






FACE

Field and Corona Effects

2018 FACE Presentation

Oct. 31, 2018

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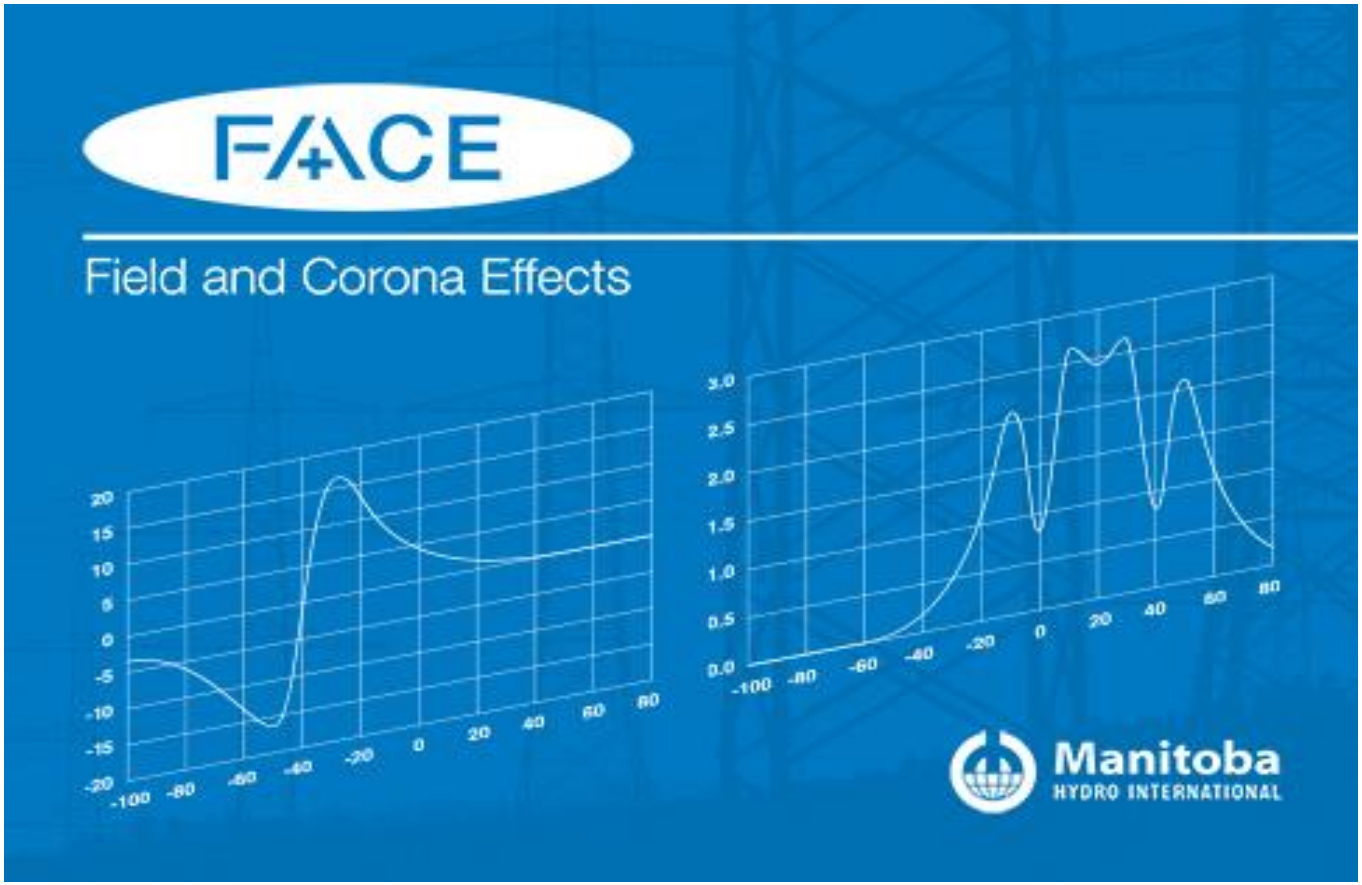
Manitoba HYDRO INTERNATIONAL

Welcome to FACE



Introduction

1. FACE (Field and Corona Effects) Basics
    1. What is FACE
    2. FACE History
    3. Salient Features
    4. Application Areas
2. User-Friendly and Intuitive GUI
3. Examples & Validations
4. Questions & Answers

