SOURCES OF ELECTRIC AND MAGNETIC FIELDS IN THE TRUMBULL SUBSTATION

The proposed 115 kV Trumbull Substation would be located at the intersection of two existing transmission line corridors. Presently, two existing 115 kV transmission lines are located within the existing UI corridor and the existing CL&P corridor. These overhead power lines are existing sources of power-frequency electric and magnetic fields.

The design for the proposed 115 kV Trumbull Substation would include new 115 kV line taps to route power from the existing 115 kV transmission lines into the substation, the addition of buswork, two electric power transformers, circuit breakers, switchgear, and related auxiliary equipment. Each of these proposed facilities would potentially be new sources of power-frequency electric and magnetic fields.

Some substation equipment, such as transformers, switchgear, and auxiliary equipment, are enclosed within metal housings, which virtually eliminate any electric field from these sources. Other equipment, such as buswork and overhead circuits, would be a potential new source of electric field. Common objects (such as fences, walls, trees, and shrubs) would provide electric field shielding within the area near these objects.

Since magnetic fields are not easily shielded by common objects (as are electric fields), the proposed new substation equipment would be additional sources for magnetic fields. Some equipment, such as transformers and switchgear, act as "point sources" and the magnetic field will attenuate very quickly with distance away from these sources. Other equipment, such as buswork and overhead circuits, will have magnetic fields, which attenuate at a rate that is inversely proportional to the distance squared. In general substations are not a major source of EMF beyond the station fence or boundary. The primary EMF source is always the overhead transmission lines and transmission line taps that serve the substation.

METHODS FOR MEASURING ELECTRIC AND MAGNETIC FIELDS

Measurement Protocol

All electric field measurements were taken as spot measurements. Readings were taken at a height of 1 meter above ground level in accordance with IEEE Standard 644-1994 - "IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines". The values were read from the LCD display on the meter and manually recorded. Spot measurement locations were selected on-site to characterize the electric field due to the overhead 115 kV transmission lines.

Magnetic field measurements were taken with a recording magnetic field meter. Field readings were recorded at a measurement height of 1 meter above the ground in accordance with IEEE Standards. The meter recorded magnetic field data once every 1.5 seconds. Magnetic field values were continuously recorded while traversing the proposed site boundary.

Instrumentation

An EMDEX II Magnetic Field Digital Exposure Meter was used to record the magnetic field levels. The EMDEX II is a computer-controlled, three axis, AC exposure meter. Each of the three-axis sensors was used to measure the magnetic field and the on-board computer calculated a resultant field value. The resultant field is the square root of the sum of the squares for all three orthogonal axes. The data was stored in the computer's memory and downloaded to a personal computer for analysis following the measurement session. The EMDEX II was setup to sample every 1.5 seconds. Event markers registered in the data denote measurement values that correspond to various site locations and distances of interest. The EMDEX II meter has a measurement range from 0.1 mG to 3000 mG (3 Gauss). Typical accuracy of the EMDEX II meter is +/-2%.

An E-PROBE electric field sensor that is specially designed for performing electric field measurements with an EMDEX II meter was used to measure the electric field. The E-PROBE consists of two aluminum plates separated by 4 insulators, calibrated to produce an induced current that the EMDEX II meter can read and convert to determine an equivalent electric field measurement value. The E-PROBE has a range of 0.010 to 13 kV/m (10 to 13000 Volts per meter), with an accuracy of approximately +/- 5% and a resolution of approximately 1 V/m (this conforms to the IEEE Standard).

Calibration

All magnetic field instruments were calibrated using a 91 cm diameter Helmholtz coil in the Enertech research laboratory in accordance with IEEE Standards and traceable to NIST. Vertical magnetic fields were generated with magnitudes ranging from 0.5 mG to 2200 mG and with absolute accuracy's of +/-2% above 10 mG and +/- 15% at 1 mG.

