

**CONIND™**  
**Pipeline Electrical Interference Analysis Tool**

**REFERENCE MANUAL**

**Ground-it.com Consulting Ltd.**  
**4030 Felix Court**  
**North Vancouver, B.C.**  
**Canada, V7G 2P3**  
**Telephone: 604 986 7890    Facsimile: 604 929 5630**  
**[www.ground-it.com](http://www.ground-it.com)**

## **COPYRIGHTS**

All software and all accompanying written materials in the CONIND™ package are copyrighted with all rights reserved.

## **LICENCE AGREEMENT AND LIMITATION OF LIABILITY**

The software and accompanying materials which form part of this package and which are referred to as the “CONIND package” are copyrighted. All rights are reserved world-wide. The CONIND package is licensed to you, the Licensee and may not be transferred to another party without the previous written consent of Ground-it.com Consulting Ltd.

Copies of the software and written materials may only be made for backup purposes. The software may only be used on one machine at a time. The software and written materials may not be modified, merged or included with other software or with other written materials without the explicit written consent of Ground-it.com Consulting Ltd.

The licensee may not use, copy or transfer the CONIND package in whole or in part, except as expressly provided for in this licence agreement.

Under the terms of this Licence Agreement, Ground-it.com Consulting does not warrant that the functions contained in the CONIND package will meet the user's requirements or that the operation of the programs will be uninterrupted or error-free. In no event shall Ground-it.com Consulting Ltd. be liable to the Licensee for any damages, including lost profits, lost savings or other special, incidental or consequential damages arising out of the use or inability to use the software or the written material of the CONIND package, even if Ground-it.com Consulting Ltd. has been advised of the possibility of such damages, or for any claim by any other party.

The CONIND package is provided “as is”, without warranty of any kind, either expressed or implied. The entire risk as to the quality and performance of the program is with the user. Should the contents of the CONIND package prove defective, the user assumes the entire responsibility for all necessary servicing, repair or correction. The liability of Ground-it.com Consulting Ltd. and the Licensee's exclusive remedy shall be limited to the replacement of any diskette or printed material that is physically damaged when received by the Licensee.

Ground-it.com Consulting Ltd. reserves the right to revise or make changes to the contents of the CONIND package without obligation to notify any person of such changes.

## TABLE OF CONTENTS

<b>1. OVERVIEW.....</b>	<b>1</b>
<b>2. DOING CALCULATIONS.....</b>	<b>2</b>
<b>3. ANALYSIS OF MODELS .....</b>	<b>4</b>
3.1 DEVELOPING THE INPUT DATA FILES.....	4
3.1.1 <i>Units of Measure</i> .....	4
3.1.2 <i>Definitions</i> .....	4
3.1.3 <i>Calculation Frequency</i> .....	5
3.1.4 <i>Mitigation Wires</i> .....	5
3.1.5 <i>Files Required</i> .....	6
3.1.6 <i>File #1 Pipeline Model Data File</i> .....	6
3.1.7 <i>File #2 Power Line Currents Data File</i> .....	9
3.1.8 <i>File #3 File Of Different Currents Information</i> .....	9
3.2 SAMPLE DATA FILE .....	10
3.3 DOING THE CALCULATION .....	15
3.4 REVIEWING THE RESULTS OF THE CALCULATION.....	15
<b>4. CALCULATION METHODOLOGY .....</b>	<b>20</b>
4.1 NETWORK RESOLUTION.....	21
4.2 CALCULATION OF PIPELINE $Z_0$ AND $\gamma$ .....	21
4.3 PIPELINE THEVENIN CALCULATION .....	22
4.4 COMBINATION OF THEVENIN IMPEDANCES .....	23
4.5 ELECTRIC FIELD CALCULATION .....	23
<b>5. PROGRAM KEYWORDS .....</b>	<b>24</b>
<b>6. REFERENCES.....</b>	<b>35</b>

### 1. OVERVIEW

CONIND is a sophisticated oil or gas pipeline electrical interference analysis tool. It is used to analyze the electrical effects of induced voltage on pipelines from parallel power lines operating under normal steady state load conditions as well as during power system faults.

CONIND represents the pipeline network in a segmented format consisting of discrete lengths of pipeline and mitigation wires, for which the power line coupling effects are constant. The results of the calculations contain all pipeline and mitigation wire voltages and currents that flow through the pipeline network.

The program calculation is based on an iterative development of the Thevenin equivalents of the pipeline segments. It does not use a matrix-based solution method. It requires data entry to describe each pipeline segment and the coupling between that segment and each current carrying parallel power line conductor.

CONIND has been used for relatively complicated models. In one case a complete network consisting of a about 500 km of main pipeline, a number of branch pipelines and many parallel power lines operating at different voltage levels, was modelled. Once all the data was prepared, CONIND automatically calculated the worst-case pipeline voltages at each point along the pipeline so that hazardous areas could be identified and appropriate measures implemented to reduce the hazard level.

### 2. DOING CALCULATIONS

The security key supplied with the program, must be attached to the computer parallel printer port to enable the programs to run.

The present version of CONIND is a windows 95/NT “console” program. This means that it is a text-based program that runs in a text window. There is no Graphical User Interface. Therefore, the first thing to do is to open a Command Prompt window. This can be done from the Windows Start Menu by selecting the **Programs** Sub-Menu item and **Command Prompt** from the programs listing. Alternatively, if there is a desktop icon for the **Command Prompt**, it is only necessary to double click on the icon.

The CONIND program **CONIND.EXE** should be installed in a directory that is on the PATH of the computer. This enable running the program by typing only the name, rather than a full path description. For example, if it is in a directory that is on the computer’s PATH, the following command line could be used to do an analysis:

```
CONIND MODEL1 RESULTS1 STEADY1 LOG
```

If it is in a directory on drive **C:** called **PIPEPROG** that is not on the PATH, it may be necessary to enter the following:

```
C:\PIPEPROG\CONIND MODEL1 RESULTS1 STEADY1 LOG
```

CONIND must be run from a “DOS Window” because it requires command line parameters containing file names and an optional instruction to produce a logging file of the program operation. Once the **Command Prompt** Window is open, it is best to change to the disk drive and directory where the data files and results are required. The current directory is the directory where the logging file will be saved, if the logging option is selected. Also, if the current directory contains the data files, only their names need be typed after the program name.

To change to a different disk drive, type the new drive letter followed by a colon. For example, if the current disk drive is C: and you want to use Drive F:, type:

```
F:
```

Then change to the desired working directory using the DOS CD command. Example:

```
CD \PIPECALC
```

It is possible to use full path names for the files to place them in any desired directory. Example:

```
CONIND F:\PIPECALC\MODEL1 F:\PIPECALC\RESULTS1 F:\PIPECALC\STEADY1
```

However, the logging file, if used, will always be placed in the current directory.

Example file names are used to illustrate the program use, but any valid file name could be used. There are two main usage options. Each can have the logging output added as desired. If the logging file is not wanted, the word **LOG**, at the end, is omitted.

The first option is for a single calculation.

## CONIND REFERENCE MANUAL

---

---

### CONIND MODEL1 RESULTS1 STEADY1 LOG

File **MODEL1** contains all the pipeline information using the keywords that are described in Section 5. This is called the “Pipeline model data file”.

File **RESULTS1** will contain the calculation results after the program has run. If a file by that name already exists, it will be overwritten and the information it contained before, will be lost.

File **STEADY1** contains information about the currents flowing in the power line conductors. This is called the “Power line currents data file”.

The second option has another input data file that has been named **DIFF1**. Of course, any valid name could be used.

### CONIND MODEL1 RESULTS1 STEADY1 DIFF1 LOG

Files **MODEL1**, **RESULTS1** and **STEADY1** have the same function as before. The extra file **DIFF1** contains different sets of current data for some of the power lines. Elsewhere this is called the “File of different currents information”. Using the extra file, it is easy to examine the effect of different phase rotations of the power lines or faults on different phases or circuits.

CONIND is a “filter” program because it filters the input data to produce an output file of results.

The sample files provided, can be used for demonstration. They are regular text files that can be edited with the Windows Notepad editor or any other text editor. If a word processor such as Word Perfect or Word for Windows is used, the files must be saved in text mode.

## 3. ANALYSIS OF MODELS

The term “model” is used frequently to refer to the computer model of the actual pipeline system. As discussed in Section 2, CONIND uses a “filter” process to filter input data and generate an output file of results from it. There are three main steps to carrying out a CONIND analysis:

1. Develop the input data files.
2. Do the calculation.
3. Review the results and extract the required information.

### 3.1 *Developing the Input Data Files*

#### 3.1.1 Units of Measure

The program uses metric units as a default. Metres are used for all the dimensions except the pipe wall thickness, wire diameter and pipe coating thickness, which are in mm. Also, the coating resistance is in  $k\Omega\text{-m}^2$ , soil resistivity is in  $\Omega\text{-metres}$  and metal resistivity is in  $\mu\Omega\text{-metres}$ .

As an option, some of the data can be entered in English measure (inches and mils) by using the **MIXED\_DATA** keyword. This option is useful in North America, but still requires that some data be in metric measure. Pipeline lengths and the distances to power lines must always be provided in metres. Soil resistivity is always in  $\Omega\text{-metres}$  and metal resistivity is always in  $\mu\Omega\text{-metres}$ . However, pipe diameter, depth and wall thickness are entered in inches and pipe coating resistance is in  $k\Omega\text{-ft}^2$ . The **MIXED\_DATA** keyword is more likely to introduce errors in the data files due to the unusual mixture of measurement units and should be avoided. Its main purpose was to provide backward compatibility with older versions of CONIND.

