REVIEW OF

POWERLINE AC INTERFERENCE
CENTRAL QUEENSLAND GAS PIPELINE
KP 320 TO 393

Prepared for Enertrade
by
Geoff Cope & Associates Pty Ltd

Rev O 18 May 2007

Index

1. Summary

This document provides a desktop review of the Powerline AC Interference Report, KP 320 to 393, Central Queensland Gas Pipeline, (hereinafter generally referred to as the Report), as prepared for Enertrade by Brian Martin & Associates Pty Ltd, dated 11 February 2007. It concludes that the calculations and conclusions in that report are valid and that the voltages that would be induced on the pipeline under normal powerline operating conditions and under powerline fault conditions would be well above acceptable limit values. The recommendation to relocate part of the pipeline is considered as being correct in respect to safety requirements as specified in AS/NZS 4853:2000 Electrical Hazards on Metallic Pipelines and in relation to corrosion that is likely to result from the continuous presence of excessive AC voltage.

2. Introduction

The proposed Central Queensland Gas Pipeline traverses approximately 435 km of countryside, including a section covering approximately 60 km where it runs in the vicinity of electric power transmission lines. Initial calculations carried out by Brian Martin & Associates in August 2005 revealed that unacceptable levels of AC would be induced on the pipeline both under normal operating and fault current conditions. The calculations also showed that the situation could not be adequately remedied by installation of mitigative earthing systems. It was therefore advised that re-routing of some of the pipeline would be required, placing the pipeline further away from the powerlines. Supplementary data was subsequently obtained and further calculations carried out to confirm the original calculations, with a report including this information being issued on 11 February 2007.

It had been advised that the revised pipeline route traverses an area of some environmental sensitivity. Geoff Cope & Associates Pty Ltd was engaged to conduct a review of the Report and provide an independent opinion on its contents and recommendations in relation to the original route.

3. Methodology

The review process has been to conduct a desktop study based on the data provided in the AC Interference Report and supplementary data provided separately as requested from Brian Martin & Associates. Calculation sheets as appended to the Report were examined and a number of these have been checked using alternative approaches. The outcomes were also considered against the reviewers' experience elsewhere with similar situations as a means of providing a check on the reasonableness of the results obtained.

In conducting this review, it has been assumed that the pipeline and powerline data provided is accurate and that the field data such as soil resistivity measurements is reliable. No additional field surveys have been carried out nor has any contact been made with powerline companies in relation to powerline data. However it appears clear that powerline data in substantial detail has been provided directly by the powerline companies, and it is understood that field data was obtained at first hand by Brian Martin & Associates. Brian Martin is highly regarded in the Australian and international pipeline industry as having extensive experience in this sphere, both theoretical and practical, and it is the reviewer's considered opinion that the data input into the calculations therefore has a very high degree of integrity and reliability.

As with the Report, the software used in this review for AC induction calculations was the AC Predictive and Mitigation Software as developed under the auspices of the Pipelines Research Council International and distributed by Technical Toolboxes Inc, USA. Geoff Cope & Associates is a licensed user of this software and has received training in its use from the programs' author. This software has been widely used for AC mitigation calculations and design in the pipeline industry, and although believing it to be suitable for purpose Geoff Cope & Associates gives no express warranty as to its suitability.

A cross-check of earth potential rise calculations was also carried out using a basic formula as can be found in Standards and reference books on this subject. For simplicity this cross-check was only applied to one of the power transmission lines in a situation where no shield wires were present, however the results will be typical for all lines.

4. Criteria

The safety criteria as applied in the Report and stated therein in Clause 3.1 are drawn from AS/NZS 4853:2000 Electrical Hazards on Metallic Pipelines. This Standard is widely used in the Australian pipeline industry and the criteria are not greatly dissimilar from those called up in international standards. The maximum voltage allowed in AS 4853, under circumstances entailing restriction of access to the public or personnel without special training, is 1,000 V for durations of up to 1 second.

AC corrosion is regarded as being a substantial problem in the pipeline industry, which may not be mitigated, or may even be accelerated, by application of cathodic protection. Substantial research is presently being undertaken on an international scale to better identify the key parameters. However the present state of knowledge indicates that a limit value of 5 V AC due to induction under steady-state operating conditions is a suitable level below which metal loss due to AC corrosion is unlikely to be of any great significance.

5. Calculations and Results

Review of the AC induction scenarios as shown in Appendices A to H of the Powerline AC Interference Report revealed no discrepancies of any practical significance in the analysis. In particular, given the variability in factors such as soil resistivity and actual earthing resistance at individual powerline towers, it is considered that the output from the PRCI analysis provides a most reasonable representation of the voltages that may be expected to arise on the pipeline under the various operating and fault current conditions as advised by the powerline company. Furthermore it should be noted that the voltages in some locations as identified in the Report, even given extensive mitigation installations, remain well above the limit values recommended for safety or AC corrosion. In summary, it is the reviewer's opinion that tabulations of AC interference as presented in Sections 4.1 and 4.2 of the Report have been correctly derived for the various conditions as described, and that these conditions reasonably represent the electrical environment along the pipeline route.

As a further adjunct to the review, supplementary calculations have been carried out with mitigation earthing resistance based on mean soil resistivity at 5 metre depth rather than 50 metres as used in the Report. Along almost all of this section of the pipeline route, resistivity increases with depth, most probably due to layers of rock which typically exist beneath a relatively shallow surface layer of soil. Resistance values were calculated for 1,000 metres of earthing ribbon in each 1 km section, input as a discrete value of resistance. This provides a far more optimistic result, albeit one that would not be expected to be achieved in practice, as the generally higher resistivities at deeper soil layers will increase the true value of the earthing resistance. Software printouts of the analysis using this approach under normal operating conditions are given in Appendix 2, and print-outs under fault conditions are given in Appendices 3, 4 and 5. As a further cross-check, an assessment was also carried out using a standard formula for calculation of earth potential rise voltages. Details can be seen in Appendix 1. A summary of key comparisons is shown in Table 1 below.

Powerline & location	Mitigation condition	AC Interference Level		
		BM&A Report	GC&A software calculation	GC&A analytical calculation
Steady state operating conditions	Full mitigation #	41 V	29 V	-
Feeder 849, fault conditions at node 18 (KP 338)	No mitigation	10,441 V	10,406 V	-
Feeder 849, fault conditions at node 18 (KP 338)	Full mitigation #	2,628 V	1,409 V	-
Feeder 7167, fault conditions at node 17 (KP 337)	No mitigation	8,487 V	-	8,360 V
Feeder 7167, fault conditions at node 17 (KP 337)	Full mitigation #	15,520 V	8,597 V	-

Note # Interference levels calculations in BM&A Report are based on resistivity values at 50 metre depth.
These are the appropriate values to use for conservative design purposes.
The corresponding calculations in the GC&A column are based on resistivities at 5 metre depth and in this situation should be considered as yielding an optimistic reduction in interference voltages. They have been presented to illustrate that even on an optimistic basis the voltages under both normal operating and fault conditions are well above acceptable limits.

Table 1: AC interference voltage levels at locations of maximum exposure.

The results tabulated above show voltage levels, under the various scenarios as shown, to be much higher than the maximum acceptable values as discussed earlier in this review.

6. Discussion

The results of calculations to cross-check those in the report by Brian Martin & Associates have revealed no significant variations from the results shown in that Report. Furthermore, calculations using a much less conservative model have shown that even under highly optimistic conditions the voltages that would arise on the pipeline in the originally proposed route would be well above those regarded as acceptable from the viewpoints of both safety and corrosion. It appears clearly evident, that should the pipeline be laid on the originally proposed alignment, voltages under fault current conditions would be well above safety levels as specified in the relevant Standards, and steady state voltages under normal operating conditions would be sufficiently high to result in accelerated corrosion that might not be controlled by application of cathodic protection.

