Design of a Wireless Power Transfer System using Inductive Coupling and MATLAB programming

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Abstract—Wireless power transfer (WPT) is the propagation of electrical energy from a power source to an electrical load without the use of interconnecting wires. It is becoming very popular in recent applications. Wireless transmission is useful in cases where interconnecting wires are difficult, hazardous, or non-existent. Wireless power transfer is becoming popular for induction heating, charging of consumer electronics (electric toothbrush, charger), biomedical implants, radio frequency identification (RFID), contact-less smart cards, and even for transmission of electrical energy from space to earth.

In the design of the coils, the parameters of coils are obtained by using the basic calculations and measurements.

The experimental results are presented and verified by using the MATLAB programming for the input and output wave forms.

Keywords—*Wireless power transfer, Electromagnetic Induction, MATLAB.*

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I. INTRODUCTION

The goal of the present research is to develop a method of wireless power transmission. The idea of wireless power transfer originated from the inconvenience of having too many wires sharing a limited amount of power sockets. We believe that many people have the same experience of lacking enough sockets for their electronic organized. Wireless power transfer can be divided into two major types – electromagnetic induction and electromagnetic radiation. Electromagnetic induction can be of three type's electrodynamics, electrostatic and evanescent wave coupling. Electromagnetic radiation can be divided into two categories – microwave power transfer (MPT) and laser.

Electromagnetic Induction: It is the production of an induced voltage in a circuit which is excited by means of the magnetic flux. The condition for an induced current to flow in a closed circuit is that the conductors and the magnetic field must rotate relative to each other

Electromagnetic Radiation: Electromagnetic radiation travels through vacuum at the speed of light and propagates by the interaction of time varying electric and magnetic fields. It has a wavelength and a frequency.

There are a number of limitations to the full implementation of wireless energy transfer:

a) Size: The size of the transmitter or the receiver sometimes becomes too large to implement in a smaller system devices. Thus by creating a wireless power transfer system, it would help clean up the clutter of wires around power sockets making the space more tidy and

b) Range: The range of wireless energy transfer is just a few meters, which represents a major hurdle towards its practical implementation.

c) Efficiency: Typical efficiency of wireless energy transfer ranges between 45% and 80% and is less efficient than conventional wire based energy transfer methods.

In our experiment we have considered electrodynamic or inductive coupling. An inductive link is formed by a loosely coupled transformer consisting of a pair of coils that are usually placed in a coaxial arrangement .The external or the primary coil is excited by an alternating current, and thus an electromagnetic field is produced with its magnitude dependent on the dimensions of the coil, the drive current and the frequency of operation. A portion of the alternating flux lines generated this way link to the internal or the secondary coil, and the change in flux linkage produces a voltage in the secondary coil, which is proportional to the rate of change of the flux and the number of turns in the

3817

secondary coil (Faraday's law of electromagnetic induction). If the number of turns is *n* and the magnetic flux linking each turn is *ψm*, then the induced voltage for the circuit can be written as, v=n (d ψm/dt).

Hardware design for different turns in the receiver and transmitter coil is shown and the MATLAB programming is written for the input and output, finally the comparative graph is plotted and checked for input and output of hardware and programming.
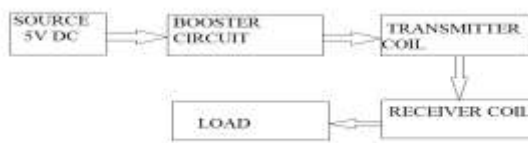
II. BLOCK DIAGRAM

Fig.i Block Diagram of a Wireless power transfer system

A. Source*:* The supply given here is 5V(DC).

B. Booster circuit: A booster circuit is a DC-DC power converter with an output voltage greater than its input voltage. It is of switched-mode power supply (SMPS) containing one semiconductor (a transistor), at least one energy storage element, a capacitor, an inductor, or the two in combination.

C. Transmitter coil: The transmitter coil is the one which transmits power wirelessly to the receiver coil.

D. Receiver coil: The receiver coil is the one which receives power from the transmitter coil. The receiver coil consists of filter circuit.