#### 3.1.2 Definitions

The following terminology is used:

- ground** The terms **ground**, **grounded**, **grounding** etc. are used to indicate an electrical connection to the earth. This terminology is widely used in North America. It is equivalent to the use of earth, earthed, earthing etc. in many other countries.
- keyword** A **keyword** is a special word that the program recognises and uses to read input data. Most, but not all, **keywords** expect other data in a certain format. Keywords can be in upper or lower case or a mixture of cases.
- node** A **node** is a point in the pipeline network that has one or more pipe segments connected to it. **Nodes** are identified by numbers - examples 23 1 267. Any numbering scheme can be used, however, the present version of the program will allocate memory based on the highest node number. Therefore, it is best to use a con-

secutive numbering scheme starting with 1, which is the lowest node number allowed.

**WARNING** The numbering of nodes and model configuration is completely flexible. Any scheme can be devised by the user. Particularly with large models, a numbering scheme should be used that makes it difficult to accidentally use the same numbers in different parts of the model. There is presently no reasonable way to check for errors of this type. For example, if the number 239 is used at one end of a long pipeline model and, in error, the same number is used somewhere else, they will be interpreted as the same nodes. CONIND will solve the model as if the two places in the pipeline are interconnected.

**potential** The term potential is often used to mean the voltage relative to ground. It is the same as voltage. Its use has been avoided in this manual and in the CONIND software.

**segment** A **segment** is a length of pipeline that has constant parameters such as diameter, wall thickness, coating resistance and burial depth. The distance to parallel power line conductors can be variable in some **segments** as the distance can be specified at the start and end of the **segment**. A **segment** must be located between two nodes. Segments are described using keywords, numbers and, in some cases, power line codes.

### 3.1.3 Calculation Frequency

Pipeline impedance and power line coupling are frequency dependent. The keyword **FREQUENCY** can be used to specify a particular calculation frequency. The following lines somewhere in the input data file will set the frequency for calculations to **50.0 Hz** for all data in the input file.

```
FREQUENCY  
50.0
```

If no frequency is specified, CONIND will use a frequency of **60 Hz**.

### 3.1.4 Mitigation Wires

CONIND includes the capability to model the effects of mitigation wires. A mitigation wire is a length of buried bare wire that is placed in such a location that the inductive coupling effect between the power lines and the wire, opposes the coupling effect to the pipeline. This arrangement can be used to reduce the induced voltages on the pipeline.

The application of mitigation wires is believed to be rare for the following reasons:

- It is expensive to implement. Long wires must be buried. Other methods of making the pipeline voltage rise safe, such as ground grids at valve stations, are cheaper.
- It usually requires that the wire be installed on the opposite side of the power line. The pipeline company usually does not have right-of-way in that area.

### 3.1.5 Files Required

The input data files for CONIND analyses are standard text files. They can be created, viewed and modified with any text editor such as the Windows NotePad program or a word processor such as Microsoft's Word for Windows in text mode.

For complicated models with many pipeline segments and parallel power line conductors, a spreadsheet program can be used to generate part or all of the input data. With a spreadsheet it is possible to assign numbers to pipeline nodes and have the numbers increase in sequence where there are many similar segments. The appropriate area of the spreadsheet can be saved in text mode or blocked and copied to a NotePad file. Spreadsheet programs often use tab characters as column separators when the spreadsheet is saved in text mode. This does not present a problem as CONIND treats tabs as if they are spaces.

At least two data files must be developed before analyses can begin. File #3 is optional.

- File #1: Pipeline model data file.
- File #2: Power line currents data file.
- File #3: File of different currents information.

### 3.1.6 File #1 Pipeline Model Data File

The backbone of the data format is to represent the pipeline network as a series of segments. Each end of a **segment** must be connected to a **node**. Any number of **segments** can be connected to the same **node**. The number of nodes and segments is only limited by computer memory. Data storage is efficient and it is difficult to conceive of a pipeline model that would exceed the memory available in any recent model computer.

The data description usually starts at one end of the pipeline network or the end of a branch (however, it can start anywhere in the network). It is not necessary that the pipeline be continuous. There can be one or more completely separate parts to the pipeline system. The effects of installing insulating flanges or removing segments of pipeline for maintenance, can be examined by breaking the model at the point of interest.

The data format is progressive in the sense that, as one progresses through the input data, conditions remain the same until they are changed.

For example, soil resistivity is a parameter that can be specified. The default value is 100  $\Omega$ -metres. Therefore, this value of soil resistivity will be used for all pipeline segments up to the point in the input data file where the soil resistivity is changed to another value, say 470  $\Omega$ -metres. The new value then applies from that point on. The soil resistivity can be changed to other values as often as required, further along in the model.

As mentioned, pipeline segments can start anywhere in the network, but it is prudent to select a starting point with a view to the required results. Usually, the voltage profile will be required along part of the pipeline. By using a continuous sequence of node numbers for that part of the pipeline, it is easy to extract the voltage data from the calculation results. The keyword **NODES**

## CONIND REFERENCE MANUAL

---

can be used to limit output to only the required set of nodes, but they will always be listed in numerical order.

Input data consists of keywords and numbers. The keywords **SEC**, **CSEC**, **VCSEC** are used to specify the pipeline segments. **SHUNT** is used to specify shunt impedances that are added between the pipeline and ground. **LINE** and **VLINE** are used to specify the current in parallel conductors. Other keywords such as **CURRENTS**, **DETAIL**, **DIAM**, **MULT**, **SOIL** and **WALL** are used to change other parameters, program output format and the way that the program works.

The following is part of a data file that illustrates the use of some of the keywords. Keywords can be in upper or lower case or a mixture of upper and lower case.

```
currents
detail
mixed_data
soil
350
coat
1076.4
diam
10.75
wall
0.2992
vcsec
1 2 4000 0
vcsec
2 11 230 0
10.0 20.0 15.0 20.0 2L36A
12.0 22.0 17.0 22.0 2L36b
14.0 20.0 19.0 20.0 2L36c
node_diff
11 14
shunt
1 11.0 0.0 0.0
END
```

Referring to the above data:

The word **currents** is a keyword. When it is used, the calculations results will include information about currents that flow through the pipeline and how they leak out of and into the ground. If **currents** was not specified, only pipeline voltage information would be listed.

Keyword **detail** specifies that the results of multiple cases done using the difference file, will be detailed. The node voltage results for each case will be listed as well as the worst case.

Keyword **mixed\_data** specifies that the input data file used the format with some parameters in English measure of feet, inches and mils.

Keyword **soil** specifies the soil resistivity that will be used for all the pipe segments that follow until there is a new **soil** keyword. The soil resistivity is 350  $\Omega$ -metres, given on the next line.

## CONIND REFERENCE MANUAL

---

---

Similarly **coat**, **diam** and **wall** set the pipeline coating resistance to 1076 k $\Omega$ -ft<sup>2</sup>, pipeline diameter to 10.75 inches and pipeline wall thickness to 0.2992 inch. These dimensions would be in k $\Omega$ -m<sup>2</sup>, metres and mm if the **mixed\_data** keyword had not been used.

The **vcsec** keyword specifies a variable distance coupled segment of pipeline. The first time this is used in the above example, it is followed by a single line: **1 2 4000 0**. This line gives the node numbers of the start and end and the length of the pipeline segment. The segment is from Node 1 to Node 2 and is 4000 metres long. Length is always in metres, even with the **mixed\_data** keyword.

The last number **0** is the soil voltage next to the pipeline. This is usually 0, but if the pipeline is buried near a substation ground grid that causes voltage rise in the soil, the effect can be included. Because there are no other data lines before the next keyword, there is no power line coupling with this segment of pipeline.

The second time the **vcsec** keyword is used, it is for a segment between Nodes 2 and 11. This time there are more lines of data such as: **10.0 20.0 15.0 20.0 2L36A** These lines specify power line coupling to the pipeline.

In this example, there is a power line conductor called 2L36A. At the start of the segment, it is 10 metres from the pipeline and 20 metres above ground. At the end of the segment, it is the same height of 20 metres, but the distance is 15 metres from the pipeline. This could be stated as <x co-ordinate at start of segment> <y co-ordinate at start of segment> <x co-ordinate at end of segment> <y co-ordinate at end of segment>

2L36A is a conductor name that could mean "Transmission line 2L36 - Phase A". When the **vcsec** keyword is used, the steady currents file must list the conductor names used and the real and imaginary currents that flow in the conductors. There can be any number of parallel conductors such as 2L36B and 2L36C in the above case. Also, the conductors need not be completely parallel, because the x-distance at the start of the segment is different from the x-distance at the end. Internally, CONIND will approximate the angled coupling by breaking the parallel exposure into small pieces, each of which is parallel to the pipeline, but at a different distance.

The **node\_diff** keyword is used to specify pairs of node numbers between which voltage difference calculations are required. Here, nodes **11** and **14** are specified. CONIND will print out the voltage difference between these nodes. This is useful for examining the voltage difference across an insulating flange in the pipeline.

The **shunt** keyword is used to add ground impedances to pipeline nodes. In this example: **1 11.0 0.0 0.0**, there is an impedance of 11.0 + j0.0  $\Omega$  from Node 1 to ground. The last number 0.0 is the soil voltage. Usually this is 0, but, as for the **vcsec** keyword above, it could be higher if the ground impedance is in soil near a substation that has a ground voltage rise or the **shunt** impedance could be a substation ground grid impedance and its ground voltage rise.

The pipeline model data must finish with the keyword **END**. CONIND will not read any more data after the word **END**.

---

---

### 3.1.7 File #2 Power Line Currents Data File

This file must exist. It lists the conductor current information for all the power line conductors. The format is as in the following example:

```
2L103A      1210      0
2L103B      -605 -1047.89
2L103C      -605  1047.89
2L104A       0      0
2L104B       0      0.00
2L104C       0      0.00
60L380A     460      0
60L380B    -230 -398.37
60L380C    -230  398.37
END
```

The file can be empty and just have the word **END**. In that case, all the power line current information must be supplied using the less convenient **LINE** and **SEC** or **CSEC** keywords in File #1.

