Field Precision LLC

Magnetic field distributions below high-voltage power lines

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We had an inquiry from a code user in the Netherlands about magnetic field profiles near the ground beneath a high voltage power line. The recommended limit for safety in most European countries is 100 μtesla or higher. There is a special limit in the Netherlands that the field created beneath new lines should be less than 0.4 μtesla in areas where children spend extended time. The user sent three-dimensional coordinates for dual three-phase power transmission lines suspended between towers. Each of the six conductors carried peak current $I = 635.0$ A at frequency $f = 50.0$ Hz. The goal was to find the 0.4 μtesla profile in a plane 1.0 m above the ground near the sag point to determine the minimum separation distance for facilities like school yards and playgrounds. Clearly, high accuracy is necesssary for a calculation of the small field levels. At the low frequency, the static field **Magnum** program can be applied to find the field distribution at a set of phase offsets.

The user submitted a text list of wire coordinates between two towers approximately 300 m apart. The wire heights above the ground at the sag point varied from 15 to 20 m. Because we are interested in the area near the sag point, the towers and the line continuations to the next towers made negligible contributions to the magnetic field. Another concern is whether the ground influences the magnetic field distribution. The penetration distance into a conductive, non-magnetic medium is given by:

$$\delta = \sqrt{\frac{\rho}{\pi \mu_o f}}. \tag{1}$$

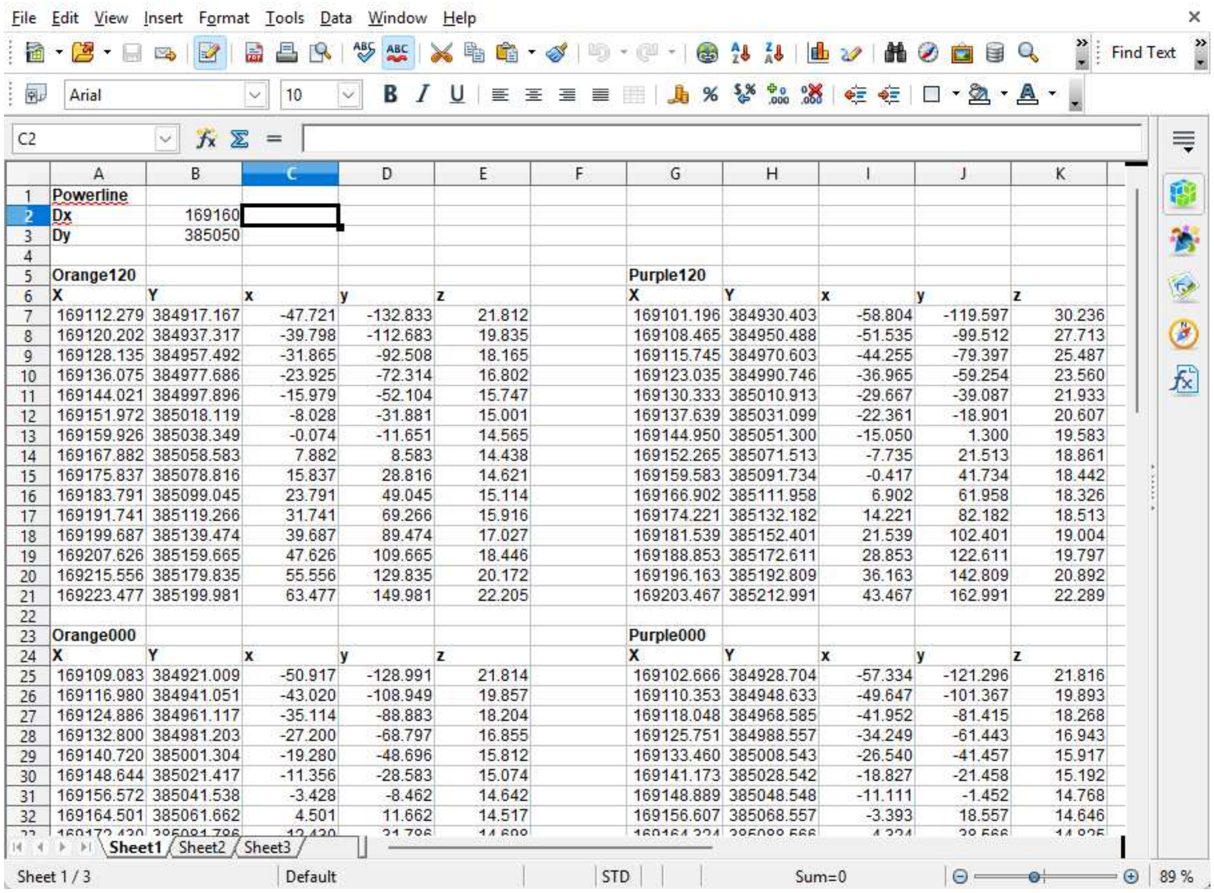
The resistivity of soil varies from about 20 Ω-m for clays and shales to 10,000 Ω-m for dry sand and gravel. At the minimum value, the distance is about 300 m for $f = 50.0$ Hz. For dry soil, the penetration depth is several kilometers. The conclusion is that the ground has little effect on magnetic field values in the region of interest. Therefore, it is possible to utilize the *Free space* mode of **Magnum** for optimal speed and accuracy.

