Electrical and Semiconductors

Exponent®

Rhode Island Reliability Project: Electric and Magnetic Field Modeling

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Acronyms and Abbreviations

AAL	Annual Average Loading
AN	Audible Noise
APL	Annual Peak Loading
BPA	Bonneville Power Authority
dBA	Decibels on the A-weighted Scale
EMF	Electric and Magnetic Fields
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
JND	Just Noticeable Difference
NEEWS	New England East West Solutions
RIRP	Rhode Island Reliability Project
RMS	Root Mean Square
ROW	Right of Way

Introduction

Exponent modeled 60 Hertz (Hz) electric and magnetic fields (EMF) and audible noise (AN) along transects perpendicular to the route of the proposed 345-kV transmission line between the West Farnum Substation and the Kent County Substation. This report summarizes the methods and results of this engineering study.

Methods

Exponent was provided data regarding the configuration and loading of existing and proposed transmission and distribution lines by National Grid and its subcontractors. This information was supplemented by phone conversations. The fields were calculated at 1 meter (3.28 feet) above ground, in accordance with IEEE Std. 0644-1994, as the root-mean-square (RMS) value of the field ellipse at each location along a transect perpendicular to the transmission centerline. No local distribution lines were included in the calculations.

Pre- and post-construction EMF and AN levels were calculated using computer algorithms developed by the Bonneville Power Administration (BPA), an agency of the U.S. Department of Energy (BPA, 1991). These algorithms have been shown to accurately predict EMF and AN measured near power lines. Representative calculations incorporating overhead lines performed using the BPA algorithms were checked against ENVIRO (Electric Power Research Institute, Inc.). The magnetic field values calculated by these programs were found to be within 2 mG where the magnetic field profile was rapidly changing (within the right of way [ROW]), and within 0.5 mG at locations beyond the ROW where the magnetic field profile was steadily decreasing. Because the BPA algorithms do not take induced currents into account in shield wires or other grounded conductors, ENVIRO was used to calculate the magnetic field profiles for underground alternatives so that the effect of the ground continuity conductor could be incorporated.

The inputs to the programs are data regarding voltage, current flow, phasing, and conductor configurations. The fields associated with power lines were estimated along profiles perpendicular to lines at the point of lowest conductor sag, i.e., closest to the ground. The program assumed that the transmission conductors were at maximum sag for the entire distance between structures and flat terrain, and was instructed to model balanced currents on all phases.

The AN levels are expressed in decibels on the A-weighted scale (dBA) as L50 values, which are the sound-pressure levels exceeded 50 percent of the time. Fair weather levels were calculated by the subtraction of 25 dBA from the calculated foul-weather values as recommended by the BPA. An altitude of 400 ft was used for all sections in the calculation and an assumed height of a sound receiver of 5 ft. At lower altitudes the levels of AN will be less.

Modeling Results

EMF profiles were calculated for a number of cross sections along the route that passed land uses of interest. In all, magnetic fields were calculated for eight ROW cross sections (numbered XS-1 through XS-8), and two underground cross sections: one near Kent County (XS-UG-NEAR-KC) and the other near West Farnum (XS-UG-NEAR-WF).

For XS-1 through XS-7, a new 345-kV transmission line (circuit 359) in a delta configuration will be added to the ROW that includes an existing 345-kV transmission line (circuit 332). For XS-1 through XS-7, the existing 115-kV transmission lines (circuits T-172N, S-171N, T-172S, and S-172S) originally configured on horizontal structures will be reconstructed as vertical structures. For XS-8, the new 345-kV circuit (circuit 359) will replace the existing 345-kV circuit (circuit 332) on the existing structures, while the existing circuit 332 will be relocated to new delta structures.

Phase Optimization Analysis

Exponent evaluated the possible phasing of the new and reconfigured lines to identify a phasing of these circuits that would minimize the magnetic field level at the edge of the ROW with the highest magnetic field. Between 6 and 216 phasing combinations were evaluated in each cross-section, the number depending on the number of circuits in the cross-section that could have their phase permuted. National Grid used the results of the phasing analysis and its assessment of the constructability of phase configurations, to select the phasing of the new and reconfigured lines. The results of the phasing optimization analysis provided by Exponent to National Grid are presented in Appendix C. The phasing configurations selected by National Grid were used in modeling post-construction EMF and AN levels.

Magnetic Field Calculations

Magnetic field profiles were calculated for existing and proposed conditions on cross sections XS-1 through XS-8 and two underground cross sections for pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) configurations at two different loading cases: annual average loading (AAL) and annual peak loading (APL). Appendix A presents the diagrams of the existing and proposed line configurations for each cross section and the corresponding magnetic field profiles at AAL loading. Tables 1 and 2 in Appendix B summarize the calculated magnetic field values on the ROW, at the edges of the ROW and at 100 ft beyond ROW edges, for AAL and APL, respectively.

Electric Field Calculations

Electric field profiles were calculated for cross sections XS-1 through XS-8. Table 3 in Appendix B summarizes the calculated electric field values on the ROW, at the edges of the ROW and at 100 ft beyond ROW edges, at AAL and APL. The electric field, which is determined by the applied line voltage, does not vary significantly with loading.

Audible Noise Calculations

The partial electrical breakdown of the air around the conductors of an overhead transmission line may be perceived as AN. This AN can be characterized as a hissing, crackling sound that may be accompanied by a 120-Hz hum at higher rain rates. The conductors of transmission lines are designed to be free of AN during fair weather but wetting of the conductors during periods of rain, fog, snow, or ice, and debris increase AN.

Audible noise was calculated for cross-sections XS-1 through XS-8. Table 4 in Appendix B summarizes the calculated audible noise values at the edges of the ROW at AAL and APL. The audible noise, which is determined by the applied line voltage, altitude, and weather conditions, does not vary significantly with loading.

In fair weather the levels of audible noise of lines under existing or proposed conditions would be hard to detect because the calculated levels on all cross sections evaluated would be below assumed background levels for a quiet, rural area (30-35 dBA), similar to a quiet library.

The human ear requires almost a doubling of the sound intensity (3 dBA) in order to perceive a noticeable increase or just-noticeable-difference (JND) in the loudness of the sound. During foul weather, on the side of the ROW closest to the existing 345-kV line (circuit 332) the post-construction noise levels would increase by less than 3 dBA, with the exception of XS-8. For this cross section, and for the opposite side of the ROW of cross sections 1 to 7, which are closest to the reconstructed 115-kV lines, the AN levels will increase by about 5 dBA in foul weather. Given that background noise levels also increase during foul weather and AN will diminish with distance from the ROW, this increase would be detectable at the edge of the ROW under some conditions but masked by the noise of rainfall and wind so that complaints from nearby residences would be unlikely.

Appendix A. Cross section diagrams and magnetic field profiles at Annual Average Loading

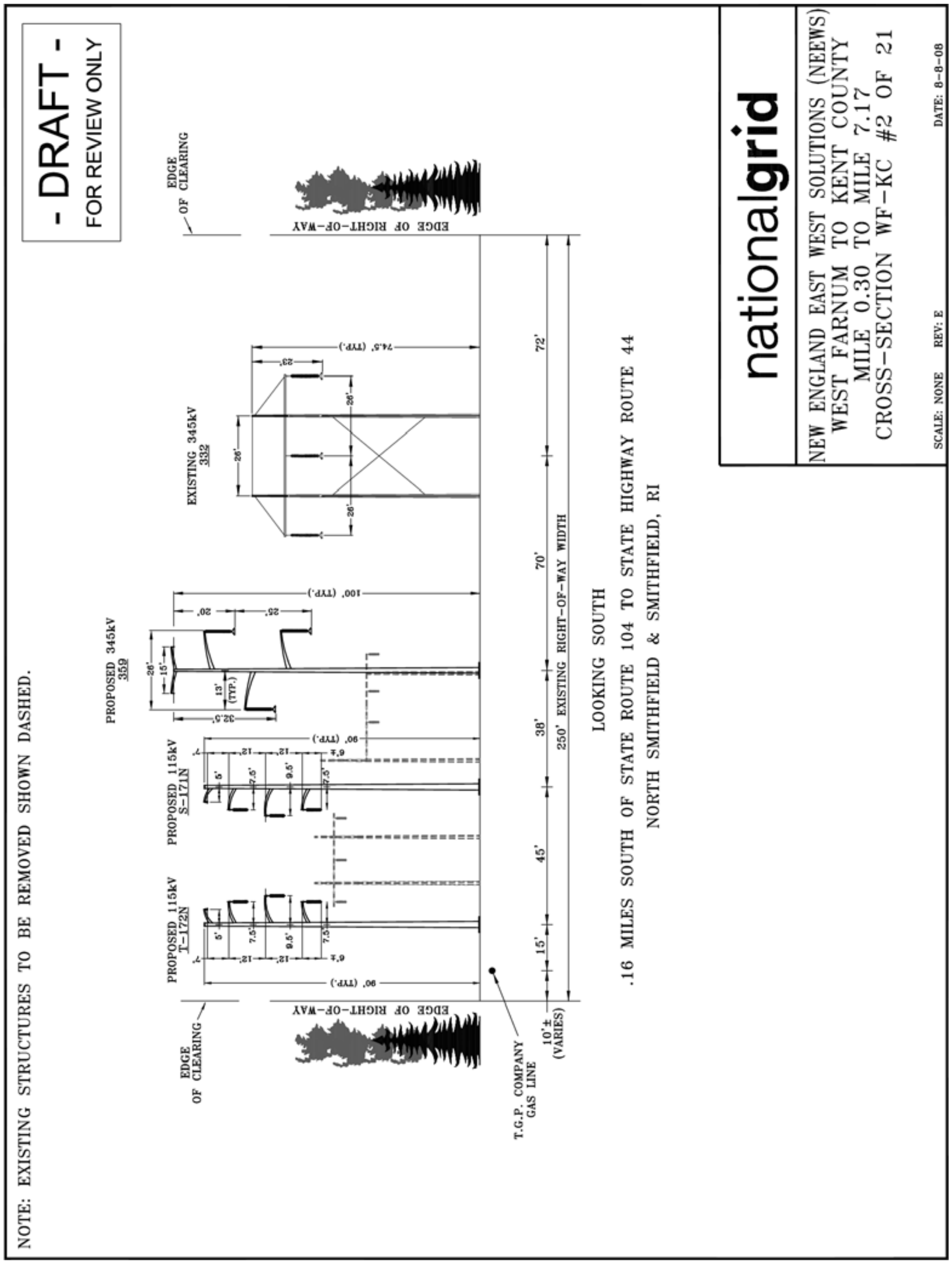

Figure 1. Cross-Section XS-1: 0.16 Miles South of State Route 104 to State Highway Route 44 between West Farnum Substation and Farnum Pike Substation (North Smithfield and Smithfield, RI).

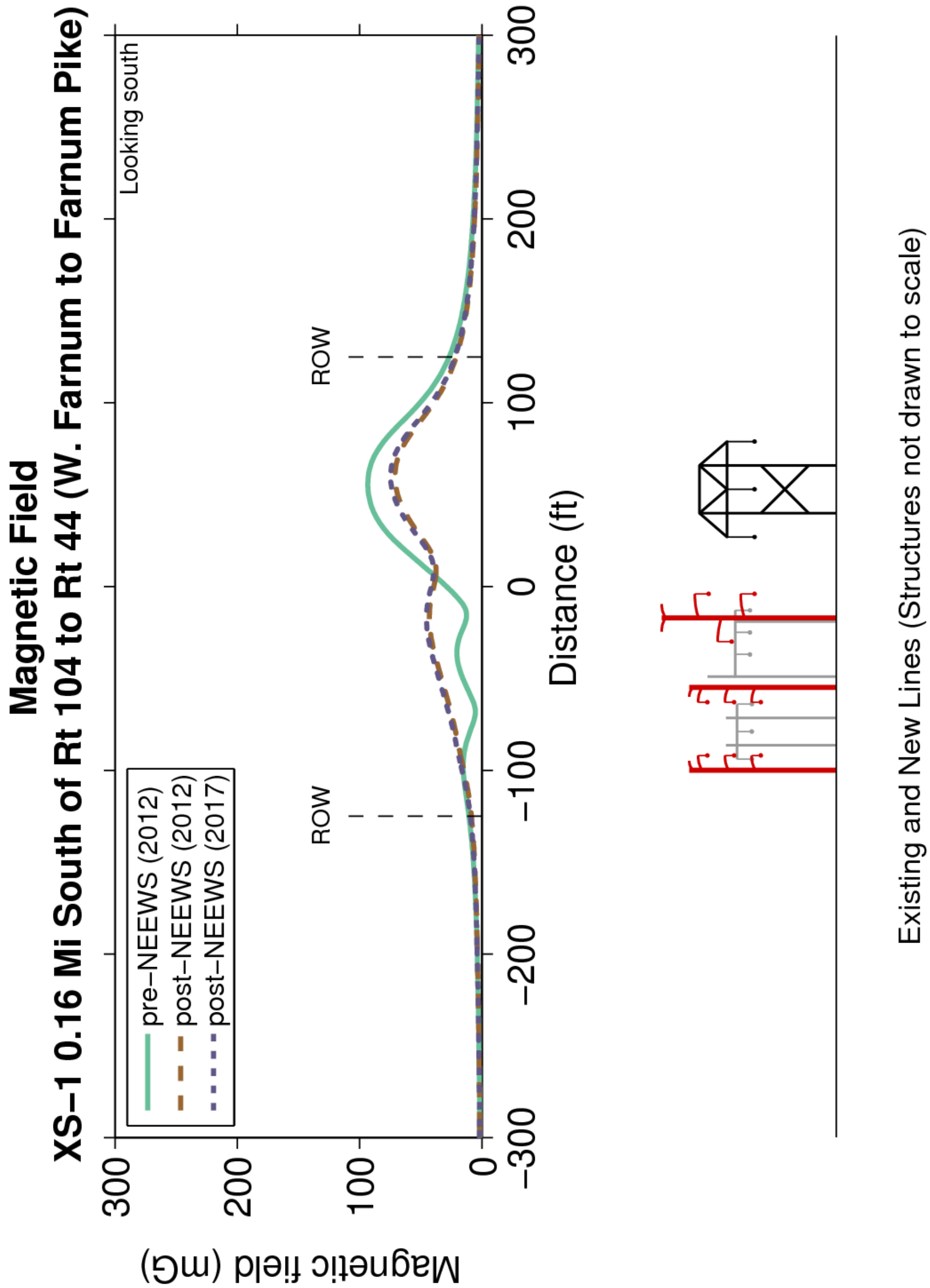

Figure 2. Profile XS-1: 0.16 Miles South of State Route 104 to State Highway Route 44 between West Farnum Substation and Farnum Pike Substation under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (North Smithfield and Smithfield, RI).