The format for each line is to use an identifier that can be any combination of letters and numbers or symbols to represent the current carrying conductors, followed by the real and imaginary parts of the actual current flowing in that conductor. For example, the line **60L380B -230 -398.37** specifies that -230 -j398.37 amps is flowing in the conductor **60L380B**. The electrical utility names its 69 kV power lines **60L\*\*\*** where the **\*\*\*** is a number for the line. In this case it is 69 kV power line number 380. The individual conductors are A, B and C for the A, B & C phases. This is just a suggested naming scheme and any other naming scheme could be used.

There must be a conductor name in File #2, to match every name used with **VCSEC**. If the same name is used twice, the program will stop with an error message. The names are considered the same regardless of the letter case used. Therefore **60L380B** is the same as **60L380b**.

### 3.1.8 File #3 File Of Different Currents Information

This file is optional. If it is used, the **MULT** keyword can only have one pipe coating resistance multiplier because the program output will be for the worst of all pipeline voltages and all calculations should use the same pipeline coating resistance.

If calculations are required for a set of different currents and different coating resistance multipliers, they can be done with separate runs of the program, each using one coating multiplier than could be set to 0.5, 1.0 and 2.0 for example.

The format is similar to File #2. It allows calculations to be repeated for different currents in some of the power line conductors. This example shows the effect of changing the phase relationship of the power line conductors from ABC to BCA and CAB. The word **END** terminates each set of conductor current changes.

```
60L380A     -230  398.37
60L380B      460      0
60L380C    -230 -398.37
```

```

END
60L380A      -230  -398.37
60L380B      -230   398.37
60L380C       460    0
END
    
```

Another application is to consider ground fault currents on some conductors. CONIND saves the worst result, which is the one giving the highest magnitude pipeline voltage at each node in the model, or the highest difference voltage where the **NODE\_DIFF** keyword has been used.

The above process is very powerful. With careful planning, many different cases can be examined to obtain the worst of all cases. The output file will list which case was the worst one. If **detail** is used, only the worst case results will be saved in the output. Otherwise the node voltages for all cases will be saved.

### 3.2 Sample Data File

A simple example has been provided to illustrate how CONIND input data files are developed. Figure 3.1 shows the layout of the pipeline and power line. Node numbers 1 through 6 have already been assigned.

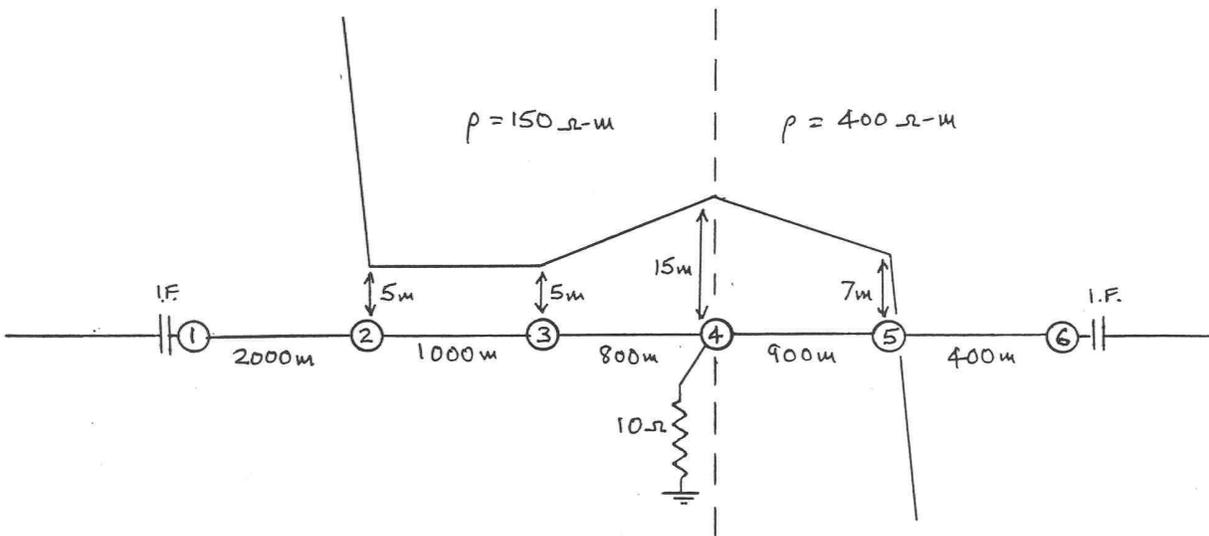


Figure 3.1. Example Pipeline Analysis

The pipeline is 5.1 km long between insulating flanges. There is no power line coupling for the first 2 km from Node 1 to Node 2. The power line comes in at right angles at Node 2 and is 5 metres to the left of the power line for 1000 metres up to Node 3. The spacing then increases over the next 800 metres to 15 metres at Node 4.

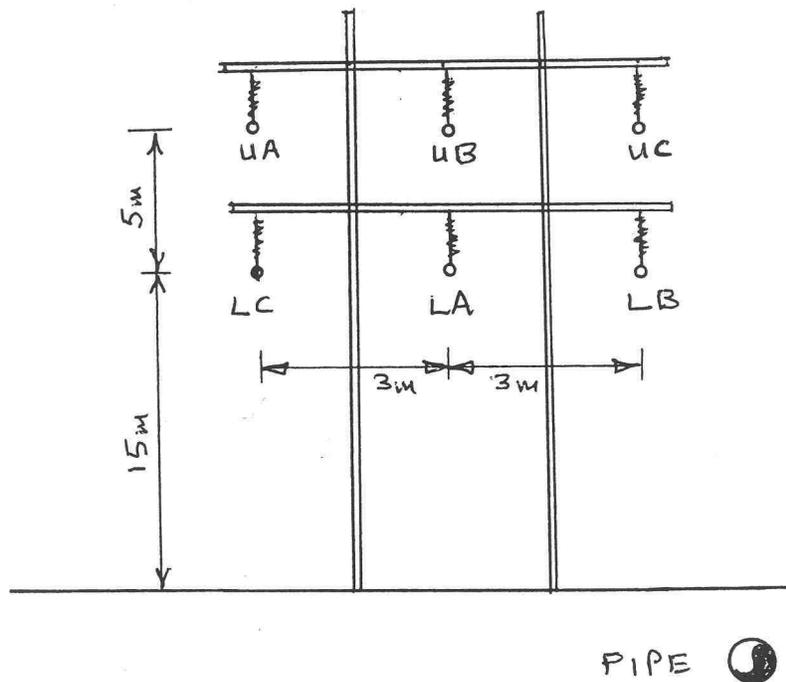
There is a ground resistance of 10 Ω at Node 4. This could be a magnesium anode or any ground electrode. The spacing decreases again over the next 900 metres to 7 metres at Node 5, at which point the power line leaves the pipeline. There is another insulating flange 400 metres further

## CONIND REFERENCE MANUAL

along. The pipeline and power line are viewed from the left of the Figure so that where the power line is parallel to the pipeline, it is to the left of the pipeline.

The soil resistivity is 150  $\Omega$ -metres up to Node 4 and then changes to 400  $\Omega$ -metres.

Figure 3.2 shows the power line configuration. It is a double circuit line. The conductor heights are the heights at the towers. It is assumed that the average height is 2 metres lower due to conductor sag. The conductors have been given names UA, UB and UC to mean the phase conductors of the upper three-phase circuit and LA, LB and LC, corresponding conductors for the lower three-phase circuit.



**Figure 3.2. Example Power Line Configuration**

Other parameters are:

Pipeline diameter	0.6 metre
Pipeline wall thickness	5 mm up to Node 3, then 7 mm
Pipeline steel resistivity	0.19 $\mu\Omega$ -metres
Pipeline steel relative permeability	365
Pipeline coating resistance	10 $k\Omega$ -metre <sup>2</sup>
Pipeline coating thickness	1.5 mm
Pipeline coating relative permittivity	2.1
Pipeline burial depth	1.5 metres below ground
Electrical power frequency	50 Hz

## CONIND REFERENCE MANUAL

---

We have chosen to develop the model from left to right. The parameters that will affect the first segment of pipeline between Nodes 1 and 2 should be stated first. They will apply until some are changed further along in the file. The keyword **CURRENTS** will list the currents in the pipeline segments:

```
CURRENTS
DIAM
0.6
WALL
5
STEEL
0.19
MU
365
COAT
10
COAT_THICK
1.5
COAT_PERM
2.1
DEPTH
1.5
FREQUENCY
50
SOIL
150
```

The first segment of pipe can now be added. The pipeline segment keywords that could be used are **SEC**, **CSEC** and **VCSEC**. The difference between these three keywords is now be discussed.

If **SEC** is used for a pipeline segment, the inductive coupling from parallel current carrying conductors must first be established using **LINE** or **VLINE** statements to set up the electric field along the pipeline. **SEC** is most useful when there are some segments with the same parallel exposure to power lines, because the parallel exposure can be set up once using **LINE** or **VLINE** and then the **SEC** statements only consist of the node information, length and soil voltage (usually 0). If the parallel exposure changes every segment, **LINE** or **VLINE** and **SEC** must be used for each segment and it becomes more complicated than using **CSEC** or **VCSEC**. (However, it must be noted that because **LINE** and **VLINE** have not yet been used, the electric field is zero and **SEC** could be used for this segment, which has no coupling. This only applies at the start of the file before **LINE** or **VLINE** have been used)

It is therefore easier and less prone to data input error, to use **CSEC** or **VCSEC** for the first uncoupled segment. Either can be used, the only difference being the keyword. To demonstrate both keywords, **CSEC** will be used. **VCSEC** will be used for later segments.

```
CSEC
1 2 2000 0.0
```

## CONIND REFERENCE MANUAL

---

There are no coupled conductor statements following the line with node numbers, length 2000 metres and 0.0 soil voltage, therefore, there is no inductive coupling of this pipe segment. The two lines specify 2000 metres of pipeline with all the parameters previously given such as soil resistivity, coating resistance, wall thickness etc.