1. FACE Basics: FACE ?

- Field and Corona performance is an important consideration when designing & operating HV lines
- Evaluates the overall environmental effects of HV AC, DC, or AC/DC hybrid power lines, namely
  - AN
  - RI
  - Corona Loss
  - Static electric and magnetic fields
  - Ion fields, ion currents, ion charges
- Produces Lateral profiles specified by users

1. FACE Basics: FACE History

- FACE Development was initiated at MH Hydro in early 1980s',
- FACE Development & validations were continued at MHI (HVDC Research Centre) from 1987 – 1995,
- Significant improvements, 04/2006-07/2007,
    - RI, advanced computation method
    - Highly Efficient ionized field computation
- User friendly and intuitive GUI, 2016-now,
- Evolved to a commercial product.

1. FACE Basics: FACE Features

- Predicts the field and corona performance of AC, DC, or **AC/DC hybrid power** lines,
- Employed a **higher-order successive image method** for the field computation
  - & Subconductors as separate conductors internally,
- Implemented Generation Functions developed by EPRI, BPA, EDF, IREQ … for user’s selections through GUI,
- Most advanced RI computation: semi– analytical method, frequency domain model transform technique.
- Highly efficient solution method for ionized fields
- Asymmetrical bundles can be handled easily

1. FACE Basics: Application Areas

- Existing transmission line studies, and monitoring
- AC, DC, or DC/AC transmission lines design
- Converting AC to DC and Vice Versa