It may be observed that the majority of the voltage rise caused by powerline faults appears to be in the immediate vicinity of the faulted tower. This is normal for fault situations, particularly in the case of high resistivity soils. Apart from in the broad vicinity of the faulted tower (and those near it on those powerlines that carry shield wires), induced voltages due to powerline faults are not particularly excessive. Nevertheless high voltages significantly above acceptable limits extend for some distances from a faulted tower under fault conditions, and should the fault occur on adjacent towers a similar spread of potential would occur. It could be argued that these voltages could be substantially reduced by judicious placement of earthing. However in practice although some reduction could be achieved the reduction is typically no greater than 50% of the value without mitigation, and the side effect is to cause correspondingly increased voltages on adjacent sections of the pipeline. Furthermore it has been advised that in many instances in higher resistivity area that buried earthing cables have been run from powerline towers in multiple directions, so as to reduce the earthing resistance of the towers. These cables can run for many tens of metres from the base of each tower, and would therefore cross the originally proposed pipeline route. Where the pipeline route was in close proximity to the towers, this would result in much greater voltage rise in the vicinity of the pipeline, such that, ignoring other factors, changes to pipeline route or powerline configuration would be essential.

It should also be noted that the voltage induced under normal operating conditions is well in excess of that which will not cause risk of accelerated corrosion. Paradoxically, corrosion due to presence of AC on a cathodically protected pipeline is enhanced by cathodic protection, such that even more corrosion may occur on a pipeline with cathodic protection subject to high levels of AC than would occur if the pipeline was unprotected. It is essential that levels of induced AC under normal daily operating conditions are less than the specified limit value. The results of the analysis clearly show that this would not be the case along a substantial length of pipeline, even given the most optimistic viewpoint of earthing effectiveness as presented in the GC&A analysis. Even if voltages under fault conditions could be reduced to acceptable levels (which in the review's opinion is not possible on the originally proposed alignment), mitigation of voltages induced under normal operating conditions would be totally impractical. To reduce levels of induced AC under normal operating conditions to acceptable values the only available option is to relocate the pipeline.

7. Conclusions

As a result of this review it has been concluded that the recommendations contained within the Powerline AC Interference Report, KP 320 to 393, Central Queensland Gas Pipeline, are well supported by the calculations within that Report and by independent analysis using alternative processes for selected scenarios. It is therefore the opinion of the Reviewer that the recommendation within the Report that the pipeline be partly relocated is both justified and necessary.

G Cope

Geoff Cope
24 April 2007

Appendix 1

Earth Potential Rise due to powerline fault on tower near KP 337

Analytical calculation

Phase to earth fault on 132 kV powerline T5 (feeder 7167).
Fault current 7,000 A.
Soil resistivity at 5 metre depth = 150 Ω-m.
Separation between pipeline & powerline = 20 metres.

As a first order approximation, consider the powerline tower as a point source 20 metres from the pipeline.

Earth potential rise is given by :

$$Er = I\rho/(2\pi r)$$

where

Er = earth potential rise
I = fault current
r = distance from tower to pipeline

Hence, substituting values:

$$Er = 7000.\ 150\ /\ (2.\ \pi.\ 20)$$

$$\approx 8{,}360\ V$$

Appendix 2

Voltages induced on pipeline
Powerlines operating under normal steady-state load conditions

Comments

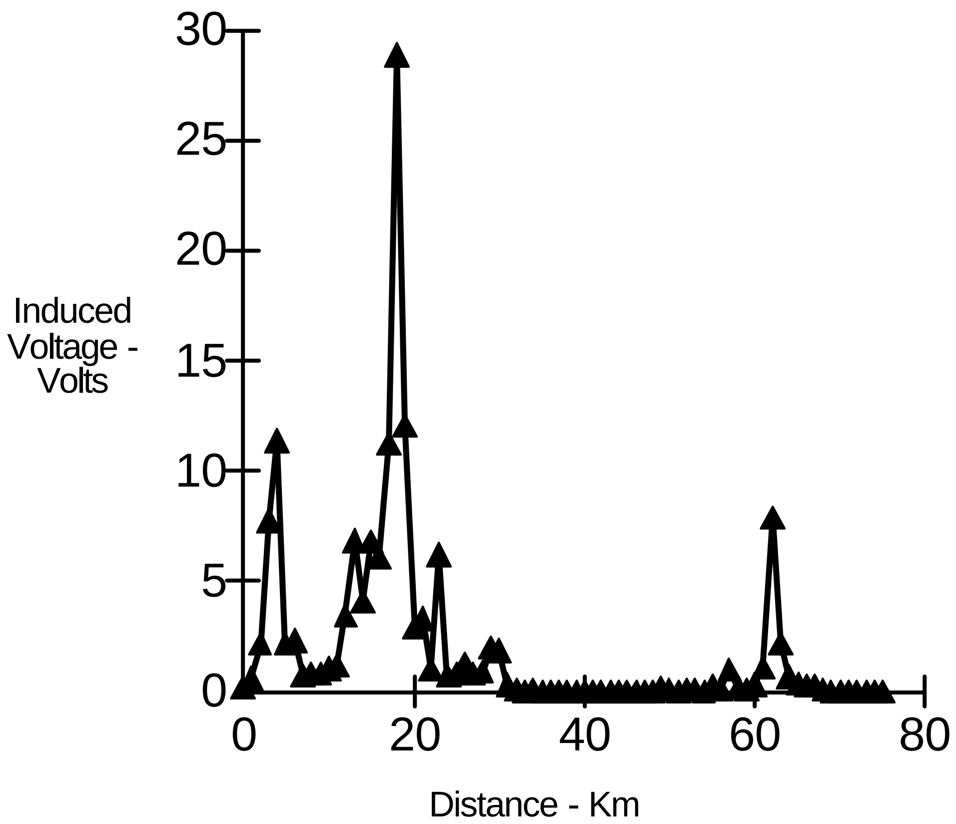
CQGP
KP 320 - 393
Operating Conditions
Mitigation as calculated using near surface (5 metre) soil resistivity values and discrete earthing.

Original data by Brian Martin & Associates
9 February 2007

Review with modifications by Geoff Cope & Associates
12 April 2007

Coating resistance increased to 1 Meg ohm - square metre.
Discrete earthing at each node as calculated for 1,000 metres of ribbon using resistivity values at 5 metre depth.
Note: This provides a less conservative anwer than using 50 metre depth resisitivities, and would provide greater reduction of induced voltages. However it is generally unrealistic giv the generally increasing pattern of resistivity with depth.

