Technical Review Memorandum
Regarding the

Power Engineers

230 kV Eastside Line Project

EMF Calculations and Report – Revision 1

Prepared for

Environmental Science Associates
5309 Shilshole Avenue NW, Suite 200
Seattle, Washington 98107

Prepared by

Enertech Consultants
494 Salmar Avenue, Suite 200
Campbell, California 95008

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Prepared by
Enertech Consultants
Campbell, California

INTRODUCTION

Power Engineers was retained by Puget Sound Energy to perform an electric and magnetic field evaluation of the various power line configurations associated with the Energize Eastside Project. The result of this effort was a report dated December 13, 2016 and entitled "230 kV Eastside Line Project – EMF Calculations and Report – Revision 1".

Enertech Consultants was retained by Environmental Science Associates (ESA) to review the electric and magnetic field report which was prepared by Power Engineers. Enertech was asked to evaluate the methodologies and assumptions used in the report; review the analysis section for accuracy, validity, and technical soundness; and evaluate the report conclusions for consistency. The results of this technical review are presented in this memorandum.

OVERALL REVIEW

The report describes the electric and magnetic field evaluation associated with the various power line configurations for the Energize Eastside Project. As described within the report, the project includes approximately 18-miles of two existing 115 kV transmission lines to be upgraded to 230 kV and higher capacity, consisting of 6 main route segments and 34 different analysis locations within those segments. The author assumes that the reader is intimately familiar with the various proposed transmission line segments and alternate routes associated with the project, as the project description is very sparse and the only diagram which illustrates the various transmission line route segments and analysis locations is located in an Appendix towards the back of the report. It would be extremely helpful to have this figure presented at the onset of the report to familiarize the reader with the overall project.

Overall, the report is written in a very confusing manner. For example, the Executive Summary presents Table 1 entitled "Summary of Results". However, this table only presents the electric and magnetic field results for a portion of one route segment (Segment 4) rather than for all route segments and analysis locations (as would typically be expected within an Executive Summary).

As stated in the Executive Summary, "For this investigation, there are 34 locations along the six segments where EMF measurements were performed." So the author states that electric and magnetic field "measurements" were performed. However there is no description of the instrumentation used to conduct field measurements, nor a measurement methodology used to measure the existing 115 kV lines. In addition, all tables of results presented within the report have a column titled "EMF Measurement Location" (even for proposed upgraded transmission line configuration locations where it is not possible to make measurements on a line not yet built). If the author did not intend to utilize the term "measurements" but instead meant to describe calculation locations, then the author should revise the report and eliminate all references to "measurements" and replace it with the term "calculation locations" and/or "calculation results".

It appears that all of the electric and magnetic field results presented within the report are calculated field values (as confirmed later in Section 4 of the report). However, the author fails to identify the calculation software which was used to perform this evaluation. In addition, the author does not identify whether the magnetic field values are either the resultant field values (the resultant is calculated as the square root of the sum of the squares for the three orthogonal axes) or a calculated maximum field value (major axis of the field ellipse). Depending on the degree of field polarization, the resultant value and maximum value could differ by up to about 40%.

METHODOLOGY

As stated within the report, electric and magnetic field values are calculated at the minimum conductor height (mid-span) at a measurement height of one meter above the ground per IEEE Standard 644-1994 (R2008), "IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines". This is accepted industry practice for evaluating power-frequency electric and magnetic fields from transmission lines, particularly when a proposed line configuration is under consideration and cannot actually be measured. Calculations are performed across the transmission line right-of-way (ROW), from ROW edge to ROW edge. Magnetic field calculations are also performed for four different loading scenarios to provide a range of field levels under various operational loading conditions.

To evaluate the calculation results, the report lists two guidelines: IEEE C95.6-2002 (9,040 mG reference limit) and ICNIRP (2,000 mG for general public). However there is no mention of standards such as ACGIH for medical device interference.

As shown in Table 1 (and only in Table 1, which only presents the electric and magnetic field results for a portion of one route segment), the calculated "maximum" values with the ROW are compared with the **IEEE** guideline while the calculated ROW edge values are compared with the **ICNIRP** guideline. There is no rationale for this confusing mixed use of the IEEE and ICNIRP standards, although use of the largest guideline (IEEE) would make the calculated maximum value seem smaller than if it were compared with the lower guideline of ICNIRP (2,000 mG). This appears to be a subjective decision to select the standard that makes the results seem smaller by comparison. If both standards are cited, then the results should be compared with both.