ELECTRIC AND MAGNETIC FIELD MEASUREMENT RESULTS

Two sets of field measurements were performed as part of this project assessment. The first set of measurements was performed at approximately 11:30 AM on May 7, 2003. Electric and magnetic field measurements were conducted at the proposed substation site on this date. An additional set of measurements was performed on May 31, 2005 to update the earlier measurements and to include additional measurement locations. The transmission line loadings on both occasions are summarized in Tables 1 and 2. The 2005 line loadings are comparable to the 2003 levels with similar EMF results, therefore only the more comprehensive 2003 results are included here. The measurement, locations D-1 through D-4, were evaluated using the 2003 loads to facilitate comparisons using all locations with the same loads.

Electric Field

Electric field spot measurements were taken at the location of the fence line directly below the 115 kV conductors that pass overhead. The 1730 line and the 1710 line cross the substation fence line in two locations (in the south and the north). A total of six measurement points were selected for each fence crossing (one measurement directly under each of the conductors of the double circuit line), totaling 12 spot measurement points all together.

Along the southern boundary, the measured electric field ranged from about 100 V/m to 390 V/m, depending upon location. Along the northern boundary, the measured electric field ranged from about 89 V/m to 191 V/m. The differences in the electric field strengths are attributable to the different geometric relationships of the nearby transmission line configurations. The existing electric field at the proposed substation fence line was due to the overhead 115 kV lines (1730 & 1710) that cross the proposed fence line from north to south (these circuits utilize 795 kcmil ACSR conductor, with a diameter of about 1.090 inches).

Magnetic Field

Magnetic field measurements were continuously recorded while traversing the perimeter of the proposed substation boundary. Figure 12 presents a diagram of the proposed substation boundary with the measurement path. Measurements were initiated at the southwest corner (location "C-1") and proceeded counter clockwise around the substation perimeter. Location markers "C-1" through "C-8" denote various perimeter locations which coincide with the proposed substation fence line.

Figure 13 presents a magnetic field graph of the 2003 measurement results. As shown, the measured magnetic field at the proposed substation fence line ranged from about 1 to 71 mG, depending upon location. The various perimeter locations denoted along the measurement path in Figure 12 are presented in Figure 13 to identify measured magnetic field levels are various locations along the path. As shown in Figure 12, the highest recorded magnetic field levels occur between locations "C-3" to "C-4" and "C-5" to "C-6". These are the two locations where the 115 kV transmission lines are present overhead.

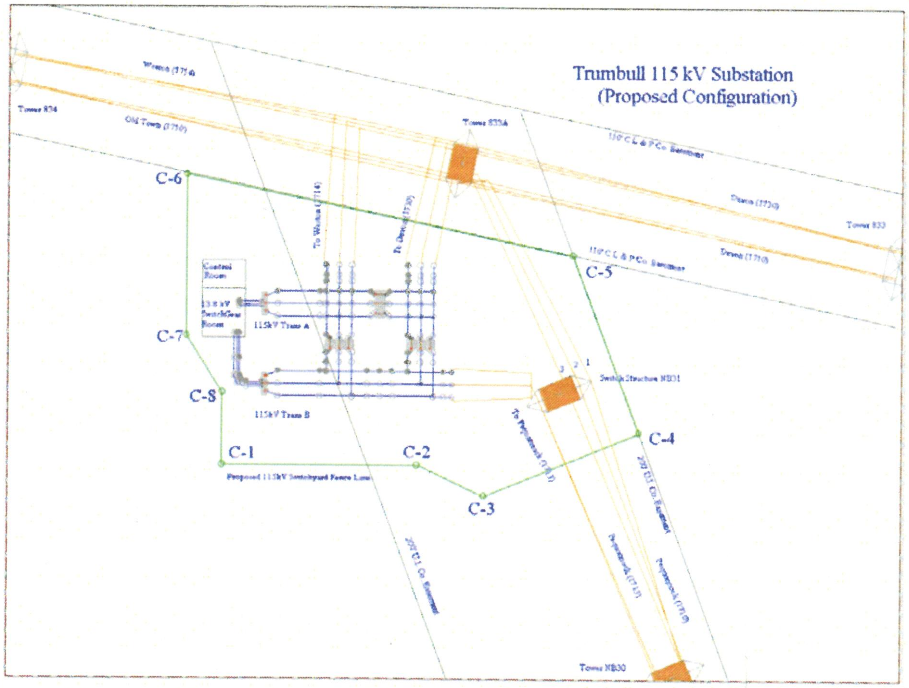

Figure 12. Diagram of Proposed Trumbull Substation Boundary with Magnetic Field Measurement Path