The towers supported two sets of wires (designated *orange* and *purple*), each with three lines at relative phases $\phi_o = 120.0^o$, 0.0^o and -120.0^o. The user supplied coordinates in meters with values of X (east) and Y (north) in terms of total distance from the power line source, about 420 km away. Small differences in large numbers degrade the accuracy of numerical calculations, so the first step was to define a local set of coordinates. Figure 1 shows a spreadsheet to find coordinates by subtracting the average position from the raw values. The z axis represents the height about the ground.

Two inputs are generally required for a **Magnum** calculation:

- Input to **MagWinder** to enable representation of the source as a number of wire segments.
- Input to **MetaMesh** to define a three-dimensional region for the magnetic field calculation.

The free-space mode of **Magnum** simply applies Biot-Savart integrals, so volume for the field calculation need to not include the current elements. The mesh for field interpolations, defined by `PowerSource.MIN`, is a box with sides of length 200.0 m in x and y with a height of 5.0 m in z. The vertical mesh is set to give interpolation planes at $z = 0.0$, 1.0, 2.0, 3.0 and 4.0 m.



	A	B	C	D	E	F	G	H	I	J	K
1	Powerline										
2	Dx	169160									
3	Dy	385050									
4											
5	Orange120						Purple120				
6	X	Y	x	y	z		X	Y	x	y	z
7	169112.279	384917.167	-47.721	-132.833	21.812		169101.196	384930.403	-58.804	-119.597	30.236
8	169120.202	384937.317	-39.798	-112.683	19.835		169108.465	384950.488	-51.535	-99.512	27.713
9	169128.135	384957.492	-31.865	-92.508	18.165		169115.745	384970.603	-44.255	-79.397	25.487
10	169136.075	384977.686	-23.925	-72.314	16.802		169123.035	384990.746	-36.965	-59.254	23.560
11	169144.021	384997.896	-15.979	-52.104	15.747		169130.333	385010.913	-29.667	-39.087	21.933
12	169151.972	385018.119	-8.028	-31.881	15.001		169137.639	385031.099	-22.361	-18.901	20.607
13	169159.926	385038.349	-0.074	-11.651	14.565		169144.950	385051.300	-15.050	1.300	19.583
14	169167.882	385058.583	7.882	8.583	14.438		169152.265	385071.513	-7.735	21.513	18.861
15	169175.837	385078.816	15.837	28.816	14.621		169159.583	385091.734	-0.417	41.734	18.442
16	169183.791	385099.045	23.791	49.045	15.114		169166.902	385111.958	6.902	61.958	18.326
17	169191.741	385119.266	31.741	69.266	15.916		169174.221	385132.182	14.221	82.182	18.513
18	169199.687	385139.474	39.687	89.474	17.027		169181.539	385152.401	21.539	102.401	19.004
19	169207.626	385159.665	47.626	109.665	18.446		169188.853	385172.611	28.853	122.611	19.797
20	169215.556	385179.835	55.556	129.835	20.172		169196.163	385192.809	36.163	142.809	20.892
21	169223.477	385199.981	63.477	149.981	22.205		169203.467	385212.991	43.467	162.991	22.289
22											
23	Orange000						Purple000				
24	X	Y	x	y	z		X	Y	x	y	z
25	169109.083	384921.009	-50.917	-128.991	21.814		169102.666	384928.704	-57.334	-121.296	21.816
26	169116.980	384941.051	-43.020	-108.949	19.857		169110.353	384948.633	-49.647	-101.367	19.893
27	169124.886	384961.117	-35.114	-88.883	18.204		169118.048	384968.585	-41.952	-81.415	18.268
28	169132.800	384981.203	-27.200	-68.797	16.855		169125.751	384988.557	-34.249	-61.443	16.943
29	169140.720	385001.304	-19.280	-48.696	15.812		169133.460	385008.543	-26.540	-41.457	15.917
30	169148.644	385021.417	-11.356	-28.583	15.074		169141.173	385028.542	-18.827	-21.458	15.192
31	169156.572	385041.538	-3.428	-8.462	14.642		169148.889	385048.548	-11.111	-1.452	14.768
32	169164.501	385061.662	4.501	11.662	14.517		169156.607	385068.557	-3.393	18.557	14.646