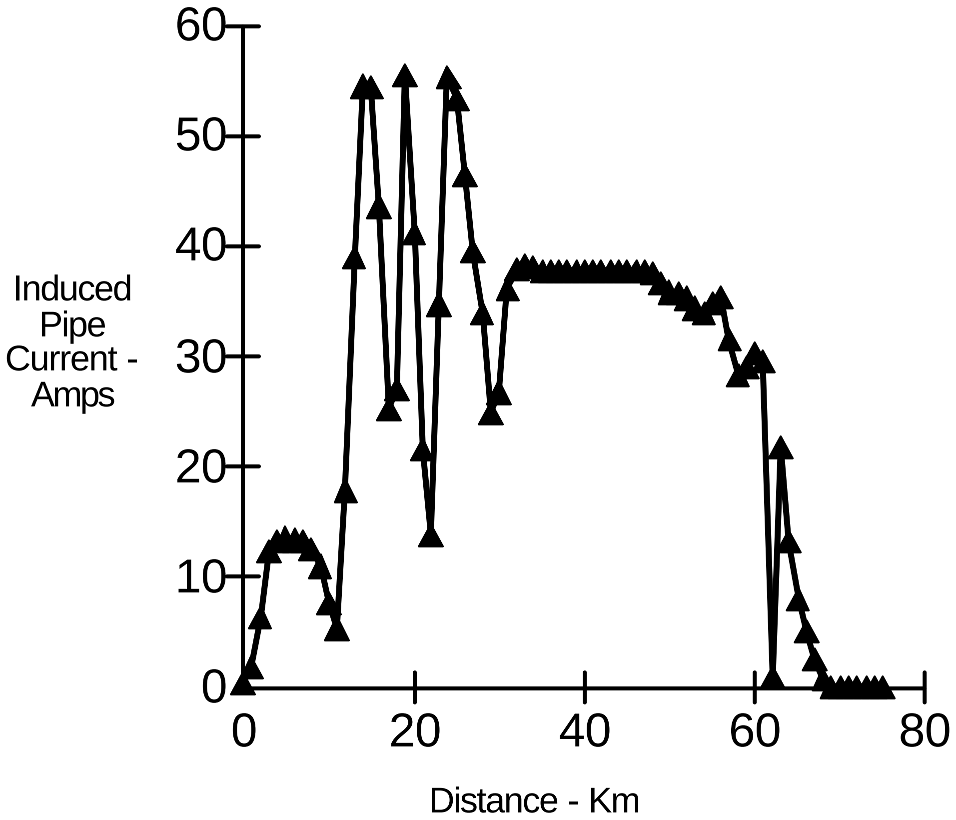
File OP2GC2sm.acd



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	Volts	Distance	Volts	Distance	Volts
0.00	0.2	27.00	0.8	54.00	0.0
1.00	0.6	28.00	0.9	55.00	0.3
2.00	2.2	29.00	2.0	56.00	0.1
3.00	7.8	30.00	1.9	57.00	1.0
4.00	11.4	31.00	0.3	58.00	0.2
5.00	2.2	32.00	0.1	59.00	0.1
6.00	2.3	33.00	0.1	60.00	0.3
7.00	0.8	34.00	0.1	61.00	1.1
8.00	0.9	35.00	0.0	62.00	7.9
9.00	0.9	36.00	0.0	63.00	2.2
10.00	1.1	37.00	0.0	64.00	0.7
11.00	1.2	38.00	0.0	65.00	0.4
12.00	3.5	39.00	0.0	66.00	0.3
13.00	6.8	40.00	0.0	67.00	0.3
14.00	4.1	41.00	0.0	68.00	0.1
15.00	6.8	42.00	0.0	69.00	0.0
16.00	6.1	43.00	0.0	70.00	0.0
17.00	11.3	44.00	0.0	71.00	0.0
18.00	28.9	45.00	0.0	72.00	0.0
19.00	12.1	46.00	0.0	73.00	0.0
20.00	2.9	47.00	0.0	74.00	0.0
21.00	3.3	48.00	0.0	75.00	0.0
22.00	1.0	49.00	0.2		
23.00	6.2	50.00	0.1		
24.00	0.7	51.00	0.0		
25.00	0.8	52.00	0.1		
26.00	1.3	53.00	0.1		

PRC INTERNATIONAL

Steady State Current
Graph and Data



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Current**	**Distance**	**Current**	**Distance**	**Current**
0.00	0.4	27.00	39.5	54.00	33.9
1.00	1.8	28.00	33.9	55.00	34.8
2.00	6.4	29.00	24.9	56.00	35.4
3.00	12.3	30.00	26.8	57.00	31.5
4.00	13.3	31.00	36.1	58.00	28.3
5.00	13.5	32.00	37.9	59.00	29.0
6.00	13.3	33.00	38.3	60.00	30.4
7.00	13.3	34.00	38.1	61.00	29.6
8.00	12.6	35.00	37.8	62.00	0.9
9.00	11.0	36.00	37.7	63.00	21.8
10.00	7.7	37.00	37.7	64.00	13.2
11.00	5.4	38.00	37.7	65.00	8.0
12.00	17.9	39.00	37.7	66.00	5.1
13.00	39.1	40.00	37.7	67.00	2.6
14.00	54.5	41.00	37.7	68.00	0.8
15.00	54.4	42.00	37.7	69.00	0.1
16.00	43.6	43.00	37.7	70.00	0.0
17.00	25.3	44.00	37.7	71.00	0.0
18.00	27.1	45.00	37.7	72.00	0.0
19.00	55.5	46.00	37.7	73.00	0.0
20.00	41.2	47.00	37.7	74.00	0.0
21.00	21.6	48.00	37.6	75.00	0.0
22.00	13.9	49.00	36.7		
23.00	34.8	50.00	35.8		
24.00	55.3	51.00	35.7		
25.00	53.4	52.00	35.3		
26.00	46.5	53.00	34.4		

T-Line #1

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-7.9	28.5	2.9	0.0008
Shield Wire #2	7.9	28.5	2.9	0.0008

	D - m	H - m	I - Amp	Phase - deg.
Phase Wire #1	-9.3	21	1012	120
Phase Wire #2	0	21	1012	-120
Phase Wire #3	9.3	21	1012	0

T-Line #2

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-7.9	28.5	2.9	0.0008
Shield Wire #2	7.9	28.5	2.9	0.0008

	D - m	H - m	I - Amp	Phase - deg.
Phase Wire #1	-9.3	21	1012	120
Phase Wire #2	0	21	1012	-120
Phase Wire #3	9.3	21	1012	0

T-Line #3

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-5.9	18.5	0.189	0.0008
Shield Wire #2	5.9	18.5	1.47	0.0008

	D - m	H - m	I - Amp	Phase - deg.
Phase Wire #1	-7.1	12.5	1961	120
Phase Wire #2	0	12.5	1961	-120
Phase Wire #3	7.1	12.5	1961	0

T-Line #4

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-5.9	18.5	0.189	0.0008
Shield Wire #2	5.9	18.5	1.47	0.0008

	D - m	H - m	I - Amp	Phase - deg.
Phase Wire #1	-7.1	12.5	1961	120
Phase Wire #2	0	12.5	1961	-120
Phase Wire #3	7.1	12.5	1961	0

T-Line #5

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-1	100	10000	0.0008
Shield Wire #2	1	100	10000	0.0008

	D - m	H - m	I - Amp	Phase - deg.
Phase Wire #1	-2.5	11.5	314	120
Phase Wire #2	2.5	13.35	314	-120
Phase Wire #3	-2.5	15.2	314	0

Pipe #1

Diameter - m	Burial Depth - m	R - Kohm-m2	Thickness - m
0.324	-1	1000	0.0013

First section **is** terminated in insulator
Last section **is** terminated in insulator

PRC INTERNATIONAL

Steady State Data
Section Information

Section	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
1	1000	4000	99999	0	99999	0	99999	0	99999	0	99999	0	0	0				
2	1000	4000	99999	0	99999	0	99999	0	99999	0	99999	0	0	0				
3	1000	4000	99999	0	99999	0	99999	0	99999	0	99999	0	0	0				
4	1000	12000	99999	0	99999	0	-216	0	-239	0	-267	0	0	0				
5	1000	12000	99999	0	99999	0	182	0	126	0	84	0	0	0				
6	1000	12000	99999	0	99999	0	390	0	355	0	368	0	0	0				
7	1000	84000	99999	0	99999	0	279	0	213	0	185	0	0	0				
8	1000	84000	99999	0	99999	0	260	0	228	0	201	0	0	0				
9	1000	43000	99999	0	99999	0	227	0	199	0	170	0	0	0				
10	1000	43000	99999	0	99999	0	197	0	168	0	136	0	0	0				
11	1000	19000	99999	0	99999	0	169	0	130	0	101	0	0	0				
12	1000	19000	99999	0	99999	0	137	0	100	0	75	0	0	0				
13	1000	19000	99999	0	99999	0	97	0	56	0	21	0	0	0				
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45	1000	1300	-20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
46	1000	1300	-20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
47	1000	1300	-20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
48	1000	1300	-20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
49	1000	1300	-20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				

50	1000	4400	-21	0	99999	0	-99999	0	-99999	0	-99999	0	0	0
51	1000	4400	-26	0	99999	0	-99999	0	-99999	0	-99999	0	0	0
52	1000	4400	-26	0	99999	0	-99999	0	-99999	0	-99999	0	0	0

Branch	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
53	1000	4400	-30	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
54	1000	4400	-33	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
55	1000	4400	-34	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
56	1000	4400	-24	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
57	1000	4400	-23	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
58	1000	4400	-51	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
59	1000	4400	-46	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
60	1000	4400	-45	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
61	1000	4400	-42	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
62	1000	4400	-26	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
63	1000	4400	20	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
64	1000	4400	123	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
65	1000	3100	184	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
66	1000	3100	275	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
67	1000	3100	412	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
68	1000	3100	771	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
69	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
70	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
71	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
72	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
73	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
74	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				
75	1000	3100	99999	0	99999	0	-99999	0	-99999	0	-99999	0	0	0				

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P2&1-Bond	P2-NodeR	P2-AnodeDR	P2-ParWire	P3&2-Bond	P3-NodeR	P3-AnodeDR	P3-ParWire	P1&3-Bond
1	0.25											
2	0.25											
3	0.25											
4	1.3											
5	1.3											
6	1.3											
7	0.83											
8	0.83											
9	0.37											
10	0.37											
11	0.15											
12	0.15											
13	0.15											
14	0.34											
15	0.34											
16	0.51											
17	0.51											
18	0.33											
19	0.37											
20	0.37											
21	0.15											
22	0.15											
23	0.15											
24	0.15											
25	0.15											
26	0.15											
27	0.15											
28	0.15											
29	0.15											
30	0.15											
31	0.11											
32	0.11											
33	0.11											
34	0.11											
35	0.11											
36	0.11											
37	0.11											
38	0.11											
39	0.11											
40	0.11											
41	0.11											
42	0.11											
43	0.11											
44	0.11											
45	0.11											
46	0.11											
47	0.11											
48	0.11											
49	0.11											