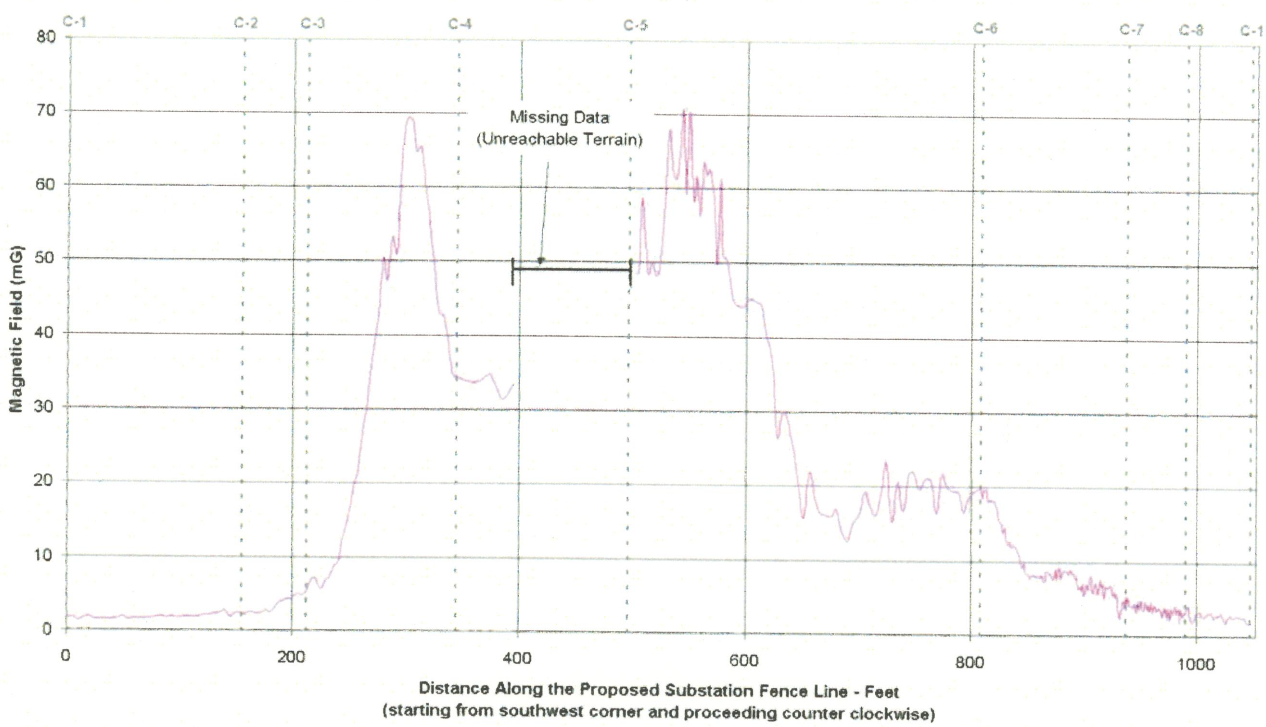

Figure 13. Measured Magnetic Field Along Proposed Substation Boundary

METHODS FOR CALCULATING ELECTRIC AND MAGNETIC FIELDS

Computer Modeling Software

Computer modeling software is often used to calculate electric and magnetic fields for various electric facility designs and loading conditions. Computer models can accurately predict electric and magnetic field levels for various configurations and can be easily modified to assess field changes due to different loading conditions or geometries.

The software program "SUBCALC", which is a module within EPRI's EMF Workstation program, was used to perform these magnetic field calculations. SUBCALC models the magnetic fields in and around transmission and distribution substations. In addition to transmission lines, primary distribution lines, and underground cables, the user can "draw" in the substation equipment such as buses and circuit breakers. The top and side view perspectives allow drawing of conductors in three dimensions. SUBCALC can also model substation equipment such as power transformers and capacitor banks.

An Enertech Consultants in-house software product, capable of calculating electric field in three dimensions, was used for the electric field calculations.

