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A Comparison of Measurement Techniques to Determine Electric Fields and Magnetic Flux Under EHV Overhead Power Transmission Lines

Technical Note
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A COMPARISON OF MEASUREMENT TECHNIQUES TO DETERMINE ELECTRIC FIELDS AND MAGNETIC FLUX UNDER EHV OVERHEAD POWER TRANSMISSION LINES

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March 1978

OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report examines magnetic field strengths and compares electric field strength measurement techniques under extra-high-voltage overhead power transmission lines. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

Floyd L. Galpin

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The author is grateful to Messrs. Edwin Mantiply and Patrick J. O'Brien for their assistance in making measurements under Maryland's hot summer skies. The efforts of Sandi Graves in helping type and ready this report for publication in this decade are also greatly appreciated.

INTRODUCTION

This report examines the maximum magnetic field strengths associated with normal procedure electric field strength measurement techniques under a 500 kV overhead power transmission line. Additionally, comparisons are made between U.S. techniques and a technique reportedly used in the USSR for measuring electric fields under EHV overhead transmission lines. Information received subsequent to this study indicates that the supposed Russian technique was not used, having been found to produce noticeable errors.

SITE DESCRIPTION

The measurement site was located in Frederick County, Maryland, about three miles south of Buckeystown on a farm belonging to Mr. Eugene Mills. The line under which the measurements were made was the Potomac Edison Company 510kV Doubs Conastone Line. The line was a single three-phase circuit with each bundle consisting of two conductors of 1.8 inch diameter spaced 18 inches apart and oriented horizontally, each bundle being spaced 35 feet apart. An open, unused hay field was selected between two support towers that was flat and free from vegetative or geographic anomalies. Short hay stubble and new weed growth varied in height from about 6 inches to about 18 inches. On the days the measurements were taken, July 27 and 28, 1976, the weather was hot and very humid with temperatures in the high 80's and humidity approaching 100 percent.

A Ranging, Inc. Model M100 optical tape measure rangefinder was used to optically determine line heights. Ten readings were made before and after data was collected. The average height after correction of meter error and inclusion of head height above ground was 46.3 feet.

INSTRUMENTATION

Two instruments were used to measure electric field strengths, one of which was also capable of measuring magnetic flux. Primary electric field strength and magnetic flux measurements were made using a Polytech Model FBM-100 field meter. This instrument is capable of measuring electric field strengths ranging from about 0.1 V/m to 3MV/m. It is also equipped with an adapter box and auxiliary probes which allow measurement of magnetic flux (.0001 to 300 gauss), space potential, short circuit current, and open circuit voltage.

Supplemental electric field strength measurements were made using a Monroe Electronics Model 238A-1 field meter. This instrument has been fully described in a previous report.[1]

PROCEDURES

ELECTRIC AC FIELD STRENGTH MEASUREMENTS

The measurement procedure was that described in an earlier report.[1] A 200 foot profile line, perpendicular to the center phase of the transmission line at its minimum height above ground, was established using a non-metallic 100 foot tape measure. The observer-meteraxis was perpendicular to the transmission line, with the observer's back toward the line. Measurements were made employing three different geometries with each of the two instruments. The first geometry was that normally used in this country, holding the instrument at one meter above ground level and at least one meter from the observer (two meters from the observer when using the Polytech FBM-100). The second method was one reportedly employed in the U.S.S.R. (later evidence indicated this not to be true), holding the meter as if attached to an 11 inch handle at 1.8 meters above ground level. A third geometry was chosen, holding the meter 1.8 meters above ground, but using the long handle technique employed in the first geometry. A few comparative measurements were made using a fourth geometry, holding the meter as if on an 11 inch handle, at one meter above ground.

The first two geometries were of primary interest, in effect comparing U.S. and assumed U.S.S.R. techniques. Therefore, measurements were made at three foot intervals when using the Polytech instrument. Nine foot intervals were used for the third geometry and when using the Monroe meter, since fewer measurement points were required for comparisons. Only a few measurements were made employing the fourth technique at random distances.

In all cases, care was taken to maintain the same geometry at each measurement site. Only one individual made all measurements as it had been previously determined that different persons caused significantly different meter readings for a given measurement site and geometry. Each instrument was held at the maximum practical distance from the body for each defined handle length. Instrument handles were marked so they would be held at the same points each time a measurement was made.