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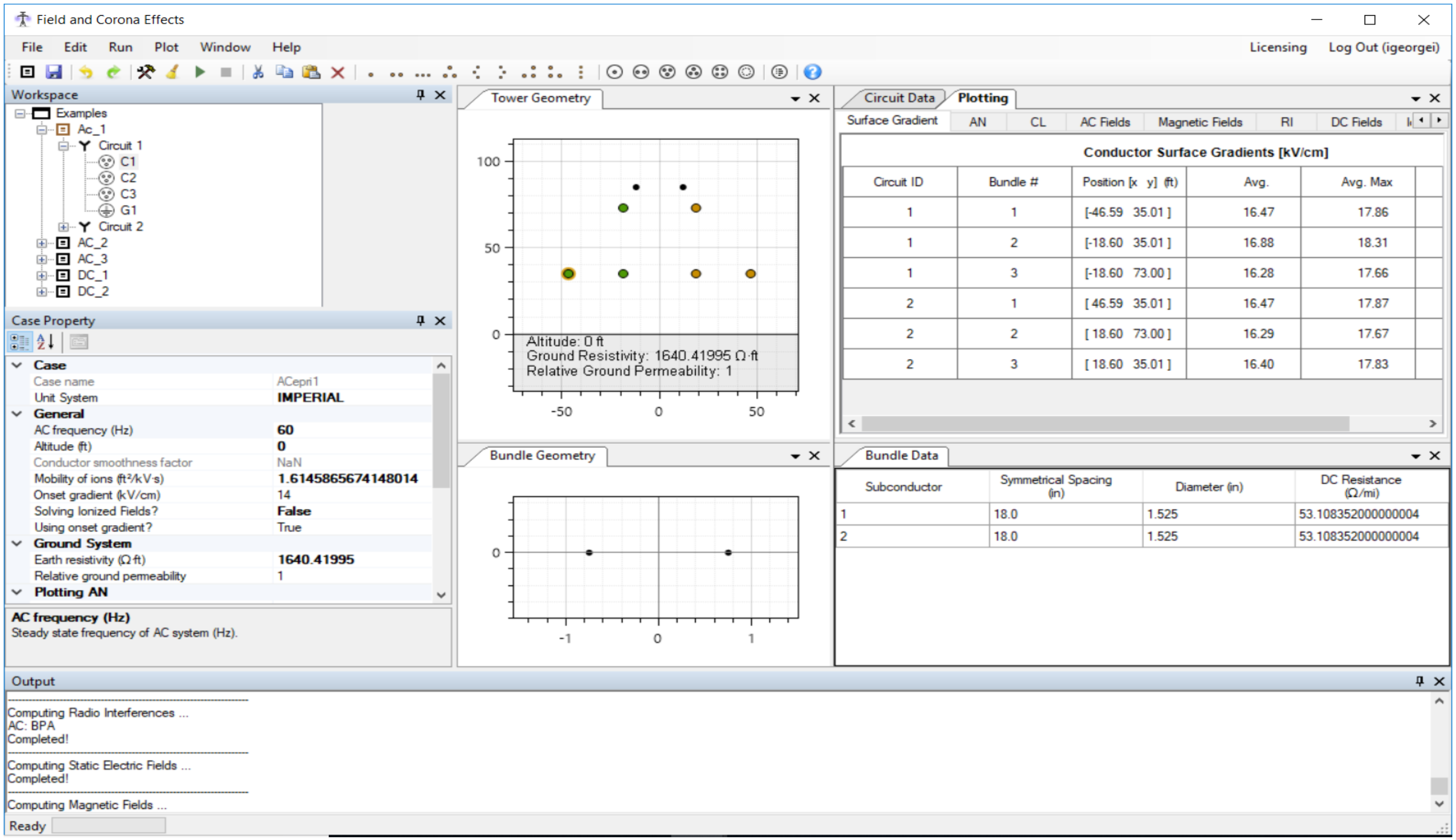
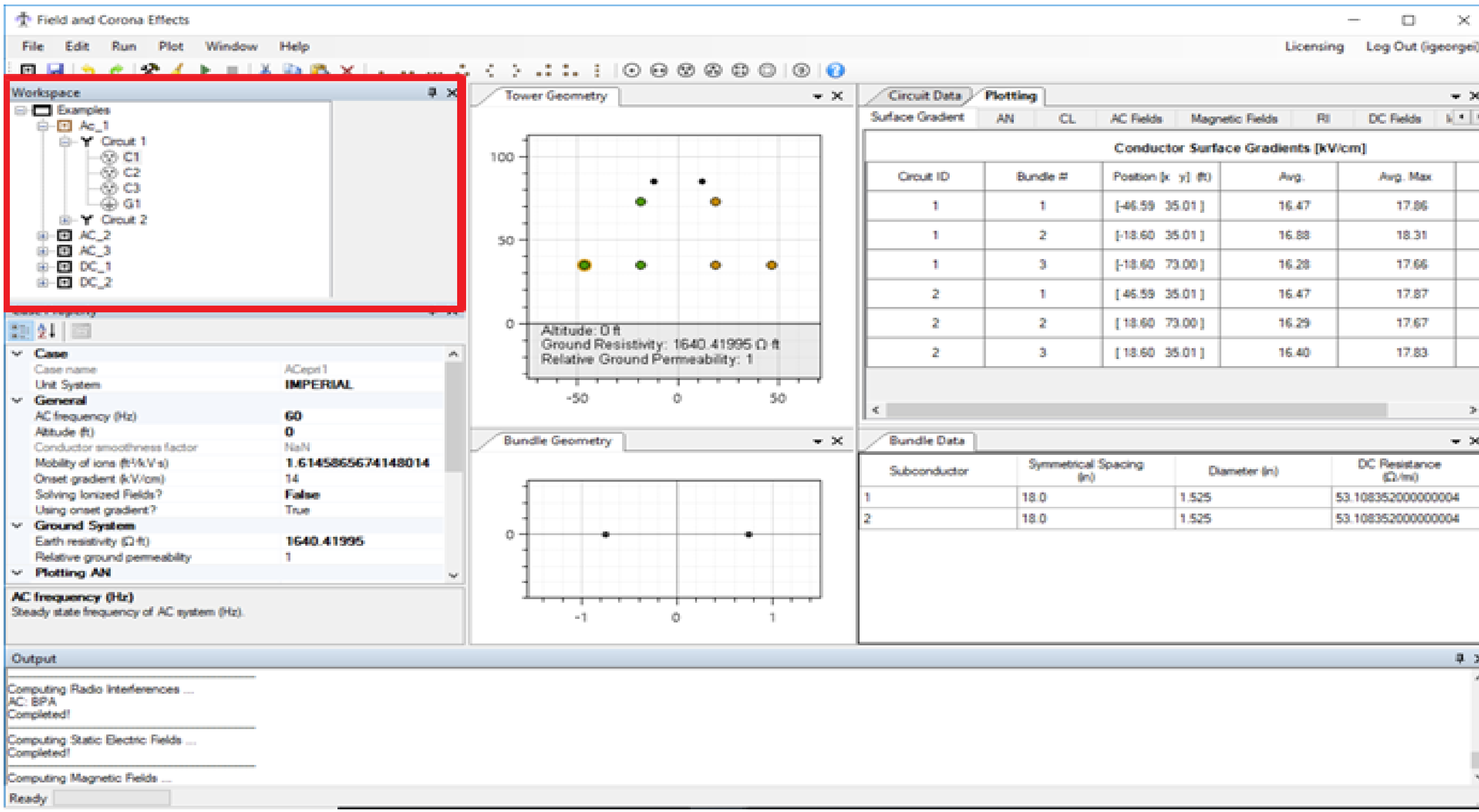
2. FACE GUI