50	**0.14**
51	**0.14**
52	**0.14**

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P1-Bonded	P2-NodeR	P2-AnodeDR	P2-ParWire	P2-Bonded	P3-NodeR	P3-AnodeDR	P3-ParWire	P3-Bonded
53	0.14											
54	0.14											
55	0.14											
56	0.14											
57	0.14											
58	0.14											
59	0.14											
60	0.14											
61	0.14											
62	0.14											
63	0.14											
64	0.14											
65	0.1											
66	0.1											
67	0.1											
68	0.1											
69	0.1											
70	0.1											
71	0.1											
72	0.1											
73	0.1											
74	0.1											
75	0.1											
76	0.1											

Appendix 3

Voltages on pipeline

Powerline T4 with phase to earth fault at KP 338; no mitigation

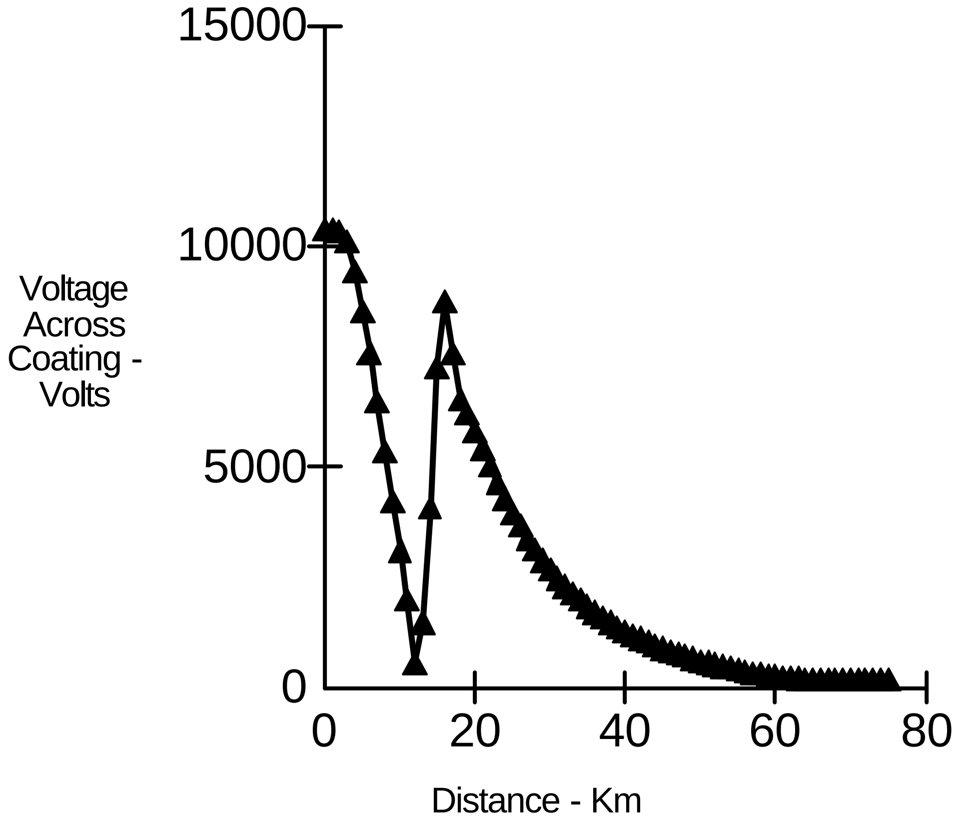
Comments

CQGP
KP 320 - 393
Fault current conditions
No Mitigation
15.5 kA fault at Node 18 (KP 338) on powerline T4 (feeder 849)

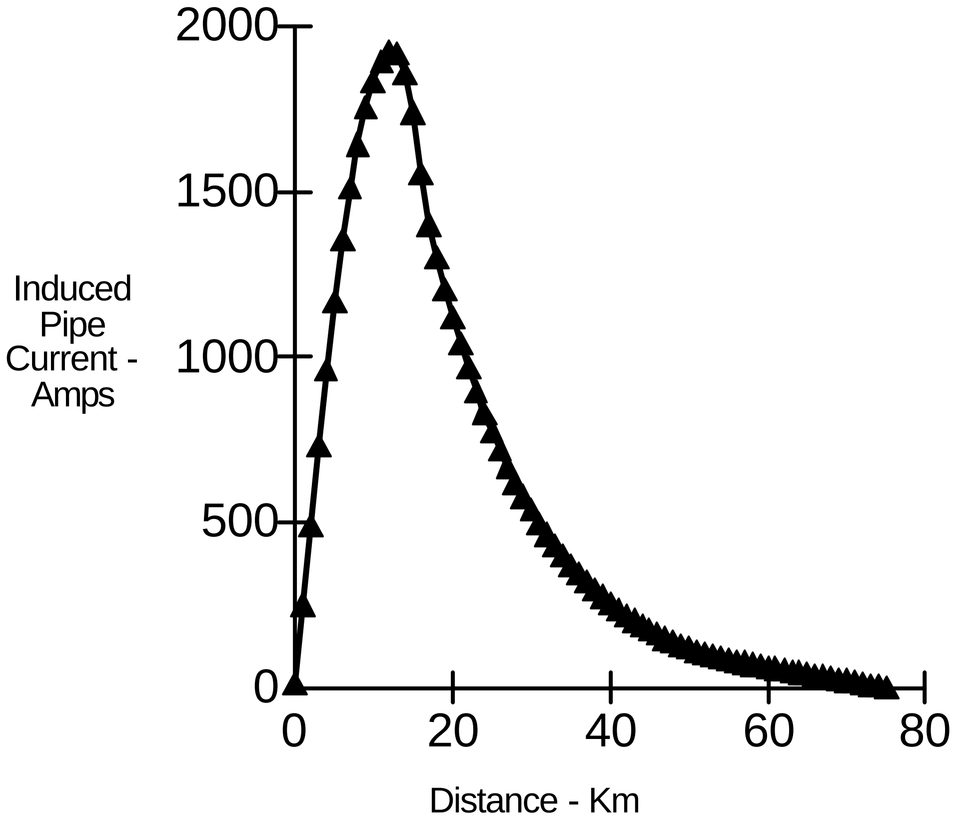
Original data by Brian Martin & Associates
9 February 2007

Review input with minor modifications by Geoff Cope & Associates
10 May 2007
Coating resistance increased to 1 Meg ohm - square metre.

File CGNT4a.acd



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Volts**	**Distance**	**Volts**	**Distance**	**Volts**
0.00	10406.3	27.00	3386.1	54.00	444.2
1.00	10392.3	28.00	3127.2	55.00	407.4
2.00	10349.9	29.00	2886.8	56.00	373.1
3.00	10106.2	30.00	2667.6	57.00	341.5
4.00	9439.8	31.00	2473.6	58.00	312.6
5.00	8531.3	32.00	2298.1	59.00	286.4
6.00	7565.8	33.00	2135.4	60.00	263.1
7.00	6484.5	34.00	1984.5	61.00	242.8
8.00	5347.2	35.00	1844.5	62.00	225.6
9.00	4224.4	36.00	1714.8	63.00	211.7
10.00	3112.2	37.00	1594.6	64.00	201.0
11.00	1992.0	38.00	1483.2	65.00	193.2
12.00	563.8	39.00	1379.9	66.00	187.8
13.00	1476.4	40.00	1284.0	67.00	184.7
14.00	4075.2	41.00	1195.1	68.00	183.4
15.00	7262.6	42.00	1112.5	69.00	183.4
16.00	8746.5	43.00	1035.7	70.00	184.1
17.00	7573.3	44.00	964.1	71.00	185.3
18.00	6520.1	45.00	897.3	72.00	186.6
19.00	6211.0	46.00	834.9	73.00	187.7
20.00	5816.8	47.00	776.4	74.00	188.4
21.00	5425.9	48.00	721.4	75.00	188.7
22.00	5029.7	49.00	668.8		
23.00	4648.6	50.00	618.3		
24.00	4296.0	51.00	570.5		
25.00	3969.1	52.00	525.7		
26.00	3666.3	53.00	483.6		