MAGNETIC FLUX MEASUREMENTS

Since magnetic flux measurements are not significantly influenced by the presence of an observer, only two geometries were used: one placing the sensing coil at one meter above ground, the other, with the coil 1.8 meters above ground. Before making measurements, care was taken to determine the position of the observer and coil relative to the power line which would maximize measured values. It was found that the observer should hold the coil handle parallel to the direction of the power line. Since the magnetic field curves in space, the coil was rotated at each position for a maximum reading. Measurements were taken at three foot intervals for the first one hundred feet and at nine foot intervals thereafter.

RESULTS

ELECTRIC FIELD STRENGTH PROFILES

Figure 1 illustrates the electric field strength profiles for three geometries using the Polytech FBM-100. The solid line curve represents the calculated theoretical profile. As expected, the measurement technique using a short handled instrument at 1.8 meters above ground, produces the highest observed values. This is due to the field focusing effect of the observer.

Figure 2 shows electric field strength profiles measured with the Monroe Electronics Model 238A-1. This meter has been used in previous studies[1] and is used here for comparison with the Polytech instrument. Approximately the same relative deviation is shown between long-handled and short-handled techniques using either instrument. Ratios of electric field strength data were calculated, comparing the short-handled technique (first geometry) with the long-handled technique (second geometry). The Polytech instrument data showed ratios varying from 1.44 to 1.73 (average 1.58). Using the Monroe instrument, the ratio varies from 1.14 to 1.60 (average 1.40). The slight differences between the two meters is probably explained by the necessity of holding the shorter handled Monroe instrument closer to the observer for the long-handled technique measurements. When compared, using identical geometries (1.8 meters above ground with an 11 inch handle), the Monroe and Polytech instruments give essentially the same results.

Louise B. Young, in her report to the EPA,[2] described a similar difference, using a Monroe Model 238A-1. Ms. Young reports observed ratios of 1.5 to 2.0 with an average of 1.6. The slight difference between Ms. Young's ratios and those reported here is probably due to different methods of holding the meter, especially with the more critical 11 inch handle.

The influence of observer position with respect to the instrument is shown by comparing data for the third geometry (long handle at 1.8 meters above ground) with the first geometry (short handle at 1.8 meters above ground). The most pronounced difference occurs when using the Polytech instrument, where the observer stands two meters from the instrument when using the long handle. (It can be seen that the Polytech measured values using the long handle at 1.8 meters above ground actually more closely approach the measurements using the long handle at one meter above ground.) The average ratio between measurements at 1.8 meters above ground and at one meter above ground, using the long handle, is only 1.10. The average ratio using the short handle is 1.58. Therefore, the technique employing a short handle significantly distorts the open field measurement. Comparing the same geometries, but using the Monroe instrument, shows that the shorter four foot handle of the Monroe also causes significant pertubations of the field. The average ratio between long handle techniques at 1.8 meters and at one meter is 1.22, compared to 1.10 for the Polytech.

