Math Applications in Electric Energy Conversion Courses Using Matlab™

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Abstract
Electrical machines and energy conversion are subjects that require a great deal of mathematical analysis. Historically math calculations have been done using slide rules, tables and/or calculators. Now with the easy access to laptops and cheap PCs must of our students are able to use mathematical packages to deal with the tedious and sometimes difficult mathematical problems. This paper attempts to demonstrate mathematical applications in our Energy Conversion and Electrical Machines course and the use of Matlab™ as a complementary tool for analysis and simulation.

Energy Conversion
Energy conversion and electrical machines have evolved into a great deal of computer simulation. Several different programs are being used in teaching this material. Matlab is the mathematical software package of choice at California State University Northridge department of electrical and computer engineering. Our students do not usually have formal training in the use of Matlab, but they do have to have a higher level programming experience before taking the energy conversion course. This helps in the understanding of the basics of Matlab. In an attempt to bring all of the students, enrolled in the energy conversion course, to the same level we offer online (Webpage) mini-tutorials dealing with fundamental concepts. This is a dynamic process and continues expanding every time the course is being offered (usually once a year). These tutorials are basically about formatting input and output data.

We believe that by knowing some data structures, algorithm creation and flow chart creation, our students can pick up any software package (knowledge acquired at the freshman level). By the way this is the same experience that our students will have in the real world.

About the Tutorials
We use our webpage to disseminate tutorial information. This process made the use of the tutorials very easy since most of the students prefer to work late at night and have access to the internet.

Some of the tutorials that were created for this class are indicated below.
Highlighted in yellow you may find the purpose of each tutorial

```
%TUTORIAL 1
% Energy tutorial
% angles are always input in radians
x=45*pi/180
y=cosx
v=sinx
```

```
%TUTORIAL 2
% Energy tutorial
% angles are always input in radians
% creating a complex number
x=80*pi/180
y=cos(x)
v=sin(x)
Z=10*y+i*10*v
```

```
%TUTORIAL 3
% Energy tutorial
% angles are always input in radians
% Using a list
t=0:10:360;
x=t*pi/180;
y=cos(x);
v=sin(x);
Z=10*y+i*10*v
```

```
%TUTORIAL 4
% Energy tutorial
% angles are always input in radians
% for-end loop
for j=1:36
        x=(j*10)*pi/180;
        y=cos(x);
        v=sin(x);
Z=10*x+i*10*v
End
```

```
%TUTORIAL 5
% Energy tutorial
% angles are always input in radians