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Current**	**Distance**	**Current**	**Distance**	**Current**
0.00	10.9	27.00	668.7	54.00	92.3
1.00	251.5	28.00	621.8	55.00	86.5
2.00	492.6	29.00	578.0	56.00	81.1
3.00	732.3	30.00	537.2	57.00	76.1
4.00	960.8	31.00	499.0	58.00	71.4
5.00	1168.8	32.00	463.5	59.00	67.0
6.00	1355.5	33.00	430.4	60.00	62.7
7.00	1511.7	34.00	399.7	61.00	58.6
8.00	1642.4	35.00	371.1	62.00	54.5
9.00	1750.9	36.00	344.4	63.00	50.5
10.00	1833.9	37.00	319.6	64.00	46.5
11.00	1892.6	38.00	296.5	65.00	42.5
12.00	1925.0	39.00	275.1	66.00	38.5
13.00	1917.3	40.00	255.1	67.00	34.4
14.00	1859.4	41.00	236.5	68.00	30.3
15.00	1739.4	42.00	219.2	69.00	26.1
16.00	1555.8	43.00	203.2	70.00	21.9
17.00	1399.2	44.00	188.3	71.00	17.6
18.00	1298.8	45.00	174.6	72.00	13.3
19.00	1206.1	46.00	162.0	73.00	8.9
20.00	1120.8	47.00	150.3	74.00	4.6
21.00	1040.4	48.00	139.6	75.00	0.2
22.00	965.5	49.00	129.8		
23.00	896.4	50.00	121.0		
24.00	832.7	51.00	112.8		
25.00	773.8	52.00	105.4		
26.00	719.3	53.00	98.5		

T-Line

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-5.9	18.5	0.189	0.0008
Shield Wire #2	5.9	18.5	1.47	0.0008

	D - m	H - m	IL - A	IR - A	Total Current
Phase Wire	-7.1	12.5	15500	0	15500

	Avg Twr Sep. - m	Avg Twr Res - ohms	Faulted Twr Location
Elec. Sys Parameters	300	10	18

Arc Distance (m) 5.5

Pipe #1

Diameter - m	Burial Depth - m	R - Kohm-m2	Thickness - m
0.324	-1	50	0.0013

First section **is** terminated in insulator
Last section **is** terminated in insulator

Faulted Tower Data
Section Information

Section	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
1	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
2	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
3	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
4	1000	12000	-239	0	9999	0	9999	0	9999	0	9999	0	0	0				
5	1000	12000	126	0	9999	0	9999	0	9999	0	9999	0	0	0				
6	1000	12000	355	0	9999	0	9999	0	9999	0	9999	0	0	0				
7	1000	84000	213	0	9999	0	9999	0	9999	0	9999	0	0	0				
8	1000	84000	228	0	9999	0	9999	0	9999	0	9999	0	0	0				
9	1000	43000	199	0	9999	0	9999	0	9999	0	9999	0	0	0				
10	1000	43000	168	0	9999	0	9999	0	9999	0	9999	0	0	0				
11	1000	19000	130	0	9999	0	9999	0	9999	0	9999	0	0	0				
12	1000	19000	100	0	9999	0	9999	0	9999	0	9999	0	0	0				
13	1000	19000	56	0	9999	0	9999	0	9999	0	9999	0	0	0				
14	1000	48000	27	0	9999	0	9999	0	9999	0	9999	0	0	0				
15	1000	48000	25	0	9999	0	9999	0	9999	0	9999	0	0	0				
16	1000	77000	31	0	9999	0	9999	0	9999	0	9999	0	0	0				
17	1000	77000	31	0	9999	0	9999	0	9999	0	9999	0	0	0				
18	1000	35000	34	0	9999	0	9999	0	9999	0	9999	0	0	0				
19	1000	16000	-69	0	9999	0	9999	0	9999	0	9999	0	0	0				
20	1000	16000	-334	0	9999	0	9999	0	9999	0	9999	0	0	0				
21	1000	9000	-429	0	9999	0	9999	0	9999	0	9999	0	0	0				
22	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
23	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
24	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
25	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
26	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
27	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
28	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
29	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
30	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
31	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
32	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
33	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
34	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
35	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
36	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
37	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
38	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
39	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
40	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
41	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
42	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
43	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
44	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
45	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
46	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
47	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
48	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
49	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

50	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0
51	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0
52	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0

Branch	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
53	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
54	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
55	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
56	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
57	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
58	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
59	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
60	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
61	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
62	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
63	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
64	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
65	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
66	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
67	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
68	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
69	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
70	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
71	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
72	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
73	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
74	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
75	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

Faulted Tower Data
Mitigation & Bond Info

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P2&1-Bond	P2-NodeR	P2-AnodeDR	P2-ParWire	P3&2-Bond	P3-NodeR	P3-AnodeDR	P3-ParWire	P1&3-Bond
1												
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3												
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Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P1-Bonded	P2-NodeR	P2-AnodeDR	P2-ParWire	P2-Bonded	P3-NodeR	P3-AnodeDR	P3-ParWire	P3-Bonded
53												
54												
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Appendix 4

Voltages on pipeline

Powerline T4 with phase to earth fault at KP 338; continuous parallel earthing mitigation

Comments

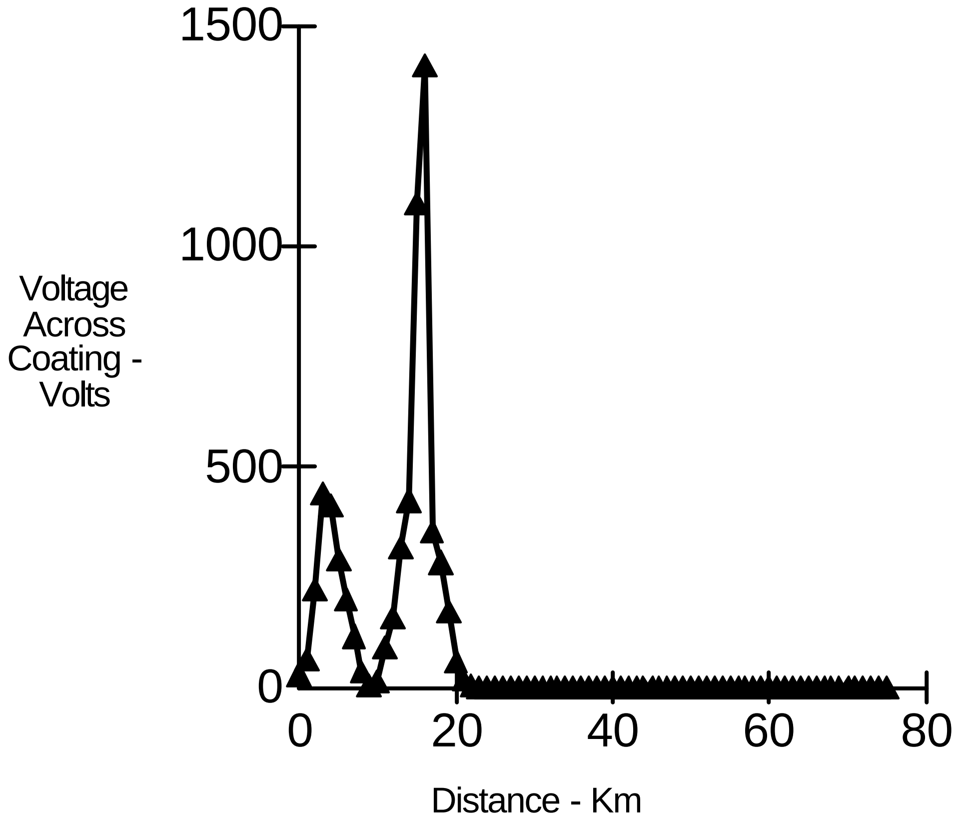
CQGP
KP 320 - 393
Fault Conditions
Powerline T4 (feeder 849) faulted at node 18 (KP 338)
Fault current 15.5 kA
Mitigation as calculated using near surface (5 metre) soil resistivity values and discrete earthing.