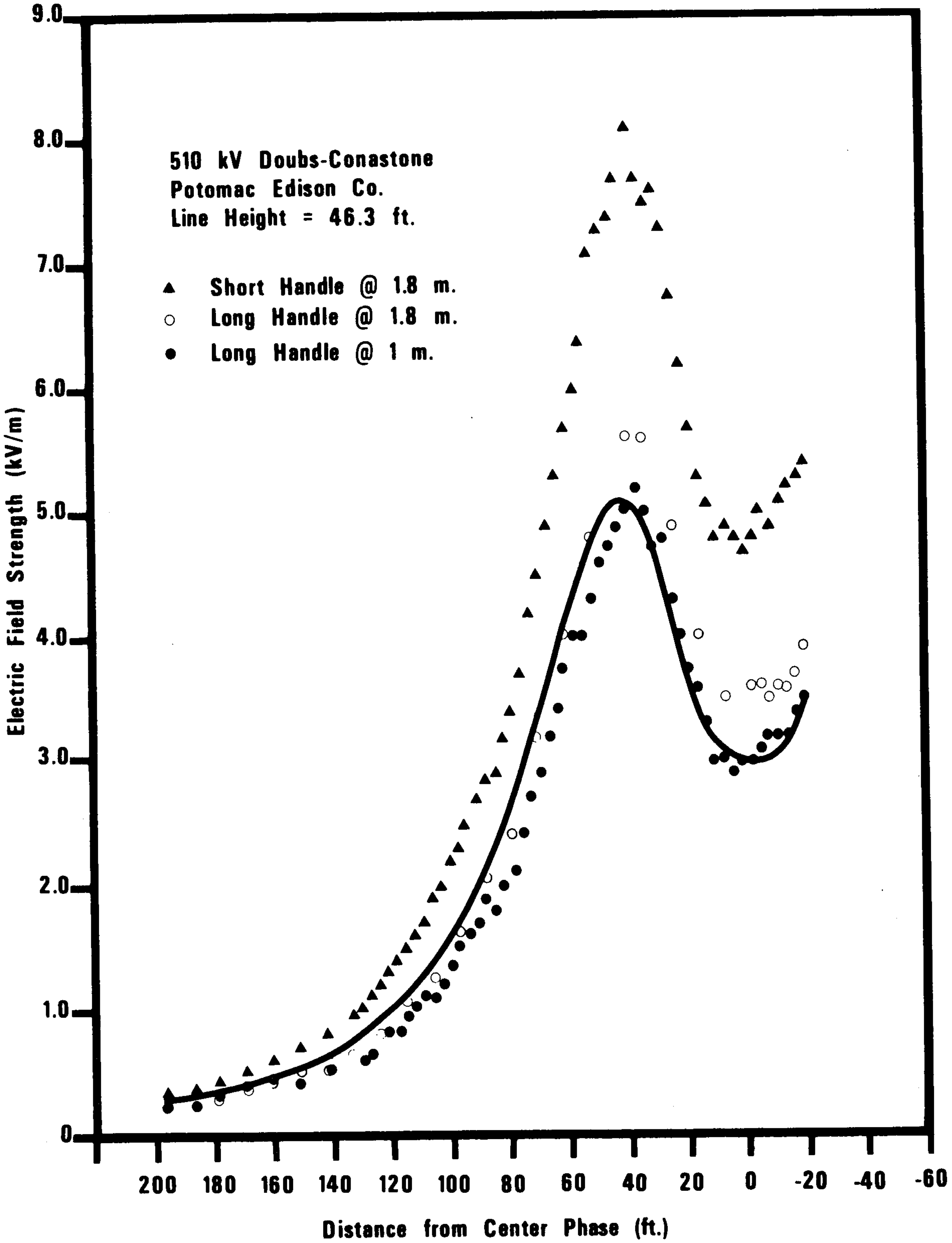

FIGURE 1. ELECTRIC FIELD STRENGTH PROFILES USING A POLYTECH FBM-100

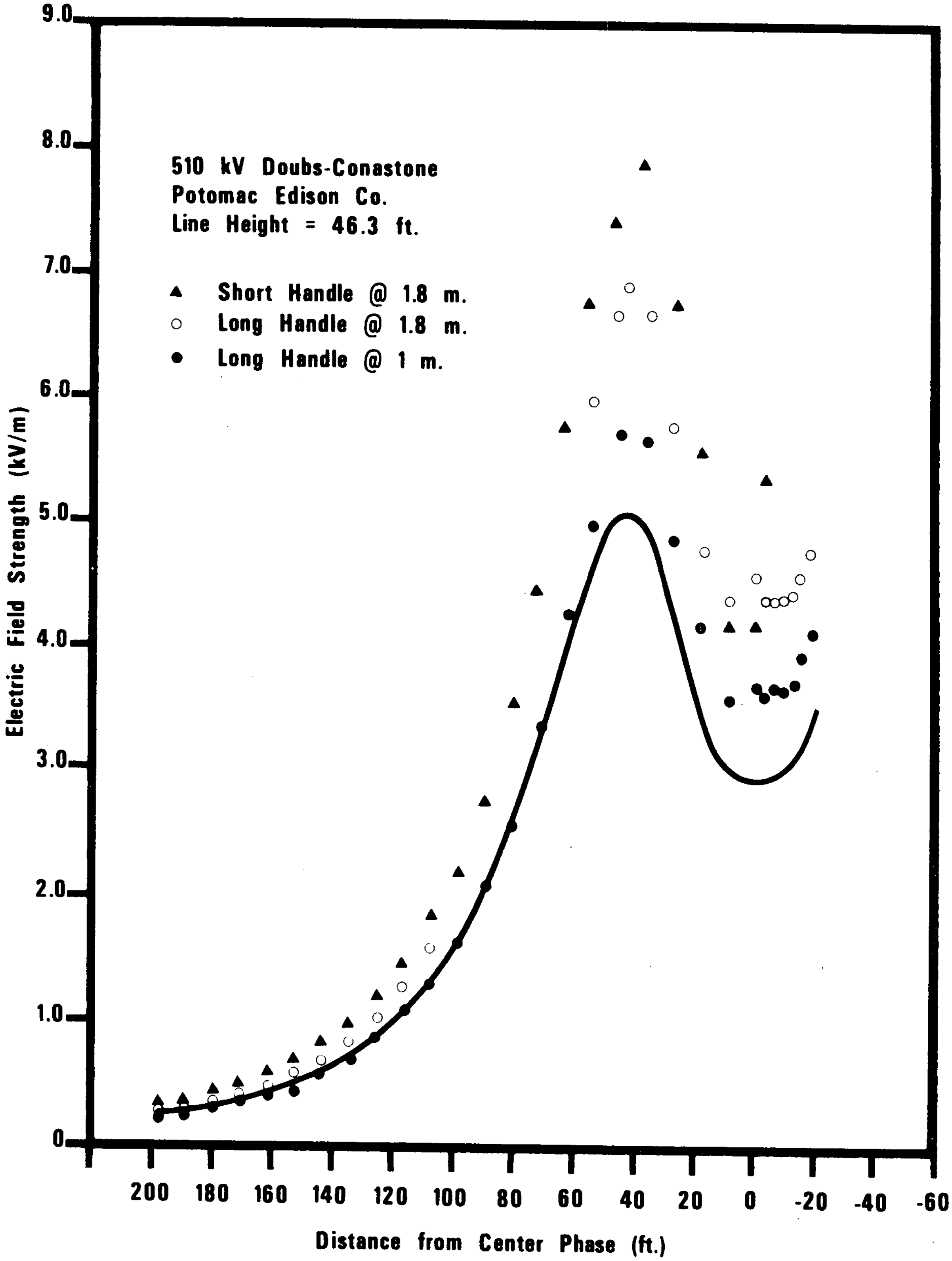

FIGURE 2. ELECTRIC FIELD STRENGTH PROFILES USING A MONROE ELECTRONICS MODEL 238A-1

A few measurements were made using the fourth geometry (an 11 inch handle held at one meter above ground). There was no significant difference between readings made at one meter above ground regardless of effective handle length for either meter. The small differences observed were neither significantly less than nor greater than corresponding reference measurements. Other studies have shown a shielding effect by the observer at this measurement height.

Measurements made at one meter above ground with the Polytech instrument show very good correlation with calculated values, and with values measured in November 1974 at the same location. The Monroe meter showed some deviation from calculated values and previously measured values, especially in the higher electric fields. This may have been due to slightly different measurement techniques than those used in previous studies by different observers.

MAGNETIC FLUX PROFILES

Figure 3 shows magnetic flux profiles measured with the Polytech Model FBM-100 with the sensing coil held at one meter and at 1.8 meters above ground. The two techniques produce virtually identical measured values at distances greater than 100 feet from the center phase. Over the first 100 feet, the average ratio between measurements at 1.8 meters and at 1.0 meter is only 1.07 and does not exceed 1.09. The magnetic flux values range from 0.006 gauss at 198 feet to 0.097 gauss near the center phase. A broad peak averaging about 0.09 gauss extends over the area covered by the three phases. The sharp, well defined peaks occurring for the electric field measurements are not observed here. The angle of the coil axis with respect to ground varies from 0° (coil parallel to ground) to 90° at 50 feet from the center phase, and 160° at 200 feet from the center phase. The change in angle is uniform and gradual as distance increases.

On the second day of measurements, a significant anomaly occurred (see Table 1). Measurements on that day were consistently higher by a factor of 1.35 (35 percent) than those taken on the previous day. This difference could not be adequately accounted for. The line current increased by only five percent. The meter functions were operating correctly with no change in readings due to range switching. Also, geometries were carefully duplicated. Further study is needed to define the cause of this anomaly.