Although it has no coupling with power lines, this segment will have induced voltage that is conducted from the other segments that are parallel to the power line. The voltage will change as one moves from Node 1 to Node 2. If more information was required, perhaps to find where the induced voltage reaches a less hazardous value, the first segment could be split into a number of shorter segments with a reorganisation of the node numbering.

The continuing segments can be specified using **CSEC** or **VCSEC**. It is more convenient to use **VCSEC** because the currents in the 6 conductors only have to be stated once in the power line currents file. It will be easier to modify them later if needed, because only one set of numbers needs to be modified in that file. The power line currents file is discussed now.

The file specifies currents using codes. Suitable codes have already been given in Figure 3.2. For the top three-phase circuit, from left to right, UA, UB and UC. For the bottom circuit, LC, LA and LB. For a three phase system carrying a balanced current of I amps, the vector currents are:

A	I	$j0.0$
B	$-I/2$	$-j^{3/2}I$
C	$-I/2$	$+j^{3/2}I$

The vectors current using 500 amps for the upper circuit and 350 for the lower one are:

UA	500	0.0
UB	-250	-433.0127
UC	-250	433.0127
LA	350	0.0
LB	-175	-303.1089
LC	-175	303.1089
END		

The above is the exact data that needs to be typed into the steady currents file. If the model direction reverses somewhere, the power line currents can be reversed by changing all the signs of the vector real and imaginary values.

The pipeline model file can now use the circuit currents by referring to the codes UA, UB, UC, LA, LB and LC. the second segment from Node 2 to Node 3 is specified as follows.

```
VCSEC
2 3 1000 0.0
-8 18 -8 18 UA
-5 18 -5 18 UB
-2 18 -2 18 UC
-8 13 -8 13 LC
-5 13 -5 13 LA
-2 13 -2 13 LB
```

## CONIND REFERENCE MANUAL

---

Note that the above has included the sag of the conductors that reduces the average height by 2 metres and that the phase order of the lower circuit is CAB while the upper is ABC. Also, the x and y co-ordinates of the start and end of the segment are the same.

In the next segment, the currents are different and the pipeline wall thickness changes to 7 mm. Therefore a **WALL** statement is needed.

```
WALL
7
VCSEC
3 4 800 0.0
-8 18 -18 18 UA
-5 18 -15 18 UB
-2 18 -12 18 UC
-8 13 -18 13 LC
-5 13 -15 13 LA
-2 13 -12 13 LB
```

The soil resistivity changes for the next segment. The **SHUNT** resistance at Node 4 can be added here. (It could be added anywhere in the model):

```
SOIL
400
SHUNT
4 10.0 0.0
VCSEC
4 5 900 0.0
-18 18 -10 18 UA
-15 18 -7 18 UB
-12 18 -4 18 UC
-18 13 -10 13 LC
-15 13 -7 13 LA
-12 13 -4 13 LB
```

The last 400 metres of the pipeline has no power line coupling.

```
VCSEC
5 6 400 0.0
END
```

The above data has been typed into the sample data files **MODEL1** and **STEADY1**. The results are provided in the file **RESULT1**. The logging file has been renamed from **LOG. \$\$\$** to **LOG1. \$\$\$**.

Another file, **MODEL2** is provided. It shows the use of the **LINE**, **SEC** and **CSEC** keywords to produce the identical results. The same **STEADY1**. file can be used for this analysis, but the information it contains is ignored because all the current information is contained in **MODEL1**. The logging file **LOG2. \$\$\$** is different in this case. It can be seen that using the **VCSEC** keyword results in a less complicated pipeline model file.

### ***3.3 Doing the Calculation***

Open a Command prompt window and change to the disk drive and directory where the sample data files are stored.

Providing **CONIND.EXE** is installed on the computer PATH, the calculations can be done by typing the following:

```
CONIND MODEL1 MYRESULT1 STEADY1 LOG
```

The calculation will be very fast because there are no pipeline loops and it is a small model. A real study model could have 100's of pipeline segments and some loops. The calculation progress is displayed on the screen as it progresses.

The output file has been named **MYRESULT1** so that it will not overwrite the sample output file **RESULT1**. The two results files should be identical except for time and date differences.

The calculation using the second version of the data file can be done in a similar way:

```
CONIND MODEL2 MYRESULT2 STEADY1 LOG
```

If there are any errors in the input data file, the program will stop and display an error message. There are many possible error messages.

### ***3.4 Reviewing the Results of the Calculation***

The calculation results can be viewed using a text editing program such as NotePad. The columns of text are quite wide and if NotePad is used, a screen size of 1280 X 1024 is needed to view the text files.

If you edit the **RESULT1** file, you will see the following:

# CONIND REFERENCE MANUAL

CONIND Version: 1.20 Date: Apr 9 2000  
 Copyright Ground-it.com Consulting Ltd.  
 NETWORK CALCULATIONS FOR INPUT FILE: C:\CONIND11\SAMPLES\MODEL1  
 Started at: Sun Apr 09 19:09:53 2000

Frequency: 50.00 Hz  
 Calculation results for Coating Resistance Multiplier 1.00

Segment Information (P = pipe, W = wire)

Seg #	From Node	To Node	----Current into segment----			---Current out of segment---			-----Current into soil-----		
			real amps	imag amps	mag amps	real amps	imag amps	mag amps	real amps	imag amps	mag amps
1P	1	2	-0.000	-0.000	0.000	0.405	-0.776	0.875	-0.405	0.776	0.875
2P	2	3	0.405	-0.776	0.875	0.554	-1.006	1.148	-0.149	0.230	0.274
3P	3	4	0.554	-1.006	1.148	0.506	-0.914	1.044	0.048	-0.092	0.104
4P	4	5	0.417	-0.730	0.841	0.165	-0.283	0.328	0.252	-0.447	0.513
5P	5	6	0.165	-0.283	0.328	-0.000	-0.000	0.000	0.165	-0.283	0.328

Node Information

#	----Node Impedance----		-----Node Voltage-----		
	real	imaginary	real	imaginary	magnitude
1	1.356	0.791	-0.921	2.287	2.465
2	1.111	0.218	-1.360	2.182	2.571
3	1.088	0.177	-0.254	0.500	0.561
4	1.144	0.242	0.890	-1.837	2.041
5	1.262	0.562	2.439	-4.615	5.220
6	1.312	0.758	2.405	-4.626	5.214

Completed at: Sun Apr 09 19:09:53 2000  
 Compute time: 0 hr. 0 min. 0 sec.

The first part of the output lists the date, time and ac frequency used. The line: Calculation results for Coating Resistance Multiplier 1.00 means that the calculation was done using the specified pipeline coating resistances. As coating resistance is a difficult parameter to determine, CONIND provides the **MULT** keyword. If **MULT** is not used, only one calculation is done, using the specified coating resistances. When **MULT** is used, it can be followed by one or more coating resistance multipliers. For example:

```

MULT
0.5
1.0
2.0
  
```

will repeat the calculation three times using coating resistances that are 50% of the specified values, then 100% and last 200%. It applies to all the coating resistances used in the model. In the sample file, only one coating resistance of 10 kΩ-metre<sup>2</sup> was used. Therefore the calculations would be done with 5, 10 and 20 kΩ-metre<sup>2</sup> coatings.

The segment information follows. Because the **CURRENTS** keyword was used, the following block of results is listed:

Segment Information (P = pipe, W = wire)

Seg #	From Node	To Node	----Current into segment----			---Current out of segment---			-----Current into soil-----		
			real amps	imag amps	mag amps	real amps	imag amps	mag amps	real amps	imag amps	mag amps
1P	1	2	-0.000	-0.000	0.000	0.405	-0.776	0.875	-0.405	0.776	0.875
2P	2	3	0.405	-0.776	0.875	0.554	-1.006	1.148	-0.149	0.230	0.274
3P	3	4	0.554	-1.006	1.148	0.506	-0.914	1.044	0.048	-0.092	0.104
4P	4	5	0.417	-0.730	0.841	0.165	-0.283	0.328	0.252	-0.447	0.513
5P	5	6	0.165	-0.283	0.328	-0.000	-0.000	0.000	0.165	-0.283	0.328

The 'P' after each segment number means that it is a pipeline segment. The letter would be 'W' if it was a mitigation wire segment. The listing shows the current flowing into one end of the

## CONIND REFERENCE MANUAL

---

---

segment and out of the other and the current flowing to ground from the segment. Each current is given in complex notation (real and imaginary part) followed by the magnitude.

As can be seen, the current flowing out of Segment 2P is the same as the current flowing into Segment 3P. This is not true for Segment 3P and 4P because there is a shunt resistance of 10  $\Omega$  at Node 4. Some current leaks into the ground at this node.

The node voltage listing follows:

### Node Information

#	----Node Impedance----		-----Node Voltage-----		
	real	imaginary	real	imaginary	magnitude
1	1.356	0.791	-0.921	2.287	2.465
2	1.111	0.218	-1.360	2.182	2.571
3	1.088	0.177	-0.254	0.500	0.561
4	1.144	0.242	0.890	-1.837	2.041
5	1.262	0.562	2.439	-4.615	5.220
6	1.312	0.758	2.405	-4.626	5.214

It can be seen that the induced voltage for this small pipeline model starts at 2.465 volts at one end and increases to 2.571 volts where the power line first meets the pipeline. It decreases to 0.561 volts at Node 3, not, as may be expected, at the grounded node, which is Node 4. It increases again to 5.22 volts where the power line leaves the pipeline.