% for-end loop and vector format
for j=1:180
        x(j)=j*pi/180;
        y(j)=cos(x(j));
        v(j)=sin(x(j));
        Z(j)=10*x(j)+i*10*v(j)
end
```

```
%TUTORIAL 6
% Energy tutorial
% angles are always input in radians
% for-end loop, vector form and
%output format
clc
clear
for j=1:16
        x(j)=(j*10)*pi/180;
        y(j)=cos(x(j));
        v(j)=sin(x(j));
        z(j)=10*x(j)+i*10*v(j);
end
%
% to format the output in matrix form
% we need to initiate a zero matrix
with
% the same size as the one we want
%
v=[0,0,0,0;0,0,0,0;0,0,0,0];
%
k=0;
for n=1:4;
        for m=1:4;
                v(n,m)=z(k+m);
        end
k=4;
end
```

```
%TUTORIAL 7
% Energy tutorial
% Angles are always input in radians
% For-end loop. Formatting the
%output
%Plotting
for j=1:16
        x(j)=(j*10)*pi/180;
        y(j)=cos(x(j));
        v(j)=sin(x(j));
        z(j)=10*x(j)+i*10*v(j);
end
% to format the output in matrix form
%we  need to initiate a zero matrix
%with the same size as the one we
%want .
%
v=[0,0,0,0;0,0,0,0;0,0,0,0];
%
k=0;
for n=1:4;
        for m=1:4;
                v(n,m)=z(k+m);
        end
k=4;
end
v
plot(real(z), imag(z))
```

```
%TUTORIAL 8
% Energy tutorial
% Creating a vector
clc
clear
for k=1:25;
        Poc(k)=133;
% this equality works only with a
%“real value” on the rhs (not a
%variable)
end
disp(poc’)
% Displays the vector
```

```
%TUTORIAL 9
% Energy tutorial
% Table form (formatted output)
% CAUTION: "fprintf" works only with
%real numbers
clc
clear
for k=1:25;
        Poc(k)=133;

% this equality works only with a
%”real value" on the  rhs (not a
%variable)
end
out=[ Poc'];
% “out” this is a vector used to
% create a formatted output
for m=1:25;
   fprintf (' %8.4f\n',out);
% formatted output use "fprintf"
end
```

```
%TUTORIAL 10
%Energy tutorial
% Table form (formatted output)
% CAUTION: "fprintf" works only
% with real numbers
% making it look better
clc
clear
for k=1:25;
        Poc(k)=133;
%this equality works only with a
%"real value" on the rhs (not a
%variable)
end
%
%title of the table
%
fprintf ('table of Poc\n\n');

%
%Column Headings
fprintf('Open circuit losses\n');
fprintf('+++++++++\n');
```

```
%
out=[ Poc'];
%this is a vector used to
%create a formatted output
fprintf (' %8.4f\n',out);
%formatted output use "fprintf"


%TUTORIAL 11
%Energy tutorial
%Table form (formatted output)
%Multiple plots on same axis
clc
clear
for k=1:25;
        Poc(k)=133;
%this equality works only with a
% " real value" on the rhs (not a
variable)
end
%
%title of the table
%
fprintf ('table of Poc\n\n');

%
%Column Headings
fprintf('Open circuit losses\n');
fprintf('+++++++++\n');
%
out=[ Poc'];
%this is a vector used to create a
%formatted output
fprintf (' %8.4f\n',out);
 %formatted output use "fprintf"
for j=1:25;
        y(j)=2*j;
        x(j)=j;
end
plot(x, y,'b-');
hold on;
plot (x, Poc,'-ko');
hold off;
legend ('2 to the 25th power','Open
circuit losses')
```