SUMMARY AND CONCLUSIONS

A study was made of electric field strengths and magnetic flux under a 510 kV overhead power transmission line. Electric field strength measurements were made using two instruments and three geometries, with brief reference to a fourth geometry. Magnetic flux measurements were made with one instrument, using two geometries.

The two meters, Monroe Electronics Model 238A-1 and Polytech Model FBM-100, were found to give essentially identical responses when used with handles of equal length.

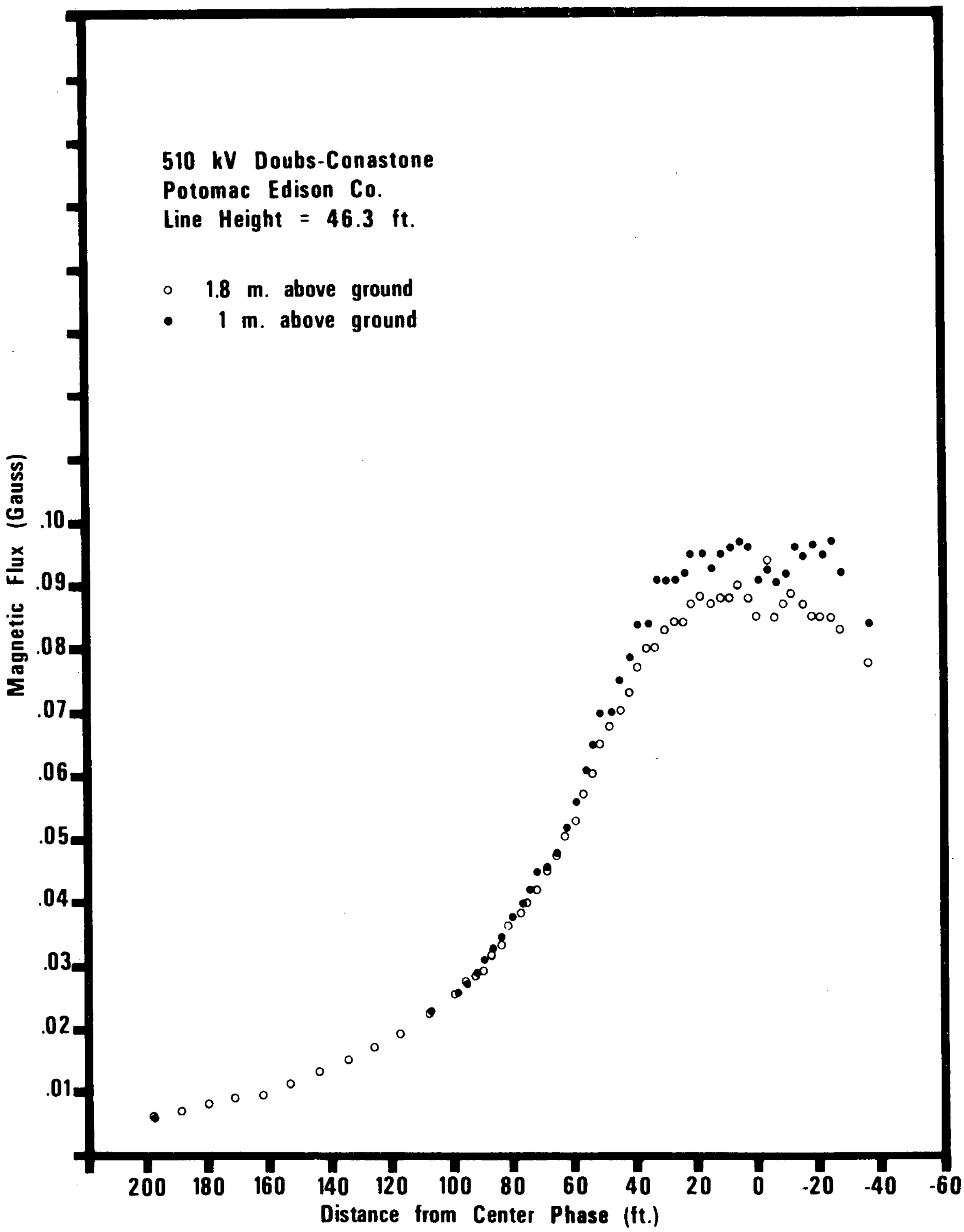

FIGURE 3. MAGNETIC FLUX PROFILE

TABLE 1

OBSERVED DIFFERENCES IN LINE CURRENT

AND MAGENTIC FLUX MEASUREMENTS

	DATE		RATIO
	7/27	7/28	Day 1/Day 2
Voltage (kV)	510	510	
Current in Each Phase (Amps)	567	595	1.05
Magnetic Flux 6 Feet From Center Phase (Typical)	.085	.115	1.35

Until recently, some observers in the U.S.S.R. reportedly used techniques for making electric field measurements under powerlines which differed in geometry from those used in the U.S. Using the same instrument, measurements with the assumed Soviet technique result in values about 1.4-1.6 times higher than those using the U.S. technique. These observations agree with those reported by Louise B. Young.[2] Di Placido et al.,[3] have recently provided theoretical results for various measurement techniques, emphasizing the short handle method, which are in close agreement with the experimental observations discussed here.[3] Information received after this report was written indicates that the short-handle technique is not used in the U.S.S.R.

The major observed difference in measured values, when using differing geometries, occurs at 1.8 meters above ground level. The closer the observer is to the instrument, the higher the electric field strength. Measurements made at one meter above ground level are not as critically affected by position of the observer with respect to the measuring device.

Holding the instrument at least two meters from the observer minimizes variations in measured values due to changes in height of the instrument above ground level. Measurements made at one meter and at 1.8 meters above ground level are essentially the same if an effective two meter handle is used.