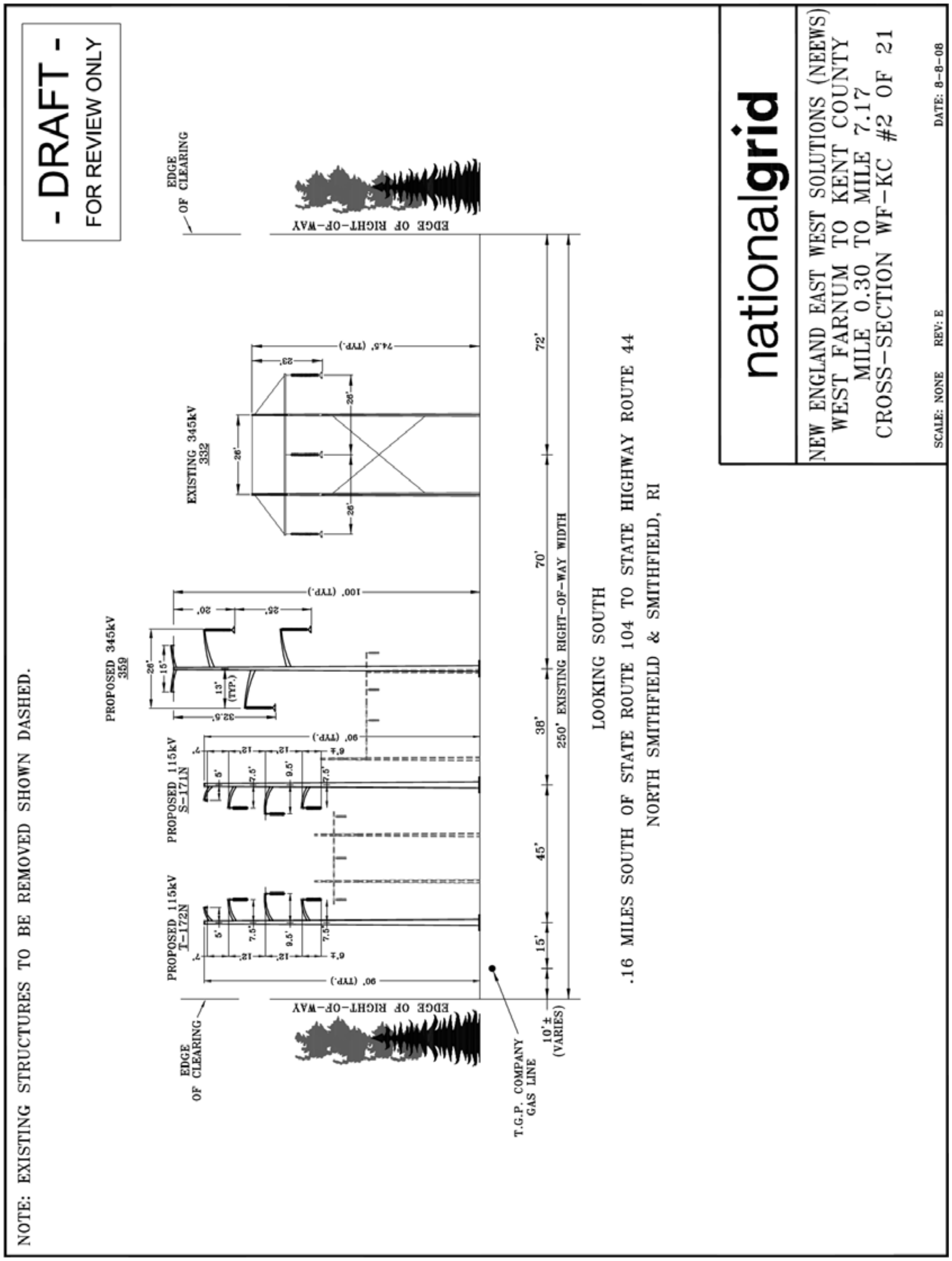

Figure 3. Cross-Section XS-2: 0.16 Miles South of State Route 104 to State Highway Route 44 between Wolf Hill Substation and Putnam Pike Substation (North Smithfield and Smithfield, RI).

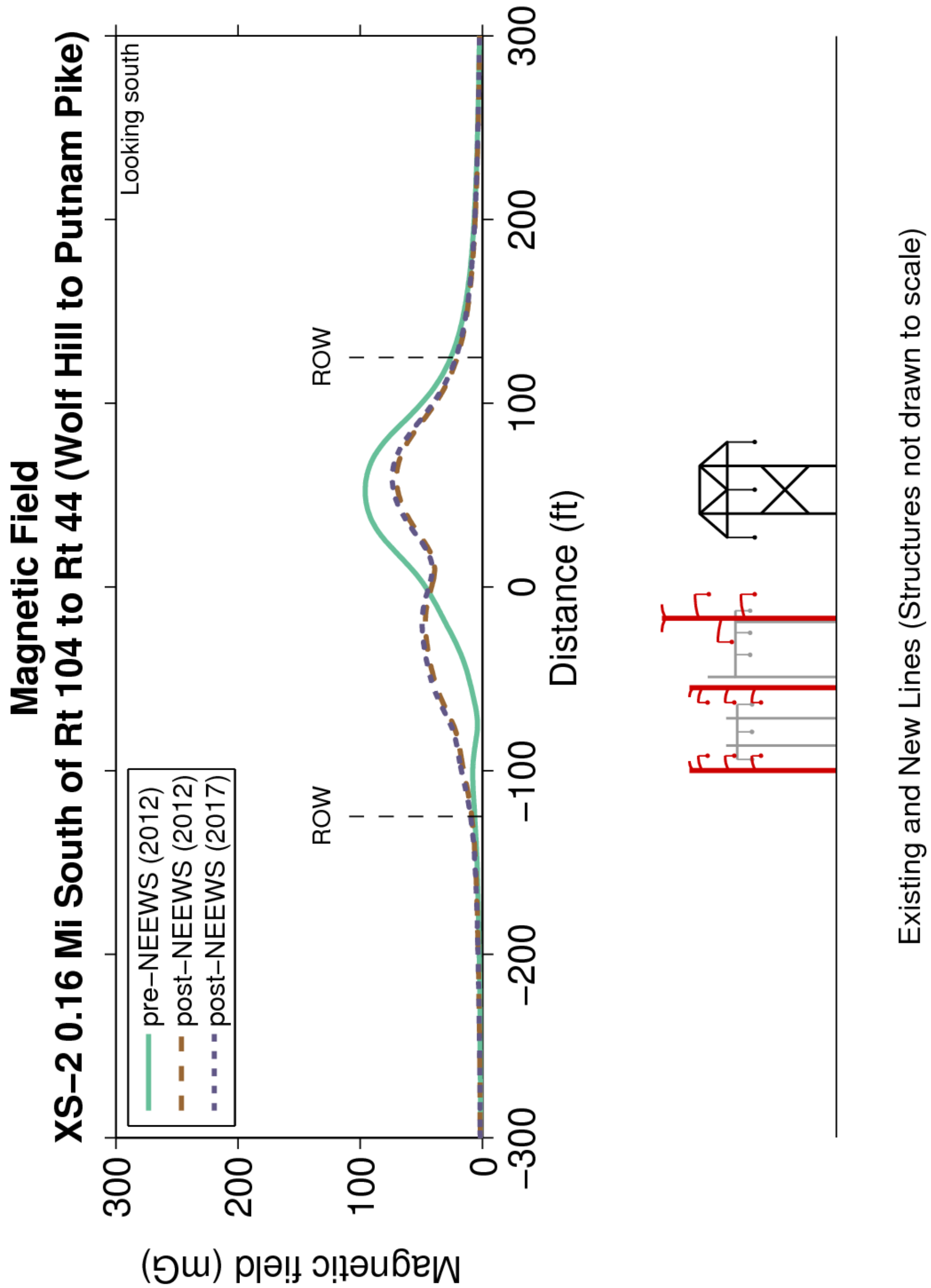

Figure 4. Profile XS-2: 0.16 Miles South of State Route 104 to State Highway Route 44 between Wolf Hill Substation and Putnam Pike Substation under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (North Smithfield and Smithfield, RI).

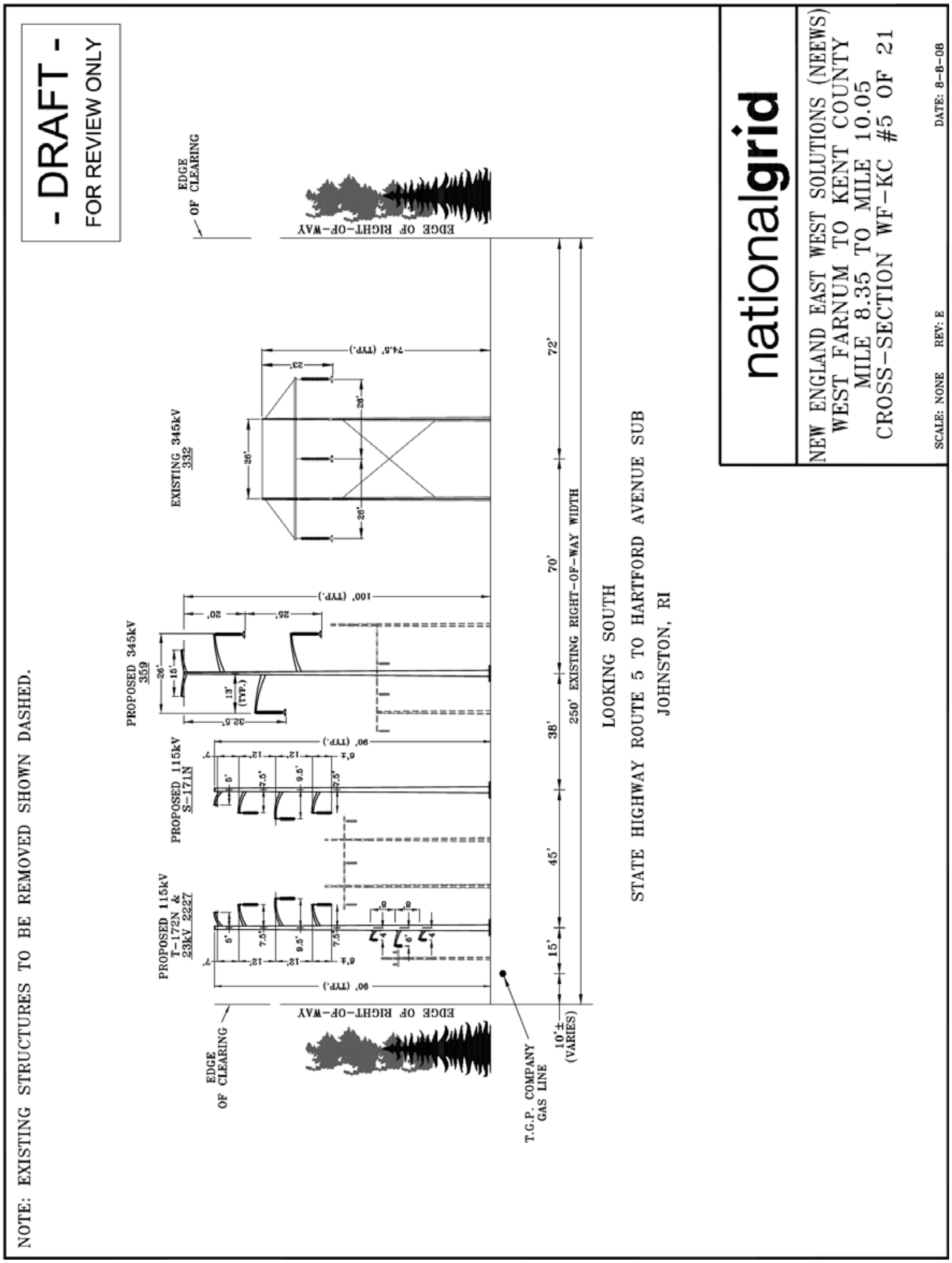

Figure 5. Cross section XS-3: State Highway Route 5 to Hartford Avenue Substation (Johnston, RI).