Figure 1: Spreadsheet to calculate a local set of coordinates for the space between towers.

The **MagWinder** input file is more interesting. After a *Global* section, the script contains several *Coil* sections where all segments carry the same current. A coil may be built of a series of *Parts* to add segments based on a variety of models. In this case, the user has already supplied the division of the wires into segments so that special part models are not necessary. Instead, we can use the *List* part type which contains a set of three-dimensional coordinates for the segments. Because **Magwinder** has considerable flexibility in recognizing delimiters, contents of the spreadsheet can be pasted directly into the input script. For example, this is the coil section for the Orange wire at 120^o phase:

```
COIL
* Phase 120
  Name: Orange1
  Current: 549.9
  Part
    Name: Orange1
    Type: List
      -47.721   -132.833    21.812
      -39.798   -112.683    19.835
      -31.865    -92.508    18.165
      -23.925    -72.314    16.802
      -15.979    -52.104    15.747
       -8.028    -31.881    15.001
       -0.074    -11.651    14.565
        7.882      8.583    14.438
       15.837     28.816    14.621
       23.791     49.045    15.114
       31.741     69.266    15.916
       39.687     89.474    17.027
       47.626    109.665    18.446
       55.556    129.835    20.172
       63.477    149.981    22.205
    End
  End
END
```

The section shown adds fourteen segments to the winding file (`WND`), each carrying current

$$635\ \sin(120^o) = 549.9\ \ \text{A} \tag{2}$$

The full file contains six such sections representing the three wires of each power line. The applied currents for each line at zero phase offset ($\Delta\phi = 0.0$) are 549.9, 0.0, -549.9 A. Figure 2 shows the segment configuration.