Magnetic flux measurements are not significantly affected by position of the observer with respect to the sensing coil. The magnetic flux increases by a factor of 1.09 or less in the area directly under the three phases of the transmission line when the coil is elevated from one meter to 1.8 meters above ground level. Magnetic flux measurements are significantly affected by angular orientation of the coil. They are also affected by changes in current flow through the transmission lines; further studies should be made to determine the relationship between magnetic flux and current flow.

REFERENCES

1. R. A. Tell et al., "An Examination of Electric Fields Under EHV Overhead Power Transmission Lines," EPA-52012-76-008, United States Environmental Protection Agency, April 1977.

2. L. B. Young, Report to the United States Environmental Protection Agency on Effects of Extremely High Voltage Transmission, received July 1, 1975.

3. J. Di Placido, C. H. Smith and B. J. Ware, "Analysis of the Proximity Effects in Electric Field Measurements," American Electric Power Service Corporation, New York, NY, presented at the 1978 IEEE Power Engineering Society Winter meeting.

APPENDIX

ELECTRIC FIELD STRENGTH AND MAGNETIC FLUX MEASUREMENTS.

Distance From Center Phase (Ft.)	ELECTRIC FIELD STRENGTH (kV/m) — MONROE ELECTRONICS MODEL 1238A-1				ELECTRIC FIELD STRENGTH (kV/m) — POLYTECH MODEL FBM-100				MAGNETIC FLUX (GAUSS) — POLYTECH MODEL FBM-100		
	Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	1 Meter Above Ground	1.8 Meters Above Ground	Angle Of Probe
-36									.078	.084	70°
-27									.083	.092	
-24									.085	.097	
-21									.085	.095	
-18	4.15	4.8			3.5	3.9		5.4	.085	.096	
-15	3.95	4.6			3.4	3.7		5.3	.087	.095	
-12	3.75	4.4			3.2	3.6		5.25	.089	.096	
-9	3.7	4.4			3.2	3.6		5.1	.087	.092	
-6	3.7	4.4			3.2	3.5		4.9	.085	.091	
-3	3.65	4.4		5.4	3.1	3.6	3.3	5.0	.094	.093	
0	3.7	4.6		4.2	3.0	3.6		4.8	.085	.091	0°
3					3.0			4.7	.088	.096	
6					2.9			4.8	.090	.097	
9	3.6	4.4		4.2	3.0	3.5		4.9	.088	.096	
12					3.0			4.8	.088	.095	
15					3.3			5.1	.087	.093	
18	4.2	4.8		5.6	3.6	4.0		5.4	.088	.095	
21					3.75			5.7	.087	.095	45°
24					4.0			6.2	.084	.092	
27	4.9	5.8		6.8	4.3	4.9		6.75	.084	.091	
30					4.8			7.3	.083	.091	