Modeling Approach

Computer models were developed of the existing transmission line configuration at the proposed Trumbull Substation site. These calculations were performed to compare with the field levels measured on May 7, 2003. The purpose for this comparison was to ensure that the transmission line geometry and loading information provided by UI and used to create the computer model was accurate and to validate the computer model.

Computer models were developed for the proposed Trumbull Substation configuration in normal (15 GW system model) and peak (27.7 GW system model) load conditions as specified by ISO New England. These models were developed for the purpose of calculating magnetic field levels and electric field levels at the fence line of the substation with the Trumbull Substation in operation after the Bethel/Norwalk and Middletown/Norwalk projects are complete. Again, these models were developed based upon drawings and facility information provided by UI.

UI Loading Information for the Computer Models

Since two sets of field measurements were conducted at the proposed substation site, analysis of the existing transmission line loading information involved two sets of load data. The first set of field measurements was performed at approximately 11:30 AM on the morning of May 7, 2003. Throughout the morning, UI monitored the load of the 1710 & 1730 lines at Trumbull Junction. Table 1 presents the loading of each of these circuits during the measurement period.

Table 1. Transmission Line Loading Information at Trumbull Junction During Field Measurements on May 7, 2003 at 11:30 AM

Line (#)	Station	Load Flow Direction	Load
1710	Old Town	Into the Substation	677 A
1730	Weston	Into the Substation	490 A
1710	Pequonnock	Out of the Substation	704 A
1710	Devon	Into the Substation	22 A
1730	Devon	Into the Substation	129 A
1730	Pequonnock	Out of the Substation	620 A

A second set of field measurements was conducted on the morning of May 31, 2005 to update the earlier site visit and to include 4 additional measurement locations (D-1 through D-4, as denoted in Figure 18). During this measurement period, UI again monitored the load of the 1710 & 1730 lines at Trumbull Junction. Table 2 shows the loading of each of these circuits during this second measurement period (there is some variation up or down in individual line loadings, but the two dates yield comparable results). The loading values presented in Table 1 were used in the computer model to calculate the magnetic field for the purpose validating the measured versus calculated electric and magnetic field values.

Table 2. Transmission Line Loading Information at Trumbull Junction During Field Measurements on May 31, 2005 at 10:00 AM

Line (#)	Station	Load Flow Direction	Load
1710	Old Town	Into the Substation	727 A
1730	Weston	Into the Substation	534 A
1710	Pequonnock	Out of the Substation	625 A
1710	Devon	Out of the Substation	108 A
1730	Devon	Into the Substation	42 A
1730	Pequonnock	Out of the Substation	537 A

The in-service date for the Trumbull Substation is December 2007. The first phase of the 345-kV system expansion is the Bethel/Norwalk 345-kV Project (Bethel/Norwalk) which extends the 345-kV transmission system into Norwalk, has an in-service date of December 2006. The second phase of the 345-kV system expansion, the Middletown/Norwalk 345-kV Project (Middletown/Norwalk), is scheduled for completion in December 2009.

Based on the above information, and because the existing transmission lines will be impacted by the operation of the Pre-Bethel/Norwalk Project, prior to the Trumbull Substation in-service date, the Trumbull Substation EMF assessment modeled the following comparisons so as to more accurately depict the changes in the electric and magnetic fields that would be attributable to the operation of Trumbull Substation, only, though this condition represents a hypothetical situation that will not occur, as the Trumbull Substation will not be in service until after the Bethel/Norwalk Project. Other modeled cases do take into account the impact of the Bethel/Norwalk Project and also a Post-Middletown/Norwalk condition. The specific modeled cases are:

Case #1: The Existing condition: This is a Pre-Bethel/Norwalk, Pre-Trumbull Substation condition, based on the existing line configuration and validates the predicted levels of electric and magnetic fields, versus the fields measured in May 2003 and May 2005, given the same loading on the transmission lines.

Case #2: The Post-Trumbull Substation, Pre-Bethel/Norwalk condition: This is a hypothetical loading condition that will not occur, as the Bethel/Norwalk Project will be in-service in December 2006, a year before the December 2007 in-service date of Trumbull Substation. However, this condition has been modeled to more accurately depict the changes in the electric and magnetic fields that would be attributable to the operation of the Trumbull Substation. By eliminating the impact of line loading changes due to the Bethel/Norwalk Project, the effect on EMF of just the substation can be evaluated for a case where the loads remain similar but before and after the substation is operational.

