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Smart Ground Test Report

Springfield Energy - Springfield Power Station Grounding System Evaluation

Prepared for

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U.S.A.

Prepared by

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*The client name and location are fictitious to protect proprietary information. As a result, the information contained in this sample report is for illustrative purposes only and is intended to provide a representation of the types of information that are typically included in a Smart Ground Report. It is not intended as a complete report. Portions of the report are abbreviated as well as a number of sections were omitted in their entirety.

Table of Contents

Grounding System Testing and Analysis of the Springfield Power Station

1. Executive Summary

This report describes the ground tests and analysis of the Springfield Power Station. The objective of the test and analysis was to evaluate the plant grounding system with respect to safety performance, and transfer voltage to control circuits and if necessary, to recommend grounding design enhancements. The report describes the development of a validated model of this plant and the utilization of the model for safety assessment. Recommendations are also provided for improving the performance of the Springfield Power Station grounding system. A quantitative analysis of the recommendations is also provided.

The design drawings of the Springfield Power Station single line diagram and grounding system were reviewed. The information of the drawings has been used to develop a preliminary integrated model of the Springfield Power Station. This model was subsequently finalized from data obtained during the site visit and ground measurements performed during the site visit. Appendix A describes the final integrated model and provides detailed model parameters.

The Springfield Power Station grounding system was tested on April 17, 18, and 19, 2007. Testing was performed using the Smart Ground Multimeter, model 4001, serial number 57, and consisted of (a) Soil Resistivity Measurements, (b) Ground Impedance Measurements, and (c) Point-to-Point Ground Impedance measurements. Using these measurements the computer model was validated. The validated model was used to perform a series of analyses for the purpose of determining whether the system meets safety standards as is, and as well as with the recommended grounding system enhancements.

Soil Resistivity Measurements: The soil resistivity tests were performed at a location near the plant. The average soil resistivity around the plant area was also indirectly measured during the ground impedance measurements. The measurements were used to construct a two layer soil model, given below:

Upper Layer Resistivity	139.7 Ohm-meter
Lower Layer Resistivity	229.2 Ohm-meter
Depth of Upper Layer	18.6 feet

Ground Impedance Measurements: The ground impedance of the generating plant was measured using the Smart Ground Multimeter. The measurement results are summarized in the table below. The table also lists the system ground impedance computed with the validated WinIGS model. The agreement between measured and computed quantities is very good.

Quantity	WinIGS model	Measured Values	Error at 99% Confidence
System Ground Impedance at 60 Hz	0.094 Ohms	0.0874 Ohms	24%

Point to Point Ground Measurements: Point to point measurements were taken to determine the status of the plant grounding system. A total of 65 point-to-point ground impedance measurements were performed. These tests are reported in Section 5 and in Appendix D. The measured point to point ground impedance measurements were compared to the computed point to point ground impedances. A summary of the measured and computed values is given in Table 5.1 in section 5. The agreement between the measured and computed values is good except in some cases that are discussed below.

(An abbreviated table on page 5 is included for the purpose of document.)

The following observations were made by comparing the measured and computed results:

- All of the tested ground connections within the switchyard area are bonded together. In most locations, the measured impedances are close to the values computed using the WinIGS grounding model.

- The impedance between the switchyard fence posts is low, but the impedance between the fence and the switchyard grounding system is substantially higher that the computed value. This suggests that the fence ground may not be bonded to the switchyard ground or the bonding is very poor. (See measurements on Figures D-3, D-14, and D-63, Appendix D).

- The impedance between the 161 kV line poles near the generator building and the generator building grounding system is substantially higher than the computed values. This suggests that the bonding between these points is made only via the overhead shield wires. (See measurements on Figures D-34, D-35, and D-36, Appendix D).

- The impedance between the substation grounding system and the microwave tower ground is considerably higher than the computed value (See measurements on Figures D-53, D-54, and D-55, Appendix D).

- The impedance between the substation grounding system and the conveyor level shift ground is considerably higher than the computed value (See measurement on Figure D-56, Appendix D).

- The impedance between the switchyard and the generator building grounding system is high. As a matter of fact it is substantially higher than the computed value assuming that the only bonding between the two grounding systems is a single 4/0 copper cable running along the control cable conduits (See measurement on Figure D-62, Appendix D).

- The impedance between the switchyard ground and the 161 kV startup and step-up line poles nearest to the switchyard is high. This suggests that the bonding between these points is made only via the overhead shield wires. In fact at one of the downlead conductors the impedance was measured to be approximately 13 ohms which indicates that the connector between the shield wire and the downlead conductor has failed. (See measurements on Figures D-64, D-65, D-66, D-67, and D-68, Appendix D).

Point to Point Measurements

Fig. #		Location	Computed Resistance (mΩ)	Measured Resistance (mΩ)	Measured Impedance (mΩ)
3	P01	Fence Bonding	**21.79**	**134.33**	**66.07**
4	P02	N.W. side, 345kV, Support St	6.85	9.329	18.88
10	P08	CCVT 345 T6	4.04	8.565	17.67
11	P09	Breaker, CB162, B-Phase	4.74	8.878	18.01
12	P10	Line Trap	5.53	12.13	26.36
13	P11	Wire Vault, 133	5.45	58.04	120.3
14	P12	S.W. Corner, Fence, 161kV Side	**10.32**	**134.56**	**65.30**
53	P48	S Yard Fence to Microwave Twr Dwn Cndtr	37.58	**323.4**	**355.5**
54	P49	S Yard Fence to Microwave Twr Bldg	37.60	**323.3**	**355.3**
55	P50	S Yard Fence to Microwave Twr Fence	39.71	**329.0**	**361.3**
56	P51	S Yard Fence to Conveyor Level Shift Tower	38.91	**216.5**	**308.4**
57	P53	S Yard Fence to Sub A-Frame Structure	55.33	46.01	88.14
58	P53	Conv. Tower to Sub Bus Support	55.33	**187.2**	**273.8**

Grounding System Safety Evaluation: The measurements, additional data and field observations were used to complete and validate the Springfield Power Station computer model. Using the validated model, the plant grounding system was analyzed to determine whether it meets the safety requirements of the IEEE Standard 80, 2000 edition. Specifically, a comprehensive safety analysis was performed at two locations: (a) Generating Plant area, and (b) Switchyard. The safety evaluation is based on the analysis of the plant grounding system performance under worst fault conditions. The analysis was performed using the validated computer model of the Springfield Power Station, and nearby transmission lines. Using the computer model, a comprehensive fault analysis was performed to determine the fault that causes maximum ground potential rise at locations (a) and (b). A detailed description of the safety analysis is presented in Section 7. The analysis results are also summarized in the Table below.

Quantity	Generating Plant	Switchyard
Fault Type	Double Line to Ground	Double Line to Ground
Fault Location	161 kV Bus	161 kV Bus
Ground Potential Rise	387 Volts	1639 Volts
Fault Current	20.89 kA, 19.78 kA	20.89 / 19.78 kA
Earth Current	2.597 kA	7.484 kA
X/R Ratio at Fault Location	7.73	7.73
Current division ratio	12.43%	35.82 %
Allowable Touch Voltage (with for 4" Gravel / Native Soil)	170 V	488 V
Maximum Touch Voltage in Substation Area	**116 V**	**625 V**
Allowable Step Voltage, for Native Soil Top Layer	199 V	199 V
Maximum Step Voltage	**23 V**	**130 V**

The safety analysis indicated that the generating plant grounding system meets the safety requirements of IEEE Std 80. ***However***, the switchyard violates the IEEE Std 80 requirements by a 28% margin.

Transfer Voltage Evaluation: An analysis was performed to evaluate the voltage transferred to control circuits located in underground conduits running from the switchyard to the generating plant. The voltage transferred to control circuits during faults and other transients is caused by a combination of (a) ground potential differences between the switchyard ground and the generating plant ground, (b) induced voltages due to currents flowing in the two 161 kV transmission lines connecting the generating plant and the switchyard, and (c) induced voltages due to current flowing in the ground conductor installed along the conduits of the communication and control circuits. It appears that presently this ground conductor is the only substantial conductor connecting the two grounding systems, and thus potential differences in the two grounding systems may result in a high current flow through this conductor. Since this conductor is in close proximity to the control circuits, the induced voltages to the control circuits can be significant.

In order to evaluate the level of transfer voltages to the control circuits a detailed representation of the power circuits as well as a typical control circuit connecting the power plant with the switchyard was included in the integrated computer model of the system. The model and the detailed analysis results are is described in section 7.3. Using this model, a transfer voltage analysis was performed for the worst fault condition, i.e. the fault that causes the highest level of induced voltage on the communication circuits.

The analysis results include the common mode and differential mode terminal voltages on the control circuit on the generating plant side, the ground potential difference between generating plant and switchyard grounding systems, and the current flowing through the conduit ground conductor. The results are summarized in the Table below.

Common Mode Voltages	893 V / 927 V
Differential Mode Voltage	37 V
Ground Potential Difference	926 V
Ground Conductor Current	2.22 kA

Recommendations: In order to make the switchyard ground system IEEE Std 80 compliant and to reduce the impact of the induced voltages and ground potential differences on the communication and control circuits it is recommended that the bonding between the switchyard and generating plant grounds is enhanced. The bonding shall be accomplished as follows:

- Install one bare 4/0 Copper conductor between the switchyard and generating plant grounding systems along the path of the 161 kV circuits.
- Install one additional 4/0 copper wire along the control circuits and on opposite side of the existing 4/0 copper ground conductor.
- Install one bare 500 mcm Copper conductor between the switchyard and generating plant grounding systems along the shortest possible straight path. The recommended path shown in Figure 8.1 is between the north east corner of the switchyard and the generator building.
- Repair the grounding and bonding connections especially around the area of the chimney stack. See also relevant comments included in section 6 (Field Observations).

- Install two 4/0 copper conductors between the switchyard grounding system and the communication tower as the present drawing shows (and the testing revealed that these bonds may not be there). See also relevant comments included in section 6 (Field Observations) and Appendix D (point to point ground measurements).

- Install two additional ground conductors in the switchyard as it is shown in the design drawings in Attachment 1.

All new ground conductors shall be buried at least 4' below grade except the ones in the switchyard that shall be buried at 1.5 feet to be consistent with the switchyard grounding. The specific routing of the conductors can be modified to avoid existing obstacles such as equipment pads, light posts, etc. The conductors shall be bonded to the grounding system via two exothermic connectors at each end. Design drawings are provided in section 8 and the Attachment section at the end of this report.

Analysis of Enhanced System: The safety and transfer voltage analyses were repeated assuming that the recommended enhancements are implemented. The analysis indicated that the enhanced grounding system will meet the IEEE Std 80 safety requirements with margin. Furthermore, the proposed enhancements reduce the level of common and differential mode voltages transferred to control circuits connecting the power plant to the switchyard. The results of the safety and transfer voltage analyses are given in section 9 and summarized below:

Safety Analysis Summary

Quantity	Generating Plant	Switchyard
Fault Type	Line to Ground Fault	Double Line to Neutral
Fault Location	Line to Green River 2 miles from Plant	161 kV Bus
Ground Potential Rise	443 Volts	780 Volts
Fault Current	15.55 kA	20.81 / 19.92 kA
Earth Current	3.65 kA	3.864 kA
X/R Ratio at Fault Location	2.65	8.45
Current division ratio	36.3%	15.8 %
Allowable Touch Voltage (with for 4" Gravel / Native Soil)	172 V	488 V
Maximum Touch Voltage in Substation Area	**132 V**	**379 V**
Allowable Step Voltage, for Native Soil Top Layer	202 V	199 V
Maximum Step Voltage	**10.7 V**	**24 V**

Transfer Voltage Analysis Summary

	Existing	Enhanced
Common Mode Voltages	893 V / 927 V	333 V / 328 V
Differential Mode Voltage	37 V	5.6 V
Ground Potential Difference	926 V	52 V
Ground Conductor Current	2.22 kA	1.19 kA

The proposed enhancements will be effective in limiting the voltages transferred to the control circuits and meet the IEEE Std 80 requirements.

2. System Network Model

This section summarizes the integrated model of the Springfield Energy Station and the local Switchyard. The initial model was developed from a number of drawings supplied by the sponsor. During the site visit data were collected and were used to update the model as well as ground measurements. The field collected data are photographs of nameplates and ground construction and observations acquired during the site visit. The ground measurements were utilized to validate the model. The details of the final integrated model are given in Appendix A.

2.1 System Network Model

The single line diagram of the network model is illustrated in Figures 2.1, 2.2, and 2.3 (overall integrated network). Note that the model consists of a detailed model of the Springfield Energy Station (Figure 2.3), a detailed model of the 161/345 kV switchyard (Figure 2.2), and a model of the 161 and 345 kV transmission lines terminating at the switchyard (Figure 2.1). The power system beyond these transmission lines is represented by equivalent sources, Substations A & B. The equivalent source parameters ware adjusted in order to matching the provided short circuit analysis results (see section 2.3). The parameters of all major components of the system model are given in Appendix A.