Distance From Center Phase (Ft.)	ELECTRIC FIELD STRENGTH (kV/m) — MONROE ELECTRONICS MODEL 1238A-1: Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	POLYTECH MODEL FBM-100: Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	MAGNETIC FLUX (GAUSS) — POLYTECH MODEL FBM-100: 1 Meter Above Ground	1.8 Meters Above Ground	Angle Of Probe
33					4.7			7.6	.080	.091	60°
36	5.7	6.7		7.9	5.0	5.6		7.5	.080	.084	
39					5.2			7.7	.077	.084	
42		6.9			5.0	5.6		8.1	.073	.079	
45	5.7	6.7		7.7	4.9			7.7	.071	.075	
48					4.75			7.4	.068	.070	90°
51					4.6			7.3	.065	.070	
54	5.0	6.0		6.8	4.3	4.8		7.1	.060	.065	
57					4.0			6.4	.057	.061	
60					4.0			6.0	.053	.056	
63	4.3			5.8	3.75	4.0		5.7	.050	.052	
66					3.4			5.3	.047	.048	105°
69					3.2			4.9	.045	.046	
72	3.4			4.5	2.9	3.2		4.5	.042	.045	
75					2.7			4.2	.040	.042	
78					2.4			3.7	.038	.040	
81	2.6			3.6	2.1	2.4		3.4	.036	.038	
84					2.0			3.2	.033	.035	
87					1.8			2.9	.032	.033	120°
90	2.1			2.8	1.9	2.05		2.85	.029	.031	
93					1.7			2.7	.028	.029	
96					1.6			2.5	.027	.027	

Distance From Center Phase (Ft.)	ELECTRIC FIELD STRENGTH (kV/m) — MONROE ELECTRONICS MODEL 1238A-1				ELECTRIC FIELD STRENGTH (kV/m) — POLYTECH MODEL FBM-100				MAGNETIC FLUX (GAUSS) — POLYTECH MODEL FBM-100		
	Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	Long Handle @ 1 Meter Above Ground	Long Handle @ 1.8 Meters Above Ground	11" Handle @ 1 Meter Above Ground	11" Handle @ 1.8 Meters Above Ground	1 Meter Above Ground	1.8 Meters Above Ground	Angle Of Probe
99	1.65			2.2	1.5	1.6		2.3	.025	.026	
102					1.35	1.45		2.2			
105					1.2	1.35		2.0			
108	1.3	1.6		1.9	1.1	1.25		1.9	.023	.023	
111					1.1	1.15		1.7			
114					1.05	1.1	1.05	1.6			
117	1.1	1.3	1.0	1.5	0.95	1.05		1.5	.019		135°
120					0.80	0.90		1.38			
123					0.80	0.88		1.30			
126	0.88	1.05		1.22	0.79	0.81		1.20	0.17		
129					0.65	0.75	0.67	1.12			
132					0.60	0.70		1.0			
135	0.70	0.85		1.0	0.60	0.64		0.97	.015		
138											
144	0.60	0.70		0.85	0.48	0.53		0.80	.013		
153	0.45	0.60	0.48	0.72	0.40	0.48	0.45	0.69	.011		
162	0.40	0.50	0.38	0.60	0.38	0.41	0.40	0.60	.0095		
171	0.35	0.40	0.32	0.50	0.32	0.35	0.32	0.51	.009		
180	0.28	0.36	0.28	0.43	0.275	0.30	0.27	0.43	.008		
189	0.25	0.32		0.38	0.25	0.25		0.36	.007		
198	0.20	0.28		0.32	0.20	0.215		0.31	.006	.006	160°

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16. ABSTRACT

Comparison is made between techniques used by the U.S. and reportedly used by the U.S.S.R. to measure electric field strengths under a 500 kV overhead power transmission line. Magnetic flux measurements were also made. Two instruments and three geometries were used in the electric field strength portion of the study. Maximum differences were noted when the measuring instrument was positioned close to the observer and at 1.8 meters above the ground as compared to one to two meters from the observer.

17. KEY WORDS AND DOCUMENT ANALYSIS

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