E. Load: The load is an LED.

III. EXPERIMENT

Fig.ii Circuit Diagram of a Wireless Power Transfer System

The fig. ii shows the circuit diagram of a wireless power transfer system. The input power to the system is DC supply of 5V is given. The booster circuit is also known as (boost converter or step-up converter) is a DC-DC power converter with an output voltage greater than its input voltage. It is a switched-mode power supply (SMPS) containing one semiconductor (a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Booster circuit also power devices at small scale applications, such as portable lighting systems. A LED typically requires 3.3V to emit light. The transmitter coil made up of copper turns of American Wire Gauge (AWG) of 18 is used to transmit power wirelessly to the receiver coil. The receiver coil is also made up of same wire gauge as transmitter coil. The magnetic field generated by the transmitter coil couples with the receiver coil, exciting the coil and causing energy to build up in it. This energy is coupled out of the receiver coil to do useful work, for example, directly powering a load. The LED is used as a load. Filters made of capacitor (sometimes in combination with inductors) is used to the output to reduce output voltage ripple. The transmitter coil and receiver coil is constructed with 4.5cm radius and we have constructed both coils with 8 turns.

SPECIFICATIONS
TRANSMITTERCOIL SIDE

Inputvoltage=5Volts
BD139Transistor
$R = 1.5K\Omega$
$C_1 = 470pF$
$C_2 = 4.7nF$
$C_3 = 100nF$
Turns = 8

RECEIVER COILSIDE

D_1 (IN4148)
$C_4 = 4.7nF$
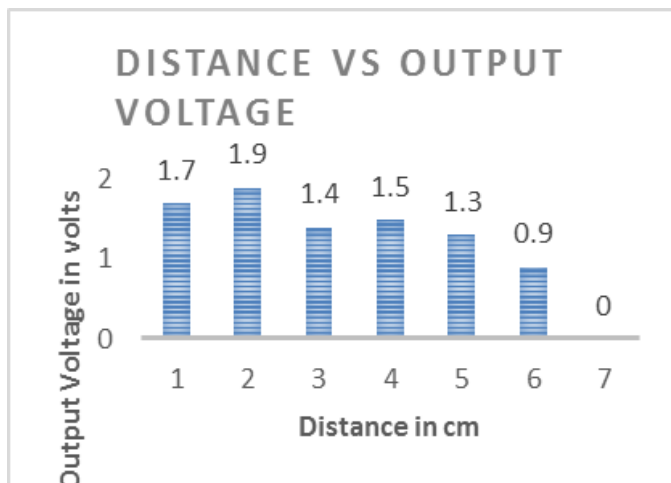Turns = 5,8,10,15

Model picture for 8 turns (single load)

Fig.iii Model picture of a Wireless Power Transfer System for single load
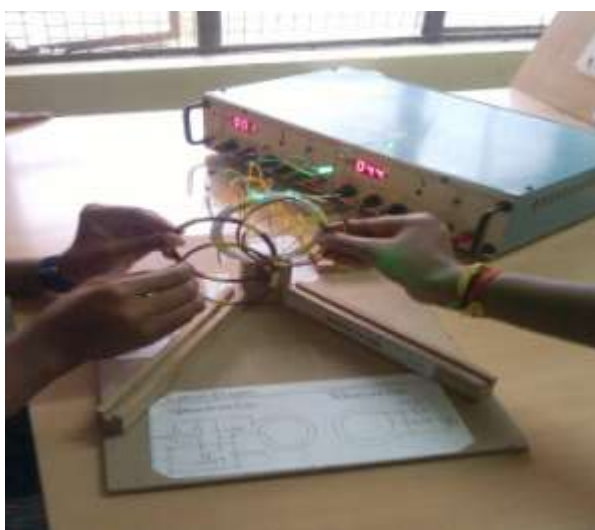
IV Experimental Results

Table 1.1: Receiver Coil with 8 turns

Input voltage (V)	Input current (A)	Output voltage (V)	Output current (A)	Input power (W)	Output power (W)	Efficiency
1	2	1.4	1.4	2	1.96	0.98
1	2	1.2	1.3	2	1.56	0.78
1	2	1.3	1.4	2	1.82	0.91
1	2	1.1	1.2	2	1.32	0.66
1	2	1	0.9	2	0.9	0.45
1	2	0	0	2	0	0

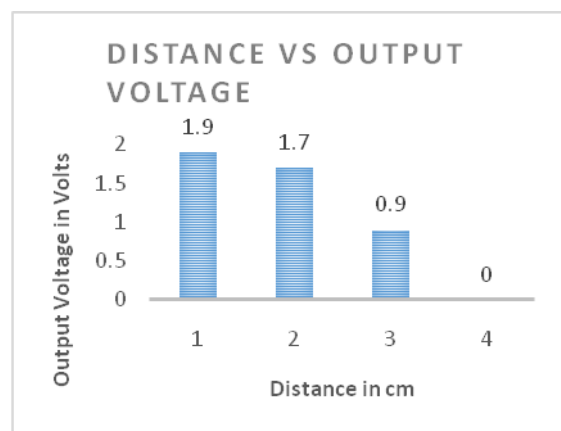Experimental graph

Model picture for multiple load

Fig .iv Model picture of a Wireless Power Transfer System for multiple load

Table 1.2: Receiver Coil of (5,8, 10, 15 turns)