This simple model shows a characteristic of pipeline coupling where there will be a peak voltage at the points where the power line and pipeline meet and zero voltage somewhere between. The zero point could be found by using smaller pipeline segments, say 100 metres long.

The logging file should be used to check that the program has interpreted the model data correctly. It contains even wider columns of numbers and is best viewed on a computer screen or printed out in landscape mode on large paper. A very small font has been used to list the logging file for this run:

```
CONIND Version: 1.20 Date: Apr 10 2000
Copyright Ground-it.com Consulting Ltd.
NETWORK CALCULATIONS FOR INPUT FILE: MODEL1
Frequency: 50.00 Hz

Pipe depth 1.0000 metres
Pipe coating thickness 1.000 mm
Pipe coating relative permittivity 2.300
Pipe steel resistivity 0.170000 micro-ohm metres
Pipe steel relative permeability 300.00
Wire depth 1.0000 metres
Wire resistivity 0.017241 micro-ohm metres
Wire relative permeability 1.00

CASE #1
New steel resistivity -> 0.190000 micro-ohm metres
New steel relative permeability -> 365.00
New pipe coating thickness -> 1.500 mm
New pipe coating permittivity -> 2.100
New pipe depth -> 1.5000 metres
```

# CONIND REFERENCE MANUAL

```

PIPE: | Length | Diam | Wall | Coating R | Soil Res | Soil pot | Electric Field | Conductor Loc | Mutual Z | Conductor Curr
From| To| km | metres | mm |k-ohm m sq| ohm-m |@ Base A |volts/km| volts/km|x metre|y metre| ohm/km| ohm/km|real amp|imag amp
  1  2  2.000 0.6000 5.000 10.00 150.0 0.00 0.00 0.00
  2  3  1.000 0.6000 5.000 10.00 150.0 0.00 0.00 0.00
Current carrying conductor -> 24.29 125.80 <<<<angled>>> 0.04858 0.25159 500.00 0.00
Current carrying conductor -> 122.34 41.14 <<<<angled>>> 0.04858 0.25448 -250.00 -433.01
Current carrying conductor -> -0.73 -1.86 <<<<angled>>> 0.04858 0.25615 -250.00 433.01
Current carrying conductor -> -90.05 -33.71 <<<<angled>>> 0.04881 0.26651 -175.00 303.11
Current carrying conductor -> -72.96 61.26 <<<<angled>>> 0.04881 0.27133 350.00 0.00
Current carrying conductor -> 1.63 -1.53 <<<<angled>>> 0.04881 0.27426 -175.00 -303.11
  3  4  0.800 0.6000 7.000 10.00 150.0 0.00 0.00 0.00
Current carrying conductor -> 24.29 122.37 <<<<angled>>> 0.04856 0.23720 500.00 0.00
Current carrying conductor -> 119.89 39.13 <<<<angled>>> 0.04857 0.24196 -250.00 -433.01
Current carrying conductor -> -1.47 -2.88 <<<<angled>>> 0.04857 0.24646 -250.00 433.01
Current carrying conductor -> -87.67 -32.94 <<<<angled>>> 0.04879 0.24567 -175.00 303.11
Current carrying conductor -> -70.59 58.88 <<<<angled>>> 0.04879 0.25211 350.00 0.00
Current carrying conductor -> 1.99 -2.75 <<<<angled>>> 0.04880 0.25857 -175.00 -303.11
  4  5  0.900 0.6000 7.000 10.00 400.0 0.00 0.00 0.00
Current carrying conductor -> 24.43 136.92 <<<<angled>>> 0.04887 0.27960 500.00 0.00
Current carrying conductor -> 132.65 46.22 <<<<angled>>> 0.04887 0.28314 -250.00 -433.01
Current carrying conductor -> -1.60 -3.07 <<<<angled>>> 0.04887 0.28567 -250.00 433.01
Current carrying conductor -> -96.49 -38.05 <<<<angled>>> 0.04901 0.29315 -175.00 303.11
Current carrying conductor -> -79.33 63.81 <<<<angled>>> 0.04901 0.29881 350.00 0.00
Current carrying conductor -> 2.04 -2.98 <<<<angled>>> 0.04902 0.30311 -175.00 -303.11
  5  6  0.400 0.6000 7.000 10.00 400.0 0.00 0.00 0.00

Total Length of pipes in model: 5.10000 Km.
Total Length of mitigation wires in model: 0.00000 Km.

Shunt impedances added to nodes:

Node      Real ohms      Imag ohms      |Soil volts|
  4         10.0000         0.0000         0.0000

Base current used for soil voltages: 1000.00 0.00

```

The first part of the logging file lists the default values that are being used by the program. Except for the **DIAM**, **WALL**, **COAT** and **SOIL** keywords, whenever a keyword is used to change a parameter, there will be a statement to indicate the new value. For example:

```
New steel resistivity -> 0.190000 micro-ohm metres
```

This is not needed for the above four keywords because the changes are included in the main listing.

The main listing gives the Electric Field, Mutual Impedance (Mutual Z) and Conductor Current in complex (real and imaginary) notation. The listing shows that the first pipeline segment is not coupled to the power line because the electric field is zero. The listing gives the nodes, length, diameter, wall thickness, coating resistance, soil resistivity and soil voltage used. Other parameters such as the coating thickness are the most recent values previously listed:

```

PIPE: | Length | Diam | Wall | Coating R | Soil Res | Soil pot | Electric Field | Conductor Loc | Mutual Z | Conductor Curr
From| To| km | metres | mm |k-ohm m sq| ohm-m |@ Base A |volts/km| volts/km|x metre|y metre| ohm/km| ohm/km|real amp|imag amp
  1  2  2.000 0.6000 5.000 10.00 150.0 0.00 0.00 0.00

```

The next segment is coupled (The column headings have been added for clarity):

```

PIPE: | Length | Diam | Wall | Coating R | Soil Res | Soil pot | Electric Field | Conductor Loc | Mutual Z | Conductor Curr
From| To| km | metres | mm |k-ohm m sq| ohm-m |@ Base A |volts/km| volts/km|x metre|y metre| ohm/km| ohm/km|real amp|imag amp
  2  3  1.000 0.6000 5.000 10.00 150.0 0.00 0.00 0.00
Current carrying conductor -> 24.29 125.80 <<<<angled>>> 0.04858 0.25159 500.00 0.00
Current carrying conductor -> 122.34 41.14 <<<<angled>>> 0.04858 0.25448 -250.00 -433.01
Current carrying conductor -> -0.73 -1.86 <<<<angled>>> 0.04858 0.25615 -250.00 433.01
Current carrying conductor -> -90.05 -33.71 <<<<angled>>> 0.04881 0.26651 -175.00 303.11
Current carrying conductor -> -72.96 61.26 <<<<angled>>> 0.04881 0.27133 350.00 0.00
Current carrying conductor -> 1.63 -1.53 <<<<angled>>> 0.04881 0.27426 -175.00 -303.11

```

The coupling is calculated by the cumulative effect of the 6 parallel conductors that were specified by UA, UB, UC, LA, LB and LC codes in the input data.

For each conductor, CONIND calculates the mutual impedance between the pipeline and the conductor from the x and y offset information and the soil resistivity. This is listed in the **Mutual Z** column. The current in the conductor is given in the **Conductor Curr** columns. Because the conductors were entered using the **VCSEC** keyword where they can be non-parallel, they are

## CONIND REFERENCE MANUAL

---

---

shown as angled. The mutual impedance is actually a sum of the mutual impedances of a number of small pieces of the 1 km long parallel segment.

The electric field is calculated from the mutual impedance and the conductor currents. It is a cumulative calculation when **VCSEC** is used. The listing shows how the field is accumulated. The field starts at 0.0. The first conductor adds an electric field of  $24.29 + j125.80$  volts/km. The second conductor adds its electric field vectorially and the cumulative field is now  $122.34 + j41.14$  volts/km. When the electric field from the third conductor is added, the total becomes  $-0.73 - j1.86$ , which is quite small, but this expected because it is a balanced three-phase system. (One can anticipate that in an unbalanced ground fault situation, the resulting electric field is going to be much greater).

The electric field continues to be added for the other three phase conductors until the combined electric field is  $1.63 - j1.53$  volts/km. This last field is the field that CONIND uses to calculate the induced voltage on the pipeline. The listing shows the electric field accumulation for each segment of the pipeline model. It is always the last listed field that is used for the induced voltage calculation.

The logging file ends with other information:

```
Total Length of pipes in model: 5.10000 km.
Total Length of mitigation wires in model: 0.00000 km.

Shunt impedances added to nodes:

Node      Real ohms      Imag ohms      |Soil volts|
  4         10.0000         0.0000         0.0000

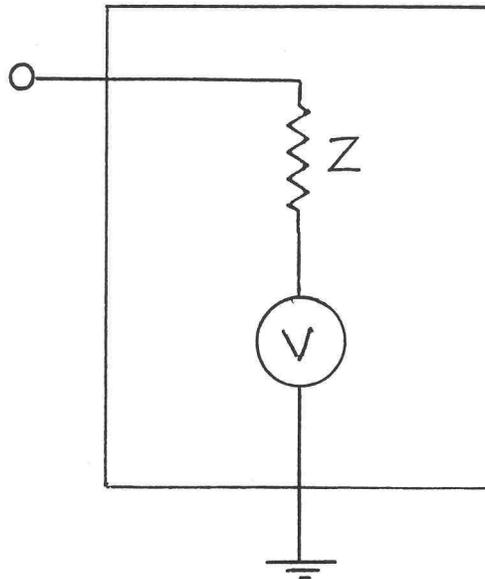
Base current used for soil voltages: 1000.00  0.00
```

There are a number of other features that can be used with CONIND, that are not illustrated by the above simple example, but are described elsewhere and in the listing of keywords.