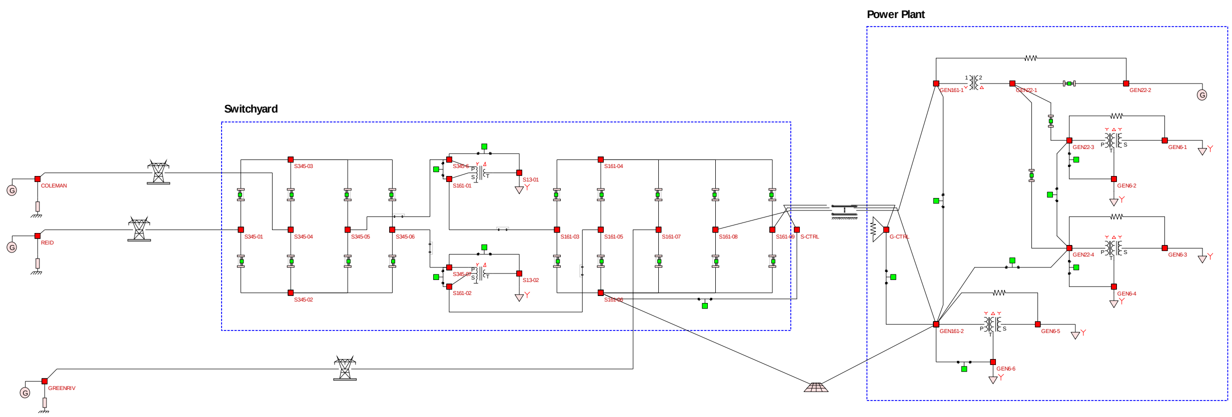
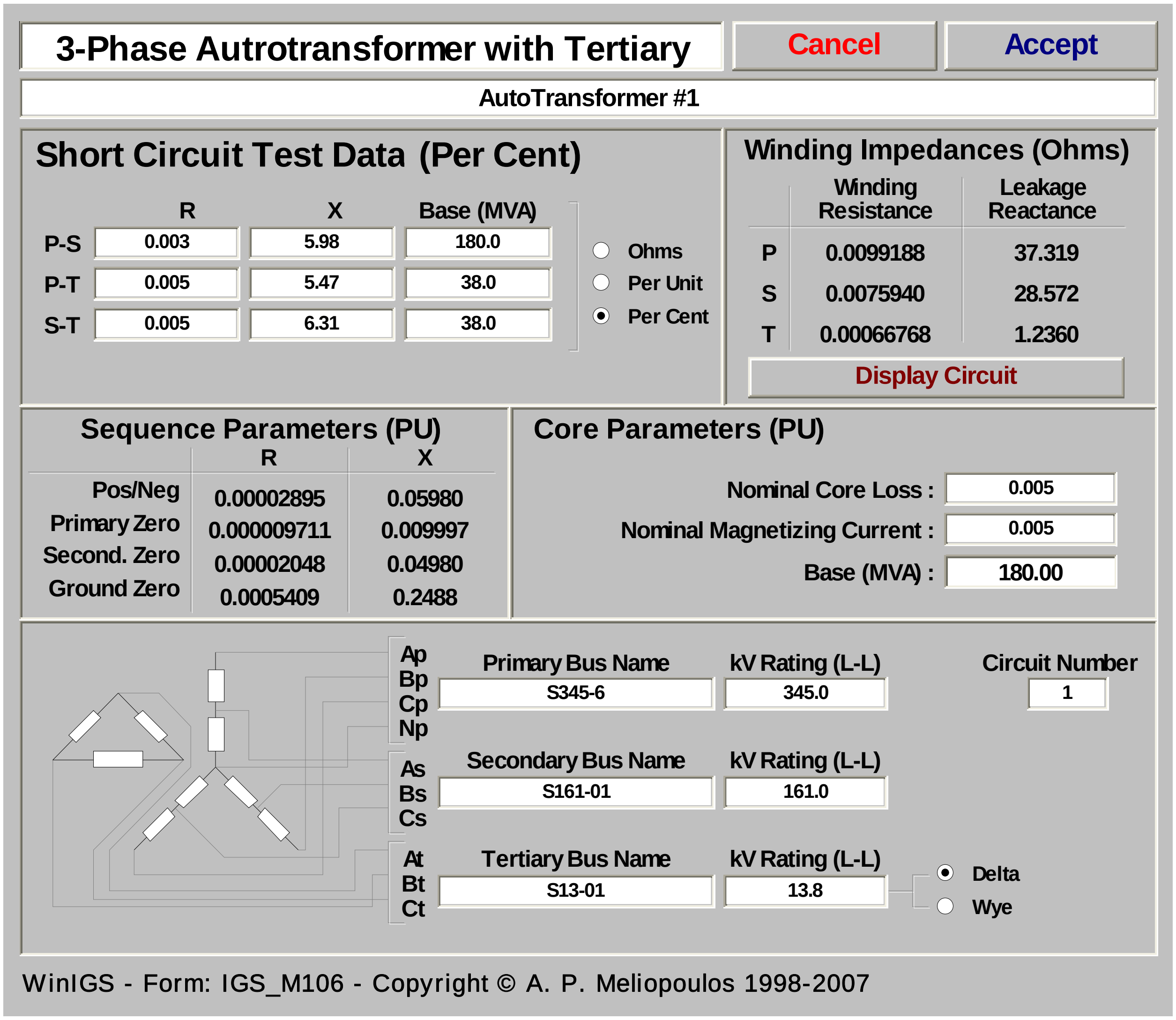


Figure 2.1 Single Line Diagram of the Overall Electric Power System



3-Phase Autotransformer with Tertiary Cancel Accept

AutoTransformer #1

Short Circuit Test Data (Per Cent)

	R	X	Base (MVA)
P-S	0.003	5.98	180.0
P-T	0.005	5.47	38.0
S-T	0.005	6.31	38.0

Ohms
Per Unit
Per Cent

Winding Impedances (Ohms)

	Winding Resistance	Leakage Reactance
P	0.0099188	37.319
S	0.0075940	28.572
T	0.00066768	1.2360

Display Circuit

Sequence Parameters (PU)

	R	X
Pos/Neg	0.00002895	0.05980
Primary Zero	0.000009711	0.009997
Second. Zero	0.00002048	0.04980
Ground Zero	0.0005409	0.2488

Core Parameters (PU)

Nominal Core Loss : 0.005
Nominal Magnetizing Current : 0.005
Base (MVA) : 180.00

Ap Bp Cp Np — Primary Bus Name: S345-6 — kV Rating (L-L): 345.0 — Circuit Number: 1

As Bs Cs — Secondary Bus Name: S161-01 — kV Rating (L-L): 161.0

At Bt Ct — Tertiary Bus Name: S13-01 — kV Rating (L-L): 13.8 — Delta / Wye

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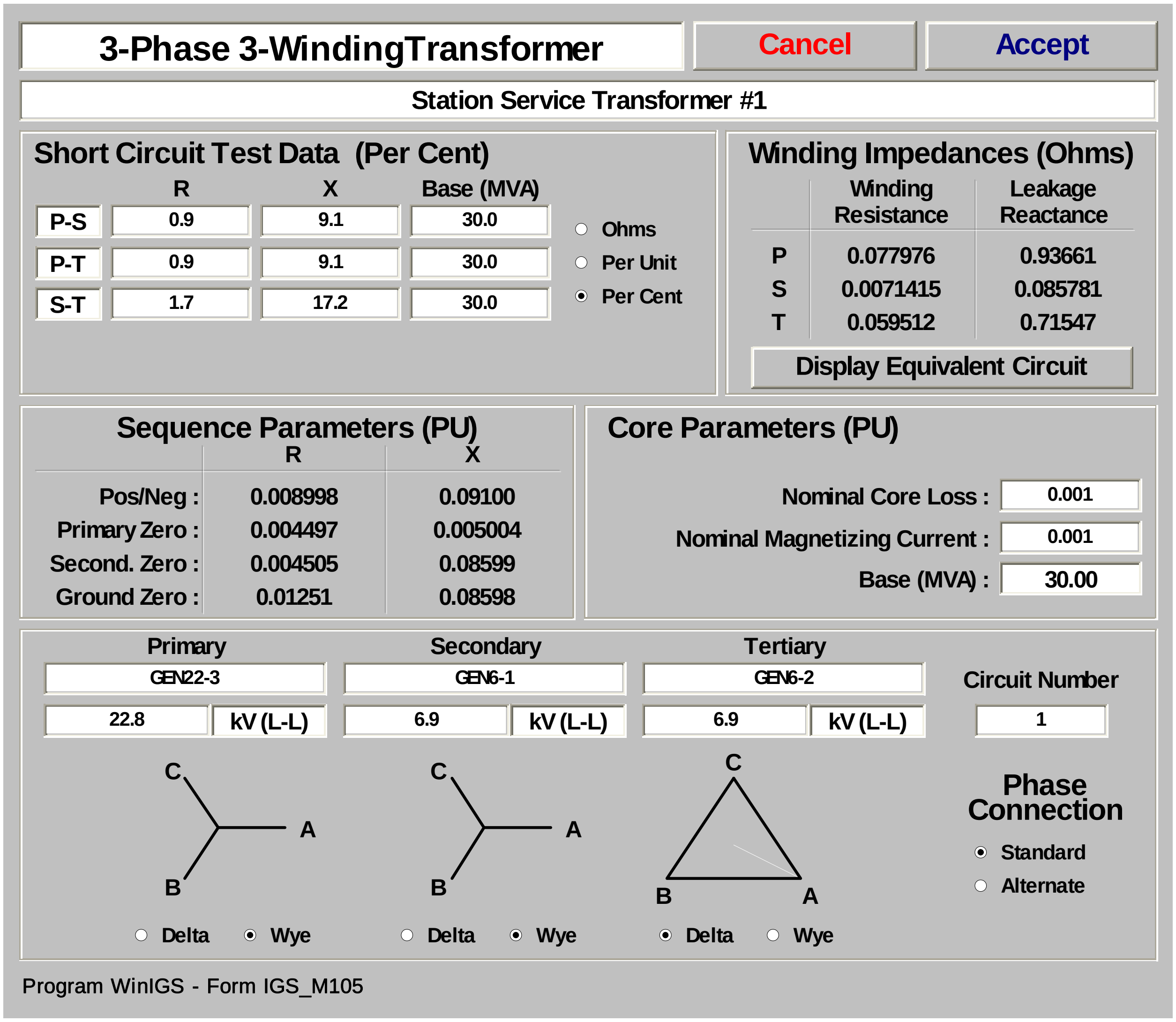
Figure A-10: Parameters of Switchyard Autotransformer Bank 1



3-Phase 3-WindingTransformer

Cancel

Accept

Station Service Transformer #1

Short Circuit Test Data (Per Cent)

	R	X	Base (MVA)
P-S	0.9	9.1	30.0
P-T	0.9	9.1	30.0
S-T	1.7	17.2	30.0

○ Ohms
○ Per Unit
◉ Per Cent

Winding Impedances (Ohms)

	Winding Resistance	Leakage Reactance
P	0.077976	0.93661
S	0.0071415	0.085781
T	0.059512	0.71547

Display Equivalent Circuit

Sequence Parameters (PU)

	R	X
Pos/Neg :	0.008998	0.09100
Primary Zero :	0.004497	0.005004
Second. Zero :	0.004505	0.08599
Ground Zero :	0.01251	0.08598

Core Parameters (PU)

Nominal Core Loss :	0.001
Nominal Magnetizing Current :	0.001
Base (MVA) :	30.00

	Primary	Secondary	Tertiary
Bus	GEN22-3	GEN6-1	GEN6-2
kV (L-L)	22.8	6.9	6.9
Connection	○ Delta ◉ Wye	○ Delta ◉ Wye	◉ Delta ○ Wye

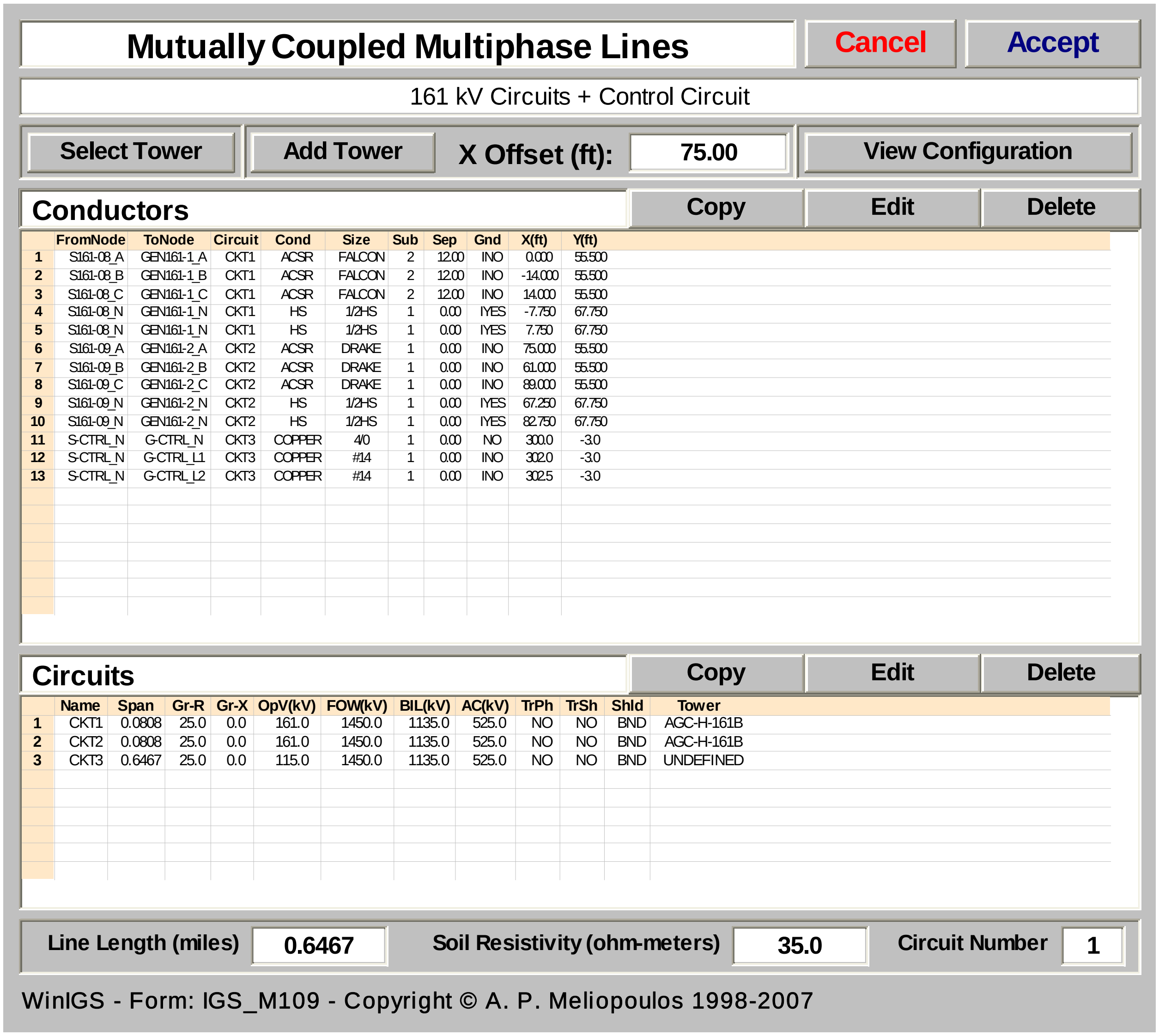
Circuit Number: 1

Phase Connection

◉ Standard
○ Alternate

Program WinIGS - Form IGS_M105

Figure A-13: Parameters of Station Service Transformer 1



Mutually Coupled Multiphase Lines

Cancel

Accept

161 kV Circuits + Control Circuit

Select Tower

Add Tower

X Offset (ft): 75.00

View Configuration

Conductors

Copy

Edit

Delete

	FromNode	ToNode	Circuit	Cond	Size	Sub	Sep	Gnd	X(ft)	Y(ft)
1	S161-08_A	GEN161-1_A	CKT1	ACSR	FALCON	2	12.00	INO	0.000	55.500
2	S161-08_B	GEN161-1_B	CKT1	ACSR	FALCON	2	12.00	INO	-14.000	55.500
3	S161-08_C	GEN161-1_C	CKT1	ACSR	FALCON	2	12.00	INO	14.000	55.500
4	S161-08_N	GEN161-1_N	CKT1	HS	1/2HS	1	0.00	IYES	-7.750	67.750
5	S161-08_N	GEN161-1_N	CKT1	HS	1/2HS	1	0.00	IYES	7.750	67.750
6	S161-09_A	GEN161-2_A	CKT2	ACSR	DRAKE	1	0.00	INO	75.000	55.500
7	S161-09_B	GEN161-2_B	CKT2	ACSR	DRAKE	1	0.00	INO	61.000	55.500
8	S161-09_C	GEN161-2_C	CKT2	ACSR	DRAKE	1	0.00	INO	89.000	55.500
9	S161-09_N	GEN161-2_N	CKT2	HS	1/2HS	1	0.00	IYES	67.250	67.750
10	S161-09_N	GEN161-2_N	CKT2	HS	1/2HS	1	0.00	IYES	82.750	67.750
11	S-CTRL_N	G-CTRL_N	CKT3	COPPER	4/0	1	0.00	NO	300.0	-3.0
12	S-CTRL_N	G-CTRL_L1	CKT3	COPPER	#14	1	0.00	INO	302.0	-3.0
13	S-CTRL_N	G-CTRL_L2	CKT3	COPPER	#14	1	0.00	INO	302.5	-3.0

