d_1 in the direction of the current flow in conductor segment 1
d_2	is a vector of length d_2 in the direction of the current flow in conductor segment 2

NOTE—The symbol \otimes is the vectorial cross product.

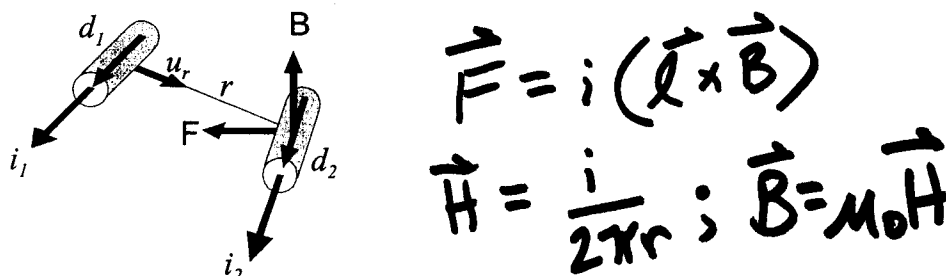


Figure 19—Illustration of two conductor segments carrying electric current

In the case of two parallel conductor segments, the cross products simply become the product of the conductor segment lengths and the force is along the line between the two segment centers, either attracting the two conductor segments or repelling them depending on the direction of the current.

This physical law is applicable to rigid bus structures as well as flexible bus structures. In the case of a rigid bus, the geometry of the bus remains practically invariant as the displacements tend to be very small. In the case of a flexible bus, the geometry of the bus varies as the forces from the fault current move the conductors around. As the distances between conductors change, so do the forces from the currents.

11.3.2 Maximum fault condition parameters

In the design process, one must consider the worst possible scenario. In terms of forces from fault currents, the fault initiation instance with respect to the source waveform is very important. Depending on the type of fault considered (phase to phase or three phased), appropriate electrical parameters need to be fixed in numerical calculations as to generate maximum fault conditions for design. The voltage angle at the initiation of fault is random in nature and should thus be fixed to:

- 0 for phase-to-phase fault for any conductor geometry