Project

Shown below is one of the many projects given to our students. This project is about the analysis of magnetic materials using a M-13 sample. This project consisted of using Matlab for a half Symmetric 60-Hz Hysteresis Loop of specific magnetic Steel. The Matlab software will do the following:

1. Plot the data
2. Calculate the area of the Hysteresis Loop in Joules
3. Find the corresponding 60-Hz core loss in Watts/Kg of the Hysteresis Loop.

Theory

$$Area_{HYS} = \int H * dB$$

$$Coreloss = \frac{AreaHys * Freq}{Density}$$

$$Density = 7.65 \times 10^3 \, g / cm^3$$
$$frequency = 60 Hz$$

Results
The following table is given and it is used to plot the Hysteresis Loop.

B,T	0	0.2	0.4	0.6	0.7	0.8	0.9	1.0	0.95	0.9	0.8	0.7	0.6	0.4	0.2	0
H,A*turns/m	48	52	58	73	85	103	135	193	80	42	2	-18	-29	-40	-45	-48

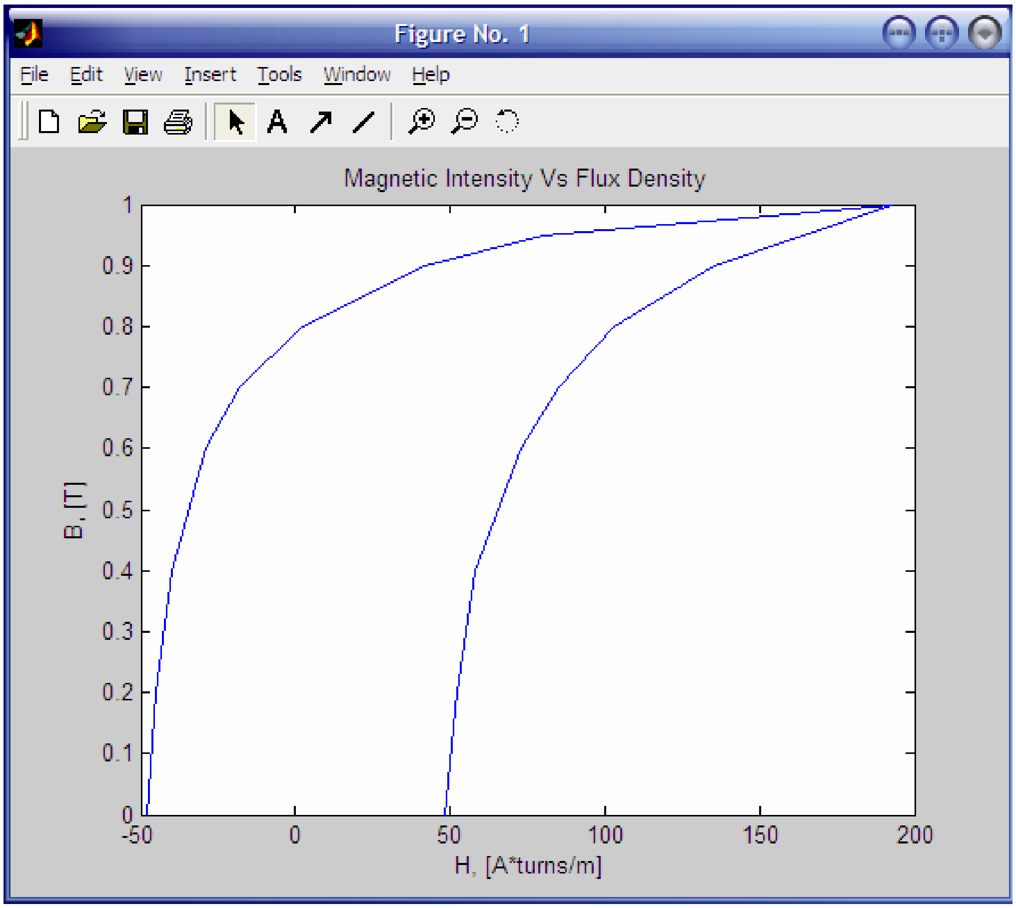
Matlab Script:

```
% Project (Magnetic Material)
% Flux Density Vs Magnetic field Intensity (data given)
%
        B=[0,0.2,0.4,0.6,0.7,0.8,0.9,1.0,0.95,0.9,0.8,0.7,0.6,0.4,0.2,0];
        H=[48,52,58,73,85,103,135,193,80,42,2,-18,-29,-40,-45,-48];
%
% Plot of H vs B
%
                plot(H,B)
                ylabel('B, [T]')
                xlabel(' H, [A-t/m]')
%
% Matlab function used to integrate (trapezoidal method).
                W=-2*trapz(H,B)            %[Joules]
% frequency in HZ
                f=60;
% Density in g/cm^3
                D=7.65e3;
% Core Loss
Pc=W*f/D                    %Watts/Kg
```

<u>Output</u>

```
W =
  190.9500
Pc =
 1.4976
```

Hysterisis Loop (Matlab Output)