Circuits

Copy

Edit

Delete

	Name	Span	Gr-R	Gr-X	OpV(kV)	FOW(kV)	BIL(kV)	AC(kV)	TrPh	TrSh	Shld	Tower
1	CKT1	0.0808	25.0	0.0	161.0	1450.0	1135.0	525.0	NO	NO	BND	AGC-H-161B
2	CKT2	0.0808	25.0	0.0	161.0	1450.0	1135.0	525.0	NO	NO	BND	AGC-H-161B
3	CKT3	0.6467	25.0	0.0	115.0	1450.0	1135.0	525.0	NO	NO	BND	UNDEFINED

Line Length (miles) 0.6467

Soil Resistivity (ohm-meters) 35.0

Circuit Number 1

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Figure A-15: 161 kV Circuits between Plant and Switchyard + Control Circuit

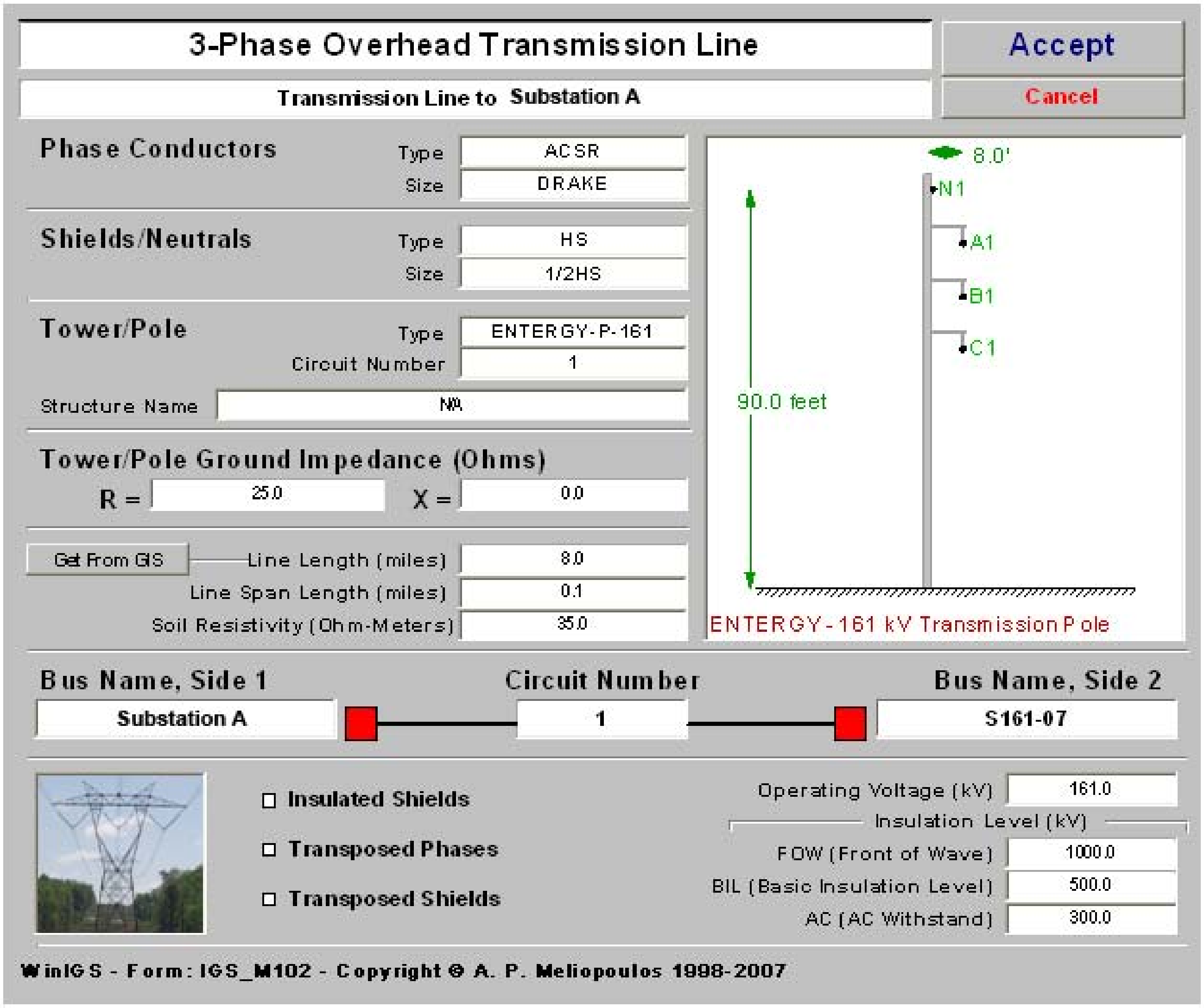


Figure A-16: Parameters of 161 kV Line to Substation A

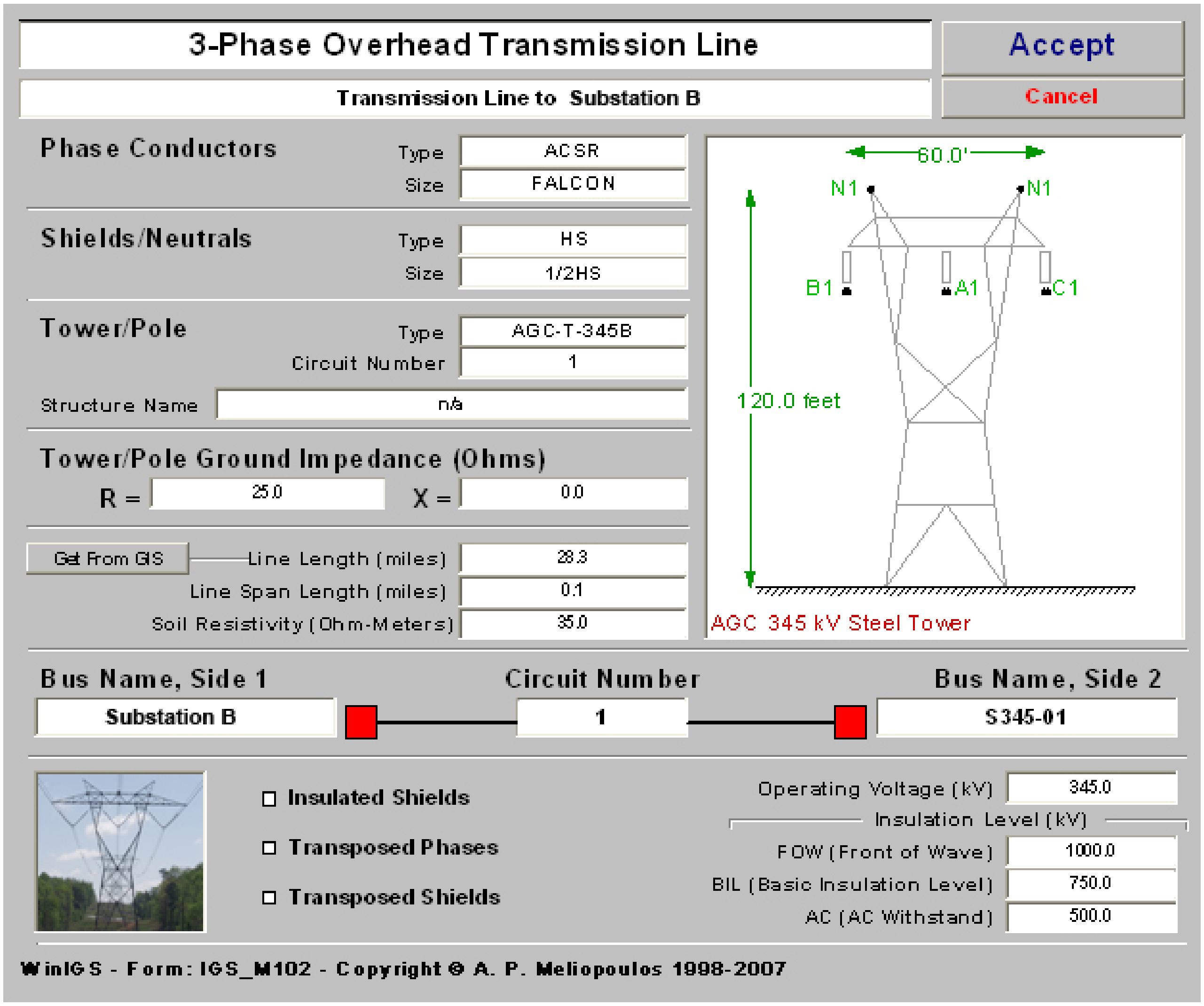


Figure A-17: Parameters of 345 kV Line to Substation B

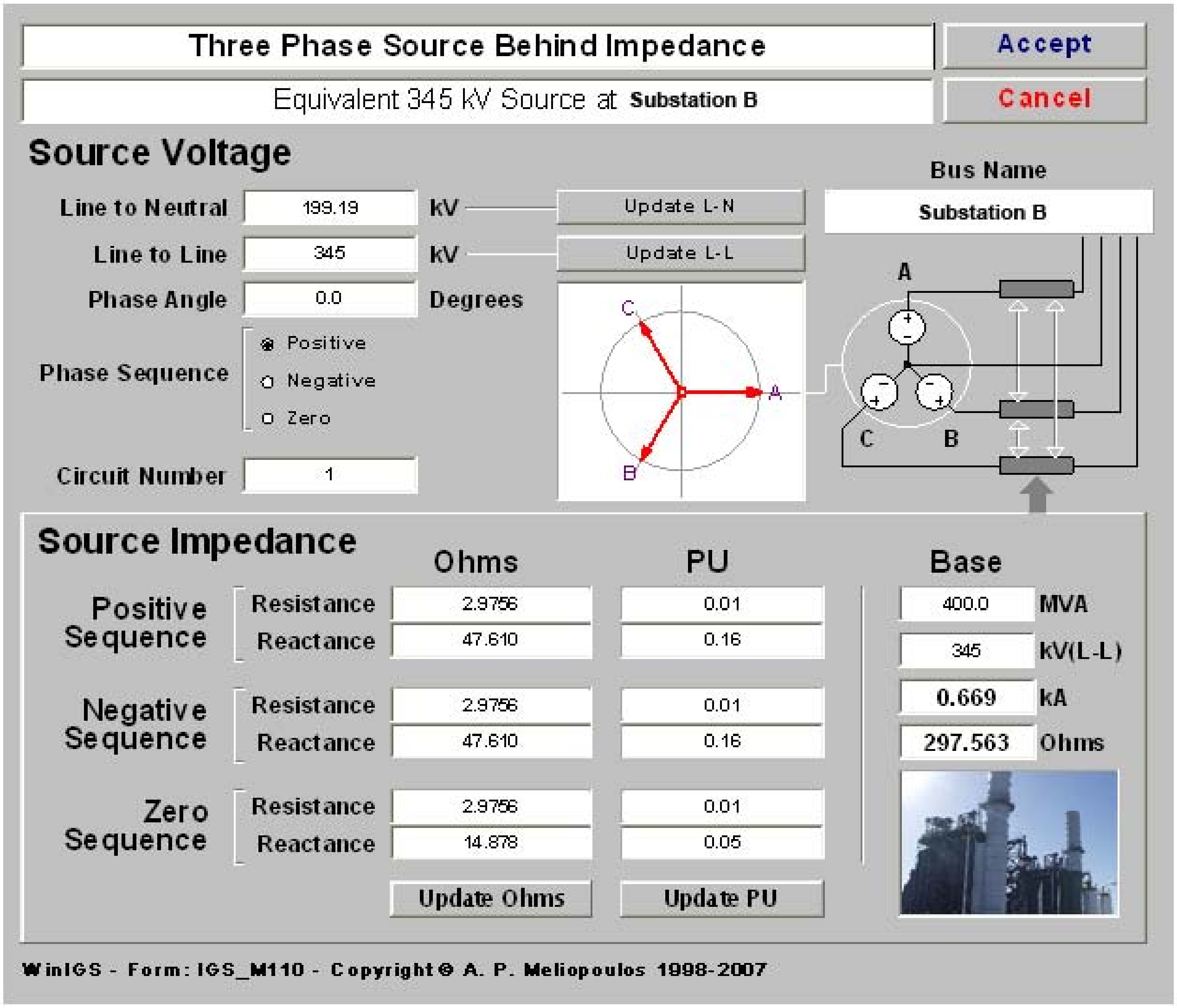


Figure A-21: Parameters of Equivalent Source at Substation B

2.2 Grounding Model

The grounding system model of the Springfield Energy Station and the local switchyard was constructed from the available drawings and photographs obtained during the site visit. The 3-D view of the grounding system is given in Figure 2.4. Note that the grounding model includes 3-D representations of all ground conductors. Figure 2.5 shows the top view of the grounding system model superimposed over a satellite photograph of the area. This model was validated with the field measurements described in Appendices B, C and D. The validated model was used for grounding system analysis to assess the safety of the plant.