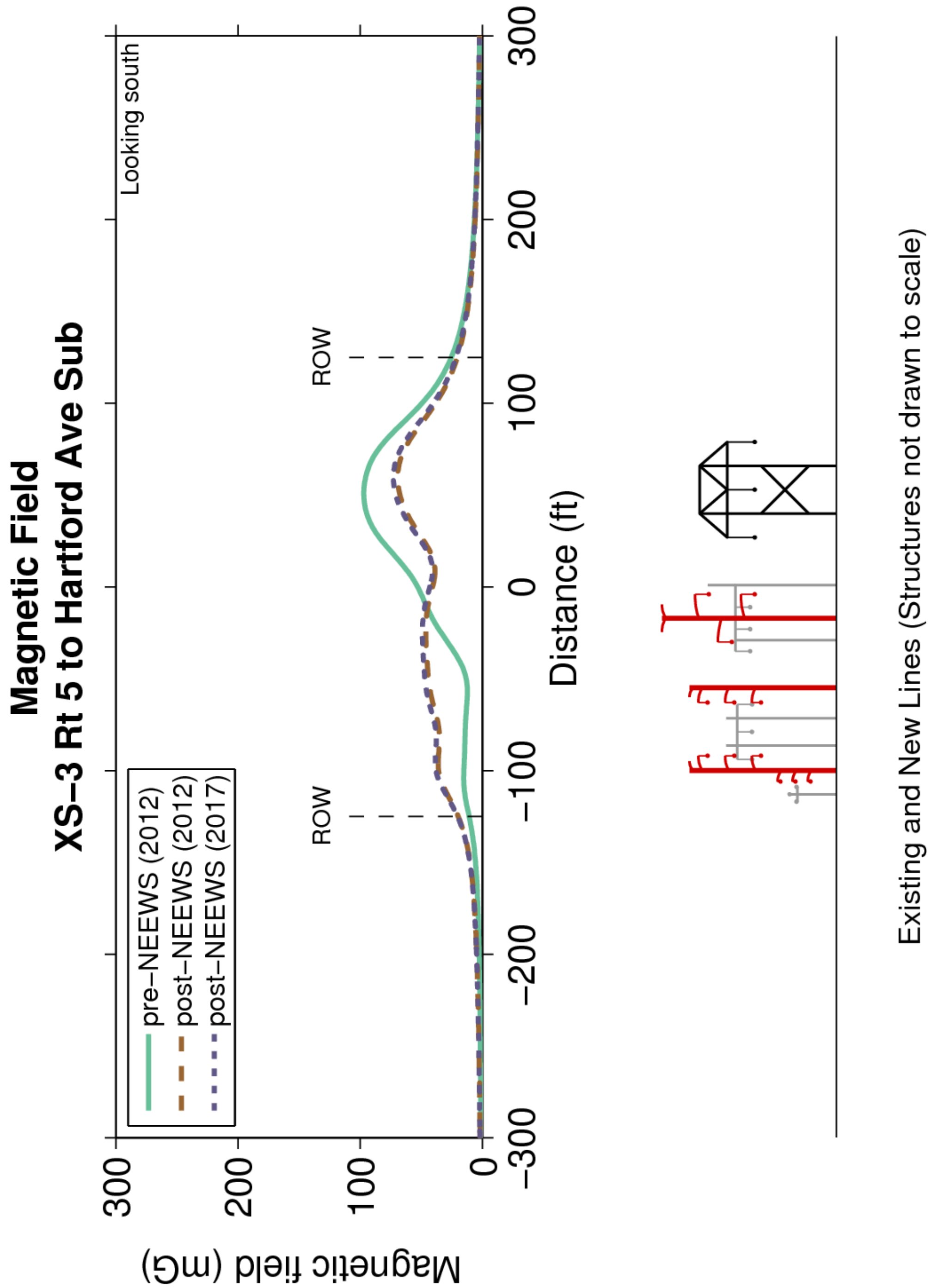

Figure 6. Profile XS-3: State Highway Route 5 to Hartford Avenue Substation under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (Johnston, RI).

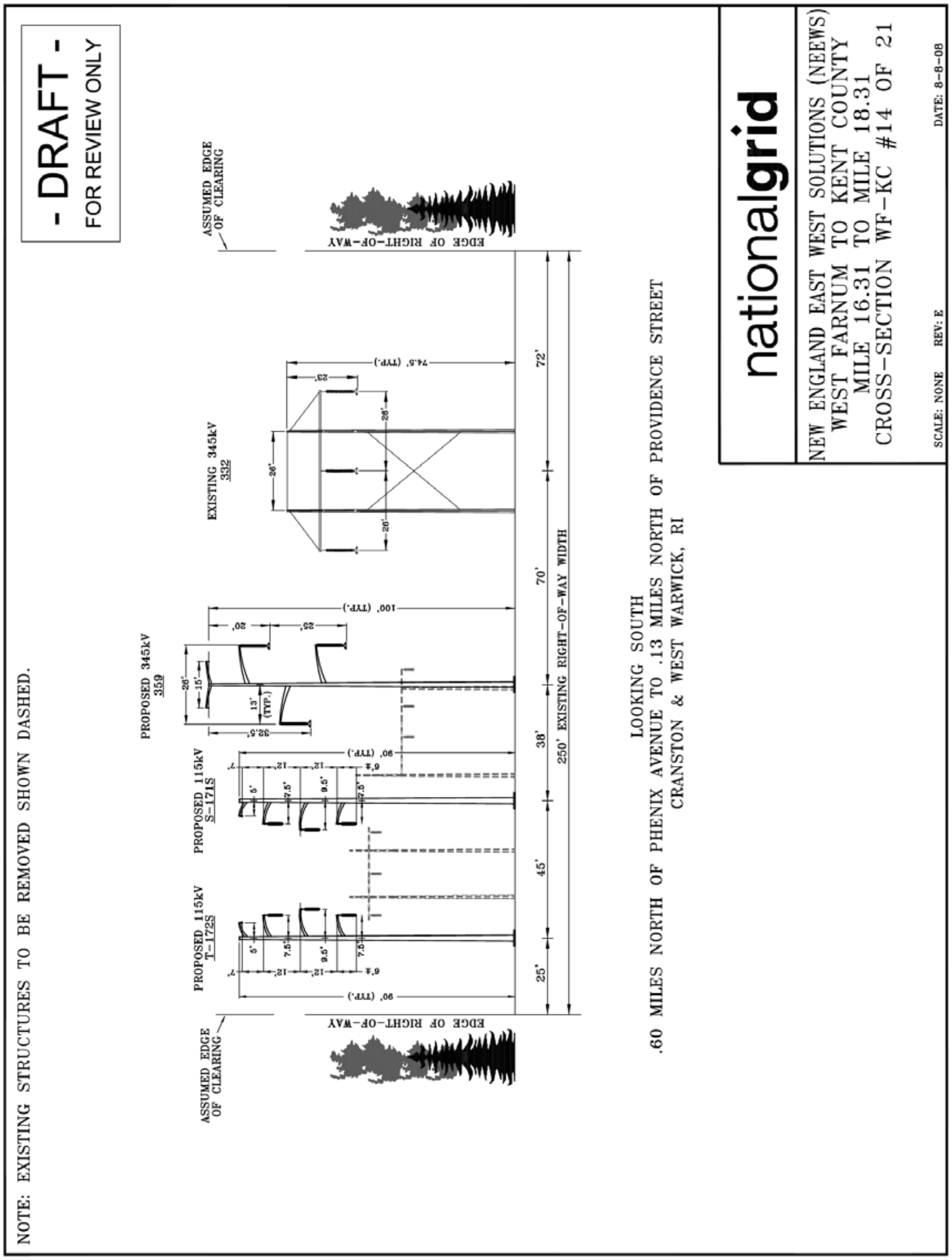

Figure 7. Cross section XS-4: 0.60 Miles North of Phenix Ave to 0.13 Miles North of Providence St (Cranston and West Warwick, RI).

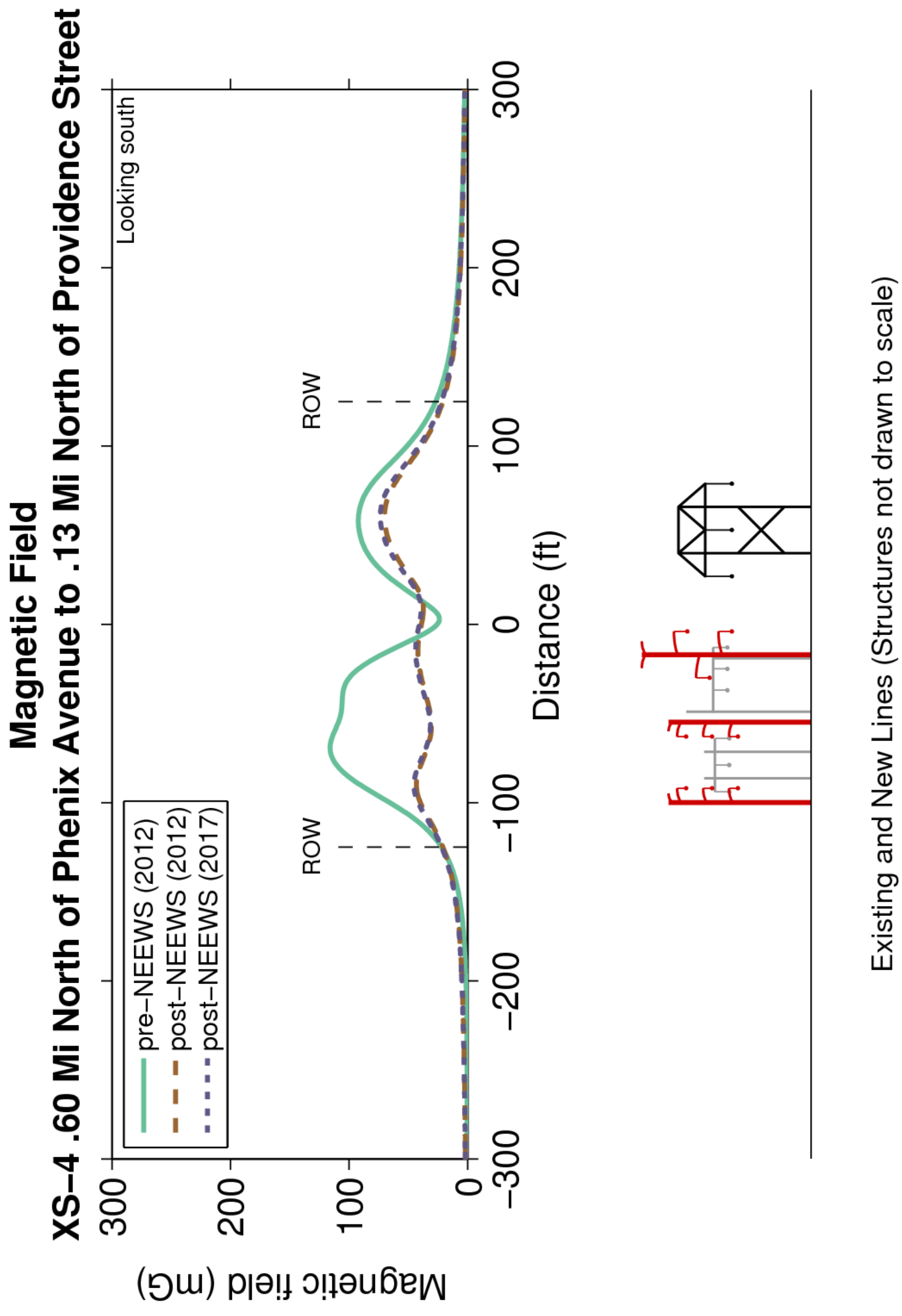

Figure 8. Profile XS-4: 0.60 Miles North of Phenix Ave to 0.13 Miles North of Providence St under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (Cranston and West Warwick, RI).