Case #3: Post-Trumbull Substation, Post-Bethel/Norwalk loading condition: This modeled condition depicts the predicted levels of electric and magnetic fields that will occur after Trumbull Substation is in service, (and which follows the in service date of Bethel/Norwalk.) Calculations are included for the normal (15 GW system load) and peak (27.7 GW system load) configurations. Loading values for each 115 kV line was based upon ISO New England normal and peak system loading conditions provided by UI.

Case #4: Post-Middletown/Norwalk loading condition: This ultimate model condition depicts the predicted levels of electric and magnetic fields that will occur after the in-service dates of all three projects, Bethel/Norwalk, Trumbull Substation and Middletown/Norwalk. Calculations are included for the normal (15 GW system load) and peak (27.7 GW system load) configurations. Loading values for each 115 kV line was based upon ISO New England normal and peak system loading conditions provided by UI.

The Post-Bethel/Norwalk and Post-Middletown/Norwalk load conditions were evaluated because the Bethel/Norwalk and Middletown/Norwalk projects have an impact on the loadings of the 115 kV transmission lines that serve the proposed Trumbull Substation. Since the transmission lines and transmission line taps were shown to be the primary source of magnetic fields (and not the substation), it was decided to evaluate magnetic field levels with and without these other projects. A review of 115 kV line loading reveals that the line loads go down (less EMF) after the Middletown/Norwalk project (with respect to the Bethel/Norwalk project) for the Weston, Old Town, Pequonnock, and Devon lines for both Normal and Peak cases. The impact of the Middletown/Norwalk project (with respect to the Bethel/Norwalk project) is to reduce the 115 kV line loadings (lower EMF). The normal and peak loading values used within the computer models for these two conditions were provided by UI and are shown in Table 3. Appendix C provides load flow diagrams of the "Post-Bethel/Norwalk" and "Post-Middletown/Norwalk" conditions for normal and peak loading.

Table 3. Summary of Loading Conditions Used for Computer Modeling with Trumbull Substation

Power Line Name (Circuit Number)	**May 2003 Load (Amps)**	**Projected Normal Load (Amps)**		**Projected Peak Load (Amps)**	
	Existing* "Pre-Bethel-/Norwalk"	Case 3: "Post-Bethel-/Norwalk"	Case 4: "Post-Middletown/ Norwalk"	Case 3: "Post-Bethel-/Norwalk"	Case 4: "Post-Middletown/ Norwalk"
Old Town (1710)	677	700	520	1164	796
Weston (1730/1714)	490	476	264	834	462
Pequonnock (1710)	704	469	388	514	425
Devon (1710)	22	231	132	650	371
Devon (1730)	129	186	46	580	278
Pequonnock (1730/1713)	620	368	296	358	288

* *These actual loads used for Case 1 (No substation) and Case 2 (with substation).*

ELECTRIC AND MAGNETIC FIELD CALCULATION RESULTS

Existing Transmission Line Configuration

A computer model was created of the existing 115 kV transmission line configurations at Trumbull Junction. Figure 14 presents a diagram of the computer model for the existing transmission line configuration. Figure 15 presents a diagram of the existing 115 kV transmission lines with the phasing designations for each circuit. These phasing arrangements are low-EMF designs due to optimum (or opposite) phasing that result in field cancellation.

The vertices of the proposed Trumbull Substation boundary (fence line) are denoted as "C-1" through "C-8" in Figure 14. Calculation of the electric and magnetic fields were performed along the fence line at a height of 1 meter above ground. The starting reference point of the fence line is the southwest corner, labeled "C-1" in Figure 14. Calculated profiles start at this initial reference point and proceed around the fence line in a counter-clockwise direction, from the corner labeled "C-1" to the corner labeled "C-8".