2. FACE GUI: Workspace Window

- Workspace- users can define multiple projects



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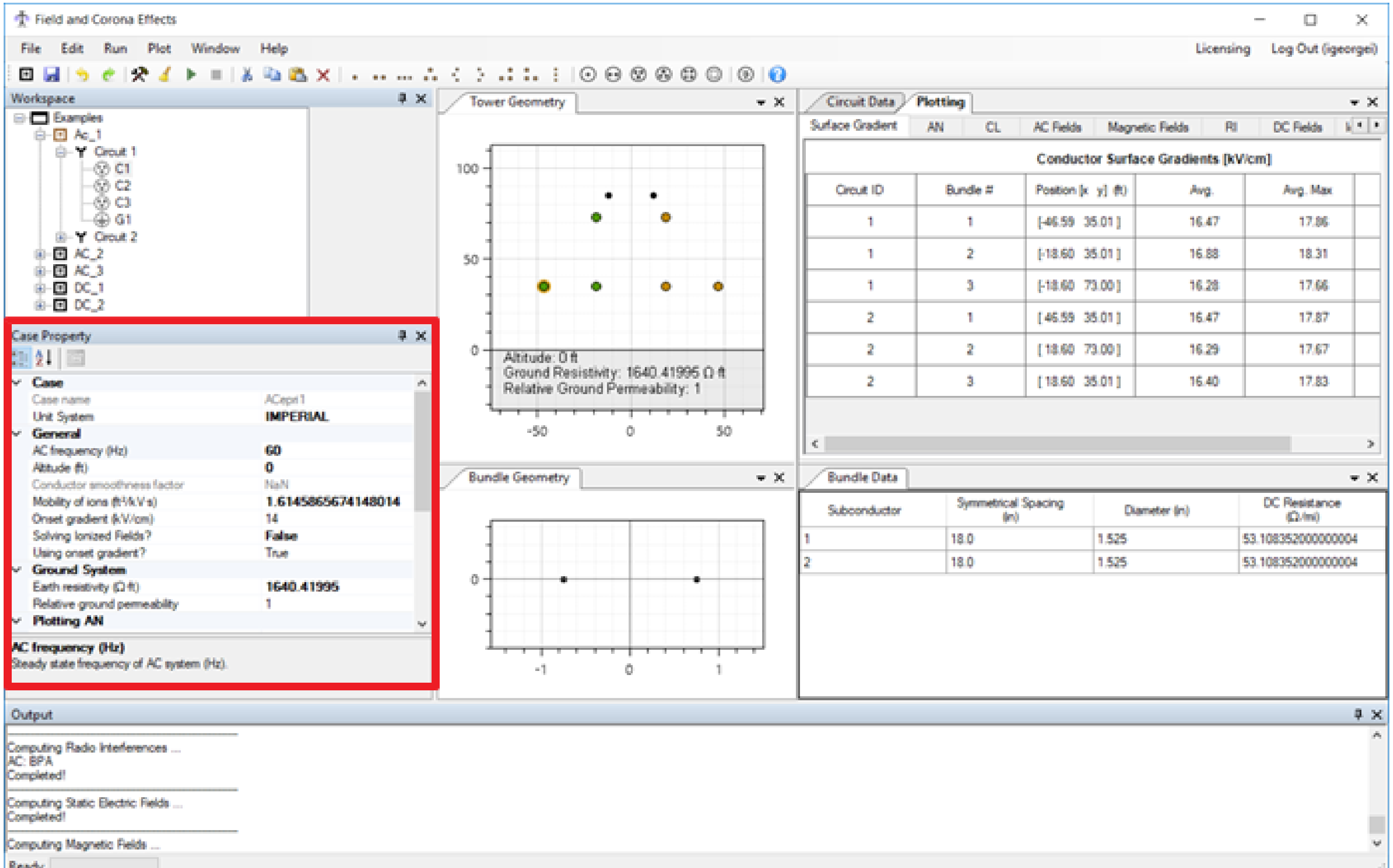
2. FACE GUI: Case Property Window