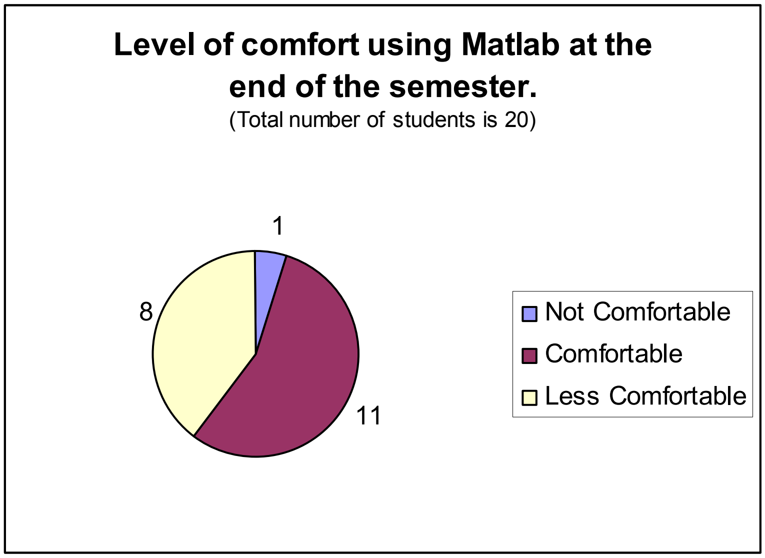


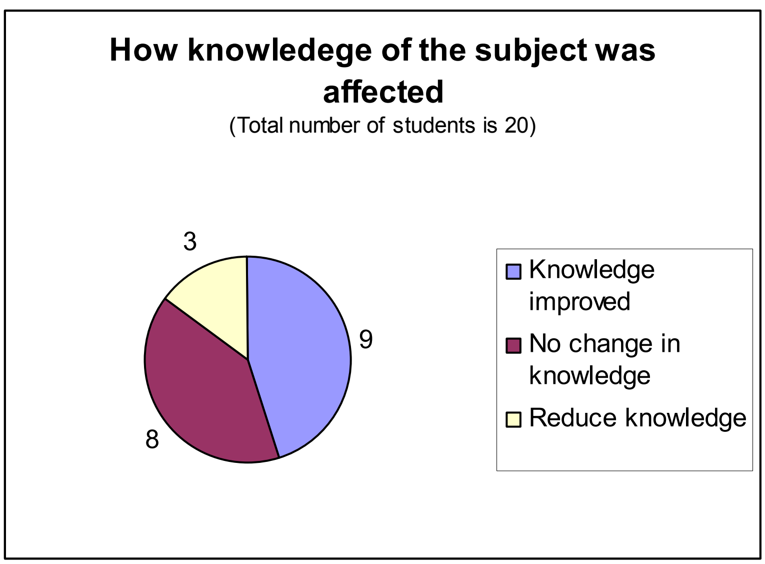
Assessment

We gave a survey form to each of our students and we found out a few interesting answers. In the energy conversion class we had 20 senior level students, 16 of them did not have programming knowledge of Matlab. However, 12 did have working knowledge of Matlab. 20 of them had taken a higher programming class at the freshman level (at least three years ago and it was mostly "C").

The first experience programming in Matlab was the writing of a program to perform complex number operations. The time used to do this assignment was about a week. Further assignments required less time in the programming process and more time in the design and solving process.

Out of the 20 students 11 felt comfortable, 8 less comfortable and 1 not comfortable at all with the skills learned using Matlab. 9 Students felt that their knowledge of the subject was improved by the use of a simulation package. 8 students felt that the knowledge of the subject did not change and 3 felt that their knowledge was reduced (too much time figuring out Matlab).





Survey

CALIFORNIA STATE UNIVERSITY NORTHRIDGE
Department of Electrical and Computer Engineering

SURVEY

This is a survey to obtain information about the course in order to improve it and make adequate changes. Your help in filling out this form is greatly appreciated

Rank from 0 to 10 the following questions. 0 is the lowest and 10 is the highest.

QUESTION	Please type from 0 to 10
Did you know Matlab before you took this class?	
Have you taken a higher programming language class before?	
How comfortable are you with the skills learned using Matlab?	
How was your knowledge of the subject affected by using Matlab?	
Do you feel prepared to learn new software packages on your own?	
Are you more aware of the consequences of programming in our society?	
Was this course what you expected it to be?	
Would you recommend this course to other students?	
Was the pace of the course adequate?	
Were the textbooks helpful?	
Was the homework adequate?	
Were the projects in tune with the course?	
Has your grade improved by using a simulation/programming package?	
In one or two sentences indicate other comments.	

Conclusions

It was determined that our students benefited in the learning process by using Matlab. They, also, developed a new skill to analyze design and solve energy and electrical machines problems. Also it was observed that the manipulation of higher mathematics using a software package further improved the learning process and made our students more marketable. The ultimate experience was the development of a new skill, which was the self learning of new tools used in problem solving.

As a further benefit from the learning of this new tool was the fact that we will use Matlab extensively in the next upper division courses, Power Systems and Power Electronics.

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