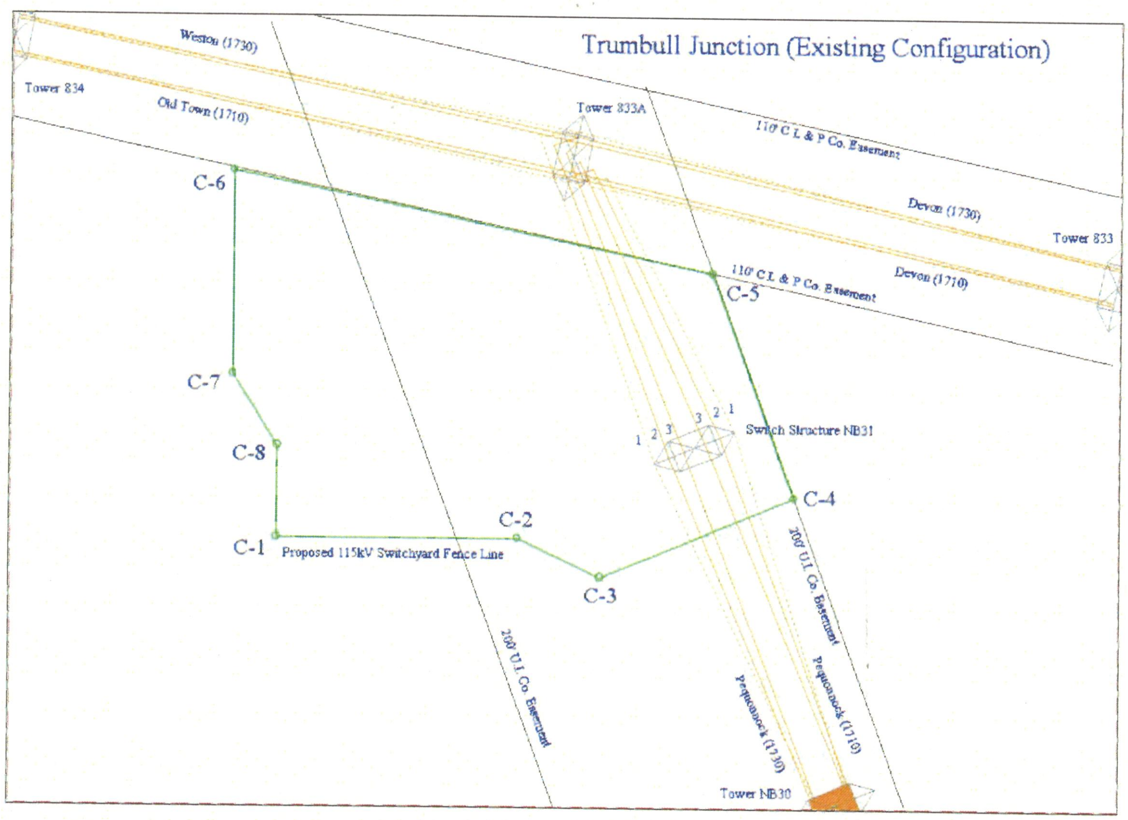

Figure 14. Computer Model of Existing 115 kV Lines at the Proposed Trumbull Substation