- Case Property – users can edit parameters for a selected project



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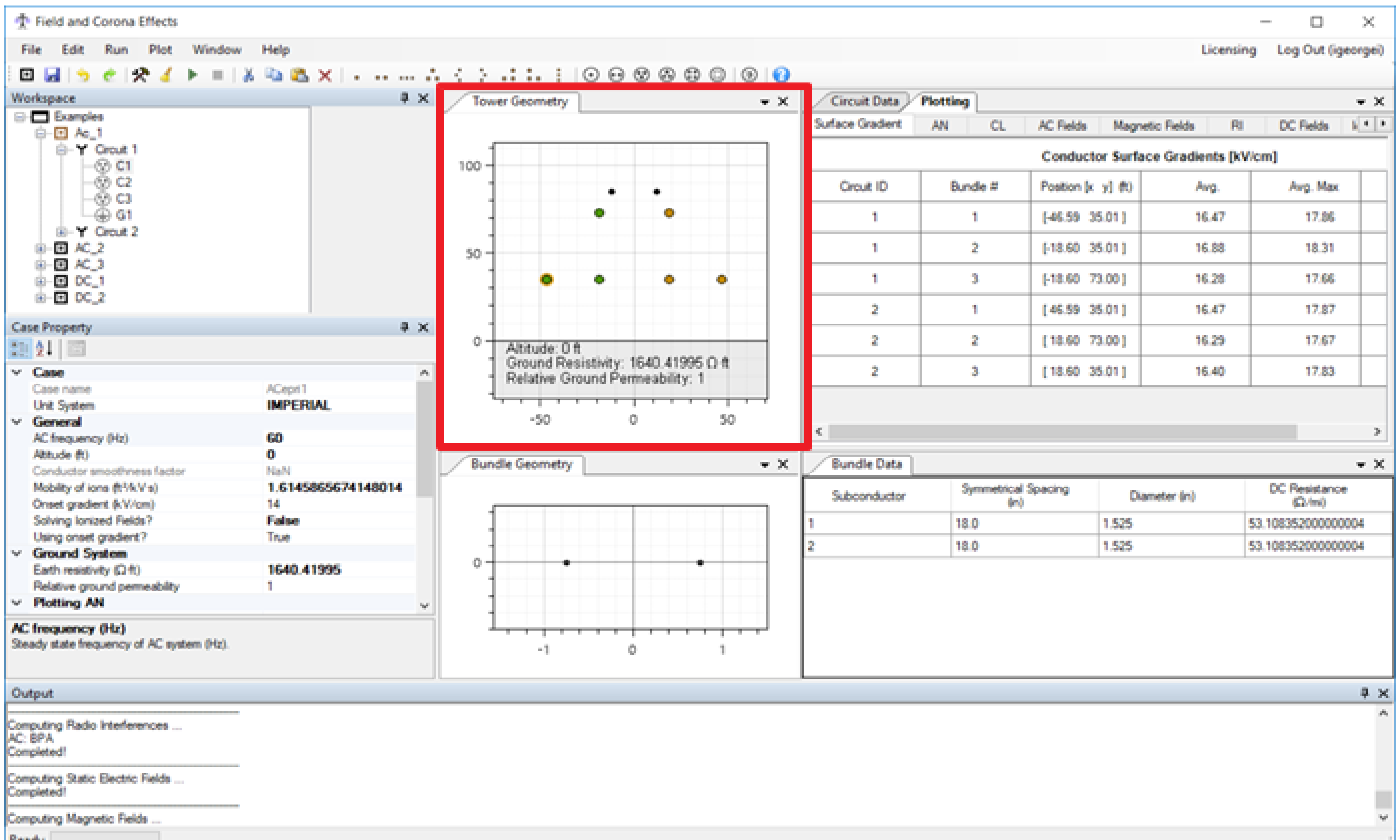