Original data by Brian Martin & Associates
9 February 2007

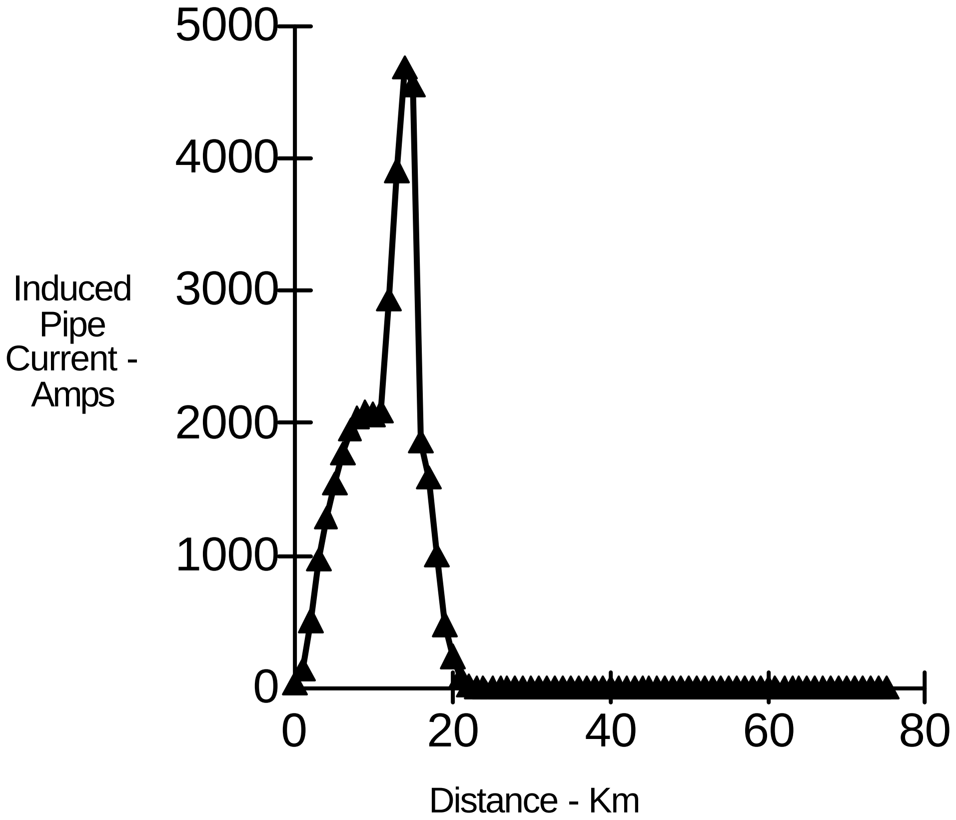
Review with modifications by Geoff Cope & Associates
10 May 2007

Coating resistance increased to 1 Meg ohm - square metre.
Discrete earthing at each node as calculated for 1,000 metres of ribbon using resistivity values at 5 metre depth.
Note: This provides a less conservative anwer than using 50 metre depth resisitivities, and would provide greater reduction of induced voltages. However it is generally unrealistic giv the generally increasing pattern of resistivity with depth.

File GCMT4a.acd



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Volts**	**Distance**	**Volts**	**Distance**	**Volts**
0.00	29.6	27.00	0.1	54.00	0.0
1.00	62.6	28.00	0.4	55.00	0.0
2.00	223.8	29.00	0.4	56.00	0.0
3.00	441.2	30.00	0.3	57.00	0.0
4.00	413.1	31.00	0.3	58.00	0.0
5.00	290.1	32.00	0.1	59.00	0.0
6.00	199.5	33.00	0.0	60.00	0.0
7.00	116.3	34.00	0.0	61.00	0.0
8.00	38.5	35.00	0.0	62.00	0.0
9.00	6.8	36.00	0.0	63.00	0.0
10.00	13.2	37.00	0.0	64.00	0.0
11.00	90.4	38.00	0.0	65.00	0.0
12.00	157.7	39.00	0.0	66.00	0.0
13.00	318.6	40.00	0.0	67.00	0.0
14.00	424.0	41.00	0.0	68.00	0.0
15.00	1096.0	42.00	0.0	69.00	0.0
16.00	1408.5	43.00	0.0	70.00	0.0
17.00	353.2	44.00	0.0	71.00	0.0
18.00	283.4	45.00	0.0	72.00	0.0
19.00	174.5	46.00	0.0	73.00	0.0
20.00	60.2	47.00	0.1	74.00	0.0
21.00	18.6	48.00	0.0	75.00	0.0
22.00	6.4	49.00	0.1		
23.00	1.1	50.00	0.1		
24.00	0.4	51.00	0.0		
25.00	0.2	52.00	0.0		
26.00	0.1	53.00	0.0		



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Current**	**Distance**	**Current**	**Distance**	**Current**
0.00	33.4	27.00	1.9	54.00	0.1
1.00	145.3	28.00	2.4	55.00	0.1
2.00	506.8	29.00	6.7	56.00	0.1
3.00	969.4	30.00	6.0	57.00	0.1
4.00	1286.1	31.00	1.0	58.00	0.1
5.00	1549.2	32.00	0.2	59.00	0.1
6.00	1774.5	33.00	0.1	60.00	0.0
7.00	1947.9	34.00	0.1	61.00	0.0
8.00	2044.8	35.00	0.1	62.00	0.1
9.00	2088.6	36.00	0.1	63.00	0.3
10.00	2067.2	37.00	0.1	64.00	0.3
11.00	2089.0	38.00	0.1	65.00	0.1
12.00	2931.5	39.00	0.1	66.00	0.0
13.00	3911.0	40.00	0.1	67.00	0.0
14.00	4685.9	41.00	0.0	68.00	0.0
15.00	4549.3	42.00	0.0	69.00	0.0
16.00	1860.5	43.00	0.0	70.00	0.0
17.00	1588.6	44.00	0.0	71.00	0.0
18.00	1001.8	45.00	0.0	72.00	0.0
19.00	479.9	46.00	0.0	73.00	0.0
20.00	237.0	47.00	0.1	74.00	0.0
21.00	77.8	48.00	0.9	75.00	0.0
22.00	14.0	49.00	0.9		
23.00	8.5	50.00	0.1		
24.00	5.1	51.00	0.1		
25.00	3.3	52.00	0.1		
26.00	2.4	53.00	0.1		

T-Line

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-5.9	18.5	0.189	0.0008
Shield Wire #2	5.9	18.5	1.47	0.0008

	D - m	H - m	IL - A	IR - A	Total Current
Phase Wire	0	12.5	15500	0	15500

	Avg Twr Sep. - m	Avg Twr Res - ohms	Faulted Twr Location
Elec. Sys Parameters	300	10	18

Arc Distance (m) 5.5

Pipe #1

Diameter - m	Burial Depth - m	R - Kohm-m2	Thickness - m
0.324	-1	1000	0.0013

First section **is** terminated in insulator
Last section **is** terminated in insulator

Section	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
1	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
2	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
3	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
4	1000	12000	-239	0	9999	0	9999	0	9999	0	9999	0	0	0				
5	1000	12000	126	0	9999	0	9999	0	9999	0	9999	0	0	0				
6	1000	12000	355	0	9999	0	9999	0	9999	0	9999	0	0	0				
7	1000	84000	213	0	9999	0	9999	0	9999	0	9999	0	0	0				
8	1000	84000	228	0	9999	0	9999	0	9999	0	9999	0	0	0				
9	1000	43000	199	0	9999	0	9999	0	9999	0	9999	0	0	0				
10	1000	43000	168	0	9999	0	9999	0	9999	0	9999	0	0	0				
11	1000	19000	130	0	9999	0	9999	0	9999	0	9999	0	0	0				
12	1000	19000	100	0	9999	0	9999	0	9999	0	9999	0	0	0				
13	1000	19000	56	0	9999	0	9999	0	9999	0	9999	0	0	0				
14	1000	48000	27	0	9999	0	9999	0	9999	0	9999	0	0	0				
15	1000	48000	25	0	9999	0	9999	0	9999	0	9999	0	0	0				
16	1000	77000	31	0	9999	0	9999	0	9999	0	9999	0	0	0				
17	1000	77000	31	0	9999	0	9999	0	9999	0	9999	0	0	0				
18	1000	35000	34	0	9999	0	9999	0	9999	0	9999	0	0	0				
19	1000	16000	-69	0	9999	0	9999	0	9999	0	9999	0	0	0				
20	1000	16000	-334	0	9999	0	9999	0	9999	0	9999	0	0	0				
21	1000	9000	-429	0	9999	0	9999	0	9999	0	9999	0	0	0				
22	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
23	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
24	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
25	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
26	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
27	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
28	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
29	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
30	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
31	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
32	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
33	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
34	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
35	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
36	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
37	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
38	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
39	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
40	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
41	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
42	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
43	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
44	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
45	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
46	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
47	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
48	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
49	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