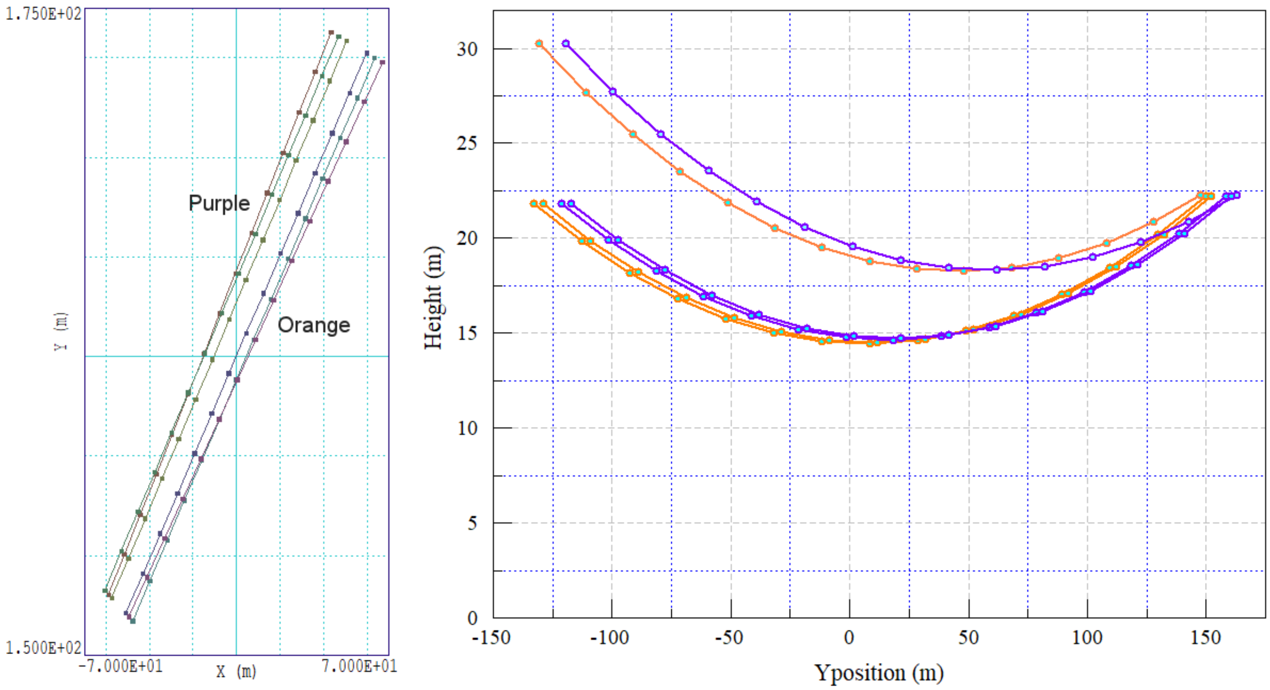


Figure 2: Representation of dual 3-phase power lines as a series of current elements. Left side: overhead view. Right side: line height above ground projected along the y axis.

The Magnum script is relatively simple:

```
* MagNum script (Field Precision)
* File: PowerLine000.GIN
SolType = Free
Mesh = PowerLine
Source = PowerLine000
DUnit =   1.000000E+00
EndFile
```

It specifies the following:

- The calculation is performed in the free-space mode.
- Calculations and interpolation are performed around the sag point over the space near the ground defined by the **MetaMesh** file `PowerLine.MDF`.
- The current source is the **MagWinder** file `PowerLine000.WND` at $\Delta\phi = 0.0$, .
- Distances are in meters.

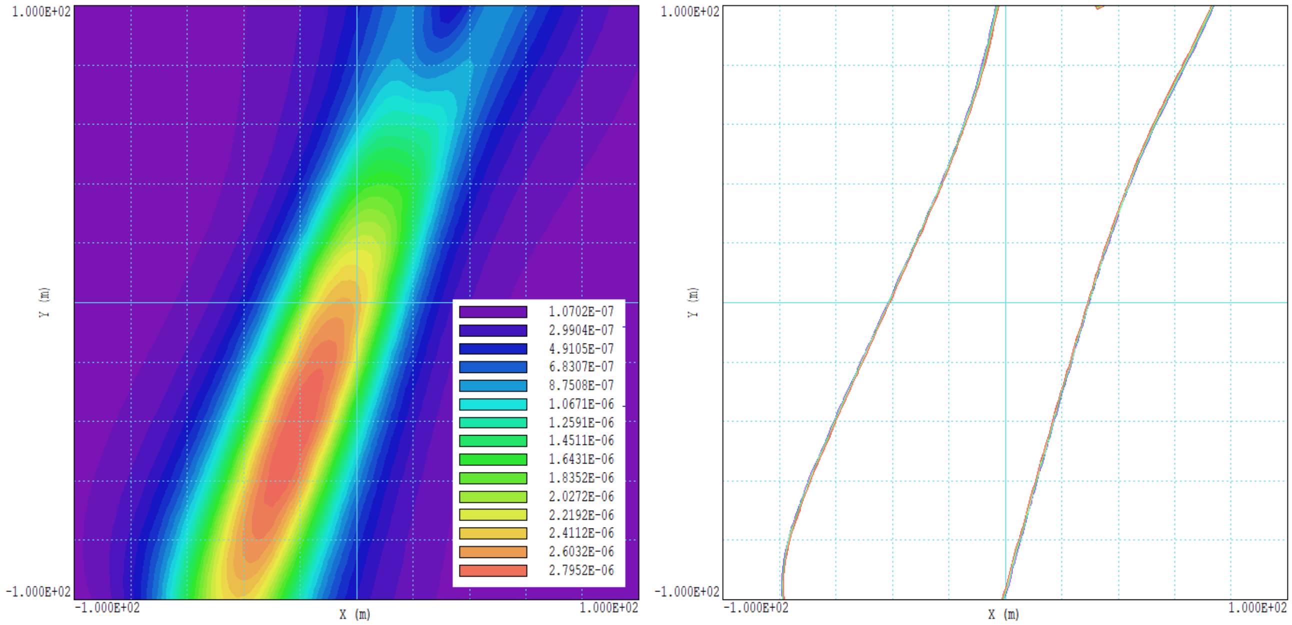


Figure 3: Magnetic field magnitude at phase offset $\Delta\phi = 0.0^o$. Left side: filled contour plot. Right side: contour lines for $|\mathbf{B}| = 0.4 \ \ \mu$tesla.