#### 4. CALCULATION METHODOLOGY

CONIND uses a progressive Thevenin impedance resolution method to solve the pipeline network.

A Thevenin impedance is a combined impedance and driving voltage. It can be thought of as a “black box” shown in Figure 4.1, with two terminals, one of which is connected to ground. The “black box” contains a voltage source and an internal impedance, both of which are complex quantities, that form the “Thevenin impedance”. The Thevenin voltage would be measured at the open-circuit terminals of the black box. If the terminals are short circuited, the current  $I$  that flows will be established by the Thevenin voltage  $V$  and impedance  $Z$ :  $I = \frac{V}{Z}$ .



**Figure 4.1 Thevenin Circuit**

The procedure followed is based on the algorithms developed in Reference [1]. CONIND can only analyze coated pipelines, i.e. pipelines that have the steel pipe covered by an imperfect insulating material of some kind. Buried bare pipelines cannot be modelled, however, it is possible to include buried bare wires in the models.

Pipeline segments are analyzed as if they are lengths of ac transmission line. In the pipeline context, the transmission line is similar to a co-axial cable transmission line. While this concept is more commonly used for radio frequencies, it is equally applicable to coated pipelines with 50 or 60 Hz power systems.

A co-axial cable transmission line has a characteristic impedance usually called  $Z_0$  and a propagation constant  $\gamma$ . For typical co-axial cables,  $Z_0$  may be purely resistive with a resistance of 50 or 75  $\Omega$ . The pipeline is similar to a coaxial cable in that it has a core conductor, which is the pipe. The outer screening conductor is the soil, which is usually much more conductive than the pipe

coating. The insulating dielectric between the conductor and screen, is the pipe coating. For pipelines,  $Z_0$  will be complex ( $R + jX$ ), much lower than for co-axial cable in the range of a few  $\Omega$ 's or even less than 1  $\Omega$ .

### **4.1 Network Resolution**

CONIND starts the analysis at the “from node” of the first pipeline or mitigation wire segment in the data file. If there is an impedance to ground at that node, it will be the starting Thevenin impedance, otherwise a very high value of impedance is used. The starting Thevenin voltage will be 0.0 or, if a soil voltage was specified, it will be that voltage. If there are any other pipeline segments connected to the “from node”, they are added in parallel.

The combined Thevenin impedance now becomes a load on the end of the first pipeline or mitigation wire segment. Reference [1] develops algorithms that are used to calculate the Thevenin equivalent looking into the segment at the “to node”. The calculation includes all the effects along that segment. These are electric field due to the parallel power lines, physical structure of the segment such as coating resistance, wall thickness and steel permeability if it is a pipe or wire permeability and resistivity, if it is a wire segment.

The new Thevenin equivalent now becomes the starting point for the next step through the pipeline and mitigation wire network. Other Thevenin impedances due to shunt impedances of other pipelines, if they exist at this node, will be combined and the next segment of pipe will be evaluated.

In previous versions of the program, the analysis would start at open ends of the network and progress through the network until all the Thevenin equivalent circuits were solved. This resulted in one, fairly quick pass in each direction through the network and a definite solution. It did not permit pipeline looping. When there are loops, some pipeline segments cannot be resolved in this way, because all the Thevenin impedances at the end of a segment, may not yet be known and a combined result cannot be obtained.

The methodology now used, is to set all the Thevenin impedances to an arbitrary starting value of 1.0 +j0.0 volt and 1.0 + j0.0  $\Omega$ . CONIND then makes several passes through the network, replacing the starting values with new values that it calculates. It continues until the impedances stabilize. For networks that do not have loops, it will usually only require two or three passes to solve them. For networks with loops, 20 passes may be needed.

The method appears to be stable and to converge on a solution with minimal error. However, the input data configuration is so flexible that it may be possible to develop a model that will not converge. Such a model has not yet been created.

### **4.2 Calculation of Pipeline $Z_0$ and $\gamma$**

The pipeline  $Z_0$  and  $\gamma$  can be calculated using equations (2-9) and (2-10) from [1]. However, there are some errors in these equations and the effects of coating capacitance are not included. The equations are based on work by Sunde [2].

CONIND uses modified equations that include capacitance and are based on the original work by Sunde [2].

### 4.3 Pipeline Thevenin Calculation

The calculation of induced voltage on the pipeline is illustrated in Figure 4.2. For every pipeline segment in a pipeline model, it is possible to develop the equivalent of Figure 4.2. It consists of:

- A Thevenin equivalent on the right side, with voltage  $V_L$  and Impedance  $Z_L$  (both complex).
- A length of pipeline  $L$  km long that has a constant electric field  $E_0$  volts/km from the parallel power line conductors. The pipeline diameter, wall thickness, coating resistance, soil resistivity and other parameters are represented by the characteristic impedance  $Z_0$  and propagation constant  $\gamma$ .

The Thevenin calculation is based on equations (3-10b) and (3-10c) in [1]. When it is carried out, a new Thevenin impedance with voltage  $V_\theta$  and impedance  $Z_\theta$ , is calculated looking into the pipeline from the left side. The new Thevenin equivalent becomes the  $V_L$  and  $Z_L$  for the next pipeline segment. It may need to be combined with other Thevenins due to other pipeline segments and ground electrodes.

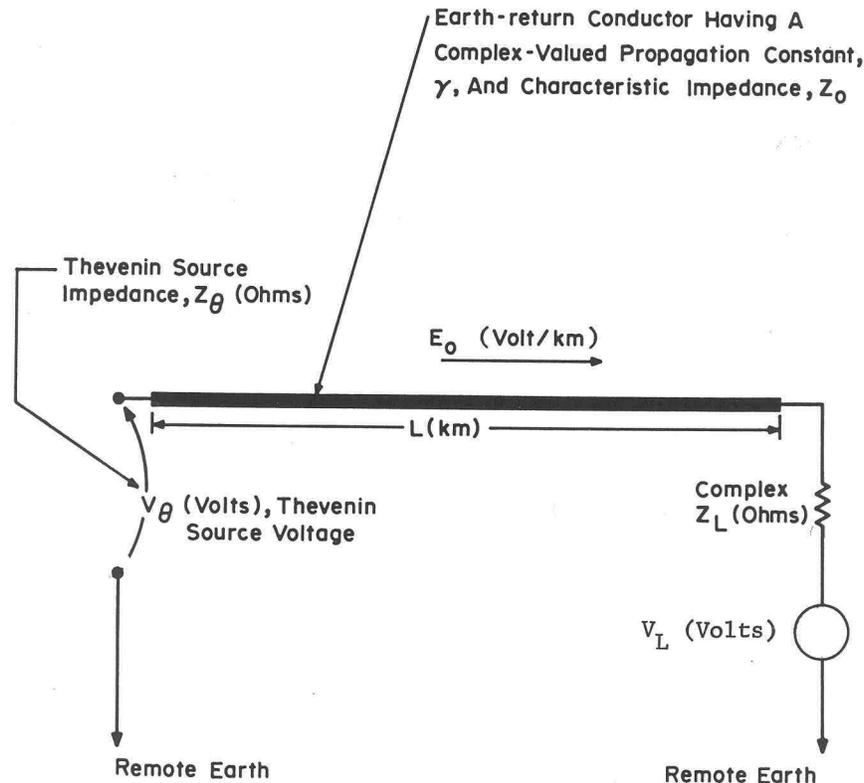


Figure 4.2 Pipeline Thevenin Calculation

#### 4.4 Combination of Thevenin Impedances

Where branch pipelines join and/or there are ground impedances, more than one Thevenin impedance must be combined. The following parallel combination calculation is done to produce a combined impedance.

The impedance part is a simple parallel combination:  $Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$ . The voltage part involves both

the impedance and voltage:  $V = \frac{Z_2 V_1 + Z_1 V_2}{Z_1 + Z_2}$

#### 4.5 Electric Field Calculation

The electric field along the pipeline is calculated from the mutual impedance between the power line conductors and the pipeline. Figure 4.3 shows a power line conductor 'a' and a second conductor 'b', which could be the pipeline if it were located below ground level.

Carson's infinite series [3,4] is used to calculate the mutual impedance (complex) between each power line conductor and the pipeline. The electric field  $E_0$  along the pipeline due to each power line conductor, is given by the product of the conductor current  $I$  and mutual impedance  $Z$ :  $E_0 = IZ$ . All are complex values.

If there is more than one parallel conductor, as is usually the case, the fields are added vectorially.

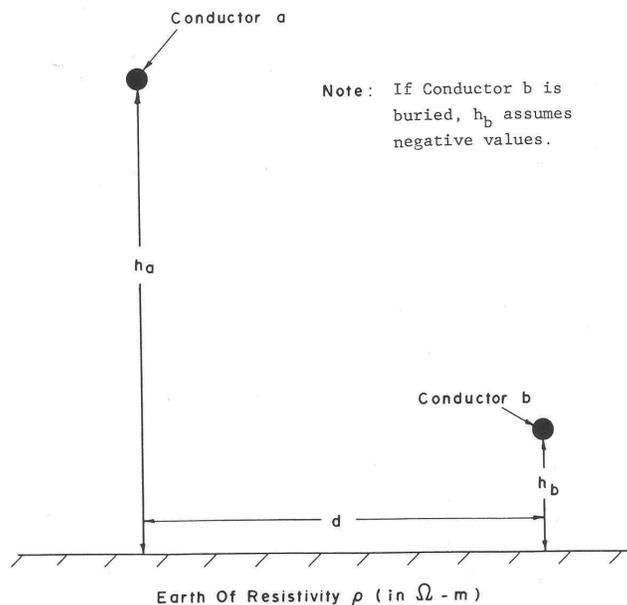


Figure 4.3 Conductor Geometry for Mutual Impedance Calculation

## 5. PROGRAM KEYWORDS

The CONIND input data format makes use of keywords. They can be in upper or lower case or a mix of upper and lower case.