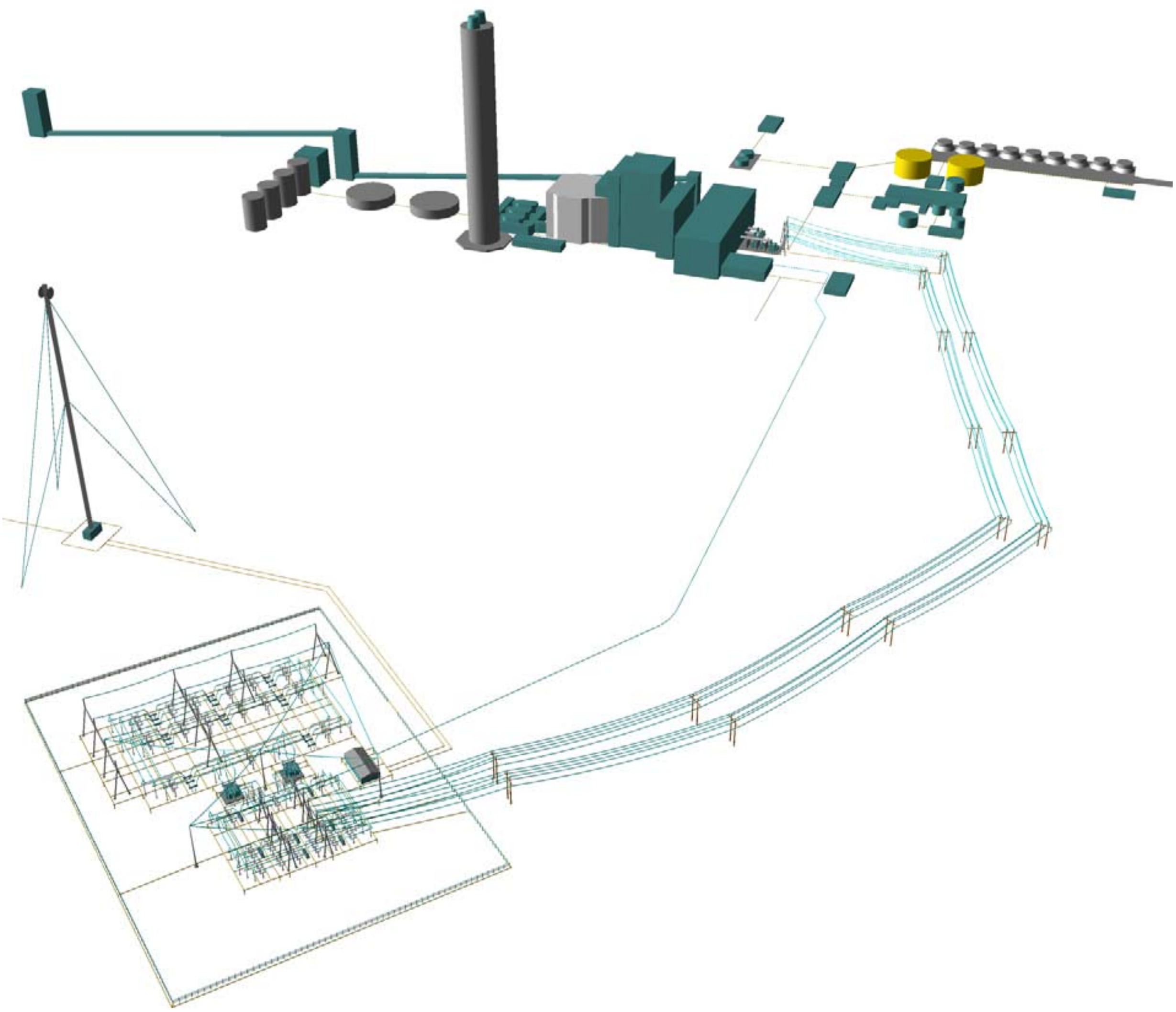


Figure 2.4: Grounding Model of Springfield Energy Station – 3-D Rendered View

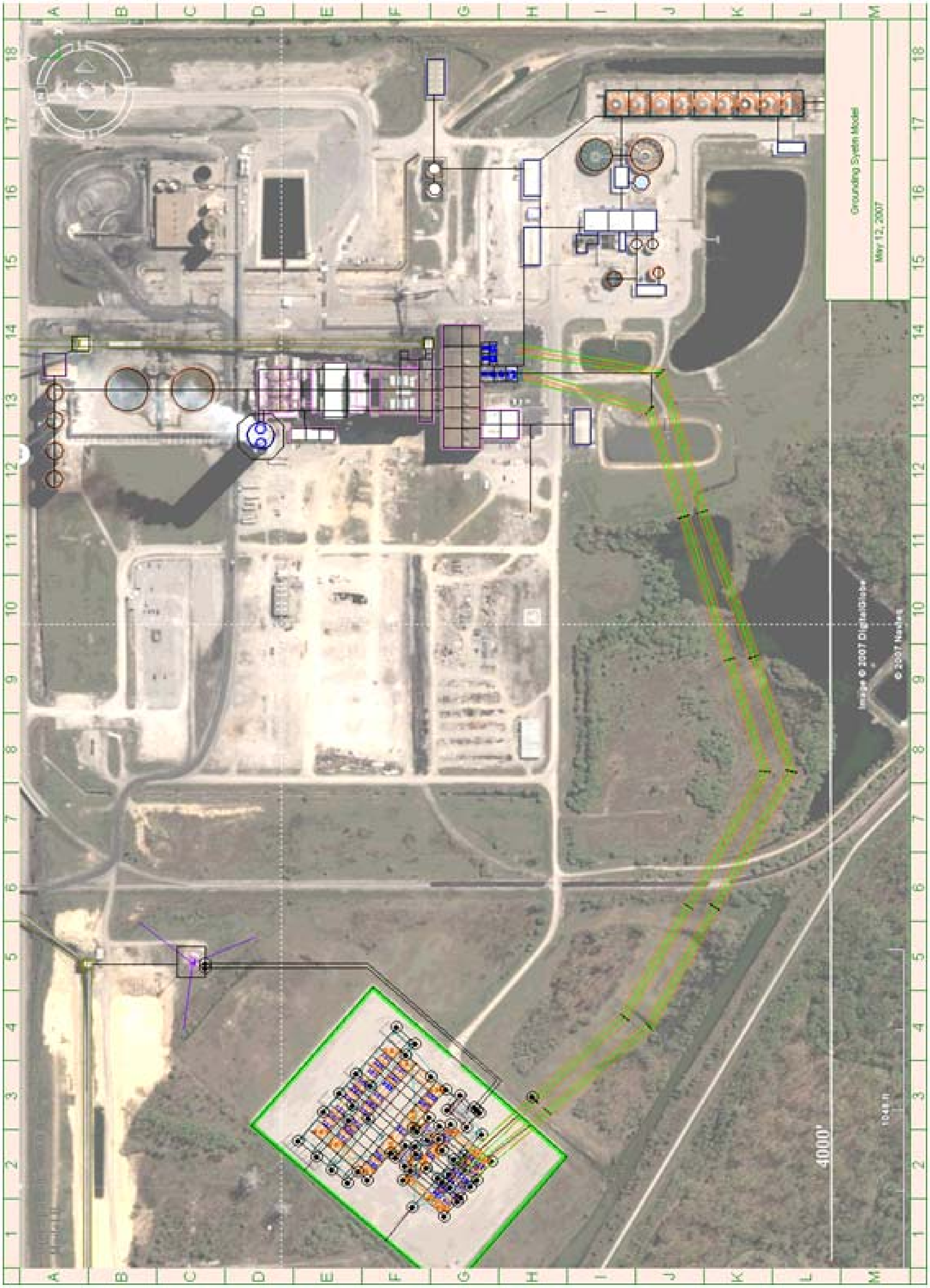


Figure A-4: Top View of the Grounding System – Overall View

2.3 Fault Current Analysis

This section presents the fault analysis of the Springfield Energy Station power system. The fault analysis results are summarized in Table 2.1. The fault currents computed with the WinIGS model are shown under the column titled **WinIGS Model**. The results of the provided short circuit analysis are listed in the column titled **Provided Study**. The detailed WinIGS fault analysis reports are shown in Figures 2.6 through 2.13.

The short circuit analysis results are used to select the appropriate size of grounding conductors (see section 8.1), and also to validate the WinIGS model by comparing the results with data computed by previous studies.

Table 2.1 Fault Analysis Summary

	Fault Current (kA)	
Fault Type	**Provided Study**	**WinIGS Model**
3-Phase Fault 345 kV Bus	9.193 kA	9.302 kA 9.204 kA 9.150 kA
Single Phase Fault on 345 kV Bus	10.015 kA	9.988 kA 9.929 kA 9.911 kA
3-Phase Fault on 161 kV Bus	18.667 kA	18.877 kA 18.862 kA 18.786 kA
Single Phase Fault on 161 kV Bus	21.685 kA	21.082 kA 21.054 kA 20.966 kA

3. Soil Resistivity Measurements

A series of soil resistivity measurements were performed near the Springfield Energy Station site on April 18, 2007. The measurements were performed using the Smart Ground Multimeter (Model 4001, SN57). Weather conditions were dry, about 70 Degrees Fahrenheit. The test location is illustrated in Figure 3.1.

Figure 3.1: Soil Resistivity Test Site

The soil model parameters are summarized in Table 3.1. The detailed soil resistivity measurement data are given in Appendix B. The "Best-Fit" soil resistivity report is shown in Figure 3.2. This report shows the results obtained by processing all soil resistivity measurements together. The final soil model used in grounding system performance analyses is given below:

Upper Layer Resistivity	**39.7**
Lower Layer Resistivity	**29.2**
Upper Layer Height	**9.6**

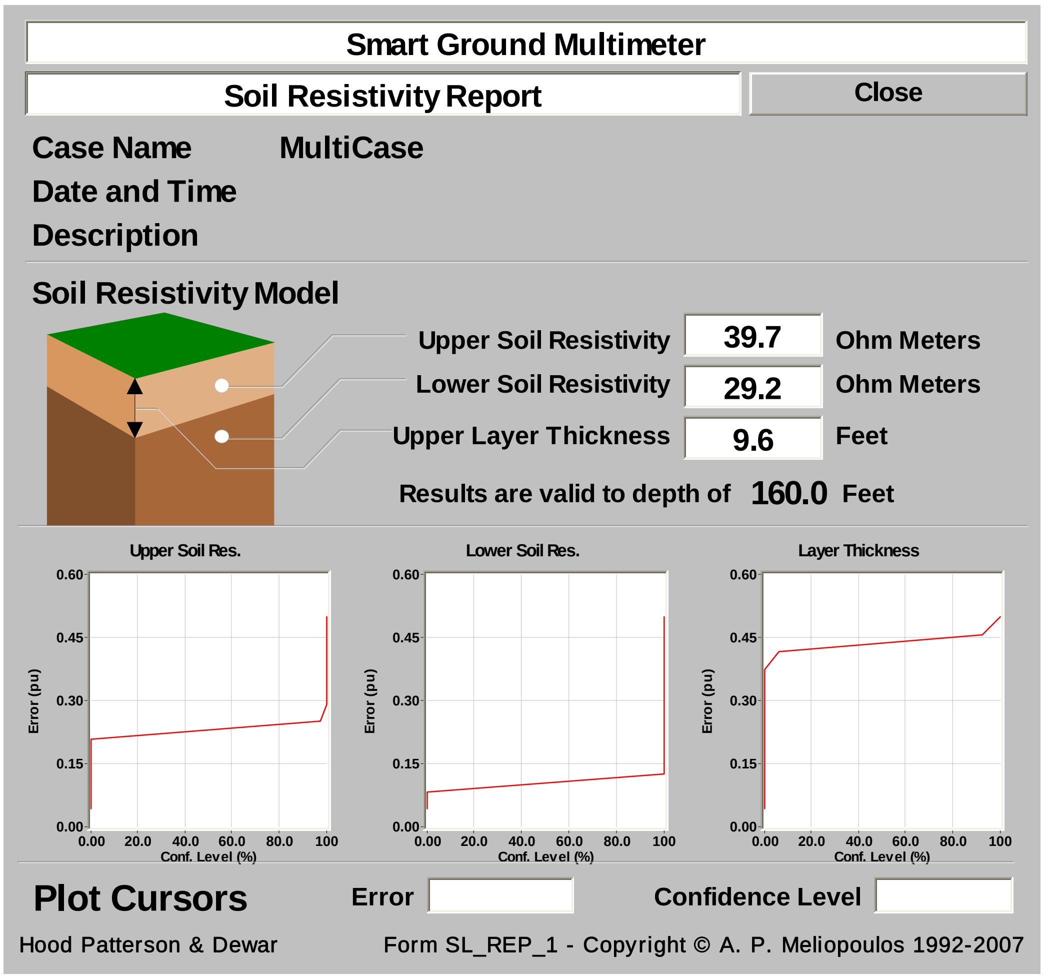


Figure 3.2 Soil Resistivity Report

4. Ground System Impedance Measurements

This section summarizes the results of the ground impedance measurements at the Springfield Energy Station. The measurements were performed on April 18, 2007 using the Smart Ground Multimeter, model 4001, SN57. The weather conditions were dry with ambient temperature 70 degrees Fahrenheit. A detailed description of the measurements and the results are given in Appendix C.

The ground impedance measurement report is given in Figure 4.1. The results are summarized in Table 4.1, below. The table also lists the ground system impedance computed with the WinIGS model. The WinIGS impedance report is shown in Figure 4.2. The computed values are in good agreement with the measured values.

Table 4.1: Ground Impedance Measurement Result Summary

Quantity	WinIGS model	Measured Values	Error at 99% Confidence
System Ground Impedance at 60 Hz	0.059 Ohms	0.0524 Ohms	24%

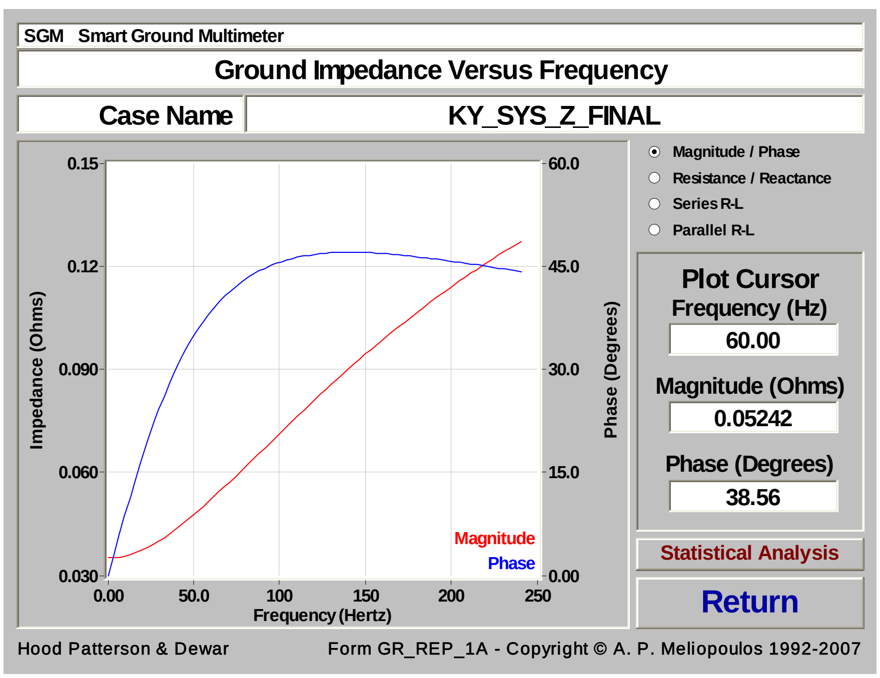


Figure 4.1: Ground System Impedance Measurement Report

5. Point to Point Ground Impedance Measurements

This section summarizes the Springfield Station point to point ground impedance tests. Detailed results are given in Appendix D. The measurements were performed on April 16-19, 2007 using the Smart Ground Multimeter, model 4001, (Serial Number 57). The weather conditions were dry with ambient temperature of 70 degrees Fahrenheit. The point to point ground impedance measurements focused on the following areas:

- Integrity of the grounding system
- Bonding of equipment to the ground mat
- Bonding of Fences to the Ground Mat.