50	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**
51	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**
52	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**

Branch	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
53	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
54	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
55	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
56	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
57	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
58	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
59	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
60	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
61	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
62	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
63	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
64	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
65	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
66	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
67	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
68	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
69	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
70	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
71	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
72	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
73	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
74	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
75	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P2&1-Bond	P2-NodeR	P2-AnodeDR	P2-ParWire	P3&2-Bond	P3-NodeR	P3-AnodeDR	P3-ParWire	P1&3-Bond
1	0.25											
2	0.25											
3	0.25											
4	1.3											
5	1.3											
6	1.3											
7	0.83											
8	0.83											
9	0.37											
10	0.37											
11	0.15											
12	0.15											
13	0.15											
14	0.34											
15	0.34											
16	0.51											
17	0.51											
18	0.33											
19	0.37											
20	0.37											
21	0.15											
22	0.15											
23	0.15											
24	0.15											
25	0.15											
26	0.15											
27	0.15											
28	0.15											
29	0.15											
30	0.15											
31	0.11											
32	0.11											
33	0.11											
34	0.11											
35	0.11											
36	0.11											
37	0.11											
38	0.11											
39	0.11											
40	0.11											
41	0.11											
42	0.11											
43	0.11											
44	0.11											
45	0.11											
46	0.11											
47	0.11											
48	0.11											
49	0.11											

50	**0.14**
51	**0.14**
52	**0.14**

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P1-Bonded	P2-NodeR	P2-AnodeDR	P2-ParWire	P2-Bonded	P3-NodeR	P3-AnodeDR	P3-ParWire	P3-Bonded
53	0.14											
54	0.14											
55	0.14											
56	0.14											
57	0.14											
58	0.14											
59	0.14											
60	0.14											
61	0.14											
62	0.14											
63	0.14											
64	0.14											
65	0.1											
66	0.1											
67	0.1											
68	0.1											
69	0.1											
70	0.1											
71	0.1											
72	0.1											
73	0.1											
74	0.1											
75	0.1											
76	0.1											

Appendix 5

Voltages on pipeline

Powerline T5 with phase to earth fault at KP 337; continuous parallel earthing mitigation

Comments

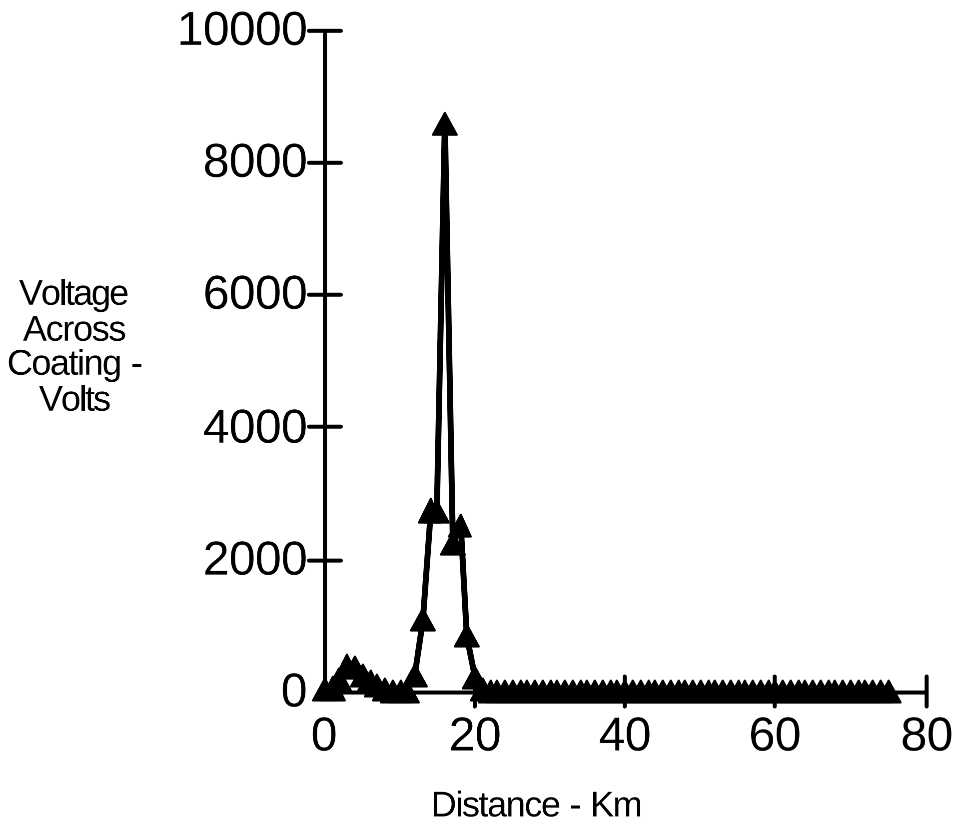
CQGP
KP 320 - 393
Fault Conditions
Powerline T5 (feeder 7167) faulted at Node 17 (KP 337)
Fault current 7,000 A
Mitigation as calculated using near surface (5 metre) soil resistivity values and discrete earthing.

Original data by Brian Martin & Associates
9 February 2007

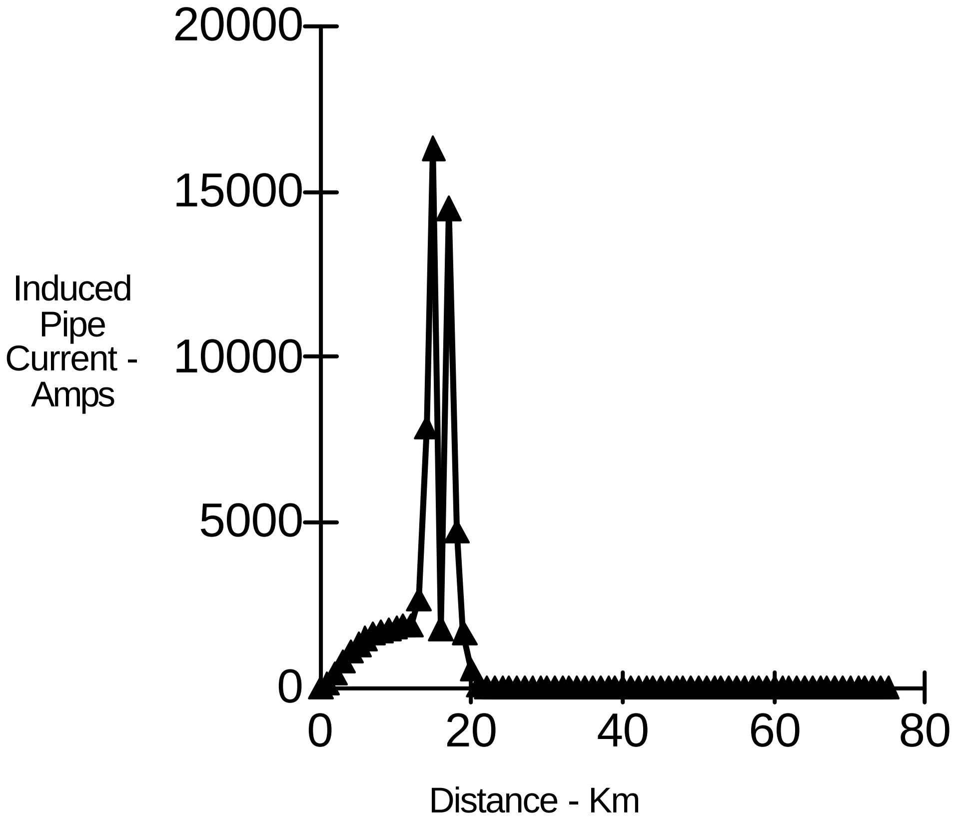
Review with modifications by Geoff Cope & Associates
12 April 2007

Coating resistance increased to 1 Meg ohm - square metre.
Discrete earthing at each node as calculated for 1,000 metres of ribbon using resistivity values at 5 metre depth.
Note: This provides a less conservative anwer than using 50 metre depth resisitivities, and would provide greater reduction of induced voltages. However it is generally unrealistic giv the generally increasing pattern of resistivity with depth.