Input current (A)	Output voltage (V)	Output current (A)	Input power (W)	Output power (W)	Efficiency
2	1.9	1.87	10	3.55	0.35
2	1.7	1.63	10	2.77	0.27
2	0.9	0.7	10	0.63	0.06
2	0	0	10	0	0

Experimental graph

IV   MATLAB PROGRAMMING

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building.
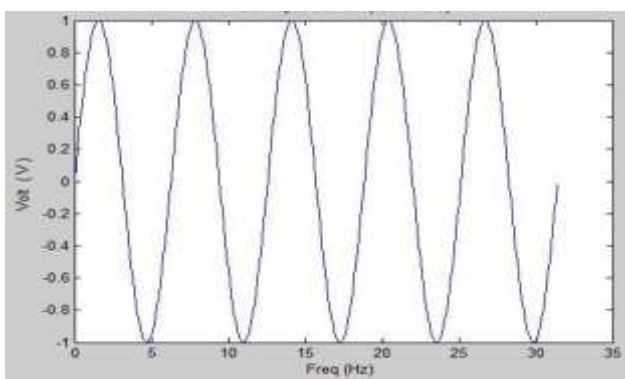
MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPAC and eispack projects.

3819

Today, MATLAB engines incorporate the LINPAC and blast libraries, embedding the state of the art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

Input Program for an wireless power transfer system

```
t = 0:.1:pi * 10;
y = sin(t);
figure
plot(t,y);
xlabel ('Freq (Hz) ');
ylabel ('Volt ( V ) ');
title (' Coil Input Voltage(Sine wave)');
disp ('Dr. TTIT, Kolar');
```

Input waveform:

Output Program for an wireless power transfer system

```
vo = 1;
c = 45e-6;
r = 1800;
f = 50;
tf = 70e-3;
w = 2 * pi * f;

t = 0:0.05e-3:tf;

n = length (t);
state = 'on';

fori = 1:n
vs(i) = vo * sin(w * t(i));
```
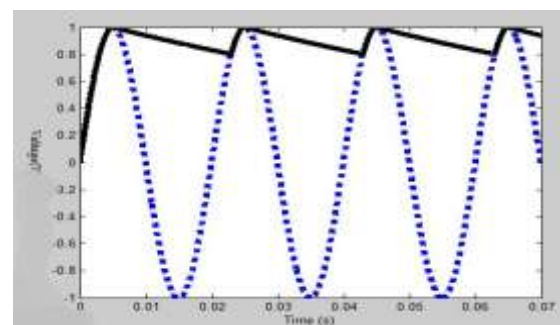
```
switch state
case'on'
vr(i) = vs(i);
ir = vs(i)/r;
ic = w * c * vo * cos(w * t(i));
sumi = ir + ic;
ifsumi<= 0
state = 'off'
ta = t(i);
end
case'off'
vr (i) = vo * sin (w * ta) * exp(-(t(i)
- ta)/(r * c));
ifvs(i) >= vr(i)
state = 'on';
end
end
end

plot (t, vs, ':',t,vr,
'k','linewidth',5)
xlabel('Time (s)');
ylabel ('Voltage (v)');
```

Output Waveform:

Program for Magnetic field distribution

```
clc
clear
closeall

%Define global variables
global u0

u0=4*pi*1e-7; %permeability of free
space

%Define coil parameters

I0=1; %Coil current in Amps
a=.1; %Coil radius in m
```

```
x_p=0; y_p=0; z_p=0; %Define coordinates
of coil center point

%First we see how to calculate the
magnetic field at a single point in
%space

%Input test point
x=0; y=0; z=.1;

[Bx,By,Bz] =
magnetic_field_current_loop(x,y,z,x_p,y_
p,z_p,a,I0)

%Now showing how to calculate points
along a straight line

clear xyz

%Input vector of points

x=0; y=0; z=linspace(0,.25,100); %These
default coordinates calculates the
magnetic field along the z axis through
the center of the coil

[Bx,By,Bz] =
magnetic_field_current_loop(x,y,z,x_p,y_
p,z_p,a,I0);

figure
plot(z,Bz)
xlabel('z [m]')
ylabel('Bz [T]')
title('1D magnetic field tests')

%now we test how to calculate a 2D grid
of points

clear xyz

%input mesh of points in 2D plane

x=0; [y,z]=meshgrid(linspace(-
.05,.05,25),linspace(0,.1,25)); %this is
a 2d plane over the x=0 plane that
extends away from the coils in the yz
plane.

[Bx,By,Bz] =
magnetic_field_current_loop(x,y,z,x_p,y_
p,z_p,a,I0);
```
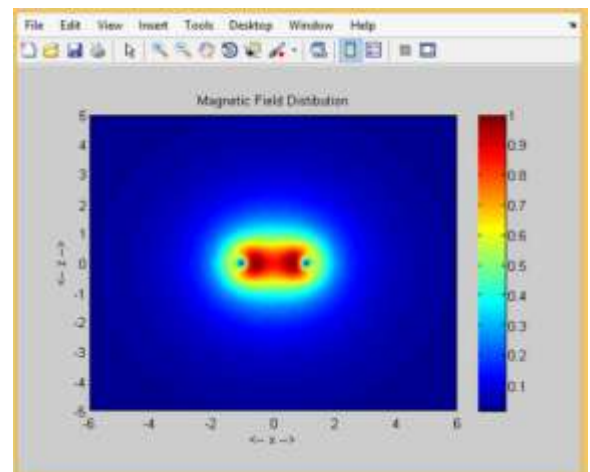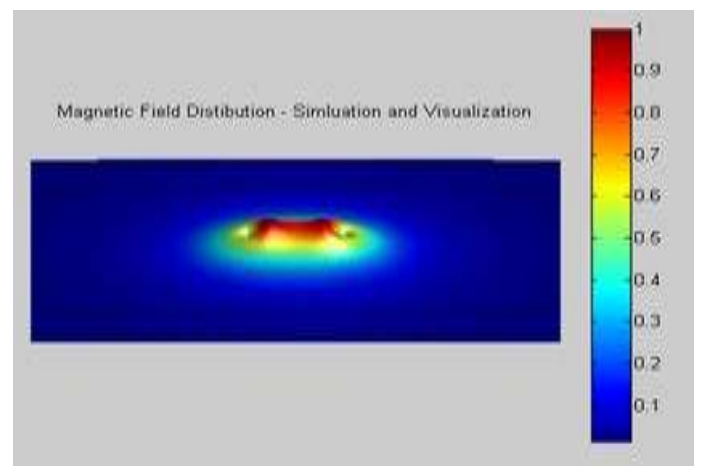
```
figure
surf(y,z,Bz)
xlabel('y [m]')
ylabel('z [m]')
zlabel('Bz [T]')
title('2D magnetic field tests')
colorbar %addcolorbar
shading flat %Removes black lines from the
mesh
```

Simulates the magnetic field distributions in a given X-Y-Z plane - 3D Space Model. You can change the parameters for example, number of turns, radius of the coil etc. can be changed and simulate the magnetic field distributions. Simulation of Vector Field Usage of Biot Steverts Law for magnetic Field Simulations. Between Two thin Parallel Conductors lying on XY plane @ origin (Z=0)..Field distribution is calculated on XZ plane @ origin (Y=0)..
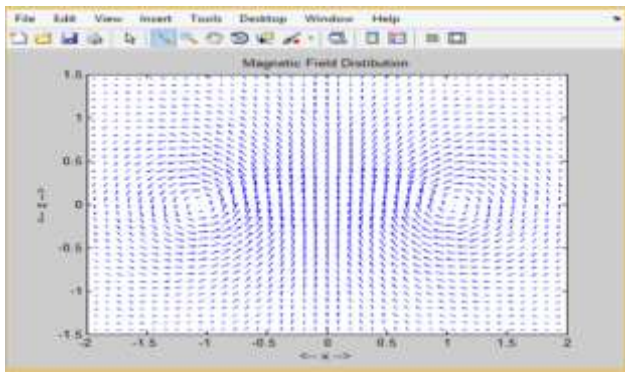
Output for the magnetic field distribution.