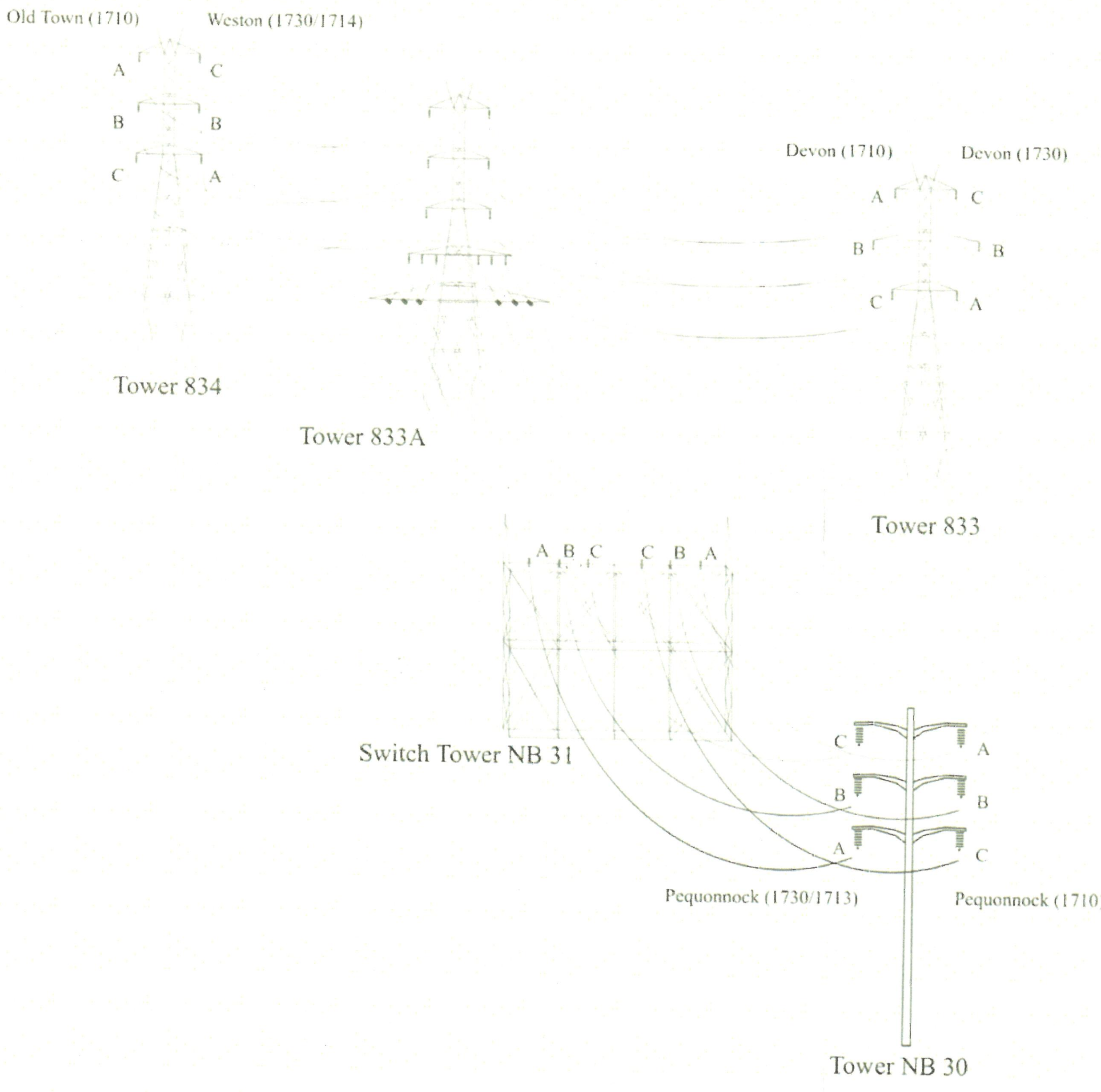

Figure 15. Phasing Diagram for the Existing 115 kV Transmission Lines at the Proposed Trumbull Substation

The electric field was calculated using an in-house software program developed by Enertech Consultants. This software is capable of calculating electric field in three dimensions. The results of the calculated versus measured values are shown in Figure 16. The electric field values show good correlation between the measured and calculated values. The maximum calculated electric field value at the fence line is approximately 515 V/m, at a location where the double circuit 115 kV lines pass overhead.

The calculated electric field for the existing configuration at normal and peak loading conditions is the same as that shown in Figure 16. Electric fields are due to the voltage of the conductors, and do not change under different loading conditions.

For magnetic fields, the field measurements recorded on May 7, 2003 were compared with calculated values (May 31, 2005 loads are comparable to 2003 and yield similar results). Figure 17 presents the results of the measured versus calculated magnetic field along the proposed substation perimeter. The loading values shown in Table 1 were used for the magnetic field calculations. The magnetic field measurements and calculations at the Trumbull Substation fence line generally compare well and have good correlation. There were, however, a few notable discrepancies in the comparison, especially between fence points "C-5" and "C-6". These discrepancies are due to the amount of trees and brush in the measurement area, which prohibited walking at a steady pace and in a perfectly straight line along the proposed substation boundary. When comparing calculated and measured magnetic field values, the most critical parameter to match is the maximum field, which occurs directly underneath the transmission lines. For this comparison, these values match very well.