Finally, the comparison between the calculated field values and the standards shown in Table 1 are presented as a **"Difference Below Guideline (%)"**. This is a convoluted way to provide comparisons (difference below) and it is unnecessarily difficult to understand for non-technical people. Rather, perhaps it would be simpler and more direct to show the mG level for each standard so that a non-technical reader could make a direct comparison of the calculation results to the standard's limit value and clearly understand that the results are below the guidelines. Also since both IEEE and ICNIRP are cited as guidelines, results should either compare to both, use the lowest allowable guideline (ICNIRP) or perhaps give a range that includes both.

DATA AND ASSUMPTIONS

The assumptions and data used to perform the electric and magnetic field computer calculations are presented in Sections 2 (Data) and 3 (Assumptions and Notes), Appendix A (Analysis Data), and Appendix C (Structure Drawings). In general, most of the data and assumptions used to perform the field calculations are correct and documented.

In Section 2, the report states that "EMF from transmission lines are primarily dependent on conductor geometry, conductor size/bundling, line phasing, circuit configuration, current, voltage, and the **altitude** of the line". However, altitude is not a parameter listed in the Appendix A summary of calculation input data. The report should explain how altitude affects the calculated ground level electric and magnetic field levels if it does for this project.

In Table 2, the first column is labeled: "Voltage Level". The correct label for the line voltages listed in this table is: **"Nominal Voltage"**. The term "nominal voltage" is correctly used in Appendix A listing input data.

In Section 3, the assumption for phasing configuration is described. The report states: "For double circuit structures with conductors side by side the phase configuration is assumed to be the same on both sides (ABC-ABC). This provides the **worst case scenario**." This is not necessarily correct unless the report author is certain that current flow in each circuit of a double circuit line is exactly in the same direction. If this is unclear or unknown at this time, then the report must accurately clarify this by saying that if current flow is assumed to be in the same direction this is worst case (producing the maximum calculated values); otherwise it is not the worst case configuration.

In this Section, the report also states that: "The EMF **measurements** were performed based on existing transmission line configurations (that currently exist in the routes) and load conditions at the time of the measurements. Calculated EMF levels for upgraded transmission line configurations are based on future load conditions. Therefore, the EMF measurements cannot be compared directly with calculations for the upgraded transmission line route configurations." However, in Section D of the report which presents the results, existing calculated electric field values for existing configurations are compared with calculated electric field values for proposed configurations. If this statement is meant to identify why calculated magnetic field values for existing configurations are not compared with calculated magnetic field values for proposed configurations, then it should state it as such (rather than using the general term "EMF levels"). However, simply because the loading is different between existing and proposed configurations does not provide a substantial argument as to why before and after calculation results cannot be compared.

In Section 4, the report states: "Electric field strength is calculated from the line voltage and is independent of the current through the line". This statement is possibly misleading as voltage is one parameter used to calculate electric fields. The sentence can be corrected by saying either of these more inclusive and accurate statements:

- Electric field strength is calculated primarily from the line voltage, line geometry, and

phasing; it is independent of the current through the line, or

- Electric field strength is calculated from the line voltage and other parameters; it is independent of the current through the line.

In Section 4.2, the report states: "Note that the results are directly proportional to the loading of the line; therefore, 50% loading would be exactly half of the 100% loading condition". To be accurate, the sentence should be modified to state: "Calculated results are directly proportional only if conductor height and other line configuration parameters are assumed to be unchanged between these two conditions".

ANALYSIS

Sections 5 through 10 present the calculation results in tabular format for each of the six route segments respectively. In addition, Appendix D presents an abbreviated tabular summary along with graphs of the calculation results.

As described previously, the word "Measurement" should be removed from every results table as this term is misleading and inappropriate (since these are calculation results).

Comparison between the "Existing" and "Upgraded" calculation results would be much easier to evaluate if report combined similar calculation cases for a direct comparison (i.e. compare maximum values with maximum values side-by-side rather than segmenting them within the table).

No load information is provided for the existing peak load, only for the existing average load condition. It is unclear why this information was omitted from the data and should be provided.