File GCMT5a.acd



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	Volts	Distance	Volts	Distance	Volts
0.00	24.8	27.00	0.0	54.00	0.0
1.00	52.4	28.00	0.3	55.00	0.0
2.00	187.0	29.00	0.3	56.00	0.0
3.00	381.8	30.00	0.2	57.00	0.0
4.00	364.1	31.00	0.3	58.00	0.0
5.00	246.9	32.00	0.0	59.00	0.0
6.00	157.9	33.00	0.0	60.00	0.0
7.00	90.0	34.00	0.0	61.00	0.0
8.00	37.8	35.00	0.0	62.00	0.0
9.00	17.3	36.00	0.0	63.00	0.0
10.00	10.2	37.00	0.0	64.00	0.0
11.00	18.5	38.00	0.0	65.00	0.0
12.00	251.1	39.00	0.0	66.00	0.0
13.00	1092.2	40.00	0.0	67.00	0.0
14.00	2739.5	41.00	0.0	68.00	0.0
15.00	2734.3	42.00	0.0	69.00	0.0
16.00	8596.7	43.00	0.0	70.00	0.0
17.00	2246.0	44.00	0.0	71.00	0.0
18.00	2503.1	45.00	0.0	72.00	0.0
19.00	853.7	46.00	0.0	73.00	0.0
20.00	226.1	47.00	0.0	74.00	0.0
21.00	42.4	48.00	0.0	75.00	0.0
22.00	8.0	49.00	0.1		
23.00	1.4	50.00	0.1		
24.00	0.3	51.00	0.0		
25.00	0.1	52.00	0.0		
26.00	0.1	53.00	0.0		



Pipe #1		Pipe #1 (cont.)		Pipe #1 (cont.)	
Distance	**Current**	**Distance**	**Current**	**Distance**	**Current**
0.00	28.0	27.00	1.3	54.00	0.1
1.00	121.7	28.00	1.8	55.00	0.1
2.00	424.5	29.00	5.4	56.00	0.1
3.00	811.4	30.00	4.9	57.00	0.0
4.00	1080.5	31.00	0.9	58.00	0.0
5.00	1308.1	32.00	0.1	59.00	0.0
6.00	1494.4	33.00	0.1	60.00	0.0
7.00	1631.9	34.00	0.1	61.00	0.0
8.00	1718.1	35.00	0.1	62.00	0.1
9.00	1780.8	36.00	0.1	63.00	0.3
10.00	1831.7	37.00	0.1	64.00	0.3
11.00	1888.0	38.00	0.1	65.00	0.1
12.00	1875.5	39.00	0.0	66.00	0.0
13.00	2699.2	40.00	0.0	67.00	0.0
14.00	7883.8	41.00	0.0	68.00	0.0
15.00	16296.7	42.00	0.0	69.00	0.0
16.00	1797.3	43.00	0.0	70.00	0.0
17.00	14492.1	44.00	0.0	71.00	0.0
18.00	4746.8	45.00	0.0	72.00	0.0
19.00	1679.6	46.00	0.0	73.00	0.0
20.00	558.5	47.00	0.1	74.00	0.0
21.00	102.3	48.00	0.8	75.00	0.0
22.00	16.4	49.00	0.8		
23.00	4.4	50.00	0.1		
24.00	3.1	51.00	0.1		
25.00	2.1	52.00	0.1		
26.00	1.6	53.00	0.1		

T-Line

	D - m	H - m	R - ohms/Km	GMR - m
Shield Wire #1	-1	100	10000	0.0008
Shield Wire #2	1	100	10000	0.0008

	D - m	H - m	IL - A	IR - A	Total Current
Phase Wire	-2.5	11.5	7000	0	7000

	Avg Twr Sep. - m	Avg Twr Res - ohms	Faulted Twr Location
Elec. Sys Parameters	400	10	17

Arc Distance (m) 5.5

Pipe #1

Diameter - m	Burial Depth - m	R - Kohm-m2	Thickness - m
0.324	-1	1000	0.0013

First section **is** terminated in insulator
Last section **is** terminated in insulator

Faulted Tower Data
Section Information

Section	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
1	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
2	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
3	1000	4000	99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
4	1000	12000	-267	0	9999	0	9999	0	9999	0	9999	0	0	0				
5	1000	12000	84	0	9999	0	9999	0	9999	0	9999	0	0	0				
6	1000	12000	368	0	9999	0	9999	0	9999	0	9999	0	0	0				
7	1000	84000	185	0	9999	0	9999	0	9999	0	9999	0	0	0				
8	1000	84000	201	0	9999	0	9999	0	9999	0	9999	0	0	0				
9	1000	43000	170	0	9999	0	9999	0	9999	0	9999	0	0	0				
10	1000	43000	136	0	9999	0	9999	0	9999	0	9999	0	0	0				
11	1000	19000	101	0	9999	0	9999	0	9999	0	9999	0	0	0				
12	1000	19000	75	0	9999	0	9999	0	9999	0	9999	0	0	0				
13	1000	19000	21	0	9999	0	9999	0	9999	0	9999	0	0	0				
14	1000	48000	20	0	9999	0	9999	0	9999	0	9999	0	0	0				
15	1000	48000	20	0	9999	0	9999	0	9999	0	9999	0	0	0				
16	1000	77000	20	0	9999	0	9999	0	9999	0	9999	0	0	0				
17	1000	77000	20	0	9999	0	9999	0	9999	0	9999	0	0	0				
18	1000	35000	-216	0	9999	0	9999	0	9999	0	9999	0	0	0				
19	1000	16000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
20	1000	16000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
21	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
22	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
23	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
24	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
25	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
26	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
27	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
28	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
29	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
30	1000	9000	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
31	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
32	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
33	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
34	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
35	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
36	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
37	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
38	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
39	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
40	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
41	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
42	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
43	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
44	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
45	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
46	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
47	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
48	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
49	1000	1300	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

50	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**
51	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**
52	**1000**	**4400**	**-99999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**9999**	**0**	**0**	**0**

Branch	Length	Soil Res	L1 - D	L1 - A	L2 - D	L2 - A	L3 - D	L3 - A	L4 - D	L4 - A	L5 - D	L5 - A	P1 - D	P1 - A	P2 - D	P2 - A	P3 - D	P3 - A
53	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
54	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
55	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
56	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
57	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
58	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
59	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
60	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
61	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
62	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
63	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
64	1000	4400	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
65	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
66	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
67	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
68	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
69	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
70	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
71	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
72	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
73	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
74	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				
75	1000	3100	-99999	0	9999	0	9999	0	9999	0	9999	0	0	0				

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P2&1-Bond	P2-NodeR	P2-AnodeDR	P2-ParWire	P3&2-Bond	P3-NodeR	P3-AnodeDR	P3-ParWire	P1&3-Bond
1	0.25											
2	0.25											
3	0.25											
4	1.3											
5	1.3											
6	1.3											
7	0.83											
8	0.83											
9	0.37											
10	0.37											
11	0.15											
12	0.15											
13	0.15											
14	0.34											
15	0.34											
16	0.51											
17	0.51											
18	0.33											
19	0.37											
20	0.37											
21	0.15											
22	0.15											
23	0.15											
24	0.15											
25	0.15											
26	0.15											
27	0.15											
28	0.15											
29	0.15											
30	0.15											
31	0.11											
32	0.11											
33	0.11											
34	0.11											
35	0.11											
36	0.11											
37	0.11											
38	0.11											
39	0.11											
40	0.11											
41	0.11											
42	0.11											
43	0.11											
44	0.11											
45	0.11											
46	0.11											
47	0.11											
48	0.11											
49	0.11											

50	**0.14**
51	**0.14**
52	**0.14**

Sec/Node	P1-NodeR	P1-AnodeDR	P1-ParWire	P1-Bonded	P2-NodeR	P2-AnodeDR	P2-ParWire	P2-Bonded	P3-NodeR	P3-AnodeDR	P3-ParWire	P3-Bonded
53	0.14											
54	0.14											
55	0.14											
56	0.14											
57	0.14											
58	0.14											
59	0.14											
60	0.14											
61	0.14											
62	0.14											
63	0.14											
64	0.14											
65	0.1											
66	0.1											
67	0.1											
68	0.1											
69	0.1											
70	0.1											
71	0.1											
72	0.1											
73	0.1											
74	0.1											
75	0.1											
76	0.1											