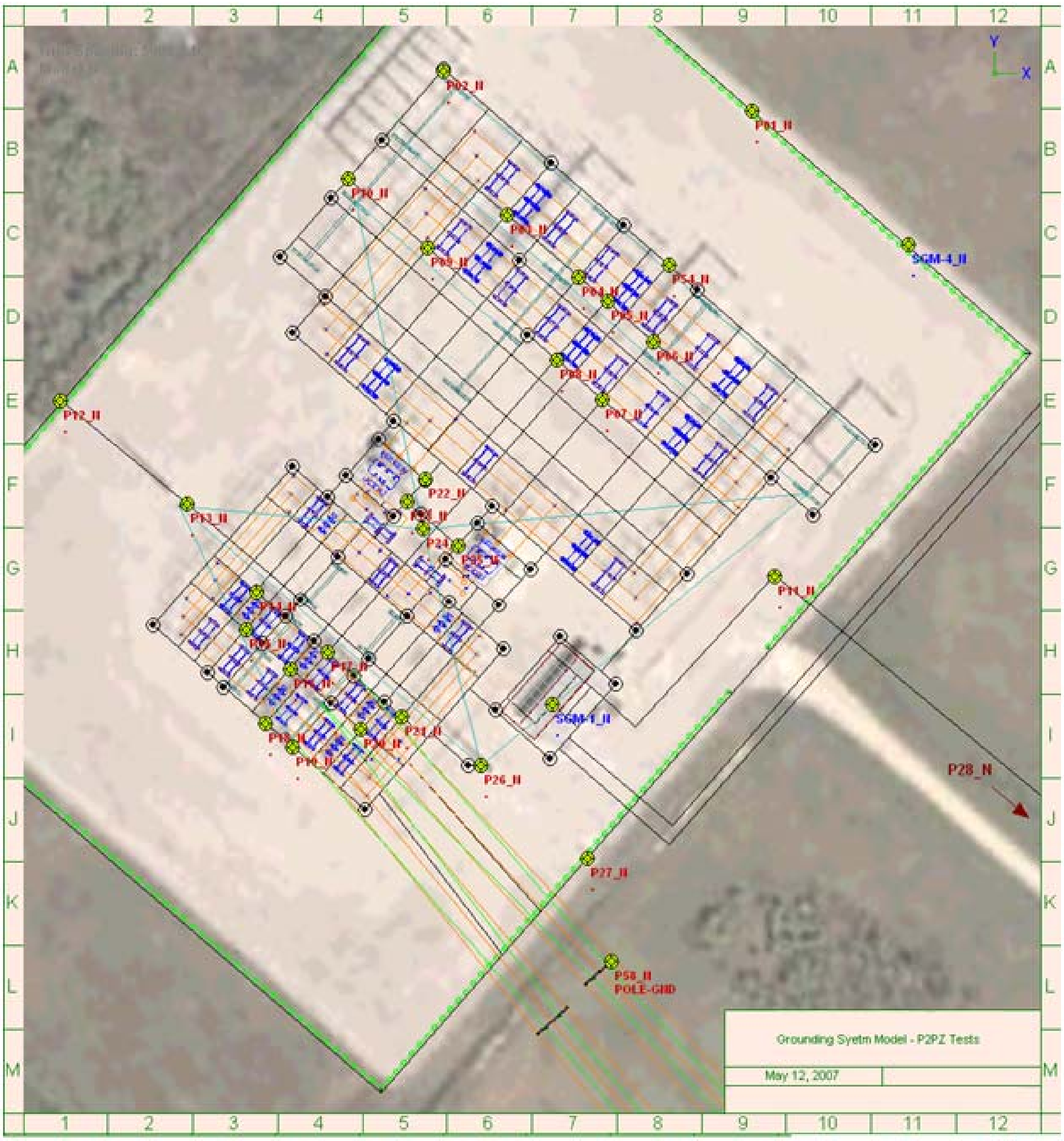


Figure 5.1: Point-to-Point Impedance Measurement Locations (1 of 4)

Figure 5.2: Point-to-Point Impedance Measurement Locations (2 of 4)

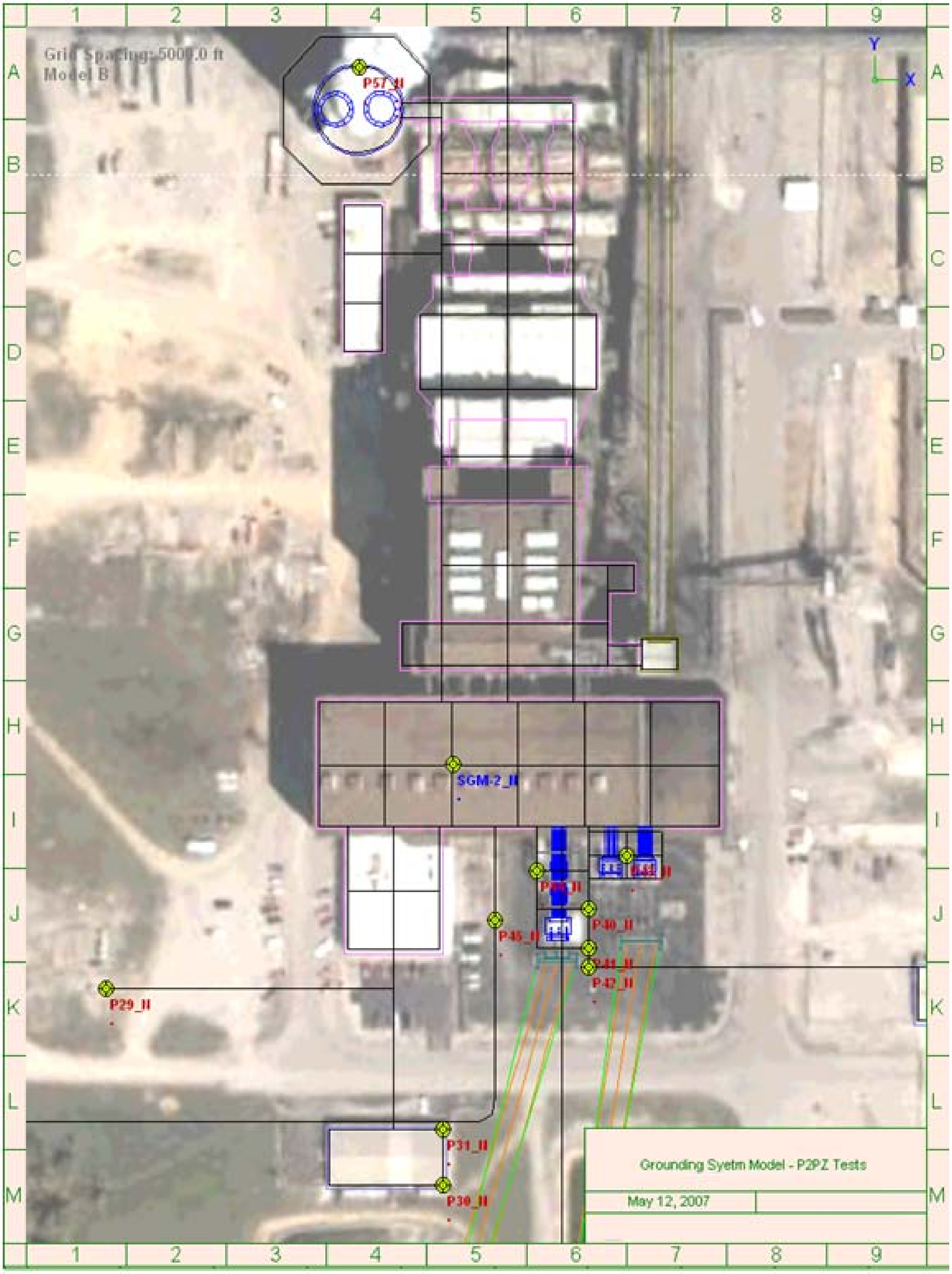


Figure 5.3: Point-to-Point Impedance Measurement Locations (3 of 4)

Figure 5.4: Point-to-Point Impedance Measurement Locations (4 of 4)

6. Field Observations

Not included

7. Evaluation of Present Grounding System – Safety Assessment

This section provides the safety assessment of the validated grounding system of the Springfield Station Power plant. Safety assessment was performed in two areas (a) Power Plant Area and (b) Switchyard. The grounding system in these areas was analyzed to determine whether it meets the safety requirements of the IEEE Standard 80, 2000 edition. The safety evaluation is based on the analysis of the plant grounding system performance under worst fault conditions. The analysis was performed using the computer model of the Springfield Station, and nearby transmission lines (the system model details are described in Appendix A). Using the computer model, a comprehensive fault analysis was performed to determine the fault that causes maximum ground potential rise at areas (a) and (b). The analysis includes both single and double line to neutral faults at all buses, and along all transmission and distribution lines of the modeled network.

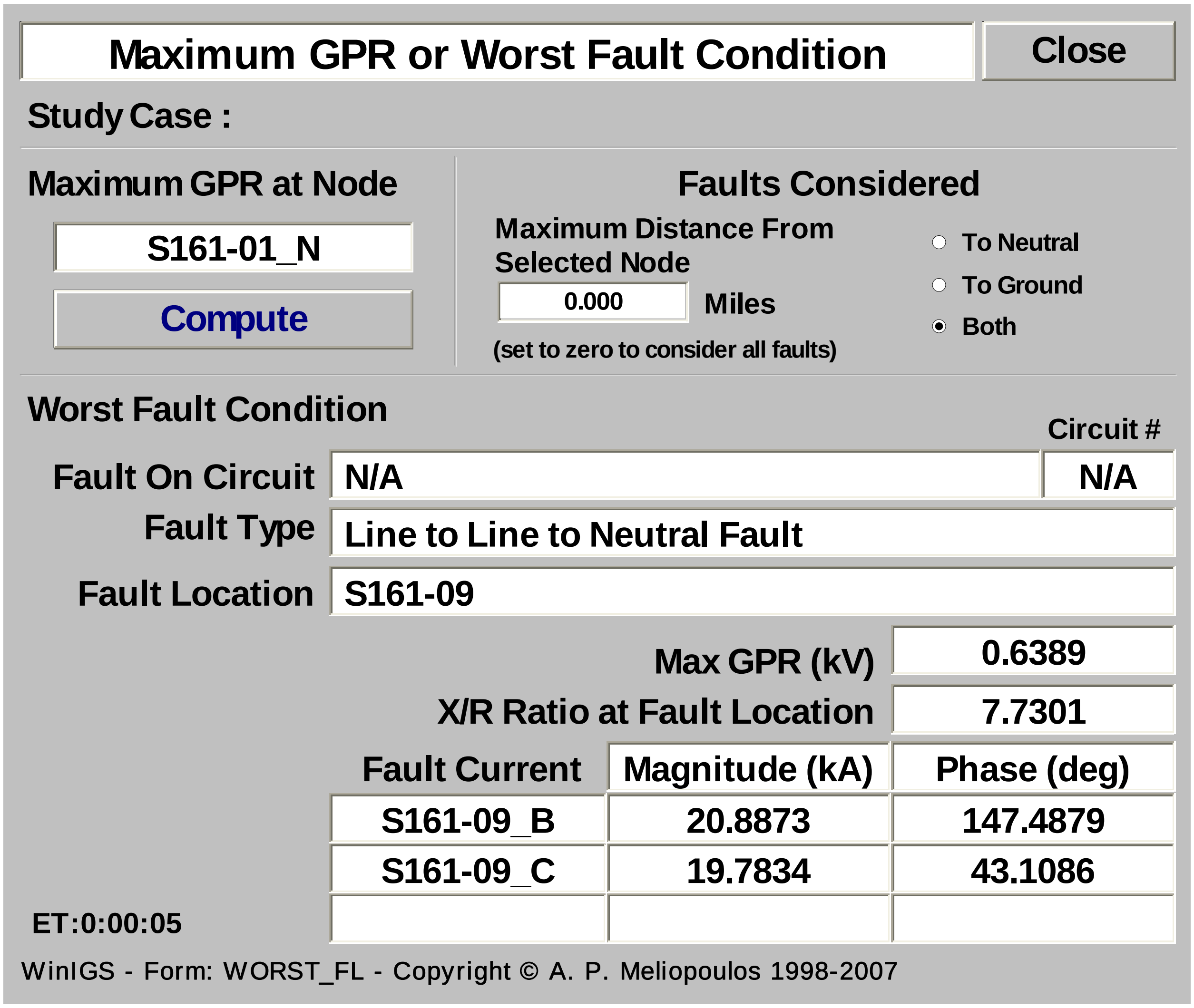
In addition to the safety analysis the voltage induced on the instrumentation cables connected between the power plant and switchyard during fault conditions was computed. The induced voltage results are given in section 7.3, entitled "Transfer Voltages".

7.1 Safety Assessment at Power Plant Area

Not included.

7.2 Safety Assessment at Switchyard

A safety assessment for the switchyard has been also performed and the results are reported here. The worst fault condition report for ground potential rise at the switchyard ground system is shown in Figure 7.12. The fault that results in maximum Ground Potential Rise (GPR) at the switchyard grounding system is a double line to neutral fault at the 161 kV bus (bus S161-09) (see Figures 7.12 and 7.13). A safety analysis for the worst fault conditions was performed based on the IEEE Std 80 guidelines. The detailed analysis results are given in Figures 7.14 through 7.20. The results are summarized in Table 7.2. Note that the maximum touch and step voltages are **lower** than the permissible touch and step voltages per IEEE Std 80.