As part of the analysis evaluation, Enertech selected a random configuration within each of the six route segments to validate the calculation results (budget constraints did not allow for validation of every route segment). Computer models were developed of the existing and proposed transmission line configurations using the line geometry data provided within the report. The software program "EMF Workstation 2015", which is the latest EPRI electric and magnetic field computer modeling program, was used to perform these electric and magnetic field calculations. Magnetic field calculation results are **resultant** magnetic field values. The following describes the results of this calculation validation:

> For the Redmond Segment, field calculations were performed for locations A-1, A-2, and C-1 (since each of these locations shares a common existing and proposed line configuration). Calculated electric and magnetic field values by Enertech matched closely the values presented in Section 5.1 and 5.2 of the report (within tenths of V/m and tenths of mG).

For the Bellevue North Segment, field calculations were performed for locations C-3 and C-4 (since each of these locations shares a common existing and proposed line configuration). Calculated electric and magnetic field values by Enertech matched closely the values presented in Section 6.1 and 6.2 of the report (within tenths of V/m and tenths of mG).

For the Bellevue Central Segment, field calculations were performed for locations E-1, E-2, and E-3 (since each of these locations shares a common existing and proposed line configuration). Calculated electric and magnetic field values by Enertech matched closely the values presented in Section 7.1.1 and 7.1.2 of the report (within tenths of V/m and tenths of mG). Field calculations were also performed for the Bypass locations 1 through 4 and F-1 (each of these locations has no existing configuration and share a common proposed line configuration). Calculated electric and magnetic field values by Enertech matched closely the values presented in Section 7.2.1 and 7.2.2 of the report (within tenths of V/m and tenths of mG). However, the tabular data in Appendix A for these Bypass locations states that the analysis **profile width is 45-feet**, but the Appendix D graphs show that the profile width is only **30-feet**.

The Bellevue South Segment is comprised of four different sub-segment route variations, identified as Oak 1, Oak 2, Willow 1, and Willow 2. Field validation calculations were performed for the Oak 1 locations I-1, I-2, K-2, K-3 and K-4. Calculated electric and magnetic field values by Enertech generally tended to match closely the values presented in Section 8.1.1 and 8.1.2 of the report (within tenths of V/m and tenths of mG); however there were a few discrepancies. For the existing electric field profiles, the edge of the ROW values were reported as **0.423 kV/m** (Table 11, locations I-1, I-2, and K-2) while Enertech's calculated values were **0.08 kV/m**. The existing ROW width is stated as 100-foot wide and the proposed ROW width is 57-feet. It appears that the proposed ROW width of 57-feet may have been applied to the existing calculation results. For the proposed electric field profiles, the edge of the ROW values were reported as **1.653 kV/m** (Table 11, locations I-1 through K-4) while Enertech's calculated values were **1.32 kV/m**. For the proposed magnetic field profiles, the edge of the ROW values for Winter Average loading were reported as **76.51 mG** (Table 12, locations I-1 through K-4) while Enertech's calculated values were **70.72 mG**. For the proposed magnetic field profiles, the edge of the ROW values for Winter Peak loading were reported as **127.46 mG** (Table 12, locations I-1 through K-4) while Enertech's calculated values were **117.8 mG**. The reason for these latter discrepancies were not immediately apparent. In Appendix D, the electric field graphs for these sections show a ROW width consistently of 57-feet (which is the proposed configuration width), which is also applied/shown for the existing configuration electric field even though the existing ROW width is 100-feet. Finally, there is no I-1 Oak1 listing of data in the tables shown in Appendix A.

For the Newcastle Segment, field calculations were performed for locations J-4, M-1, M-2, and M-3 (since each of these locations shares a common existing and proposed line configuration). Calculated electric and magnetic field values for the existing configuration by Enertech matched fairly closely the values presented in Sections 9.1 and 9.2 of the report (within tenths of V/m and a few mG). However, for the proposed configuration, it was noted that a discrepancy exists between the tabular data presented in Appendix A and the structure drawing shown in Appendix C (specifically, the offset direction of the lower conductor). After performing field calculations for both variations, it appears that the Phase C offsets from the Structure CL should be reversed for the tabular data associated with structure C_13_Pole1 and C_13_Pole2 (i.e. +9.5-foot offset for Pole1 should be -9.5-feet and -9.5-foot offset for Pole2 should be +9.5-feet to agree with the structure drawing). Electric and magnetic field calculation results using these adjusted dimensions more closely matched the values shown within the report (within tenths of V/m and several mG).