Output for Visualization for Magnetic Field Distribution

Output for Magnetic Field Distribution in X-Z Plane

3821

PROGRAM FOR CURRENT LOOPS IN MAGNETIC FIELD

```
clc
clear
closeall

%Define global variables
global u0

u0=4*pi*1e-7; %permeability of free
space

%Define coil parameters

I0=1; %Coil current in Amps
a=.1; %Coil radius in m

x_p1=0; y_p1=0; z_p1=0; %Define
coordinates of coil 1 center point
x_p2=0; y_p2=0; z_p2=a; %Define
coordinates of coil 2 center point


%input mesh of points in 2D plane

x=0; [y,z]=mesh grid(line space(-
.05,.05,25),line space(0,.1,25)); %this
is a 2d plane over the x=0 plane that
extends away from the coils in the yz
plane.

[Bx1,By1,Bz1] =
magnetic_field_current_loop(x,y,z,x_p1,y
_p1,z_p1,a,I0); %Calculate field from
first coil
[Bx2,By2,Bz2] =
magnetic_field_current_loop(x,y,z,x_p2,y
_p2,z_p2,a,I0); %Calculate field from
second coil
```

```
%Add the components
Bx=Bx1+Bx2;
By=By1+By2;
Bz=Bz1+Bz2;

%Calculate the magnitude of the vector
B_mag=sqrt(Bx.^2+By.^2+Bz.^2);

figure
surf(y,z,B_mag)
xlabel('y [m]')
ylabel('z [m]')
zlabel('B [T]')
title('2D Magnetic Field Distributions')
colorbar
shadingflat
```
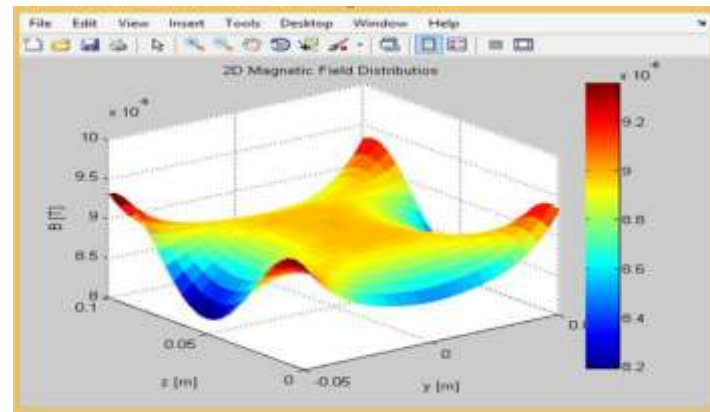
Output for the Current loop in 2D Plane