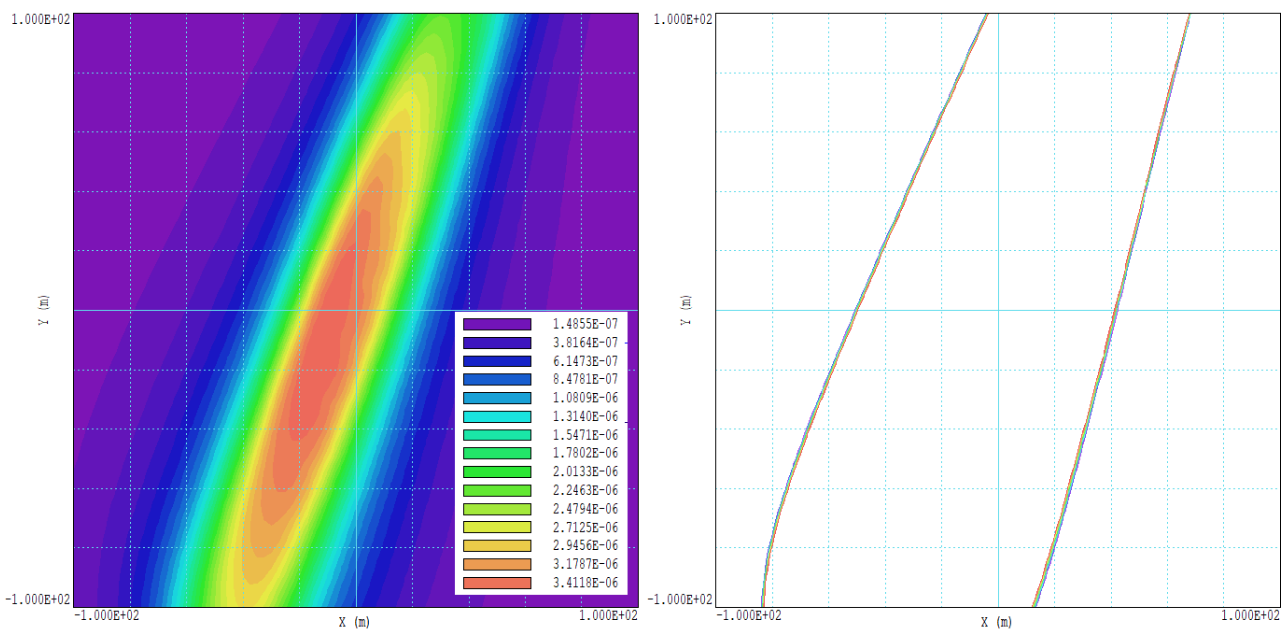


Figure 4: Magnetic field magnitude at phase offset $\Delta\phi = 60.0^o$. Left side: filled contour plot. Right side: contour lines for $|\mathbf{B}| = 0.4 \ \ \mu$tesla.

The **Magnum** solution takes less than one second. The **MagView** program can be used to analyze the output file to find values and create a variety of plots. Figure 3 illustrates field values in a plane 1.0 m above the ground for phase offset $\Delta\phi = 0.0^o$. The plot on the left hand side shows the variation of $|\mathbf{B}|$ over the region near the sag point of the cables while the plot on the right hand side shows specific contour lines for $|\mathbf{B}| = 0.4$ μtesla. The contour profiles vary with the phase offset, so several calculations were made, changing the current values carried by the cables in the **Magwinder** input file to reflect different values of $\Delta\phi$. For example. Figure 4 shows results with $\Delta\phi = 60.0^o$. On average, the conclusion is that boundaries of school yards and playgrounds should be at least 60 m from the center of the power line to meet the regulation.