For the Renton Segment, field calculations were performed for locations M-4 and M-5. Calculated electric field values by Enertech matched closely the values presented in Section 10.1 of the report (within tenths of V/m). Calculated magnetic field values by Enertech matched fairly closely with the values presented in Section 10.2 of the report (within several mG) for the **existing** configuration. However, the calculated magnetic field values for the **proposed** configuration did not match the values shown in Table 22. It appears that these latter values are a duplication of the values shown in Table 4 for the Redmond Segment (using those associated load values) and the values were never updated with the actual calculation values. In Appendix D, the magnetic field graphs for M-4, M-5, N-1, and N-2 are all identical graphs (since they all share the same proposed configuration and loading scenarios) and show the correct calculated magnetic field values. However, the tabular data to the left of the graphs all shown the incorrect calculated magnetic field values for Winter Peak loading which do not match the graphical results (i.e. they are the same incorrect tabular values as are shown in Table 22). Therefore, the magnetic field calculation results for the proposed configuration in Table 22 and the tabular results shown in the graphs all need to be updated with the correct values. Since Enertech was unable to validate each and every route segment (due to budget constraints), and due to the problematic magnetic field results shown in Table 22 for the proposed configuration, it is recommended that the author recheck their results tables and graphs for accuracy.

REPORT CONCLUSIONS

There are no formal conclusions presented within the executive summary section of the report. The only conclusive statements are made in Section 4 of the report, which states that calculated electric and magnetic fields are well below the IEEE and ICNIRP guidelines for all proposed routes. A qualitative discussion of the percent increase (or decrease) for each route segment would also be helpful in providing the overall effect of the upgrade on EMF levels. It is therefore recommended that the Executive Summary be updated to include a comparison chart of existing and proposed calculation results for each route section, along with a discussion of the conclusions resulting from this evaluation.

TECHNICAL REVIEW SUMMARY

After reviewing the Power Engineers electric and magnetic field report for the Energize Eastside Project, Enertech recommends that the following changes and updates should be made to the report:

- Relocate the segment map from its Appendix to the body of the report so the reader can be familiar with the locations being discussed.

- Eliminate all references to the term "measurements" since the results presented are calculation results.

- Identify the calculation software used to perform this evaluation and the type of calculated magnetic field values presented (resultant or maximum field).

- Consider including other standards such as ACGIH for medical device interference.

- Revise the evaluation pertaining to the IEEE and ICNIRP guidelines to be more consistent and intuitive for the reader.

- Include load information for the existing peak load conditions since calculation results are presented for this scenario.

- For the Bellevue South Segment, Oak 1 locations I-1, I-2, K-2, K-3 and K-4:
    - For the existing electric field profiles, verify the edge of the ROW values reported as 0.423 kV/m (Table 11, locations I-1, I-2, and K-2) while Enertech's calculated values were 0.08 kV/m (it appears that the proposed ROW width of 57-feet may have been applied to the existing calculation results).
    - For the proposed electric field profiles, verify the edge of the ROW values reported as 1.653 kV/m (Table 11, locations I-1 through K-4) while Enertech's calculated values were 1.32 kV/m.

- For the proposed magnetic field profiles, verify the edge of the ROW values for Winter Average loading reported as 76.51 mG (Table 12, locations I-1 through K-4) while Enertech's calculated values were 70.72 mG.
- For the proposed magnetic field profiles, verify the edge of the ROW values for Winter Peak loading reported as 127.46 mG (Table 12, locations I-1 through K-4) while Enertech's calculated values were 117.8 mG.
- In Appendix D, revise the electric field graphs to show a ROW width for both the existing as well as the proposed configuration.
- In Appendix A, update the listing of data to include route I-1 within segment Oak1.

- For the Newcastle Segment, locations J-4, M-1, M-2, and M-3, for the proposed configuration, correct the discrepancy that exists between the tabular data presented in Appendix A and the structure drawing shown in Appendix C (specifically, the offset direction of the lower conductor).

- For the Renton Segment, locations M-4 and M-5 (as well as N-1 and N-2), correct the calculated magnetic field values for the proposed configuration shown in Table 22 and the tabular data to the left of the graphs for Winter Peak loading.

- Recheck all results tables and graphs for accuracy.

- In the Executive Summary, prepare an overall summary of the calculation results for the project with a qualitative discussion of the percent increase (or decrease) for each route segment and a discussion of the conclusions resulting from this evaluation.