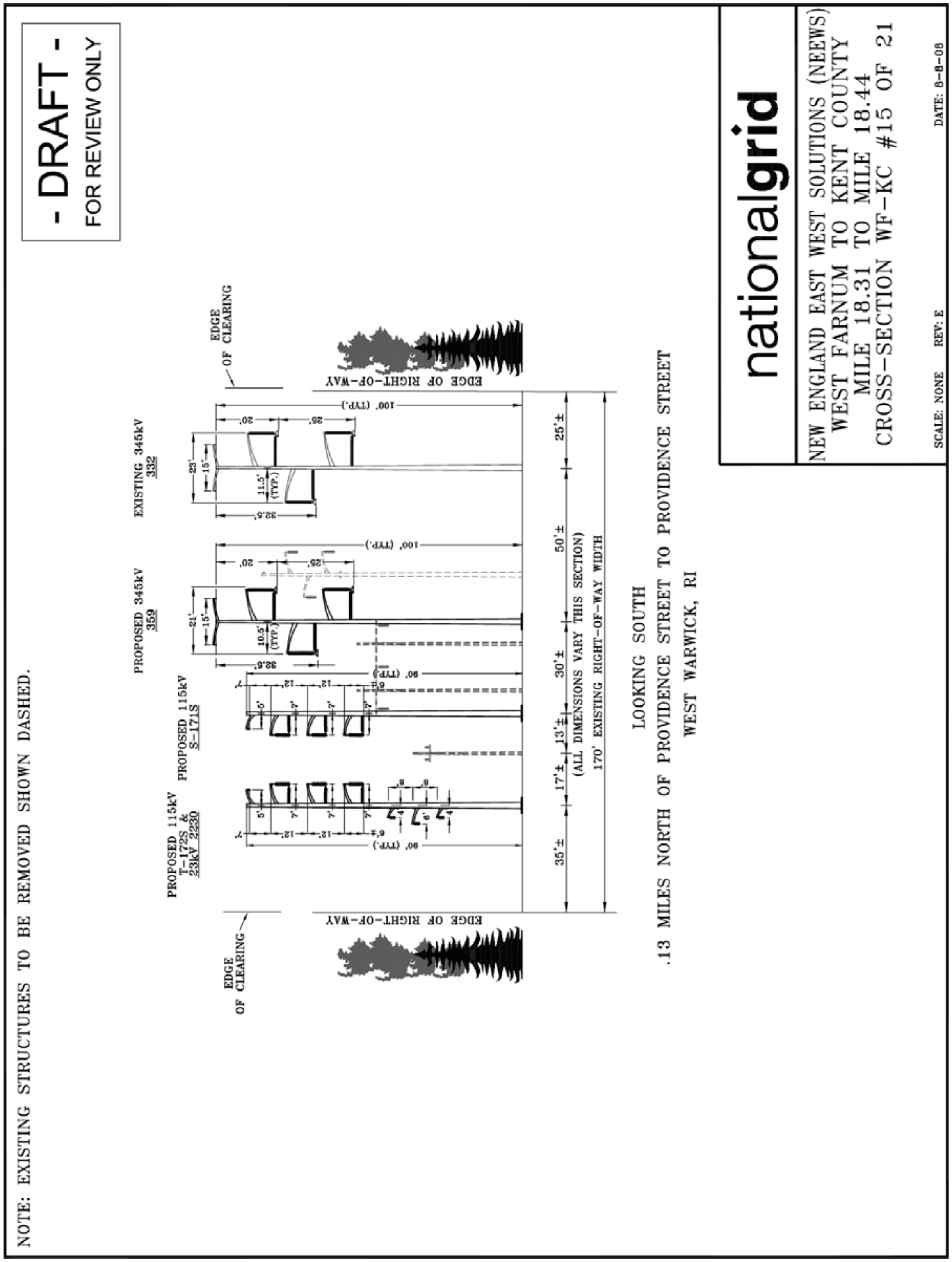

Figure 9. Cross section XS-5: 0.13 Miles North of Providence St to Providence St (West Warwick, RI).

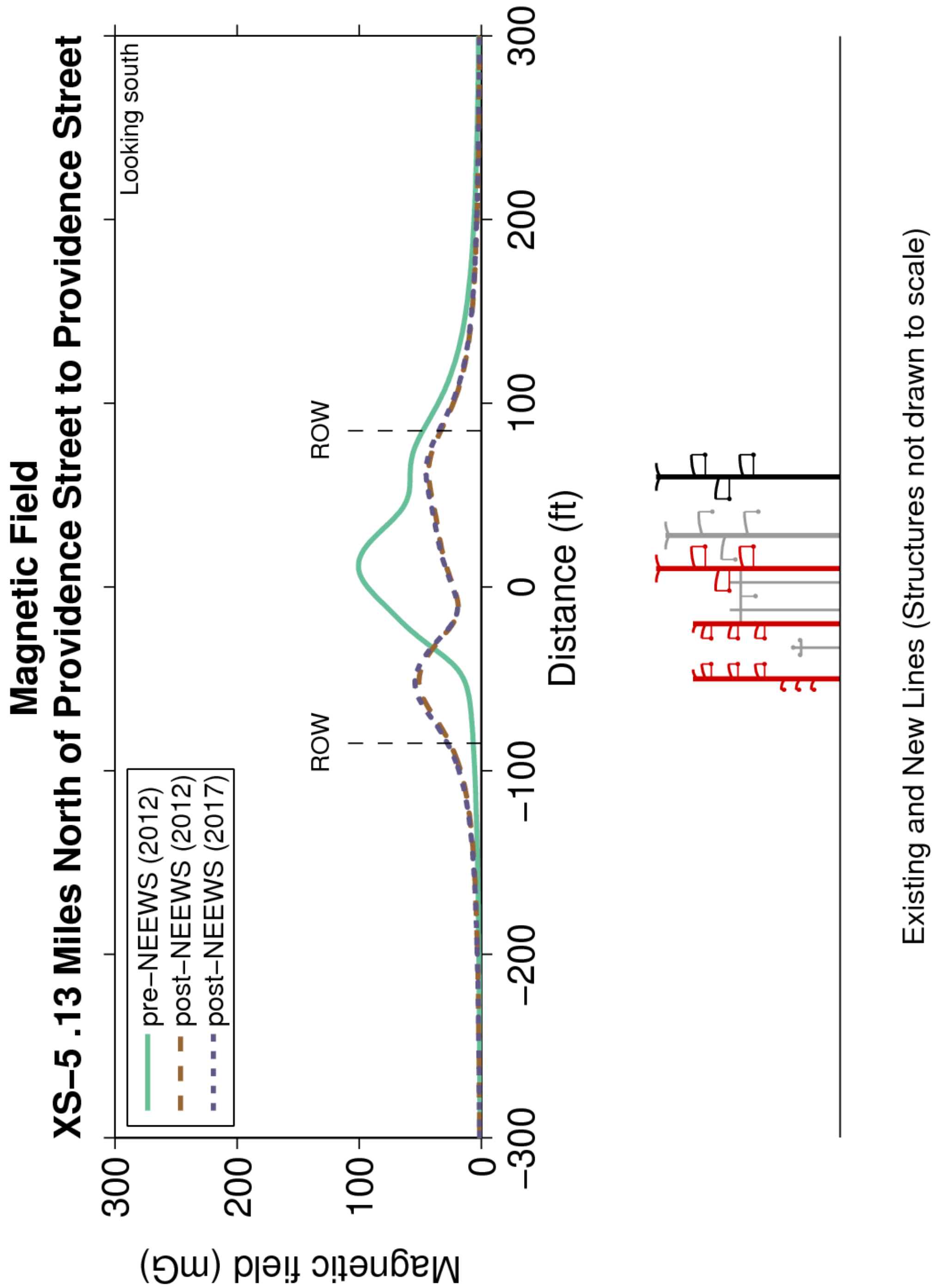

Figure 10. Profile XS-5: 0.13 Miles North of Providence St to Providence St under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (West Warwick, RI). Distribution circuits not modeled.

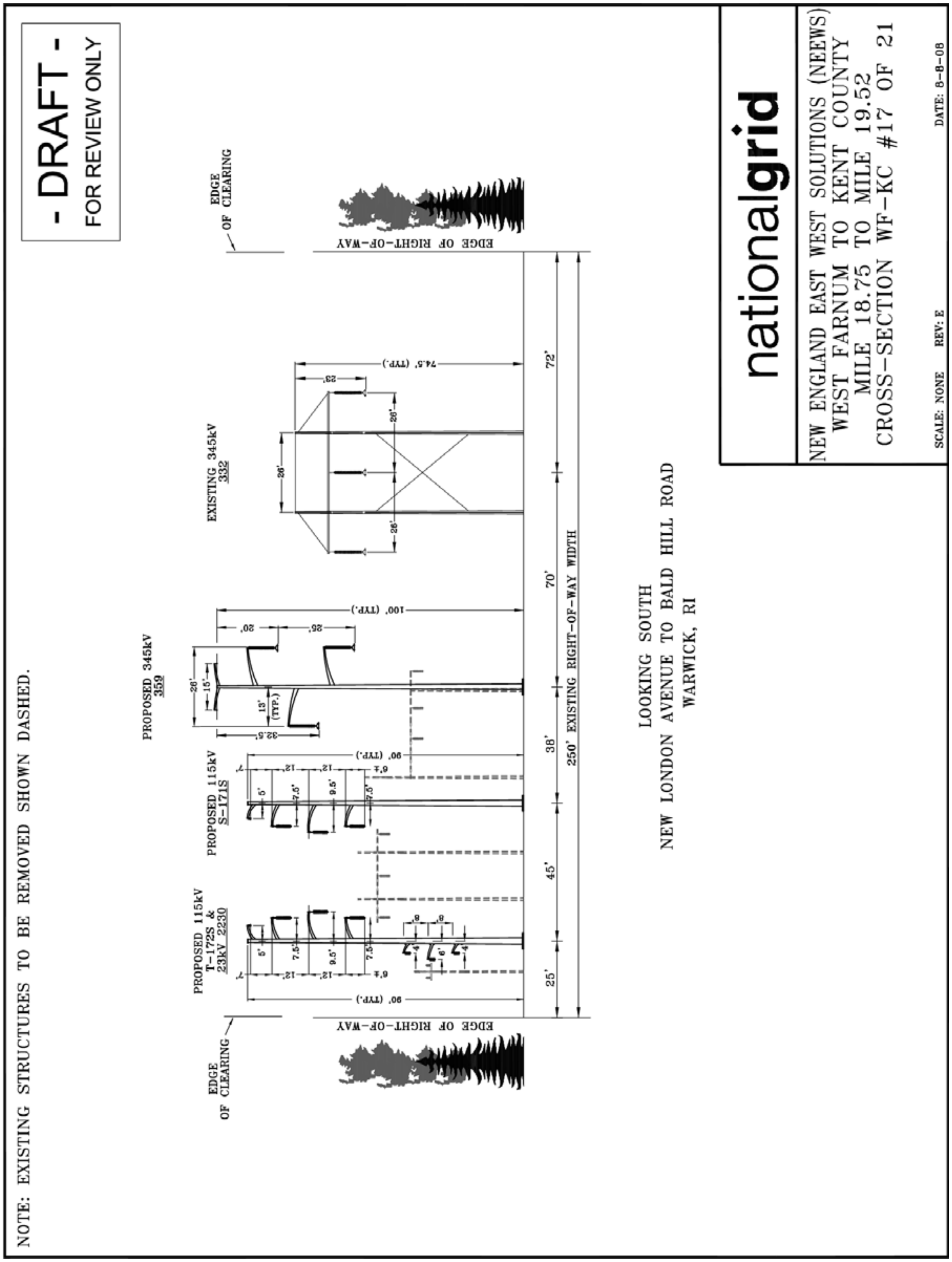

Figure 11. Cross section XS-6: New London Ave to Bald Hill Rd (Warwick, RI).

