

**INNOVATIVE (new teaching technique) COMPUTER
SIMULATION OF ROTATING MAGNETIC FIELDS IN THREE-
PHASE INDUCTION MOTORS USING MATLABTM
ANIMATION.**

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Abstract

Rotating magnetic fields in three-phase electrical machines has been one of the hardest topics to convey to our students in the area of energy conversion, because these fields are transformed into phasors that rotate in space around the stator of the electrical machine. Also, the mathematical proof of such rotation can be done quite elegantly, but the mathematics of it and the assumptions made tend to cloud the clarity of the concept. Classic textbooks approach this concept in a mathematical way and usually is left to the students to imagine the space phasor rotation. This is no longer the case, now we can simulate it and *SEE IT* in our desktop computers using MatlabTM.

Polyphase Analysis

Three phase induction machines are the work-horse of industry and these machines have what is called the “rotating magnetic field”. We consider a sequence a-b-c and a symmetric distribution of the phases by 120⁰ electrical degrees each in space and around the air gap. The basic three-phase machine will have three coils, a coil per phase, that have the following terminals:

a a' b b' c c'

These coils are excited by a time dependent sinusoidal alternating current producing a sinusoidal magnetomotive force (mmf) wave at the center of the magnetic axis of a particular phase. Therefore the three-space sinusoidal mmf waves are displaced 120⁰ electrical degrees in space. Notice that the coils are placed physically in the stator of the machine.

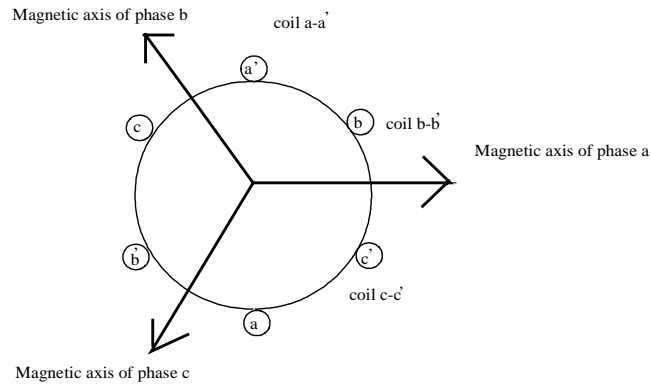


Figure 1 shows the location of these coils in space.

For balanced conditions the instantaneous currents are:

$$I_a = I_m \cos \omega t \quad (1)$$

$$I_b = I_m \cos (\omega t - 120^\circ) \quad (2)$$

$$I_c = I_m \cos (\omega t - 240^\circ) \quad (3)$$

Where I_m is the maximum value of current. Phase "a" has the following mmf.

$$F_a(\theta) = F_m \cos \theta \quad (4)$$

Since $F_m = NI$ and it is the maximum mmf value of phase "a", then: $F_a(\theta) = NI_a \cos \theta$. Where N is the number of turns in phase "a" winding. I_a is the instantaneous value of the current in phase "a" winding as well. Similarly the mmf contributions from phase "b" and phase "c" are:

$$F_b(\theta) = F_m \cos (\theta - 120^\circ) \quad (5)$$

$$F_c(\theta) = F_m \cos (\theta - 240^\circ) \quad (6)$$

Then:

$$F(\theta) = F_m \cos \theta + F_m \cos(\theta - 120^\circ) + F_m \cos(\theta - 240^\circ) \quad (7)$$

And expanding:

$$F(\theta, t) = \frac{1}{2} F_m \cos(\omega t - \theta) + \frac{1}{2} F_m \cos(\omega t + \theta) + \frac{1}{2} F_m \cos(\omega t - \theta) + \frac{1}{2} F_m \cos(\omega t + \theta - 240^\circ) + \frac{1}{2} F_m \cos(\omega t - \theta) + \frac{1}{2} F_m \cos(\omega t + \theta + 240^\circ) \quad (8)$$

Equation 8 describes what is called the *space field*. Terms with arguments $(\omega t - \theta)$ are called the “forward rotating components” and the other terms $(\omega t + \theta)$ are called “backward rotating components.” Adding up the 2nd, 4th and 6th terms from equation 8 results in zero. Therefore terms 1, 3 and 5 add up to:

$$F(\theta, t) = \frac{3}{2} F_m \cos(\omega t - \theta) \quad (9)$$

Expression 9 describes the rotating magnetic field moving in a counterclockwise direction with an angular velocity ω radians per second in the air gap. The total mmf at any instant in time has a magnitude of 1.5 and it rotates around the stator. Simulation of this equation using Matlab, gives the physical explanation of such field rotating around the stator.