Data must be organized on sequential lines in the input data file. Each line must be terminated by a carriage return. Completely blank lines are ignored. When more than one entry is required on a line, the entries must be separated by one or more space and/or tab characters. Leading spaces are ignored. Commas and other punctuation should not be used to delimitate between data items.

The present version of CONIND **does not allow** “comment lines” such as lines starting with an ‘\*’. Comments can be added after all the required data entries have been entered. For example, entering:

```
COAT
75.0
```

is the same as:

```
COAT
75.0 This is the coating of the new segment
```

Pipeline segments are considered to run **from** one node **to** another node. They are referred to as the “from node” and “to node”. Nodes can use any numbering scheme, but the present version of the program will allocate memory for the highest node number used. It is therefore best to start the node numbering at 1 (the lowest allowed number) and to keep the highest node number as small as practicable.

All vector quantities use rectangular co-ordinates of the format  $r + jx$ . The alternative polar co-ordinates  $r \angle \theta$  are not used.

Some keywords are only used once in the data file to indicate a global change for the program. Examples are: **CURRENTS**, **DETAIL**, **MULT**, **MIXED\_DATA**. When these keywords are used they apply to the complete analysis.

Other keywords can be used many times. Each time they are used, they specify a new value for some parameter, that will be used from that point on, until it is changed by another instance of the keyword.

Many keywords have default values that the program uses if other values are not specified by the user. To prevent incorrect analyses, the user should ensure that the parameter values he/she requires, are specified in the data. For example, if the keyword **SOIL** is not used, all the calculations will use a soil resistivity of 100.0  $\Omega$ -metres. The real soil resistivity may be quite different.

The keyword **MIXED\_DATA** is provided for backward compatibility with old pipeline models that used a mix of metric and English units of measure. When **MIXED\_DATA** is used, many, but not all of the dimensions, must be given in units such as inches, mils,  $k\text{-}\Omega \text{ ft}^2$  rather than metric. For

## CONIND REFERENCE MANUAL

---

---

example, pipe diameter and depth, must be given in inches rather than metres. The user is urged to avoid the **MIXED\_DATA** format and to use only metric dimensions.

Many of the keywords only allow certain ranges of values to be specified. For example, soil resistivity must be between 1.0 and 100000.0  $\Omega$ -metres. This is done to indicate use of unreasonable or impossible data and data errors. Practical models should all use data that is within these limits. If the program stops with an error message that a parameter is outside the valid range, it probably indicates an input data error that will not produce reliable results.

Keywords must be the first entry on a new line in the input text file. Keywords never have other entries on the same line. If parameters are required, they must be given on separate lines following the keyword.

The following is an alphabetical listing of the keywords used by CONIND.

**BASEA** This keyword is followed by the complex current flowing into a ground electrode which causes voltage rise in the soil adjacent to the pipe. The default is 1000 amps. When pipeline segments are specified with non-zero soil voltages, the voltages are assumed to be for 1000 amps fault current into a ground system. CONIND will scale the soil voltages to the value specified with BASEA.

Example, to scale the soil voltages for a real ground current of 1200 - j2489 amps:

```
BASEA
1200 -2489
```

**BASEA** is only useful when soil voltages are known and are not zero. It is not required in most models.

**COAT** Followed by the coating resistance in  $k\Omega$ -metres<sup>2</sup>. The default value is 10.0  $k\Omega$ -metres<sup>2</sup>. (If the **MIXED\_DATA** keyword is used, the coating resistance must be given in  $k\Omega$ -ft.<sup>2</sup> and the default value is 100.0  $k\Omega$ -ft.<sup>2</sup>)

Example to change the coating resistance to 50.0  $k\Omega$ -metres<sup>2</sup>:

```
COAT
50.0
```

**COAT\_PERM** Followed by the coating permittivity relative to free space. It is used with **COAT\_THICK** to calculate the capacitance of the coating. It is a dimensionless quantity. The default value is 2.3.

Example to change the coating permittivity to 1.9:

```
COAT_PERM
1.9
```

**COAT\_THICK** Followed by the pipeline coating thickness in mm. It is used with **COAT\_PERM** to calculate the capacitance of the coating. The default value is

## CONIND REFERENCE MANUAL

---

1 mm. (If the **MIXED\_DATA** keyword is used, the coating thickness must be given in mils (1 mil =  $1/1000$  inch) and the default value is 40 mils)

Example to change the coating thickness to 1.87 mm:

```
COAT_THICK
1.87
```

### **CSEC**

This is similar to **SEC**, but requires a complete specification of the coupled power line conductors. The full coupled line data must be entered each time **CSEC** is used and will only apply to this **CSEC**. **SEC** can also be used intermingled with **CSEC**, but **SEC** will always use the field that was determined by the most recent **LINE** data.

**Note A:** A quick way to enter a length of uncoupled pipe is to use **CSEC** with only the node, length and soil voltage data and no following lines. The field will then be zero.

The first line following **CSEC** is the same as for **SEC**. See keyword **SEC** for a full description:

<from node number> <to node number> <length in metres> <soil voltage volts>

This is followed by zero to any number (See **Note A** above) of lines describing the parallel conductors and their currents. These are similar to **LINE** data, but include both ends of each current carrying conductor. **LINE** only allows the average distance, which is considered constant. The format is:

```
x1 y1 x2 y2 r i
```

where: x1 and y1 are the x and y co-ordinates of the origin of the conductor relative to the pipeline, in meters.

x2 and y2 are the x and y co-ordinates of the extremity of the conductor relative to the pipe or wire, in meters.

r and i are the real and imaginary current in the conductor in amps

There is no default value.

Example of a 350 metre long pipeline segment, between nodes 12 and 13, with one end 10 metres from the centre of a power line and the other end 8 metres away. The power line has three phase conductors each carrying a current of 500 amps. One conductor is in the middle of the power line and the others are spaced 2 metres on each side. All are 18 metres above ground:

```
CSEC
12 13 350 0.0
8 18 6 18 500.0 0.0
10 18 8 18 -250.0 -433.01
12 18 10 18 -250.0 433.01
```

## CONIND REFERENCE MANUAL

---

---

**CURRENTS** No parameters required. This instructs the program to calculate the currents flowing in all segments of the pipe system. The default setting is that no currents will be calculated.

**DEPTH** Pipeline depth in metres. This is the depth from the soil surface to the centre of the pipeline in metres. As for the **DIAM** keyword, the pipeline depth must be greater than the diameter to ensure that the pipeline is buried, with some soil cover.

Default value is 1.0 metre. (If the **MIXED\_DATA** keyword is used, the depth must be given in inches and the default depth is 36.0 inches)

Example to change the pipeline depth to 1.25 metres:

```
DEPTH
1.25
```

**DETAIL** This keyword instructs the program to produce detailed output. For multiple runs, the full node voltage listing of all runs will be produced. The keyword can only be used once and then applies to the whole data file. It is not possible to have part of the calculation done with **DETAIL** and another part without it. It is not followed by any other data.

Example:

```
DETAIL
```

**DIAM** Followed by pipeline diameter in metres. The pipe diameter must be less than the burial depth or conversely, the pipe depth must be greater than the diameter. This ensures that there is a reasonable amount of soil over the top of the pipe and prevents the entry of meaningless data such as a pipeline with the top partially above the ground surface. Also, as stated under **WALL**, the wall thickness of the pipeline cannot be greater than 25% of the diameter.

The default is 0.3 metre. (If the **MIXED\_DATA** keyword is used, the diameter must be given in inches and the default size is 10.0 inches)

Example to change the pipeline diameter to 0.78 metres:

```
DIAM
0.78
```

**END** Keyword for the end of the data. No more data will be read. This must be the last line in the file.

Example:

```
END
```

**FREQUENCY** Sets the required frequency for the analysis in Hz. The default value is 60 Hz. The keyword can only be used once to set the frequency for the whole data file. It is

## CONIND REFERENCE MANUAL

---

not possible to do analyses with different frequencies for different parts of the model.

Example to change the power system frequency to 50.0 Hz:

```
FREQUENCY
50.0
```

**LINE** This keyword specifies any number of parallel, current-carrying conductors. Induced voltages will be calculated for pipe segments specified by **SEC** and mitigation wire segments specified by **WSEC**, using these conductors until **LINE** is called again.

The conductors must be parallel. If they are angled, the average distances must be used. See **CSEC** and **VCSEC** for a better treatment of angled conductors. **LINE** is followed by data lines with the format:

```
<x-offset> <y-height> <real current> <imaginary current>
```

x-offset and y-height are the x and y co-ordinates of a conductor relative to the pipeline. For example, if there is a conductor parallel to the pipeline that is 12 metres to the left and 15 metres above the ground and it is carrying a current of  $500 + j250$  amps, the following line of data could be used:

```
-12.0 15.0 500.0 250.0
```

Each time **LINE** is called, the fields are set to zero and a complete new set of coupling parameters must be given. These will then apply until the next call to **LINE**.

To cancel inductive coupling from a parallel power line, line can be called with a single conductor carrying zero current.

There is no default value. The field that will be used by **SEC** and **WSEC** is zero until **LINE** is used for the first time.

Example of a three phase power line 10.0 metres to the right of the pipeline and 18 metres high, carrying 500 amps.

```
LINE
8 18 500.0 0.0
10 18 -250.0 -433.01
12 18 -250.0 433.01
```

**MIXED\_DATA** This keyword instructs the program to use non-metric units for various parameters. The **MIXED\_DATA** keyword is provided for backward compatibility with older versions of CONIND that used a combination of metric and English units of measure. It should probably not be used by new users and can only be used once in a data file. The keyword is not followed by any other data.

Example:

## CONIND REFERENCE MANUAL

---

---

### MIXED\_DATA

**MU** This keyword sets a new value for pipeline steel relative permeability. It is followed by the required relative permeability, a dimensionless quantity. The default value is 300.0.