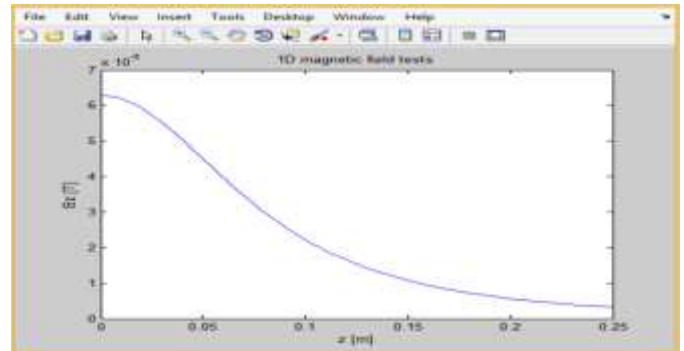**PROGRAM FOR PLACING THE COILS IN PARLLEL**

```
clc
ln = 20;
d = 2;
m = 1;
n = -1;
N = 20;
dl = ln/N;
xCm =  (d/2)*ones(1,N);    % Conductor m
located @ +d/2...
xCn = (-d/2)*ones(1,N);    % Conductor n
located @ -d/2...
yC = (-ln/2+dl/2) : dl : (ln/2-dl/2);
zC = zeros(1,N);
Lx = zeros(1,N);
Ly = dl*ones(1,N);
Lz = zeros(1,N);
NP = 125;
```
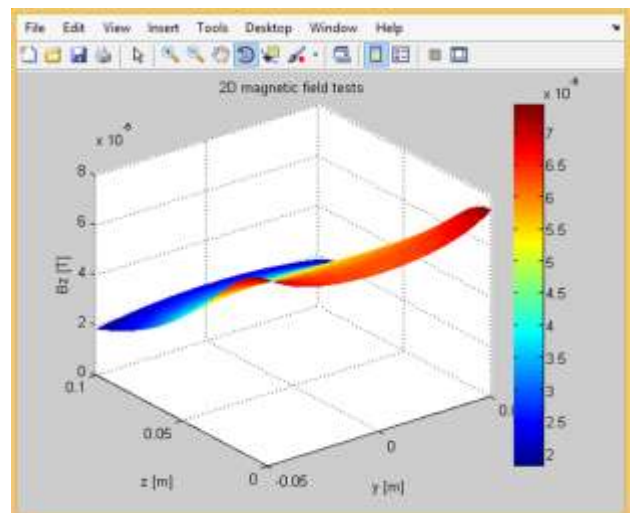
3822

```matlab
xPmax = 3*d;
zPmax = 2.5*d;
xP = linspace(-xPmax,xPmax,NP);
zP = linspace(-zPmax,zPmax,NP);
[xxPzzP] = meshgrid(xP,zP);
Bx = zeros(NP,NP);
By = zeros(NP,NP);
Bz = zeros(NP,NP);
for q = 1:N
rxm = xxP - xCm(q);
rxn = xxP - xCn(q);
ry = yC(q);
rz = zzP - zC(q);
rm = sqrt(rxm.^2+ry.^2+rz.^2);
rn = sqrt(rxn.^2+ry.^2+rz.^2);
    r3m = rm.^3;
    r3n = rn.^3;
Bx = Bx + m*Ly(q).*rz./r3m +
n*Ly(q).*rz./r3n;
% By = 0;
Bz = Bz - m*Ly(q).*rxm./r3m -
n*Ly(q).*rxn./r3n;
end
B = sqrt(Bx.^2 + By.^2 + Bz.^2);
B = B/max(max(B));
figure(1);
pcolor(xxP,zzP,B);
colormap(jet);
shadinginterp;
axisequal;
axis([-xPmaxxPmax -zPmaxzPmax]);
xlabel('<-- x -->');ylabel('<-- z -->');
title('Magnetic Field Distribution');
colorbar;
figure(2);
surf(xxP,zzP,B,'FaceColor','interp',...
'Edge Colour','none',...
'Face Lighting','phong');
daspect([1 1 1]);
axistight;
view(0,30);
camlightright;
colormap(jet);
gridoff;
axisoff;
colorbar;
title('Magnetic Field Distribution -
Simulation and Visualization')
figure(3);
quiver(xxP,zzP,Bx,Bz);
colormap(lines);
%axis tight;
axis([-d d -0.75*d 0.75*d]);
```

```matlab
title('Magnetic Field Distribution');
xlabel('<-- x -->');ylabel('<-- z -->');
zoomon;
```

Output for coil distribution in parallel plane

Output for coil distribution in parallel with 2D Plane.

V. COMPARISION OF PROGRAMMING WITH EXPERIMENTAL RESULTS

3823

Output Voltage Vs Distance

By changing the parameters for example, number of turns of the transmitter and receiver coil, radius of the coil etc. can be changed and the magnetic field distributions programming of Vector Fields Usage of Biot Steverts Law for Magnetic Field Two circular Helmholtz coil at the center of the uniform field. The experimental values is being compared with the programming values.

VI. CONCLUSION

More reliable than ground based solar power. If we develop this, we need not bother about the exhaustion of natural resources. If this project succeeds it will become a boon to next generations. Transmission without wires-a reality. Efficient, Low maintenance cost. But, high initial cost. Better than conventional wired transfer. Energy crisis can be decreased. Low loss. In near future, world will be completely wireless. WPT emerges out as the best alternative for efficient power transmission despite its few drawbacks such as very high installation cost. WPT has very high efficiency as the loss during power transmission is nearly negligible and it acts as a boon for the people of those areas where wired transmission is not possible. The power failure due to short circuit and electric faults would not be possible at all. Only need a simple design to efficiently transfer large power levels over moderate distances.

VII. FUTURE ASPECTS

It is one of the biggest challenges in today's world to transmit energy in rough terrain like mountains, forest and sea. A verified SPICE model of wireless transmission has been considered for the efficiency calculation along with the mathematical approach. Numerical calculation shows that 30-70% transmission efficiency can be achieved by using this model of transmission depending upon the transmission distance and diameter of the antenna.Furthermore, the impedance

matching between the loop and coil embodied by the coupling constant suggest that a discrete matching network can be used to directly connect the source/load to the coils, thereby simplifying the system. Clearly the advantages of high and near constant transfer efficiency at mid-range distance compared to near-field and far-field techniques make this technology exciting for many applications. There is any number of low power wireless recharging scenarios that would benefit from increased range vs. efficiency at power levels typically used in RFID. Finally this paper has focused on the delivery aspect of RF power while consumer electronics require DC power for operation and recharging. Adaptive rectifier designs will need to be developed that do not interfere with the operation of the magnetically coupled resonators.

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