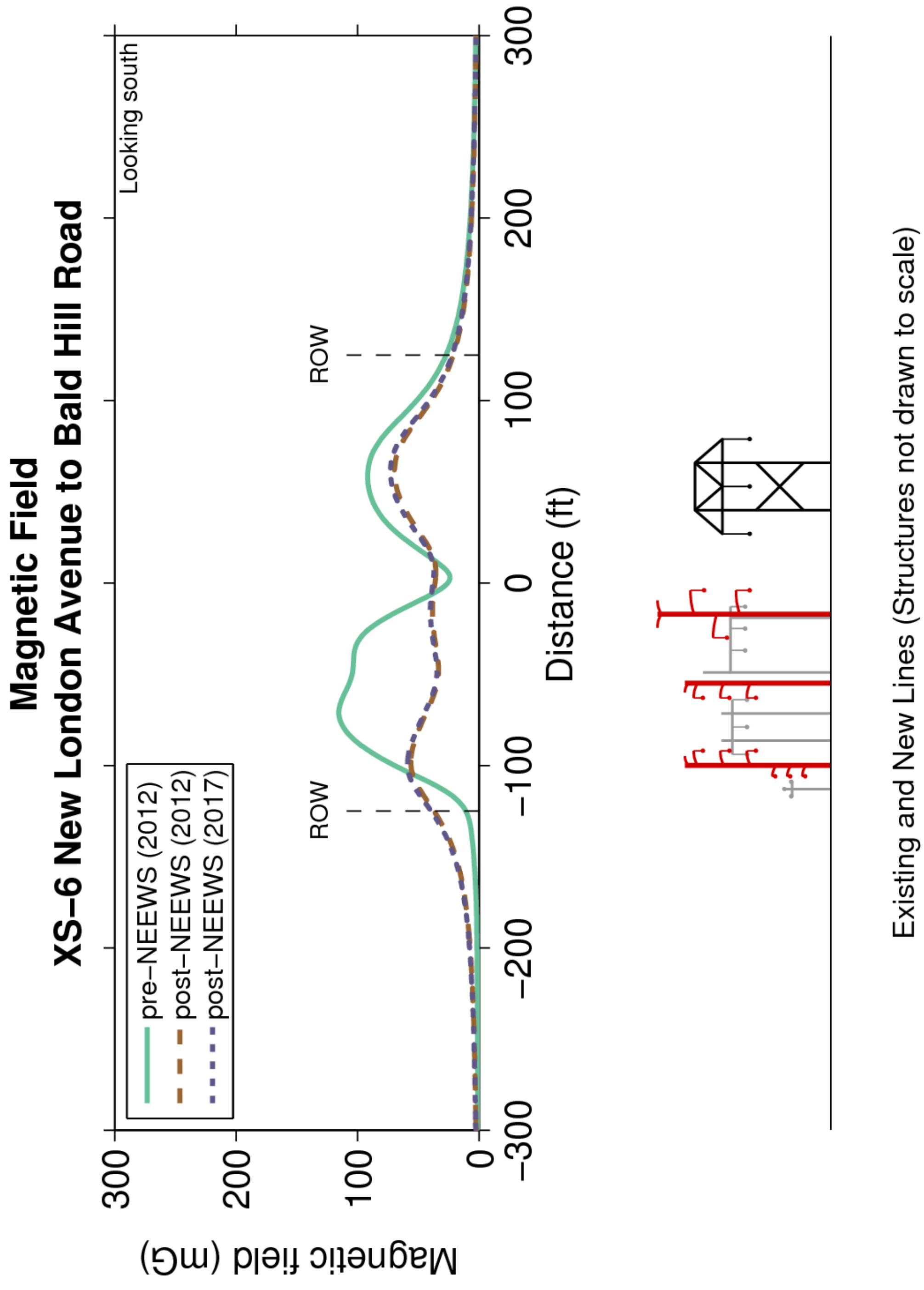

Figure 12. Profile XS-6: New London Ave to Bald Hill Rd under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (Warwick, RI). Distribution circuits not modeled.

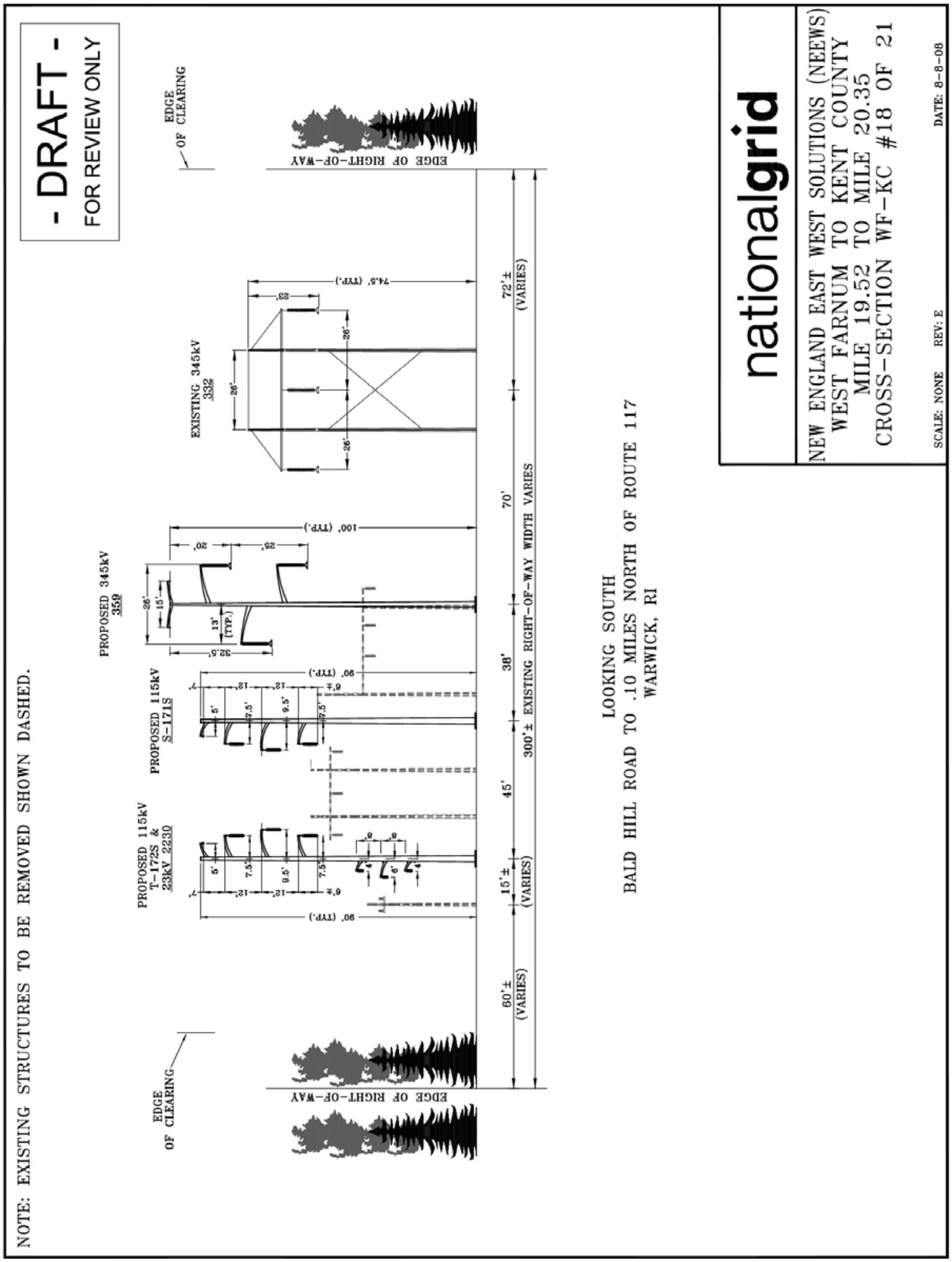

Figure 13. Cross section XS-7: Bald Hill Rd to 0.10 Miles north of Route 117 (Warwick, RI).

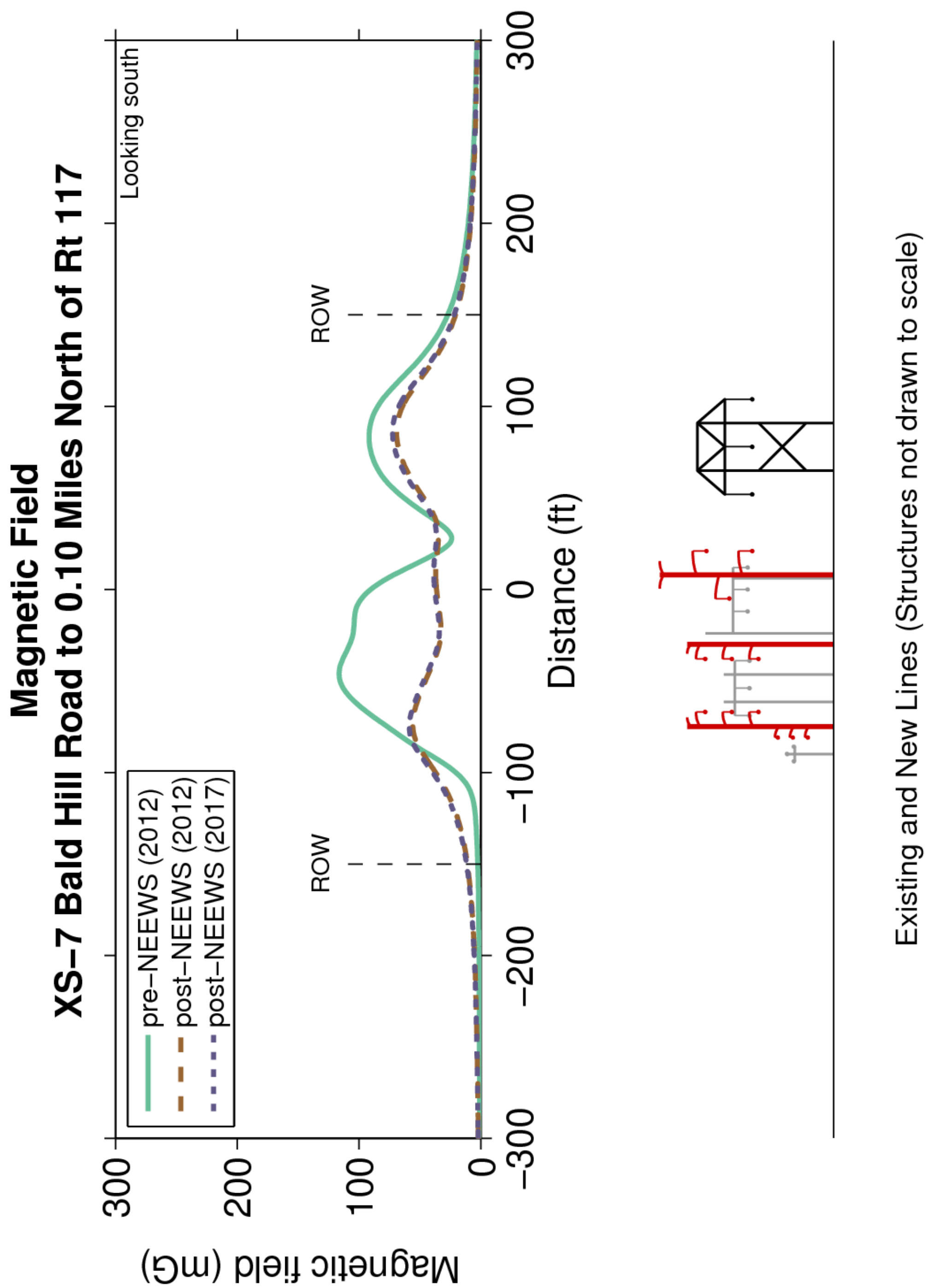

Figure 14. Profile XS-7: Bald Hill Rd to 0.10 Miles north of Route 117 under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (Warwick, RI). Distribution circuits not modeled.

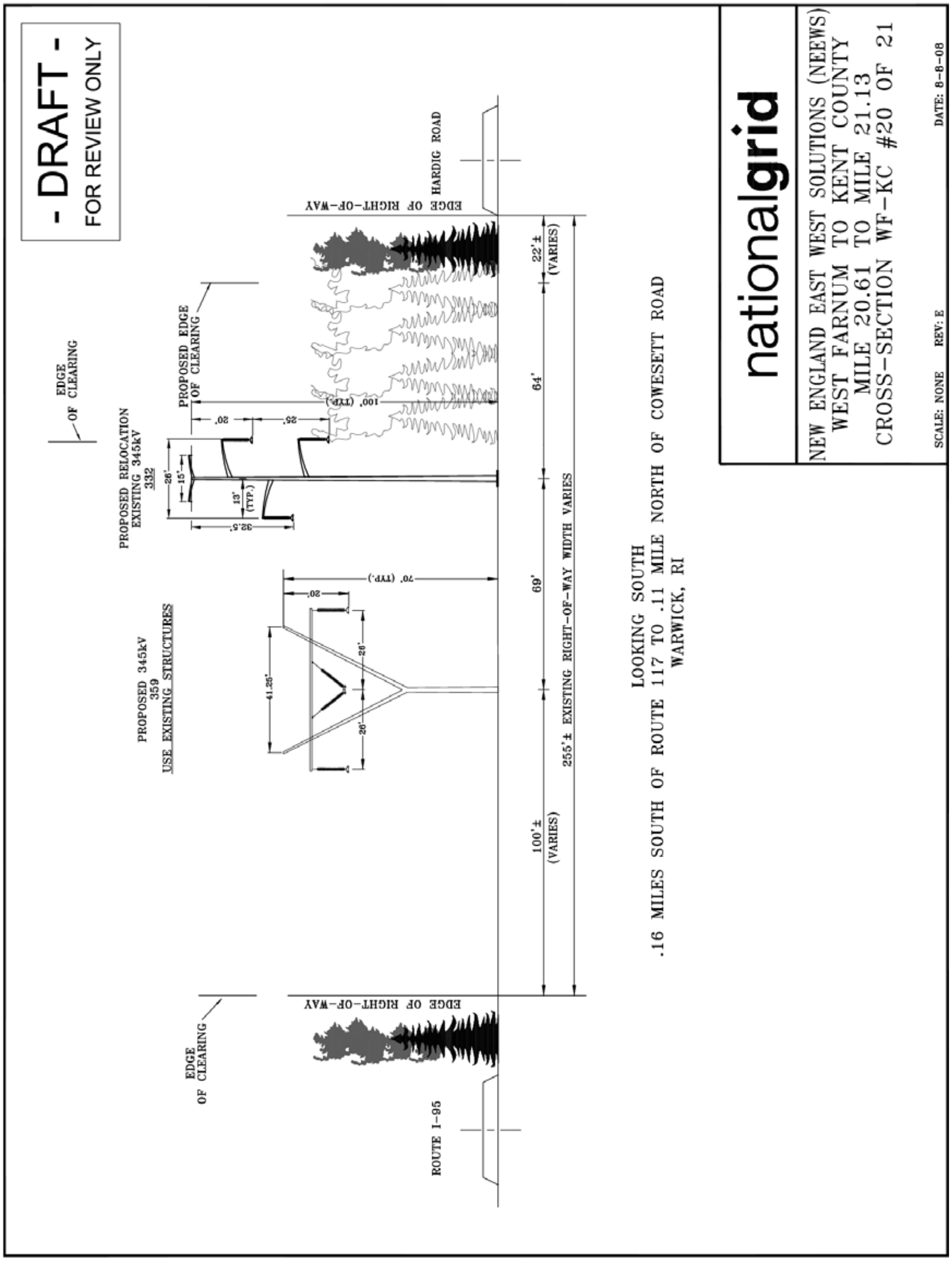

Figure 15. Cross section XS-8: 0.16 miles south of Route 117 to 0.11 miles north of Cowesett Rd (Warwick, RI).