Simulation

This a program developed using MatlabTM. We will obtain ultimately equation 9 and use animation to see the rotation of the phasors in space.

```
% -----
% CALIFORNIA STATE UNIVERSITY NORTHRIDGE
% ROTATING MAGNETIC FIELD
% FEBRUARY 2000
% -----

% CALCULATE NET MAGNETIC FIELD PRODUCED BY A THREE PHASE STATOR

% BMAX = 1
% FREQUENCY = 60 HZ
% GENERATE THREE COMPONENTS MAGNETIC FIELD

%Frequency and w (radian frequency)
hz = 60
```

```

t = 0:1/6000:1/60
omega = hz*2*3.14159
j = sqrt(-1)

% Flux for coils "a", "b" and "c".
Baa = sin(omega*t)*(cos(0) + j*sin(0))
Bbb = sin(omega * t - 2*pi/3)*(cos(2*pi/3)+ j*sin(2*pi/3))
Bcc = sin(omega*t + 2*pi/3)*(cos(-2*pi/3)+ j*sin(-2*pi/3))

%Resultant flux
Bnet = Baa + Bbb + Bcc

%Generation of circles
circle = 1.5*(cos(omega*t)+ j*sin(omega*t))

% plot the magnitude and direction of the resultant magnetic field Bnet 1.5 *
Bmax*angle
ii = 1:length(t)
k = 1

%subplot(3,1,1)
%plot([ 0 real(Baa(ii))],[0 j*(Baa(ii))],'k','linewidth',2)
%subplot(3,1,2)
%plot(circle, 'k')
%subplot(3,1,3)
%plot (Bnet,t)

iii = 59
%compass(Baa(iii),Bbb(iii),Bcc(iii))

for iii=1:101

    k(1)=Baa(iii)
    k(2)=Bbb(iii)
    k(3)=Bcc(iii)
    k(4)=Bnet(iii)

%subplot(1,2,1)
    compass(k)
    pause(.1)
end

title('plot of Baa, Bbb, Bcc and Bnet')

%subplot(1,2,2)
%polar(angle(Bnet),abs(Bnet))
%title('Magnitude of Bnet in polar coordinates')
%compass(Bnet)

```

Output

Only a small part of the numerical output is shown below. As you can see we have obtained a great solution, and this in itself is of great advantage over the regular classroom calculations. Furthermore the plotting, using animation, of this output is the most remarkable event in this paper and in the energy conversion class.

K	B_x	B_y	B_z
-0.1874	$-0.4722 + 0.8179i$	$0.3785 + 0.6556i$	$-0.1880 + 1.4882i$

k =

-0.1874	$-0.4722 + 0.8179i$	$0.3785 + 0.6556i$	$-0.2811 + 1.4734i$
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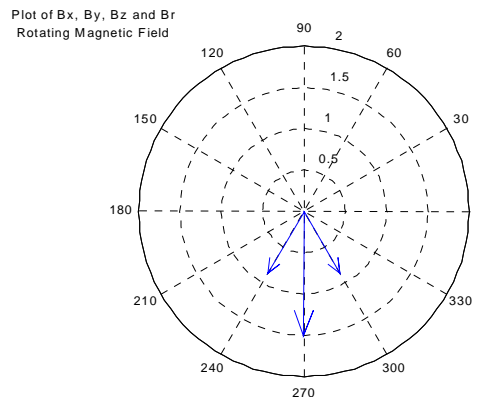
k =

-0.2487	$-0.4722 + 0.8179i$	$0.3785 + 0.6556i$	$-0.2811 + 1.4734i$
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k =

-0.2487	$-0.4816 + 0.8341i$	$0.3785 + 0.6556i$	$-0.2811 + 1.4734i$
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The graphical output is shown below. This graph is an animated graph that can only be shown if we run the program. In the meantime we show only the last calculated point. Observe that the maximum value of the resultant phasor is 1.5 as it is indicated by the circle with radius of 1.5..



Conclusions

Matlab is a very powerful simulation package that we are trying to include in our energy conversion curriculum. As it can be seen in the output of the simulation the numerical part is quite clear, yet, the graphical part emphasizes the result and “brings home” the concept of having a constant $1.5 \cdot B_{\max}$ magnitude value for the resultant magnetic flux rotating in space around the stator. The effect that this simulation has had in our students is great, due to the fact that they get very motivated to continue studying our electric machines and looking forward to perform simulations that would match their homework or concepts explained in class. For further research we will look into the rotating phasors for synchronous machines operating at different power factors.

Bibliography

- [1] Bruno Osorno “Electrical Machines Lecture Notes”, California State University Northridge, 1994.
- [2] Turan Gonen “Electrical Machines”, Power International Press, First Ed. 1998.
- [3] A.E. Fitzgerald, et.al., “Electric Machinery. McGraw-Hill, 5th Ed. 1990.
- [4] “Syed A. Nasar, “Electric Machines and Power Systems”, McGraw-Hill, 1st Ed. 1995
- [5] Guru and Hiziroglu, “Electric Machinery and Transformers”, Saunders College Publishing, 2nd Ed. 1995.

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Bruno Osorno is currently an associate professor at California State University. He has over 8 years of professional experience in industry, and holds an MSEE from the University of Colorado and a PhD (ABD) from New Mexico state University. He has written over 15 technical papers and his areas of interest are Fuzzy Logic applications in electrical machines and Power Electronics applications and simulations. He is in charge of the Electric Power Systems program at California State University. He is an officer with the IEEE San Fernando Valley Section in Los Angeles California as well as a senior member of IEEE. Also, he is the campus representative for ASEE. He belongs to the IEEE societies in Power Electronics, Power Systems and Industry Applications.