Maximum GPR or Worst Fault Condition | Close

Study Case :

Maximum GPR at Node

S161-01_N

Compute

Faults Considered

Maximum Distance From Selected Node

0.000 Miles

(set to zero to consider all faults)

- To Neutral
- To Ground
- Both (selected)

Worst Fault Condition

		Circuit #
Fault On Circuit	N/A	N/A
Fault Type	Line to Line to Neutral Fault	
Fault Location	S161-09	

Max GPR (kV)	0.6389
X/R Ratio at Fault Location	7.7301

Fault Current	Magnitude (kA)	Phase (deg)
S161-09_B	20.8873	147.4879
S161-09_C	19.7834	43.1086

ET:0:00:05

WinIGS - Form: WORST_FL - Copyright © A. P. Meliopoulos 1998-2007

Figure 7.12: Worst Fault Analysis Results for Switchyard

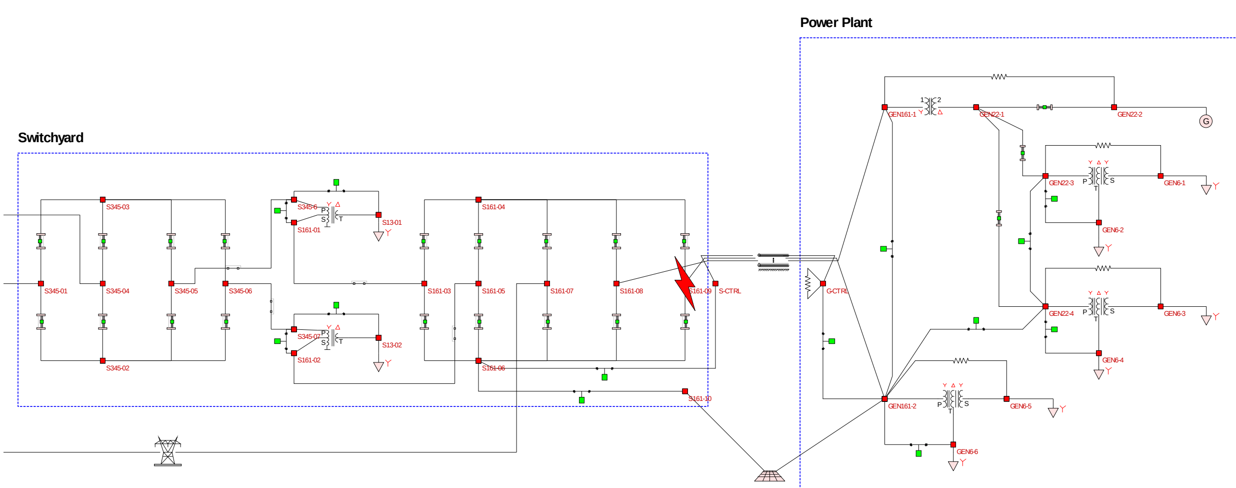


Figure 7.2: Worst Fault Location

Table 7.2: Safety Analysis Summary

Quantity	Value
Fault Type	Double Line to Ground
Fault Location	161 kV Bus
Ground Potential Rise	639 Volts
Fault Current	20.89 / 19.78 kA
Earth Current	3.728 kA
X/R Ratio at Fault Location	7.73
Current division ratio	18.85 %
Allowable Touch Voltage with for 4" Gravel	488 V
Maximum Touch Voltage in Substation Area	**250 V**
Allowable Step Voltage, for Native Soil Top Layer	199 V
Maximum Step Voltage	**100 V**

Figure 7.14 shows the ground potential rise and earth currents during the worst fault conditions. The current flowing into the grounding of the generating area is 7.12 kA, the electric current flowing into the grounding system of the switchyard is 10.78 kA, and the net current into the soil is 3.73 kA. Therefore there is a substantial fault current circulating between the two grounds during the worst fault condition.

Figure 7.15 gives the correction factor for the allowable touch voltage computations. This factor models the effect of a 2,000 Ohm-meter, 4" gravel layer.

Figure 7.16a gives the allowable touch voltage and allowable step voltage for the worst fault conditions for areas covered by a 4" gravel layer. Figure 7.16b gives the allowable touch voltage and allowable step voltage for the worst fault conditions for native soil areas. These figures are computed based on the following additional parameters:

Fault Duration 0.5 seconds
Body Weight 50 kg (110 lb)

Figures 7.17 and 7.18 illustrate the touch voltage distributions during worst fault conditions. The touch voltage is illustrated via equipotential contours (Figure 7.17) and 3-D surface plot (Figure 7.18). Note that the touch voltage does not exceed the permissible touch voltage per IEEE Std-80 in all areas.

Figures 7.19 and 7.20 illustrate the step voltage distribution during worst fault conditions in selected areas of the site, i.e. near the extremity of the generating plant. The area has been so selected because step voltages are highest in this area. The step voltage is illustrated via equipotential contours (Figure 7.19) and 3-D surface plot (Figure 7.20). Note that the maximum step voltage does not exceed the permissible step voltage. The permissible step voltage on native soil is 199 volts while the actual maximum step voltage is 100 volts.

The conclusion is that the present system meets the safety requirements of IEEE Std 80.

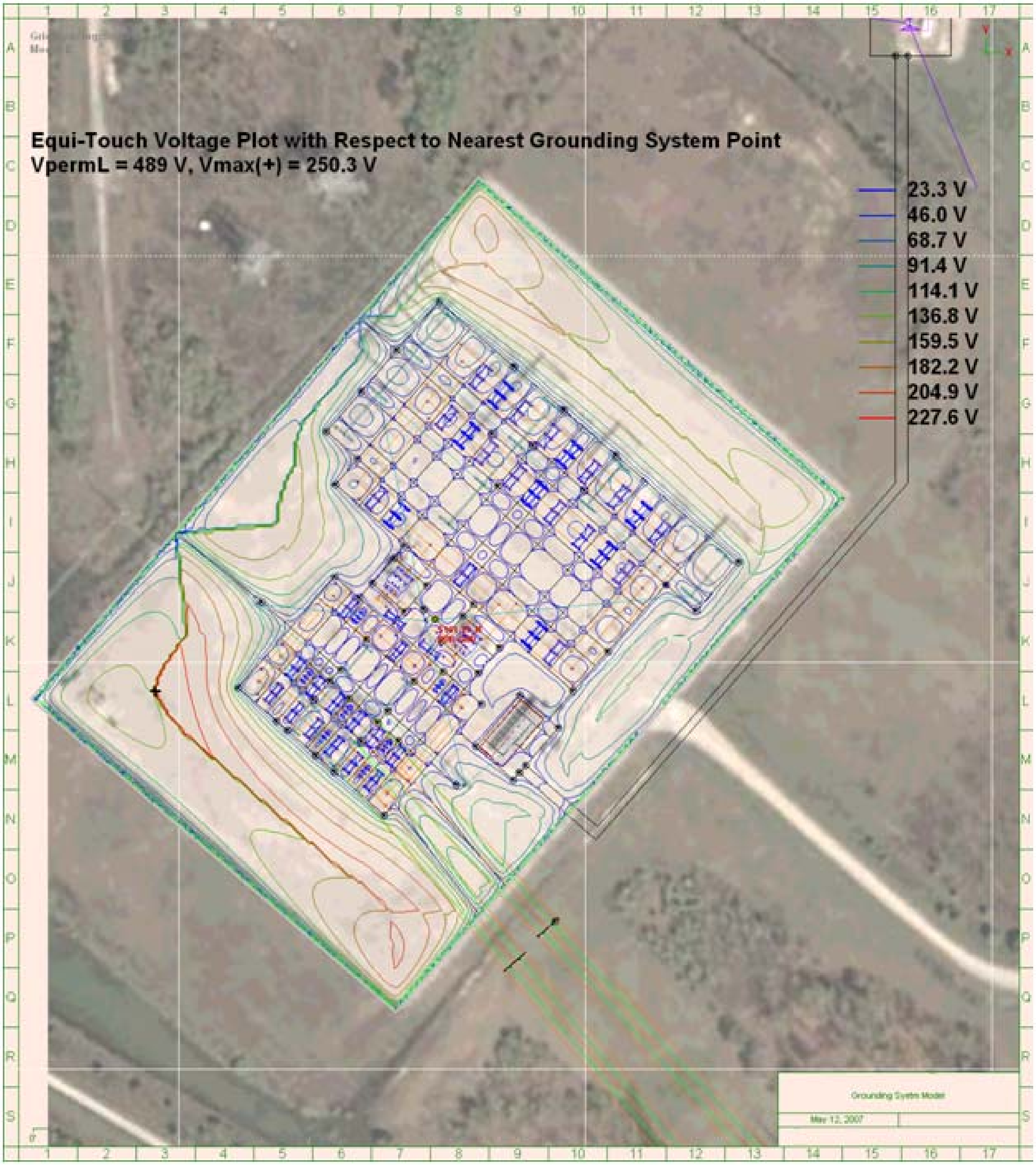


Figure 7.17: Touch Voltage – Equipotential Plot

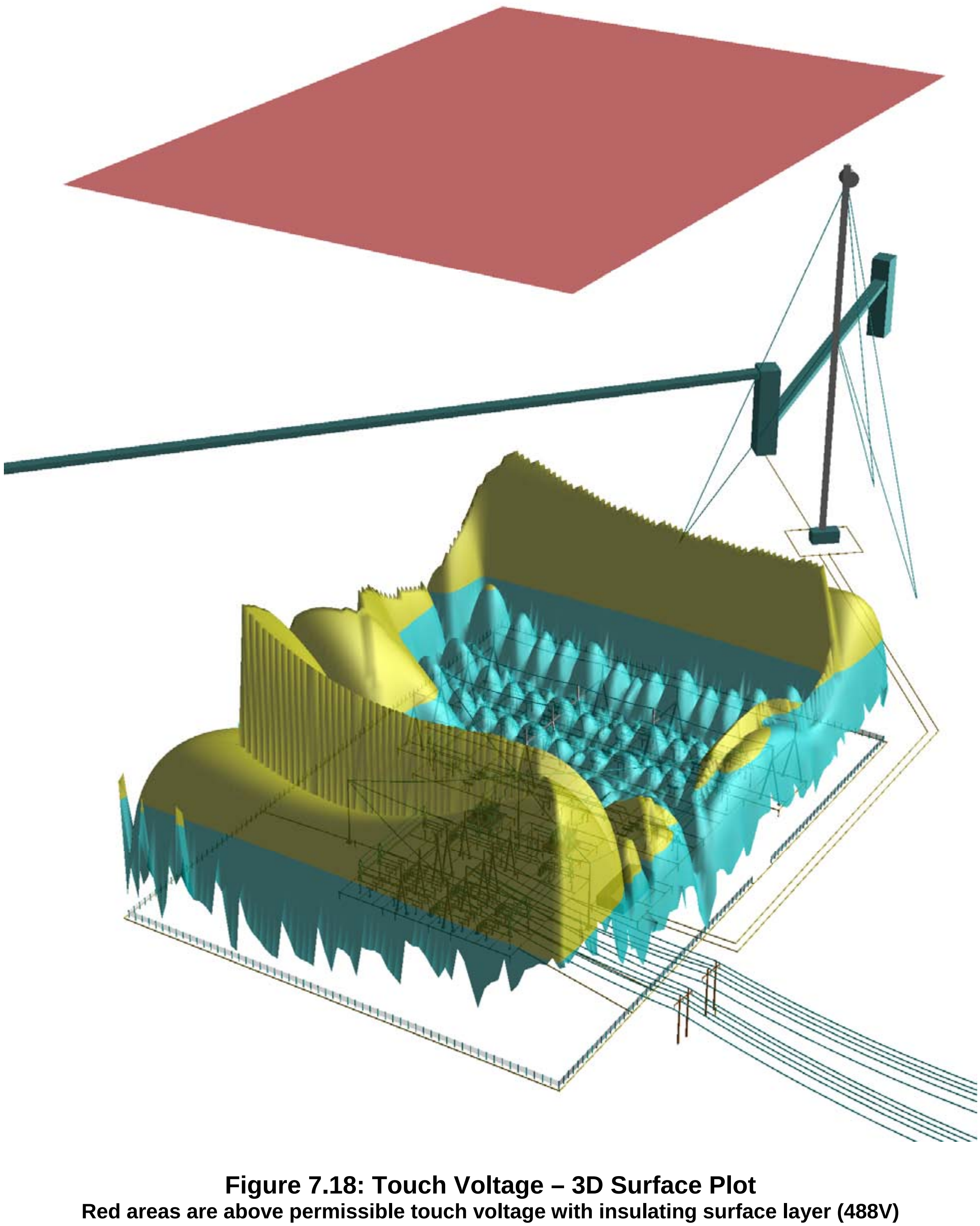


Figure 7.18: Touch Voltage – 3D Surface Plot
Red areas are above permissible touch voltage with insulating surface layer (488V)
Yellow areas indicate areas with touch voltage above (244V)