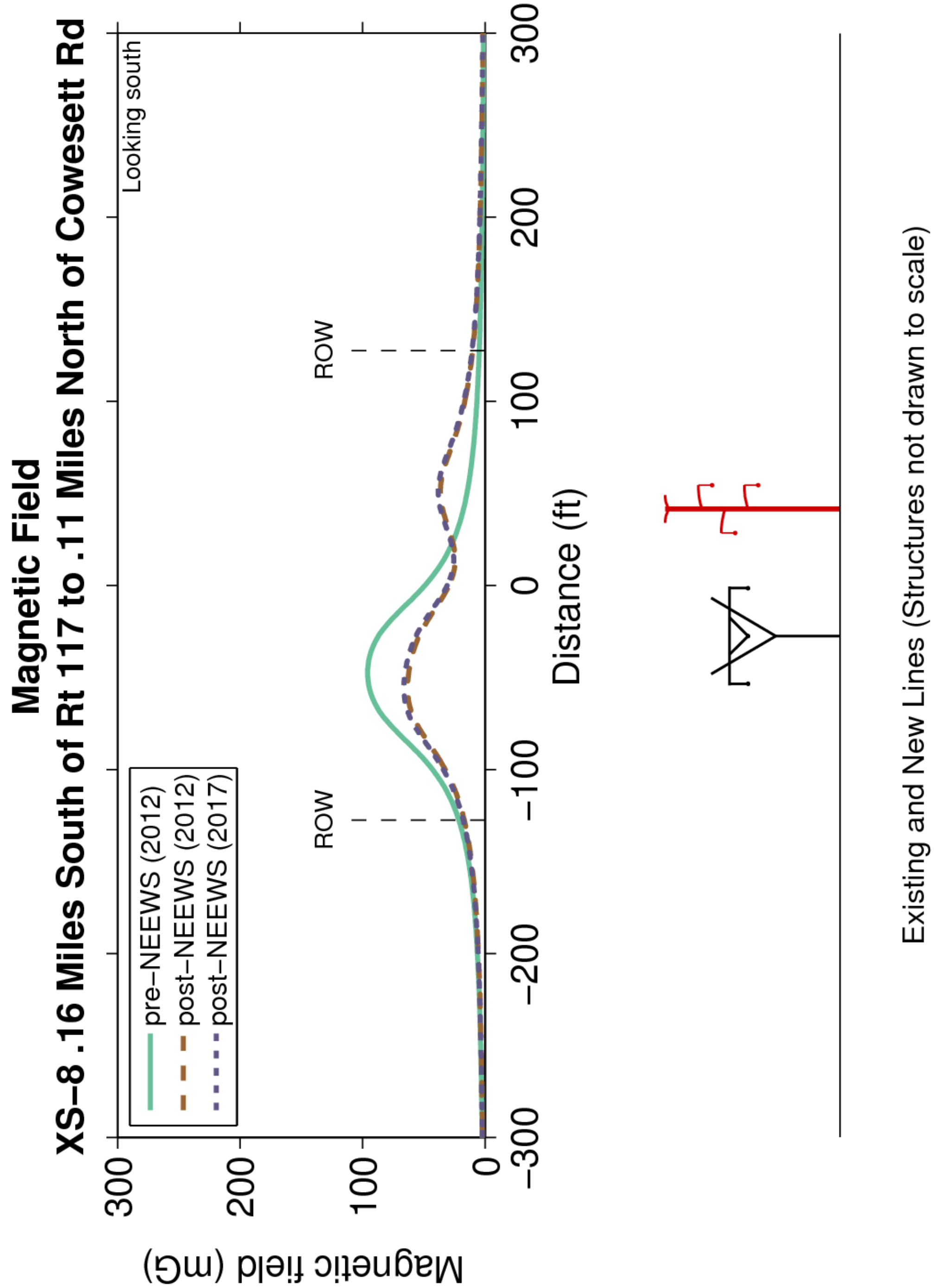

Figure 16. Profile XS-8: 0.16 miles south of Route 117 to 0.11 miles north of Cowesett Rd under pre-NEEWS (2012), post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL (Warwick, RI).

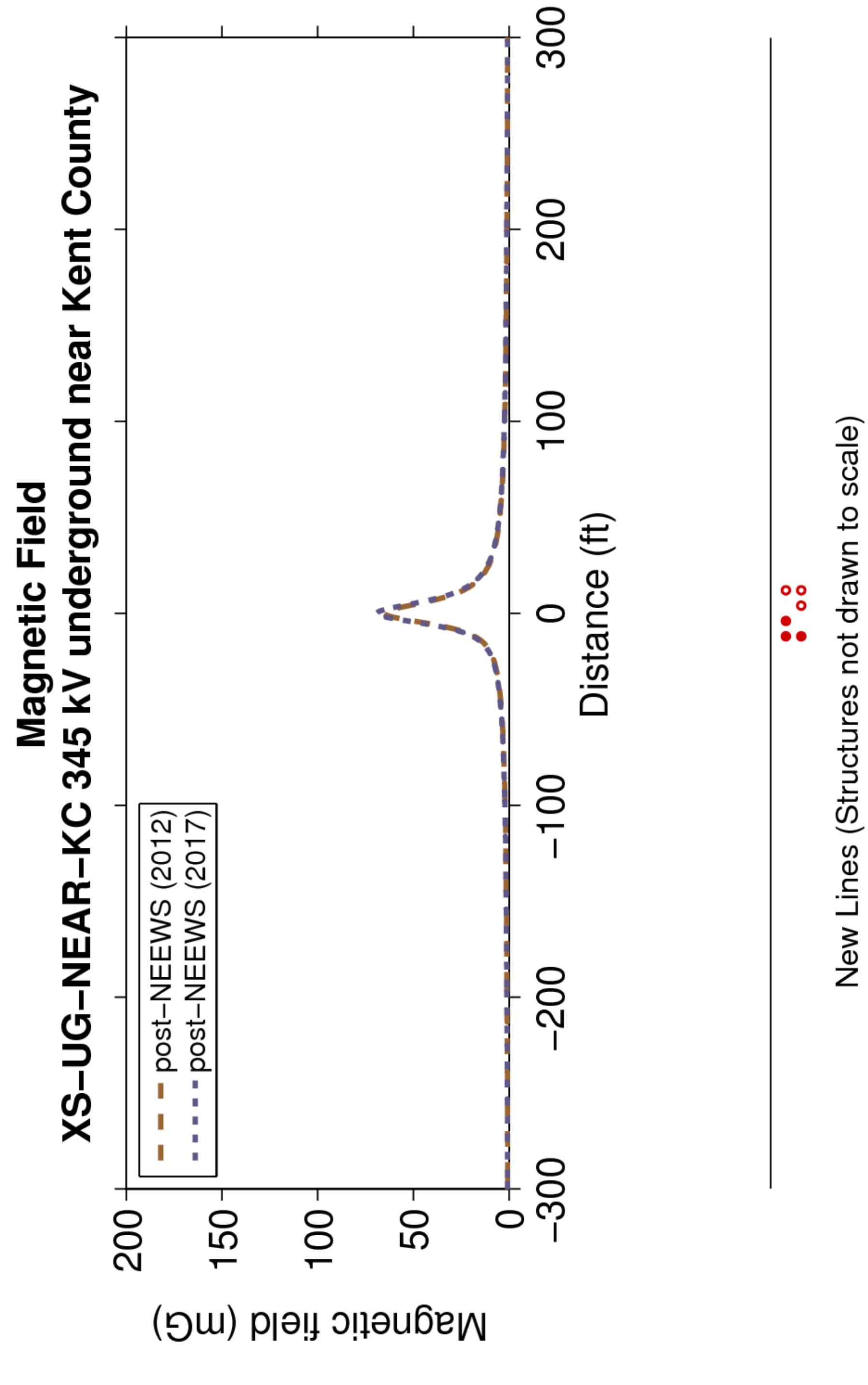

Figure 17. Profile XS-UG-NEAR-KC: 345-kV underground alternative near Kent County under post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL.

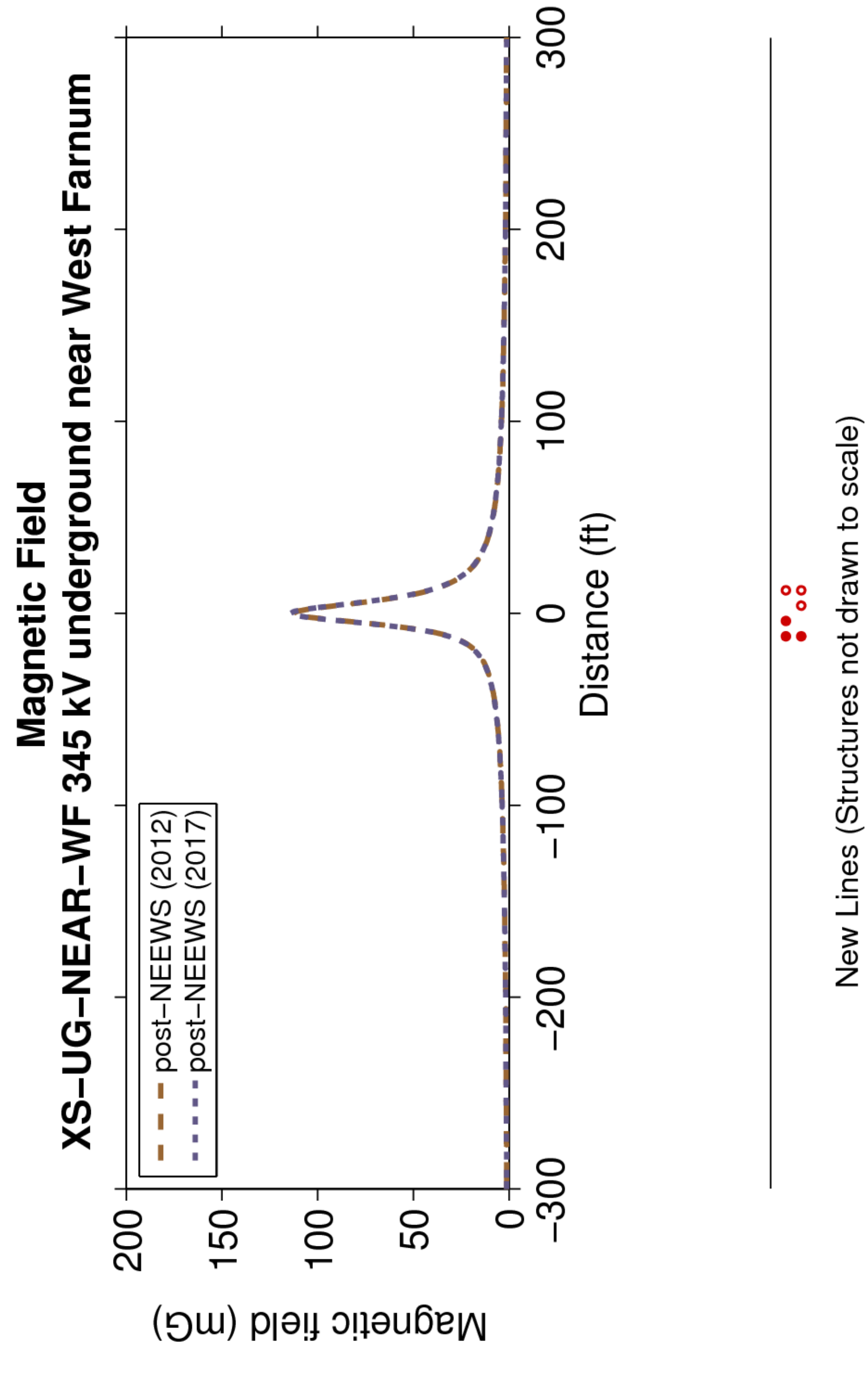

Figure 18. Profile XS-UG-NEAR-WF: 345-kV underground alternative near West Farnum under post-NEEWS (2012), and post-NEEWS (2017) conditions at AAL.