During the measurements, another small portion of the fence line near the NB31 Switch Structure was not reachable, due to a heavy amount of brush and trees that were present. Because of these obstacles, some of the measured values between fence points "C-4" and "C-5" are missing.

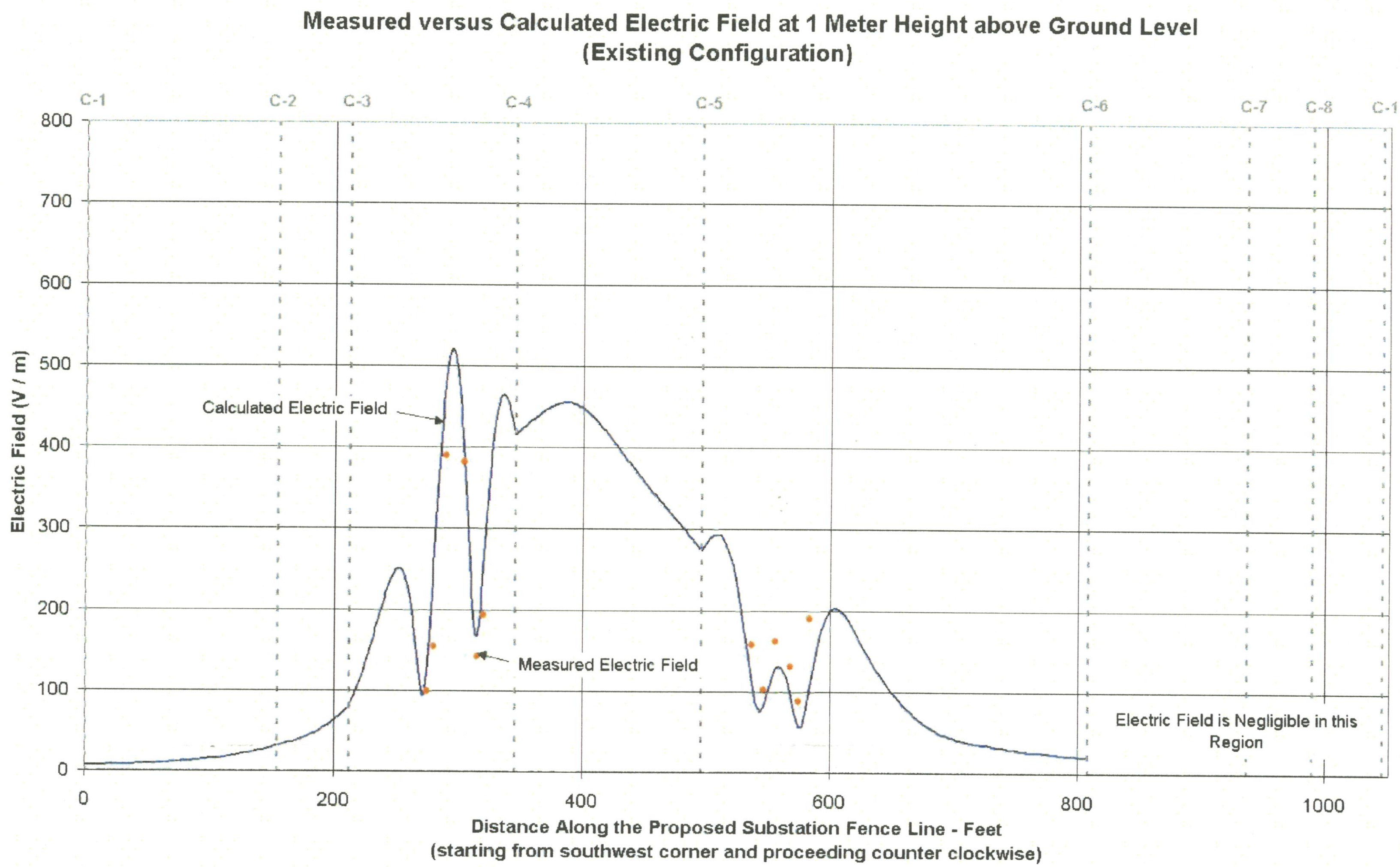

Figure 16. Comparison of Measured versus Calculated Electric Field Values Along the Proposed Trumbull Substation Fence Line For Measurements Conducted on May 7, 2003