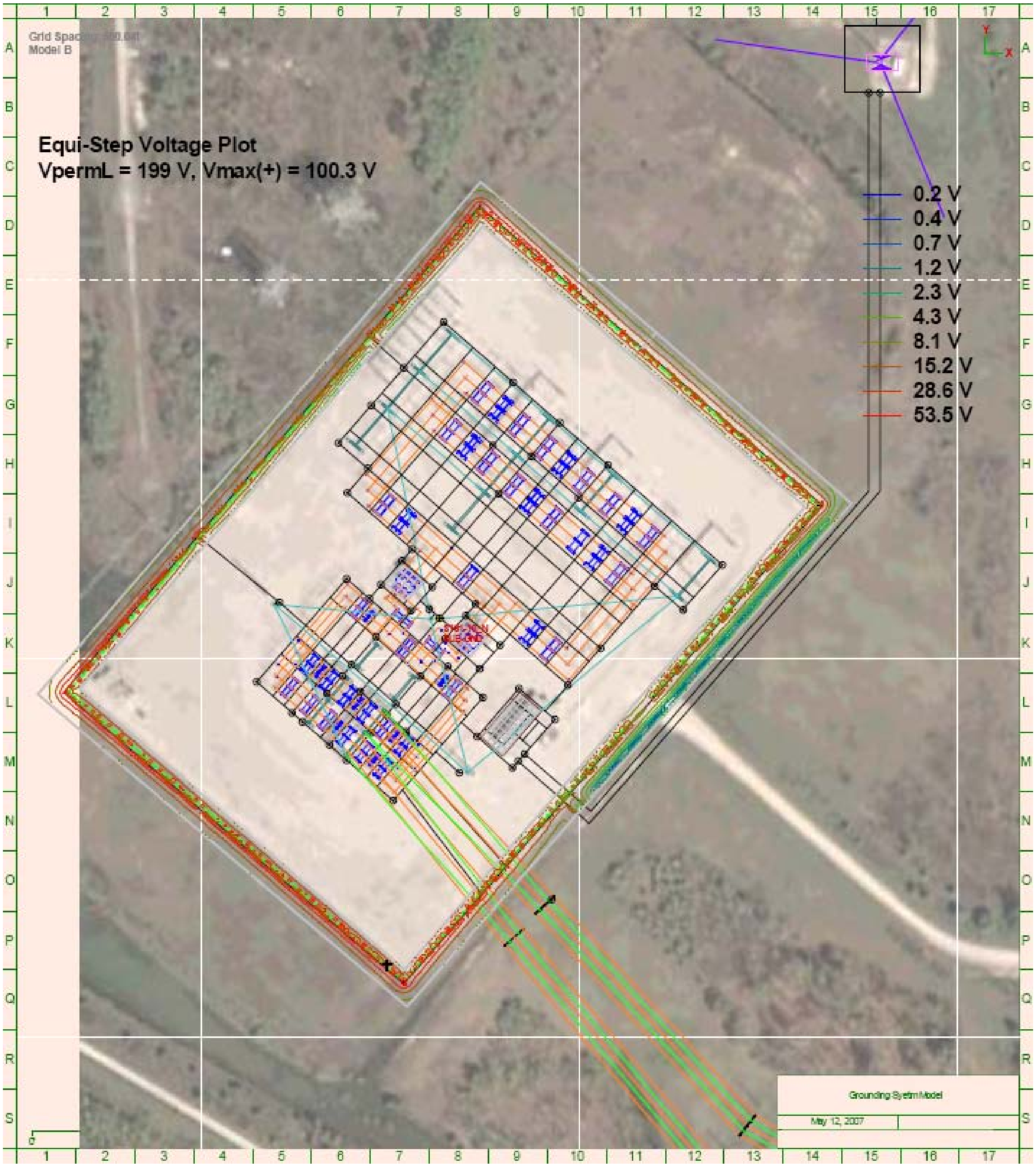


Figure 7.19: Step Voltage – Equipotential Plot

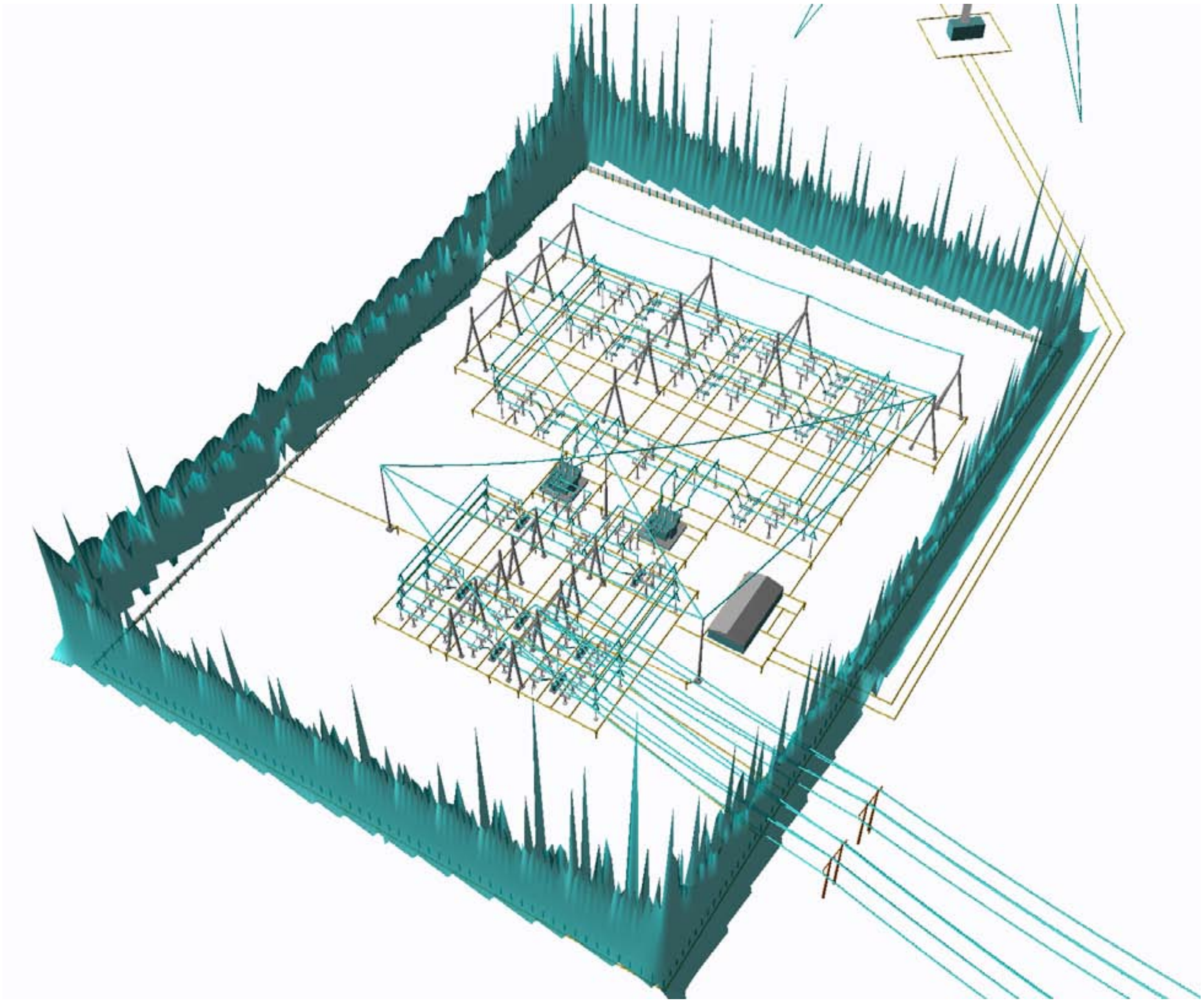


Figure 7.20: Step Voltage – 3D Surface Plot
Red areas are above permissible step voltage over native soil (199V)
Yellow areas indicate step voltage above 99.5V.

8. Recommendations

This section presents a list of recommendations for enhancement of the Springfield Station grounding system performance. The recommendations were selected with a trial and error approach for the purpose of selecting the most cost effective enhancements of the grounding system. The recommendations comprise addition of ground conductors in order to reduce the impact of the induced voltages and ground potential differences that develop between the substation and generating plant grounding systems during transients. The size of the ground conductors to be added was selected based on the following criteria:

- Adequate mechanical strength
- Prevent conductor melting under worst fault conditions with industry accepted safety margins
- Allow for increased future system capacity

The final design and bill of materials is given in this section. The final design evaluation is given in section 10.

8.1 Ground Conductor Size Selection

The ground conductor size selection is based on fault analysis. Line to neutral and three phase faults at all voltage levels were considered. The detailed results are given in section 2.3.

The parameters affecting ground conductor size selection are:

(a) Maximum Fault Current – 161 kV Level: 21.7 kA*
(b) Maximum Fault Current – 345 kV Level: 10.0 kA*
(c) Assumed Fault Clearing Time: 0.5 seconds.

The required size of the grounding conductors is computed with the aid of the equations in the IEEE Std 80-2000 assuming a specific maximum permissible temperature rise. Using exothermic connectors (which are recommended here) the recommended maximum permissible temperature is 250 or 450 degrees Celsius. It is recommended to use the lower temperature of 250 degrees Celsius. The required cross section of the grounding conductors for 97% commercial drawn copper is:

***Note:** The worst case fault used in this analysis is the one that produces the highest fault current, and thus causes highest conductor temperature rise. The objective here is to prevent melting of the ground conductors. Thus fault that produces the highest current is a fault at the 138 kV bus of substation U (26.5 kAmperes) and a fault on the 2.4 kV bus for substation H (19.4 kAmperes). This should not be confused with the worst case fault for safety analysis, where the objective is to keep touch and step voltages below a permissible value.

Figure 8.1: Recommended Grounding System Enhancements – Top Vew

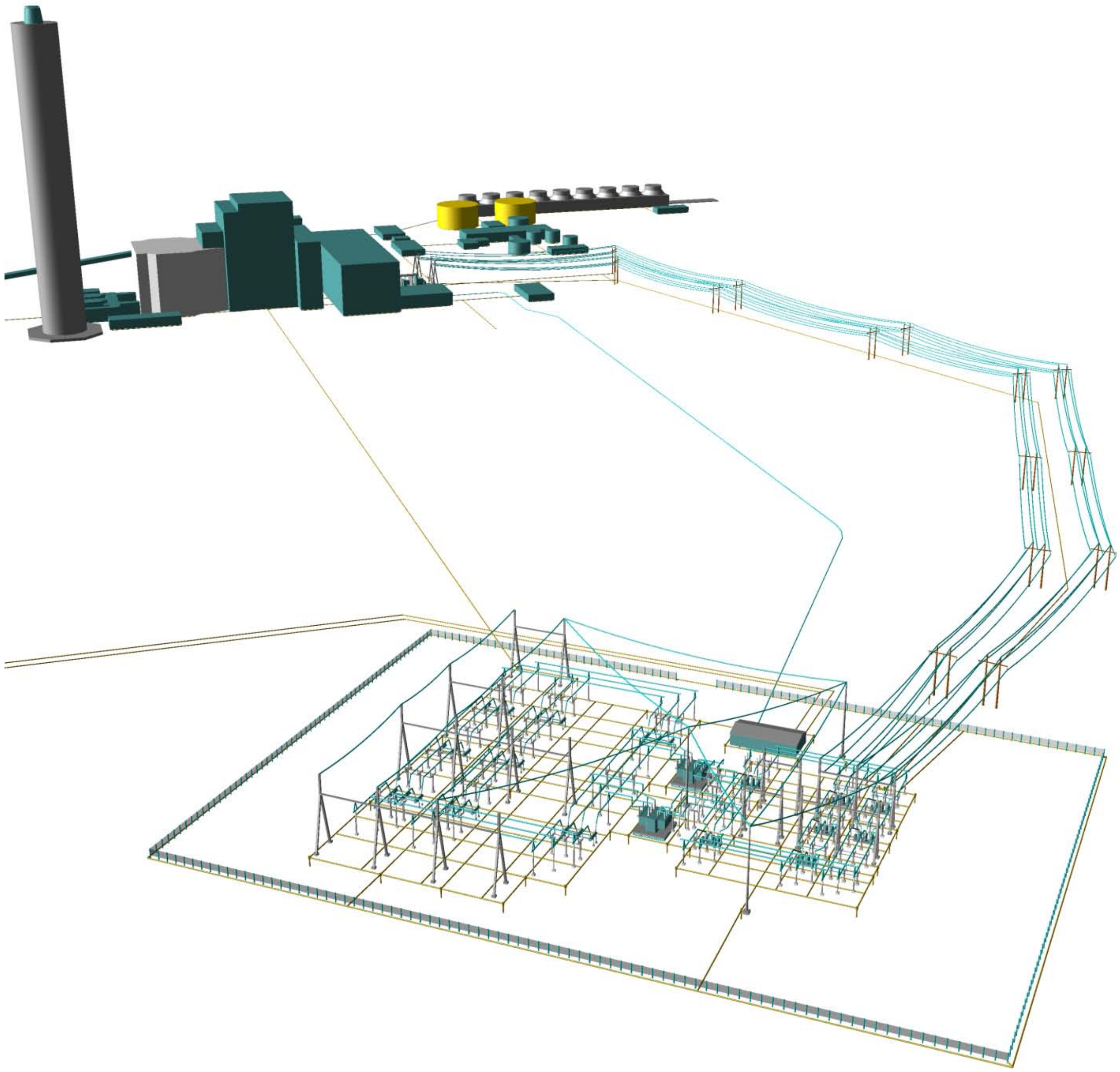
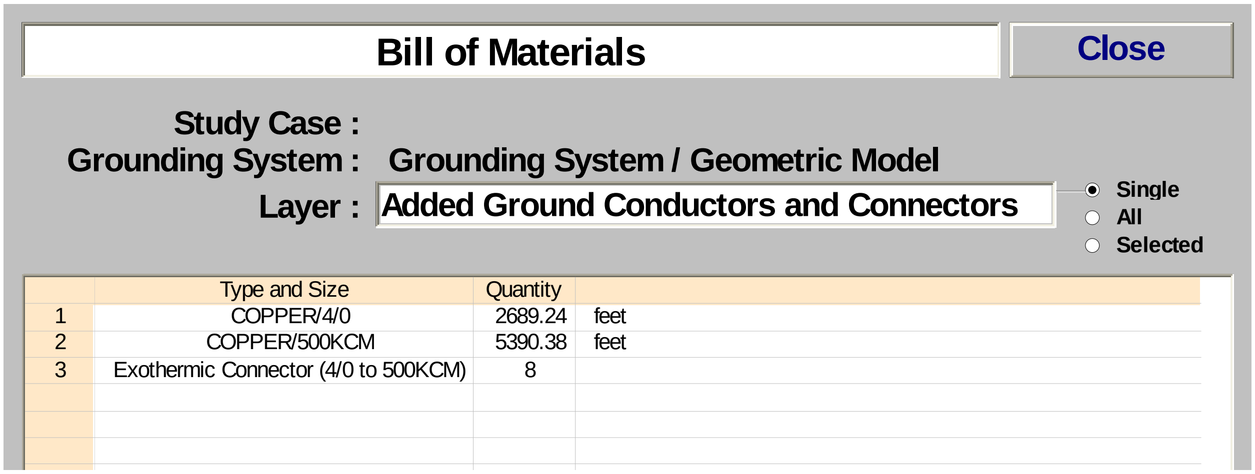


Figure 8.2: Recommended Grounding System Enhancements – 3D View

8.4 Bill of Materials

The bill of materials for the recommended design is given in Figure 8.3. The bill of materials does not include the corrections from the field observations, i.e. repairing damage conductors and reinstalling the ground bonds to the communication tower.



	Type and Size	Quantity	
1	COPPER/4/0	2689.24	feet
2	COPPER/500KCM	5390.38	feet
3	Exothermic Connector (4/0 to 500KCM)	8	

Figure 8.3: Bill of Materials - Recommended Grounding System Enhancements

9. Evaluation of Recommendations – Safety Assessment

This section provides the safety assessment of the grounding system of the Springfield Station assuming that the proposed enhancements have been implemented. The analysis procedure is similar to the one used for the existing system case, presented in section 7.