Appendix B. Tables of Audible Noise, Electric and Magnetic Field at Average Annual Loading and Annual Peak Loading

Table 1. Summary of pre-NEEWS (2012), post-NEEWS (2017), and post-NEEWS (2017) magnetic field levels at AAL

Line Section	Configuration	Magnetic field (mG) at location				
		-100 ft beyond ROW* edge	-ROW* edge	Maximum on ROW*	+ROW* edge	+100 ft beyond ROW* edge
XS-1 0.16 Mi South of Rt 104 to Rt 44 (W. Farnum to Farnum Pike)	pre-NEEWS (2012)	2.9	10.5	93.2	26.7	5.3
	post-NEEWS (2012)	2.9	8.5	71.1	21.0	4.5
	post-NEEWS (2017)	3.0	9.3	74.6	22.0	4.7
XS-2 0.16 Mi South of Rt 104 to Rt 44 (Wolf Hill to Putnam Pike)	pre-NEEWS (2012)	2.1	6.2	95.9	25.7	4.9
	post-NEEWS (2012)	2.7	8.6	70.2	20.5	4.4
	post-NEEWS (2017)	2.8	9.5	73.7	21.6	4.6
XS-3 Rt 5 to Hartford Ave Sub	pre-NEEWS (2012)	2.0	10.8	96.9	25.4	4.7
	post-NEEWS (2012)	3.5	19.7	69.3	20.5	4.4
	post-NEEWS (2017)	3.6	20.2	72.8	21.5	4.6
XS-4 .60 Mi North of Phenix Avenue to .13 Mi North of Providence Street	pre-NEEWS (2012)	0.7	21.9	115.9	26.9	5.1
	post-NEEWS (2012)	3.4	20.8	70.1	20.9	4.5
	post-NEEWS (2017)	3.6	21.8	73.6	21.9	4.7
XS-5 .13 Miles North of Providence Street to Providence Street	pre-NEEWS (2012)	2.3	6.6	100.6	47.9	7.3
	post-NEEWS (2012)	3.7	25.8	51.0	33.2	4.4
	post-NEEWS (2017)	4.0	27.8	54.3	34.7	4.6
XS-6 New London Avenue to Bald Hill Road	pre-NEEWS (2012)	1.2	10.8	115.3	27.1	5.3
	post-NEEWS (2012)	5.2	37.0	69.5	21.1	4.6
	post-NEEWS (2017)	5.5	39.4	72.9	22.1	4.8
XS-7 Bald Hill Road to 0.10 Miles North of Rt 117	pre-NEEWS (2012)	1.0	2.5	116.3	27.1	5.3
	post-NEEWS (2012)	3.0	10.9	69.1	20.7	4.4
	post-NEEWS (2017)	3.2	11.6	72.4	21.7	4.7
XS-8 .16 Miles South of Rt 117 to .11 Miles North of Cowesett Rd	pre-NEEWS (2012)	4.5	21.3	95.8	4.7	1.9
	post-NEEWS (2012)	4.0	17.0	63.2	10.1	3.1
	post-NEEWS (2017)	4.2	17.8	66.2	10.6	3.2
XS-UG-NEAR-WF 345 kV underground near West Farnum	post-NEEWS (2012)	2.9	13.5	112.7	18.4	3.2
	post-NEEWS (2017)	2.9	13.7	114.2	18.6	3.2
XS-UG-NEAR-KC 345 kV underground near Kent County	post-NEEWS (2012)	1.7	7.8	65.3	10.7	1.8
	post-NEEWS (2017)	1.8	8.3	69.2	11.3	1.9

* For underground calculations, ± ROW denotes ± 25 ft.

Table 2. Summary of pre-NEEWS (2012), post-NEEWS (2017), and post-NEEWS (2017) magnetic field levels at APL

Line Section	Configuration	Magnetic field (mG) at location				
		-100 ft beyond ROW* edge	-ROW* edge	Maximum on ROW*	+ROW* edge	+100 ft beyond ROW* edge
XS-1 0.16 Mi South of Rt 104 to Rt 44 (W. Farnum to Farnum Pike)	pre-NEEWS (2012)	1.6	7.1	130.2	34.0	6.2
	post-NEEWS (2012)	3.9	19.7	85.5	24.8	5.3
	post-NEEWS (2017)	3.9	14.7	97.7	28.6	6.1
XS-2 0.16 Mi South of Rt 104 to Rt 44 (Wolf Hill to Putnam Pike)	pre-NEEWS (2012)	0.8	12.3	136.0	32.4	5.5
	post-NEEWS (2012)	5.1	29.4	84.5	24.2	5.3
	post-NEEWS (2017)	4.7	24.1	96.6	27.9	6.0
XS-3 Rt 5 to Hartford Ave Sub	pre-NEEWS (2012)	1.1	14.8	138.7	31.8	5.2
	post-NEEWS (2012)	6.0	36.4	89.6	24.0	5.3
	post-NEEWS (2017)	5.7	33.5	95.4	27.6	6.0
XS-4 .60 Mi North of Phenix Avenue to .13 Mi North of Providence Street	pre-NEEWS (2012)	1.7	45.6	228.1	36.9	7.1
	post-NEEWS (2012)	4.7	37.8	91.7	25.4	5.5
	post-NEEWS (2017)	5.2	38.8	96.9	28.9	6.2
XS-5 .13 Miles North of Providence Street to Providence Street	pre-NEEWS (2012)	3.6	12.2	194.9	65.0	10.3
	post-NEEWS (2012)	4.0	24.8	55.3	39.4	5.4
	post-NEEWS (2017)	4.4	26.2	57.9	44.9	6.1
XS-6 New London Avenue to Bald Hill Road	pre-NEEWS (2012)	0.9	30.0	227.5	37.1	7.2
	post-NEEWS (2012)	5.7	35.7	84.2	25.5	5.6
	post-NEEWS (2017)	6.2	36.1	96.0	29.0	6.3
XS-7 Bald Hill Road to 0.10 Miles North of Rt 117	pre-NEEWS (2012)	0.5	4.1	228.5	37.1	7.2
	post-NEEWS (2012)	3.3	11.7	83.6	25.1	5.4
	post-NEEWS (2017)	3.7	12.5	95.4	28.5	6.1
XS-8 .16 Miles South of Rt 117 to .11 Miles North of Cowesett Rd	pre-NEEWS (2012)	6.0	28.7	128.6	6.3	2.6
	post-NEEWS (2012)	4.9	20.8	77.4	12.4	3.8
	post-NEEWS (2017)	5.5	23.6	88.0	14.1	4.3
XS-UG-NEAR-WF 345 kV underground near West Farnum	post-NEEWS (2012)	3.0	13.9	116.3	19.0	3.3
	post-NEEWS (2017)	3.2	14.8	123.7	20.2	3.5
XS-UG-NEAR-KC 345 kV underground near Kent County	post-NEEWS (2012)	2.2	10.2	85.4	13.9	2.4
	post-NEEWS (2017)	2.5	11.7	98.0	16.0	2.8

*For underground calculations, ± ROW denotes ± 25 ft.

Table 3. Summary of pre-NEEWS (2012), post-NEEWS (2017), and post-NEEWS (2017) electric field levels.

Line Section	Configuration	Electric field (kV/m) at location				
		-100 ft beyond ROW edge	-ROW edge	Maximum on ROW	+ROW edge	+100 ft beyond ROW edge
XS-1 0.16 Mi South of Rt 104 to Rt 44 (W. Farnum to Farnum Pike)	pre-NEEWS (2012)	0.06	0.65	4.88	1.79	0.18
	post-NEEWS (2012)	0.09	0.24	5.02	1.93	0.25
	post-NEEWS (2017)	0.09	0.24	5.02	1.93	0.25
XS-2 0.16 Mi South of Rt 104 to Rt 44 (Wolf Hill to Putnam Pike)	pre-NEEWS (2012)	0.06	0.65	4.88	1.79	0.18
	post-NEEWS (2012)	0.09	0.24	5.02	1.93	0.25
	post-NEEWS (2017)	0.09	0.24	5.02	1.93	0.25
XS-3 Rt 5 to Hartford Ave Sub	pre-NEEWS (2012)	0.04	0.28	4.88	1.79	0.18
	post-NEEWS (2012)	0.09	0.07	5.02	1.93	0.25
	post-NEEWS (2017)	0.09	0.07	5.02	1.93	0.25
XS-4 .60 Mi North of Phenix Avenue to .13 Mi North of Providence Street	pre-NEEWS (2012)	0.03	0.56	4.94	1.81	0.18
	post-NEEWS (2012)	0.06	0.36	5.02	1.92	0.24
	post-NEEWS (2017)	0.06	0.36	5.02	1.92	0.24
XS-5 .13 Miles North of Providence Street to Providence Street	pre-NEEWS (2012)	0.03	0.05	4.49	3.84	0.30
	post-NEEWS (2012)	0.03	0.12	4.27	3.80	0.30
	post-NEEWS (2017)	0.03	0.12	4.27	3.80	0.30
XS-6 New London Avenue to Bald Hill Road	pre-NEEWS (2012)	0.02	0.34	4.94	1.81	0.18
	post-NEEWS (2012)	0.06	0.27	5.02	1.92	0.24
	post-NEEWS (2017)	0.06	0.27	5.02	1.92	0.24
XS-7 Bald Hill Road to 0.10 Miles North of Rt 117	pre-NEEWS (2012)	0.01	0.07	4.94	1.81	0.18
	post-NEEWS (2012)	0.05	0.11	5.02	1.93	0.25
	post-NEEWS (2017)	0.05	0.11	5.02	1.93	0.25
XS-8 .16 Miles South of Rt 117 to .11 Miles North of Cowesett Rd	pre-NEEWS (2012)	0.13	1.31	4.77	0.15	0.04
	post-NEEWS (2012)	0.15	1.36	4.83	0.63	0.14
	post-NEEWS (2017)	0.15	1.36	4.83	0.63	0.14

Table 4. Summary of pre-NEEWS (2012), post-NEEWS (2017), and post-NEEWS (2017) audible noise levels.

		Audible Noise (dBA)			
		Fair Weather		Foul Weather	
Line Section	Configuration	-ROW edge	+ROW edge	-ROW edge	+ROW edge
XS-1 0.16 Mi South of Rt 104 to Rt 44 (W. Farnum to Farnum Pike)	pre-NEEWS (2012)	16.2	20.4	41.2	45.4
	post-NEEWS (2012)	21.7	23.2	46.7	48.2
	post-NEEWS (2017)	21.7	23.2	46.7	48.2
XS-2 0.16 Mi South of Rt 104 to Rt 44 (Wolf Hill to Putnam Pike)	pre-NEEWS (2012)	16.2	20.4	41.2	45.4
	post-NEEWS (2012)	21.7	23.2	46.7	48.2
	post-NEEWS (2017)	21.7	23.2	46.7	48.2
XS-3 Rt 5 to Hartford Ave Sub	pre-NEEWS (2012)	16.2	20.4	41.2	45.4
	post-NEEWS (2012)	21.7	23.2	46.7	48.2
	post-NEEWS (2017)	21.7	23.2	46.7	48.2
XS-4 .60 Mi North of Phenix Avenue to .13 Mi North of Providence Street	pre-NEEWS (2012)	16.5	20.6	41.5	45.6
	post-NEEWS (2012)	21.7	23.3	46.7	48.3
	post-NEEWS (2017)	21.7	23.3	46.7	48.3
XS-5 .13 Miles North of Providence Street to Providence Street	pre-NEEWS (2012)	18.9	24.6	43.9	49.6
	post-NEEWS (2012)	24.1	27.5	49.1	52.5
	post-NEEWS (2017)	24.1	27.5	49.1	52.5
XS-6 New London Avenue to Bald Hill Road	pre-NEEWS (2012)	16.5	20.6	41.5	45.6
	post-NEEWS (2012)	21.7	23.3	46.7	48.3
	post-NEEWS (2017)	21.7	23.3	46.7	48.3
XS-7 Bald Hill Road to 0.10 Miles North of Rt 117	pre-NEEWS (2012)	15.2	20.6	40.2	45.6
	post-NEEWS (2012)	20.9	23.5	45.9	48.5
	post-NEEWS (2017)	20.9	23.5	45.9	48.5
XS-8 .16 Miles South of Rt 117 to .11 Miles North of Cowesett Rd	pre-NEEWS (2012)	19.9	16.1	44.9	41.1
	post-NEEWS (2012)	21.9	21.9	46.9	46.9
	post-NEEWS (2017)	21.9	21.9	46.9	46.9

Appendix C. Phase Optimization Plots

Phase optimization calculations were carried out on several cross sections spanning from West Farnum to Kent County for AAL conditions in 2017. The following plots in Figures 19 to 21 graphically compare the magnetic field at the edge of the ROW for particular phase configurations.