Example to change the relative permeability to 280.5:

```
MU
280.5
```

**MULT** Followed by one or more pipeline coating resistance multipliers. To enable an accumulation of similar calculation results, **MULT** can only have one multiplier when the different currents option is being used. The different currents option requires an extra file with a series of new power line current values. Otherwise, it can have any number of multipliers.

The parameters apply to the whole data file. Calculations will be repeated for each multiplier, using the multiplier to multiply the coating resistance of all pipeline segments. The keyword can only be used once in a data file. It is useful for quickly examining the effect of errors in the estimation of coating resistance. Coating resistance is one of the most difficult parameters to estimate. All the coating resistances can be scaled up or down to see the effect of using the wrong coating resistance.

Default is one multiplier value of 1.0. The program will use the pipeline coating resistances specified without modifying them.

Example to repeat the calculations for four different coating resistances that are 50%, 100%, 200% and 300% of the specified values:

```
MULT
0.5
1.0
2.0
3.0
```

**NODES** This keyword is used to select an output listing of only some of the node voltage. It is useful when the model is quite large and only a small part is being examined. It is followed by lines containing the numbers of the nodes for which voltage results are to be listed.

The default is to list the voltage at all nodes.

Example to only list the voltages at Nodes 13, 14, 15 and 23:

```
NODES
13
14
15
23
```

## CONIND REFERENCE MANUAL

---

---

**NODE\_DIFF** This keyword is used to list the voltage difference between pairs of nodes. It is useful to list the voltage across an insulating flange where a pipeline segment terminates at one node on one side and another node on the other side. It is followed by one or more lines containing pairs of node numbers between which the voltage difference is to be calculated and listed.

There is no default difference listing.

Example to list the voltage between Nodes 33 and 34:

```
NODE_DIFF  
33 34
```

**SEC** This is the most basic pipeline to power line coupling keyword. It is followed by one or more lines of data containing the following:

<from node number> <to node number> <length in metres> <soil voltage volts>

The soil voltage is usually 0.0, but it can have a non-zero value near a substation that has a ground fault. In this case, the soil voltage magnitude should be calculated for 1000.0 amps ground current at the substation. The real ground current will most likely be some other value, for example 2462 + j3790 amps. The **BASEA** keyword is used to set the base current to 2462 + j3790 amps and all the soil voltages will be multiplied by 2.462 + j3.790.

**SEC** will use the most recent settings of other parameters. These include:

All pipe parameters such as diameter, wall thickness, steel resistivity, coating resistance, coating thickness, burial depth, steel relative permeability.

Soil resistivity.

Electric field from currents flowing in parallel power lines (see **LINE**).

The current flow direction (see **LINE**) is from the “from node” to the “to node”. The x-offset of the current is negative if to the left and positive if to the right, looking in the direction the current is flowing.

Specifying a segment between the same pair of nodes twice will result in an error message.

There is no default value.

Example: To specify a 460 metre long segment of pipeline between nodes numbered 19 and 36 with zero soil voltage:

```
SEC  
19 36 460.0 0.0
```

**SHUNT** This keyword allows shunt impedances such as magnesium anodes or valve ground mats, to be added to nodes in the model. The node must be connected to at least one segment of pipeline. The ground impedance can also have a soil voltage. The data format is:

<node number> <real  $\Omega$ > <imaginary  $\Omega$ > [<soils voltage real> <soil voltage imaginary>]

Real  $\Omega$  and imaginary  $\Omega$  are the real and imaginary values of the ground impedance in  $\Omega$ .

The soil voltage is optional. If used, it must be provided as a complex number with real and imaginary parts and is not scaled by the **BASEA** parameter. It has limited application.

**SHUNT** can be used in different places in the data file, but all **SHUNT** impedances are usually listed in one place. If a **SHUNT** impedance is added to the same node twice the two will not be added in parallel. Only the last added one will be used.

Example to add a **SHUNT** impedance of  $10 + j0 \Omega$  to node 12 and  $5 + j1 \Omega$  to node 18 with no soil voltage:

```
SHUNT
12 10 0
18 5 1
```

**SOIL** This keyword sets a new value for soil resistivity. It is followed by soil resistivity in  $\Omega$ -metres.

The default value is 100.0  $\Omega$ -metres.

Example to change the soil resistivity to 437  $\Omega$ -metres:

```
SOIL
437
```

**STEEL** This keyword sets a new value for pipeline steel resistivity. It is followed by resistivity in  $\mu\Omega$ -metres.

The default value is 0.17  $\mu\Omega$ -metres.

Example to change the pipeline steel resistivity to 0.19  $\mu\Omega$ -metres:

```
STEEL
0.19
```

**VLINE** This is the same as **LINE** except that the line current (complex) can be replaced by a code representing a current value. The codes must be listed with the required currents in File #2.

There is no default for **VLINE**. Example:

## CONIND REFERENCE MANUAL

---

---

```
VLINe
8 18 2L29A
10 18 2L29B
12 18 2L29C
```

**VCSEC** This keyword is the same as **CSEC** except that the r and i currents are replaced by a single code word. File #2 must contain the conductor code and real and imaginary currents.

There is no default value.

Example of a 350 metre long pipeline segment, between nodes 12 and 13, with one end 10 metres from the centre of a power line and the other end 8 metres away. The power line has three phase conductors carrying 500 amps each and named 2L23A, 2L23B and 2L23C. File #2 has the following data for these conductors:

```
2L29A 500.0 0.0
2L29B -250.0 -433.01
2L29C -250.0 433.01
```

One conductor is in the middle of the power line and the others are spaced 2 metres on each side. All are 18 metres above ground:

```
VCSEC
12 13 350 0.0
8 18 6 18 2L29A
10 18 8 18 2L29B
12 18 10 18 2L29C
```

**WALL** This keyword sets a new value for the pipeline wall thickness. It is followed by the wall thickness in mm. The default is 6 mm. (If the **MIXED\_DATA** keyword is used, the wall thickness must be given in inches and the default is 0.25 inch)

To prevent the analysis of meaningless pipeline models, the wall thickness cannot be larger than 25% of the diameter.

Example:

```
WALL
8.0
```

**WDEPTH** This keyword sets a new value for mitigation wire depth. It is followed by depth in metres. The default value is 1.0 metre. (If the **MIXED\_DATA** keyword is used, the depth must be given in inches and the default is 36.0 inches).

The mitigation wire depth must be greater than the wire diameter to ensure that the wire is fully buried.

Example to change the mitigation wire depth to 0.6 metre:

```
WDEPTH
0.6
```

## CONIND REFERENCE MANUAL

---

---

**WDIAM** This keyword sets a new value for mitigation wire diameter. It is followed by diameter in mm. The default value is 12 mm. (If the **MIXED\_DATA** keyword is used, the diameter must be given in inches and the default diameter is 0.5 inch).

The mitigation wire diameter must be less than the wire depth to ensure that the wire is fully buried.

Example to change the mitigation wire diameter to 9.6 mm:

```
WDIAM
9.6
```

**WLOAD** This keyword sets a new value for impedance loading of the mitigation wire. It is followed by the impedance real and imaginary values in  $\Omega/\text{km}$ , both on the same line. The default value is  $0.0 + j0.0 \Omega/\text{km}$ .

Loading the wire with inductive coils may be used to improve the effect of mitigation wires.

Example to change the mitigation wire loading to  $2.4 + j3.0 \Omega/\text{km}$ :

```
WLOAD
2.4 3.0
```

**WMU** This keyword sets a new value for the relative permeability of the mitigation wire. It is followed by the value, which is dimensionless. The default value is 1.0, which is the same as free space and would apply to any non-magnetic wire such as copper wire.

Example to change the wire relative permeability to 300.0:

```
WMU
300.0
```

**WSEC** This is similar to **SEC** but is for a mitigation wire and soil voltage cannot be specified. It is followed by one or more lines of data containing the following:

<from node number> <to node number> <length in metres>

**WSEC** will use the most recent settings of other parameters. These include:

All the wire parameters such as diameter, wire resistivity, burial depth, wire relative permeability, wire loading.

Soil resistivity.

Electric field from currents flowing in parallel power lines (see **LINE**).

## CONIND REFERENCE MANUAL

---

The current flow direction (see **LINE**) is from the “from node” to the “to node”. The x-offset of the current is negative if to the left and positive if to the right, looking in the direction the current is flowing.

Specifying a wire segment between the same pair of nodes twice will result in an error message.

There is no default value.

Example: To specify a 200 metre long segment of wire between nodes numbered 39 and 40:

```
WSEC
39 40 200
```

### **WRES**

This keyword sets a new value for the resistivity of the mitigation wire. It is followed by the value, which is in  $\mu\Omega$ -metres. The default value is 0.017241  $\mu\Omega$ -metres, which is the resistivity of soft wire bar copper.

Example to change the wire resistivity to 0.043  $\mu\Omega$ -metres:

```
WRES
0.043
```

### 6. REFERENCES

1. "Mutual Design Considerations for Overhead AC Transmission Lines and Gas Transmission Pipelines - Volume 1: Engineering Analysis", EPRI EL-904 Project 742 A.G.A. Cat. No. L51278 Project PR132-80 Final Report, September 1978.
2. E.D. Sunde, "Earth Conduction Effects in Transmission Systems", D. van Nostrand Co. Inc., 1949.
3. J.R. Carson, "Wave Propagation in Overhead Wires with Ground Return", Bell System Technical Journal Vol. 5 pp 539-555, October 1926.
4. H.W. Dommel: Discussion following "Electromagnetic Effects of Overhead Transmission Lines - Practical Problems, Safeguards and Methods of Calculation", IEEE Trans. vol PAS-93 issue 3 892-904, May-June 1974.