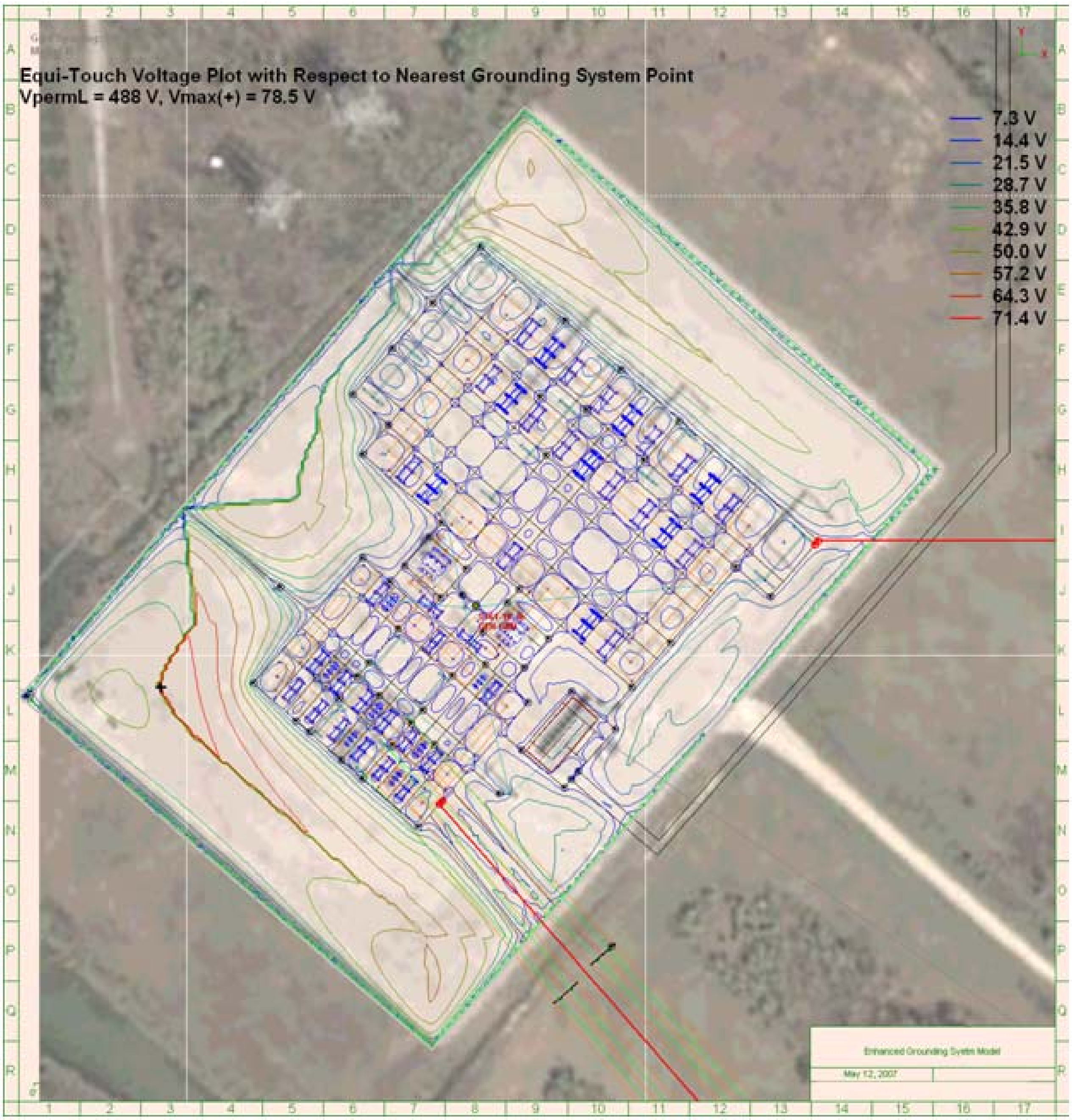


Figure 9.17: Touch Voltage – Equipotential Plot

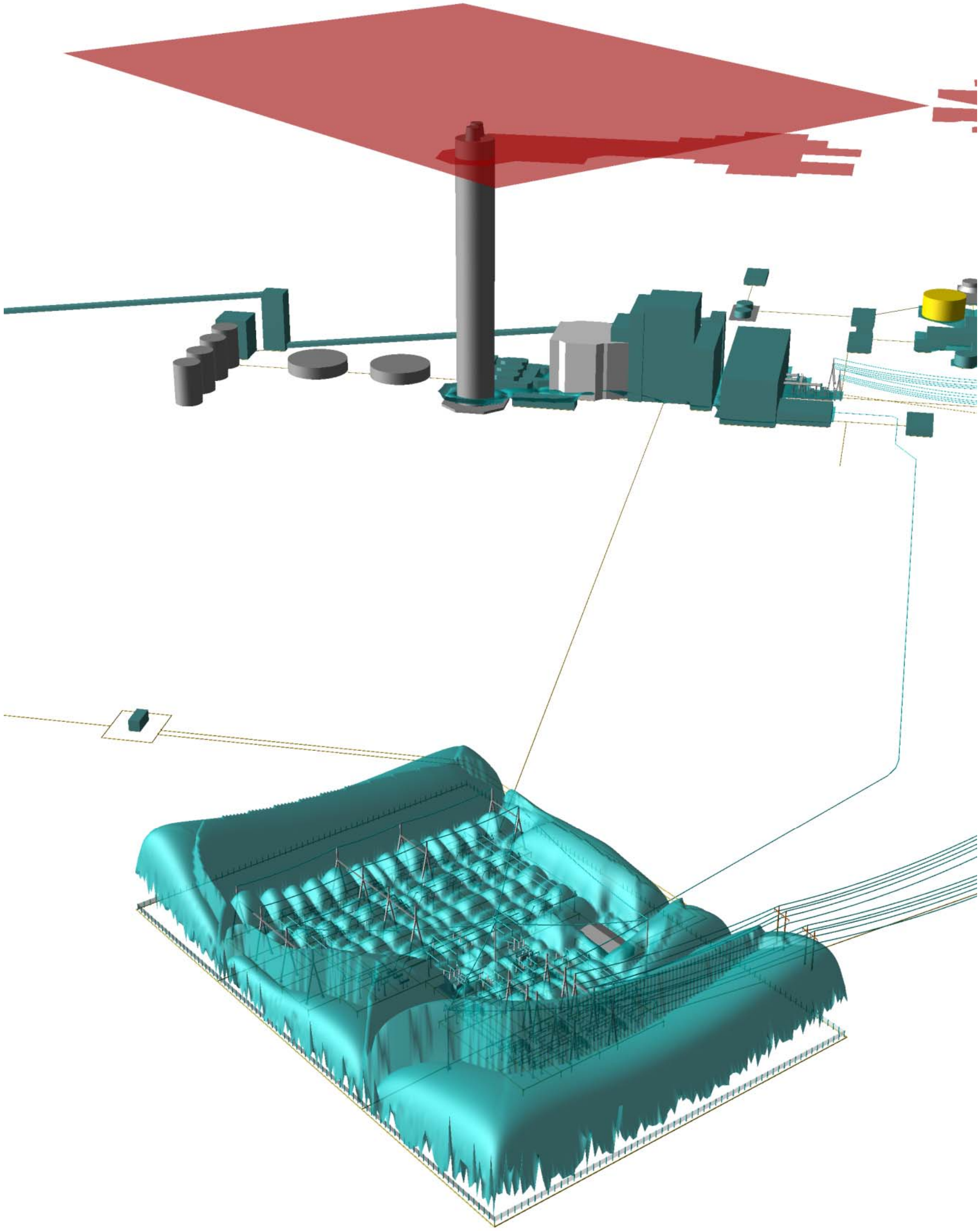


Figure 9.18: Touch Voltage – 3D Surface Plot
Red plane indicates permissible touch voltage with insulating surface layer (488V)

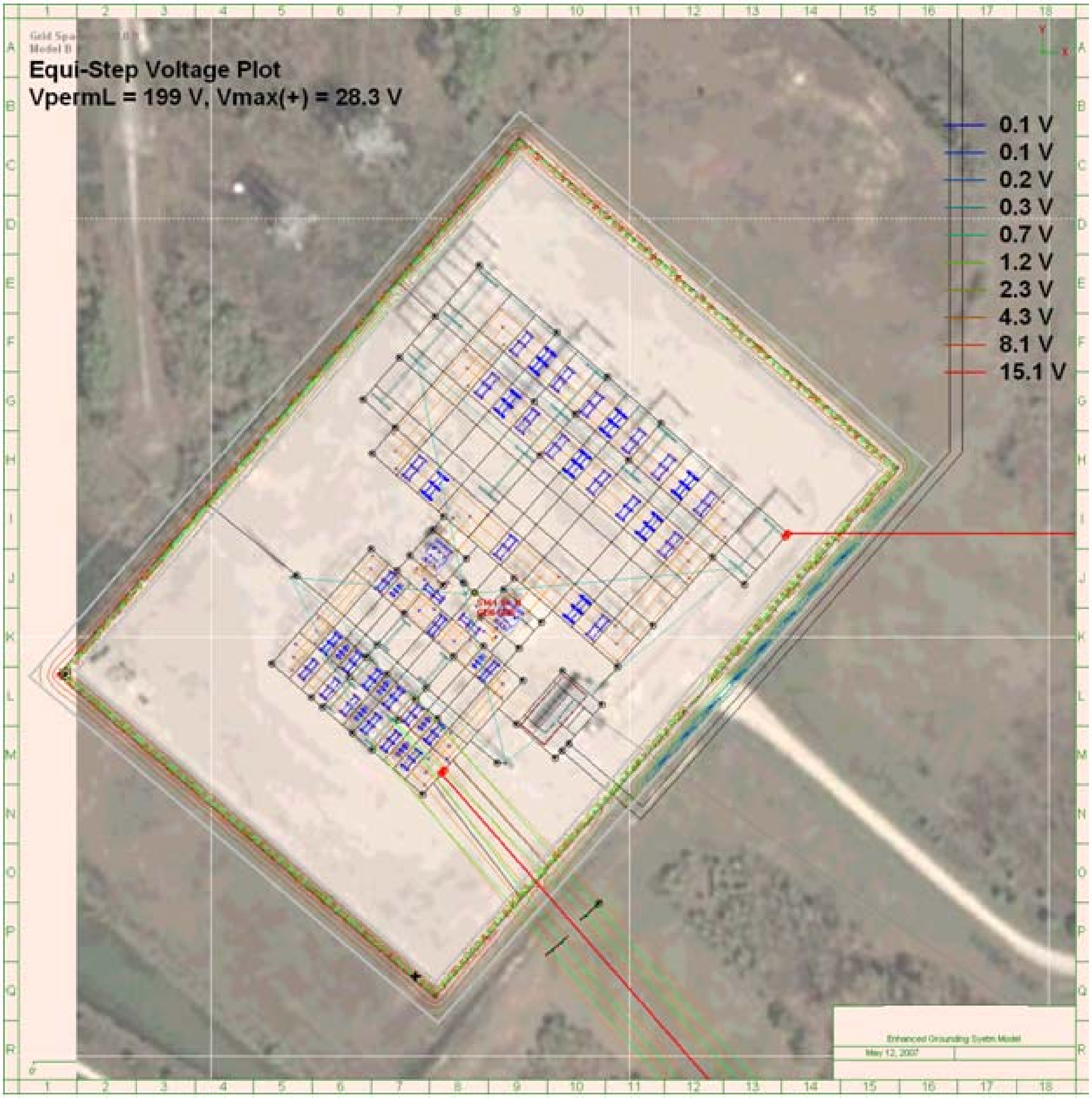


Figure 9.19: Step Voltage – Equipotential Plot

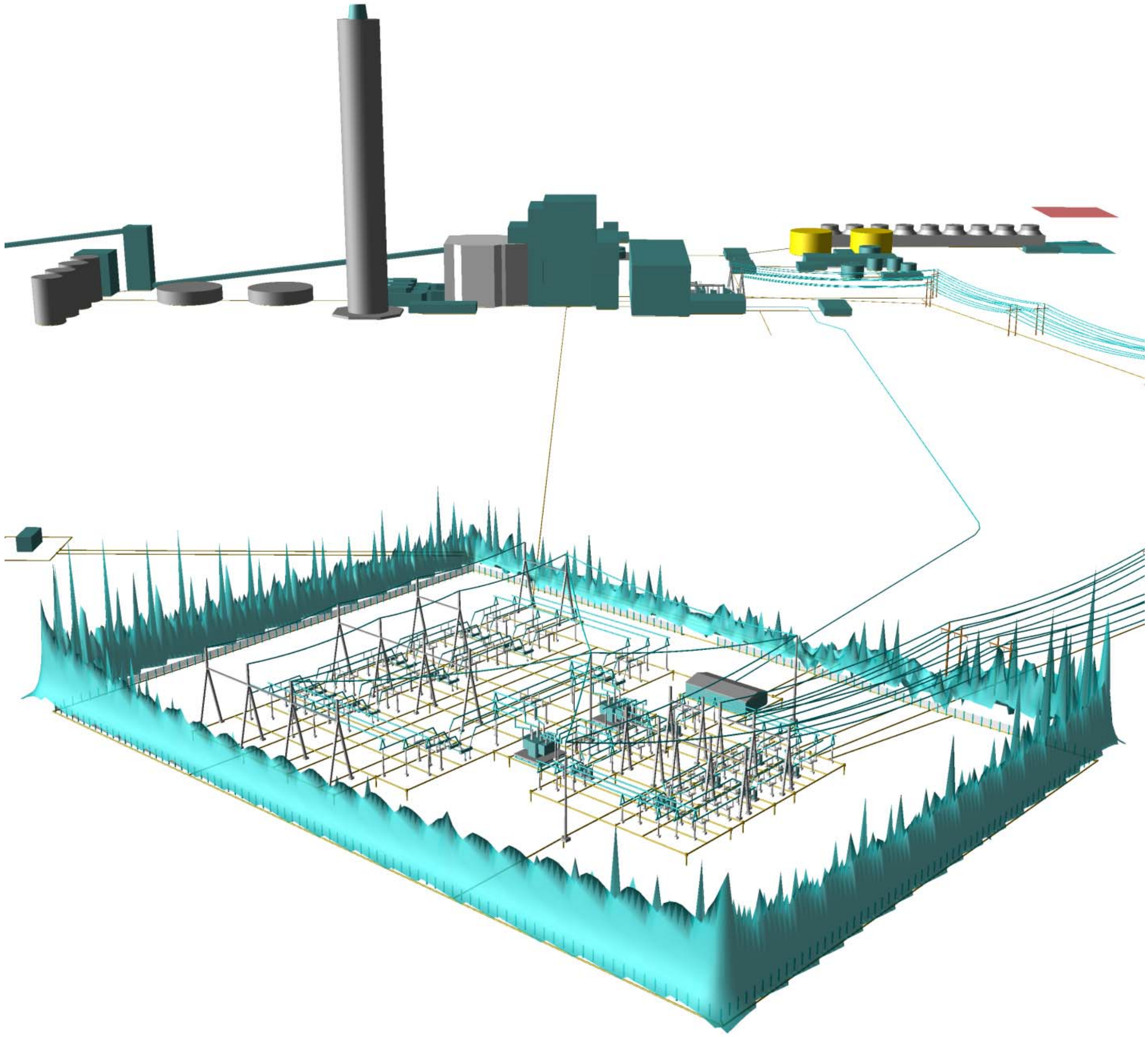


Figure 9.20: Step Voltage – 3D Surface Plot