The higher of the magnetic field values at the edge of the ROW is plotted on the vertical, y-axis for all possible phase configurations of the new or reconfigured circuits. Cross-sections that shared similar geometry and that contained circuits that, when constructed, would retain identical phasing between cross-sections, were processed together. The upper horizontal axis of each plot shows the specific phase configuration that was considered. The phasing is given from left to right (in the case of horizontal circuits) and from top to bottom (in the case of vertical circuits) as shown in the corresponding cross-section diagram. The results were sorted so that the configuration that yielded the lowest magnetic fields averaged over the cross-sections is ranked 1 and is positioned on the extreme left. The line identified as ‘average’ signifies the average magnetic field at the edge of the ROW for the plotted circuits. The numerical rankings of the phase configurations are listed on the horizontal, x-axis at the bottom of the figure.

The “proposed construction phasing” in the upper left legend of each plot was the phase configuration that was selected by National Grid because it achieved the lowest average magnetic field for constructible phase configurations. Note that the extent by which an optimal phase configuration could be chosen was constrained by the constructability of only two possible choices for the phase of circuit 359, namely ACB or BCA (from top to bottom).

The following figures show the phase optimization plots for calculations performed collectively on:

- XS-1, XS-2, and XS-3, where the phase of circuits 359, T172N, and S171N were altered;
- XS-4, XS-5, XS-6, and XS-7, where the phase of circuits 359, T172S, and S171S were altered; and

- XS-8 where the phase of 332 was altered.

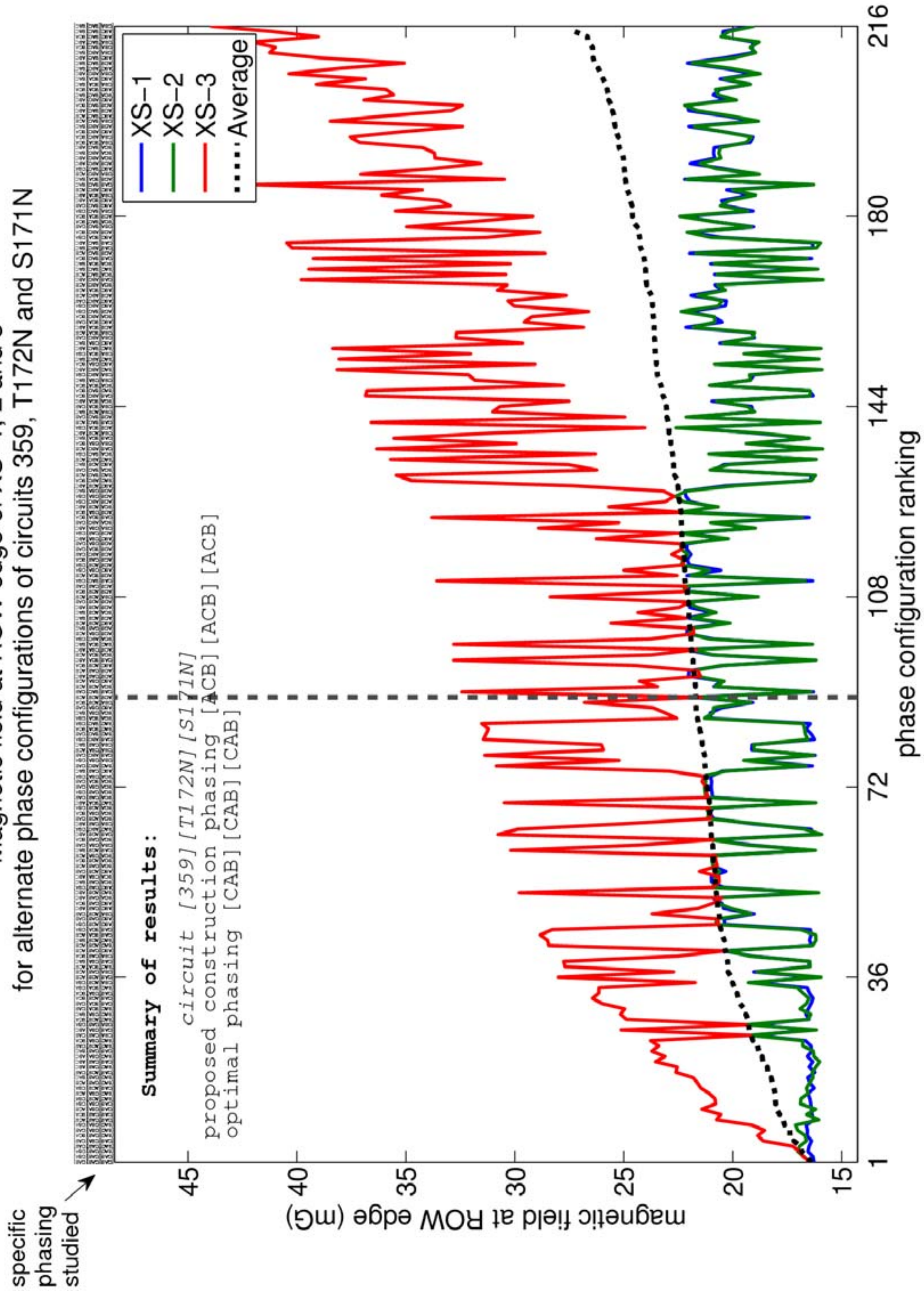

Figure 19. Phase optimization plots for XS-1, XS-2, and XS-3 at AAL (2017). All phase configurations of circuit 359, T172N, and S171N were analyzed.

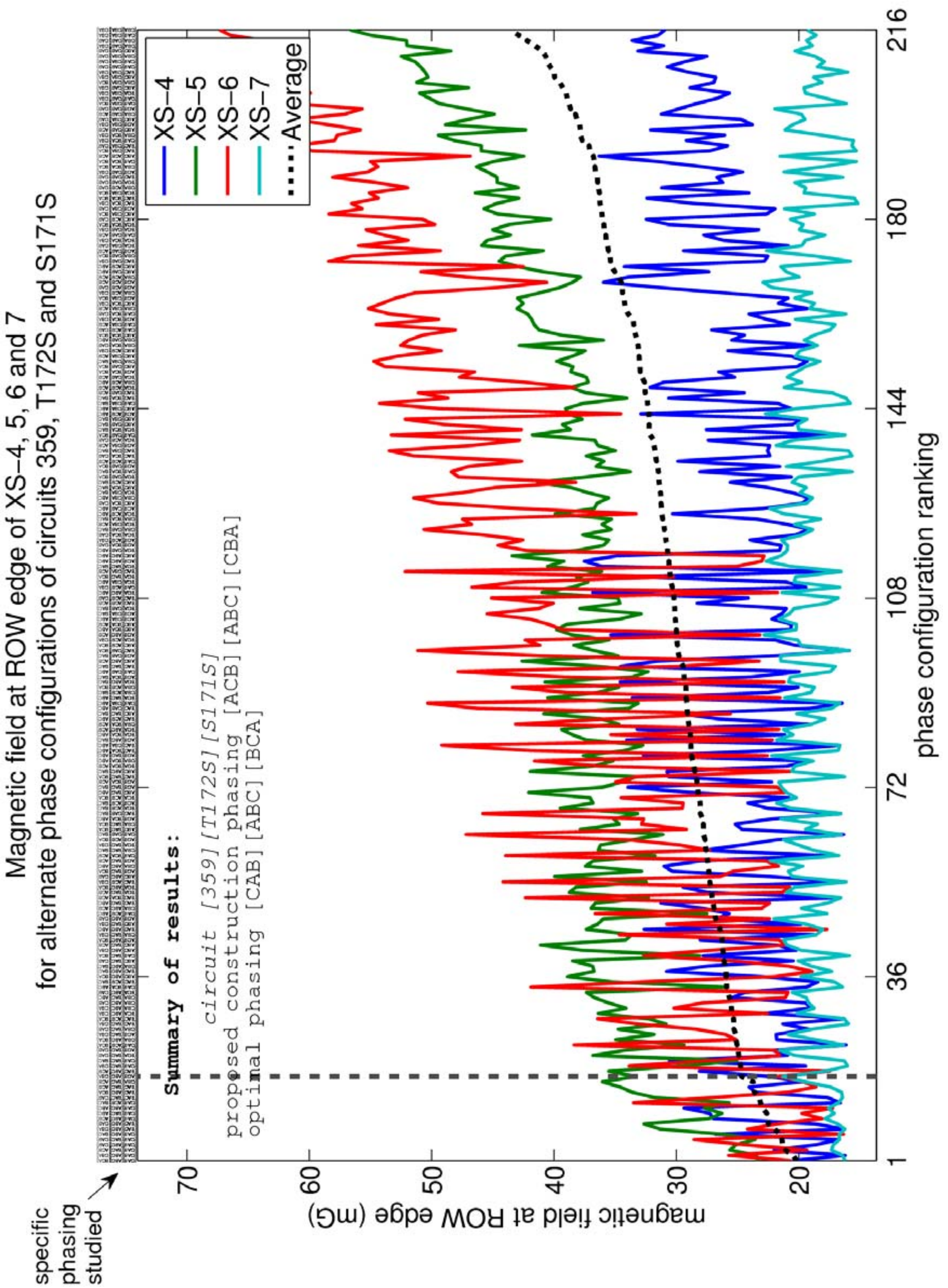

Figure 20. Phase optimization plots for XS-4, XS-5, XS-6, and XS-7 at AAL (2017). All phase configurations of circuit 359, T172S, and S171S were analyzed.

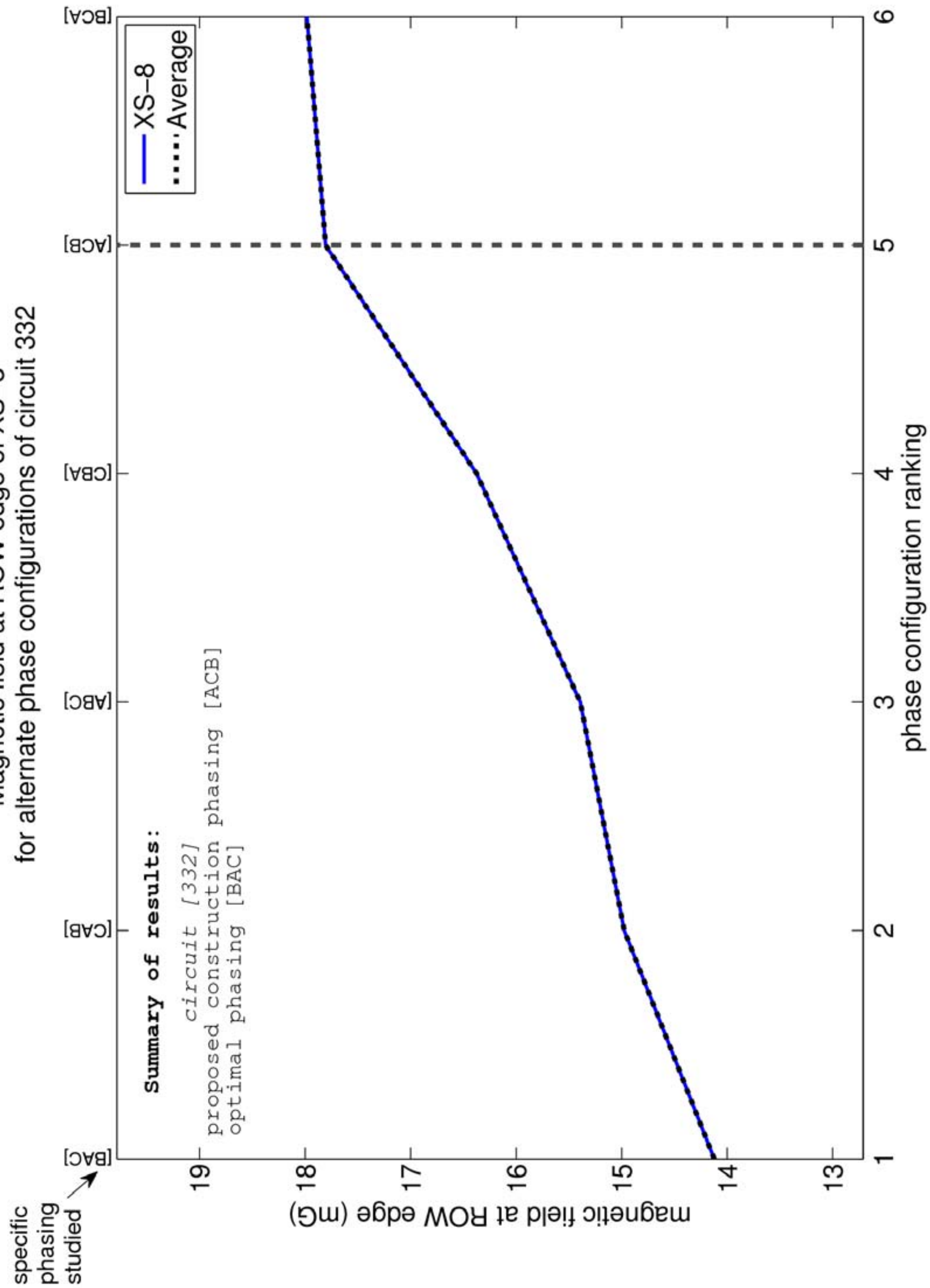

Figure 21. Phase optimization plots for XS-8 at AAL (2017). All phase configurations of circuit 332 were analyzed.