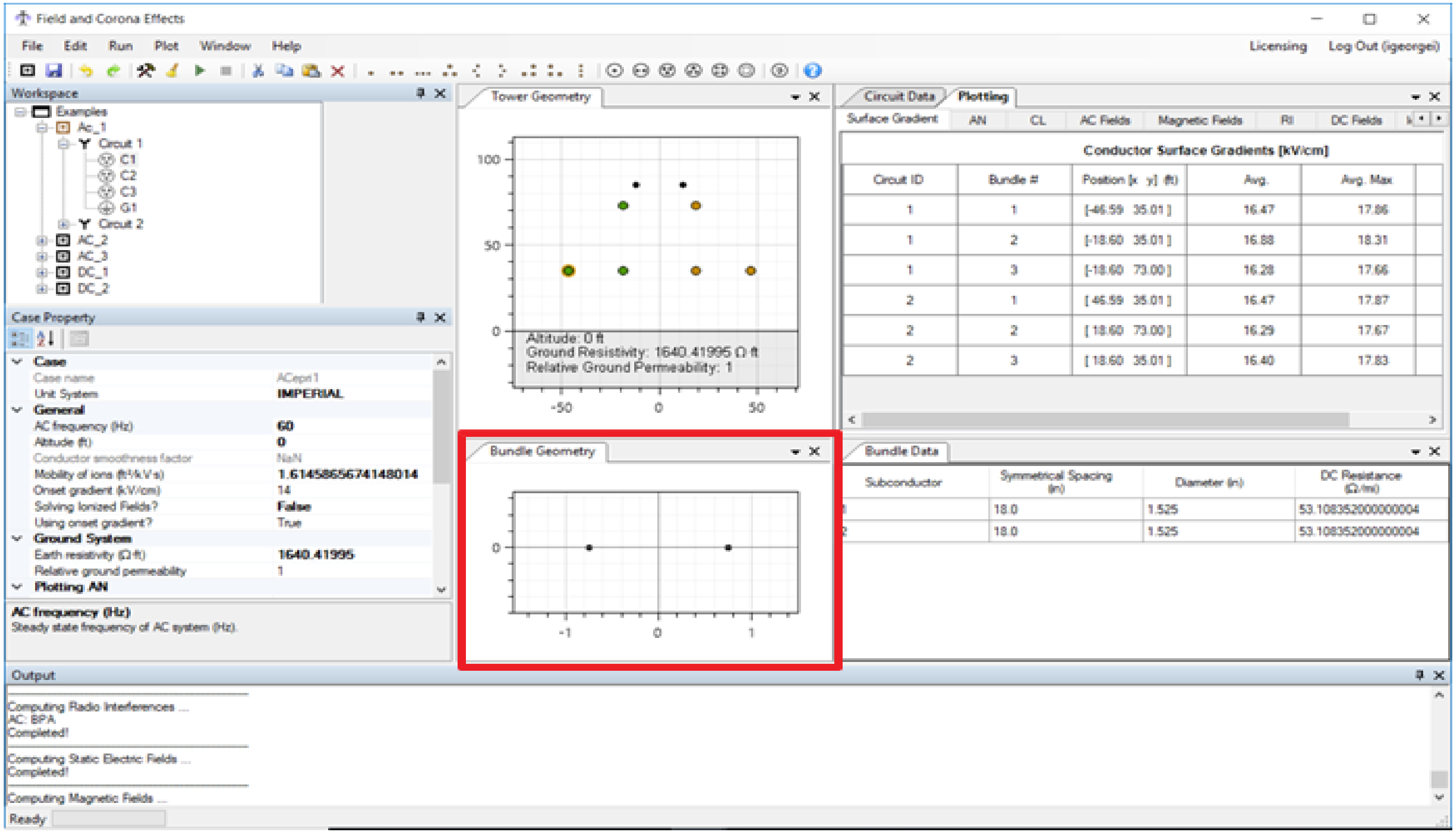
2. FACE GUI: Tower Geometry Window

- Tower Geometry Window shows cross-section that includes bundle and ground wire placement



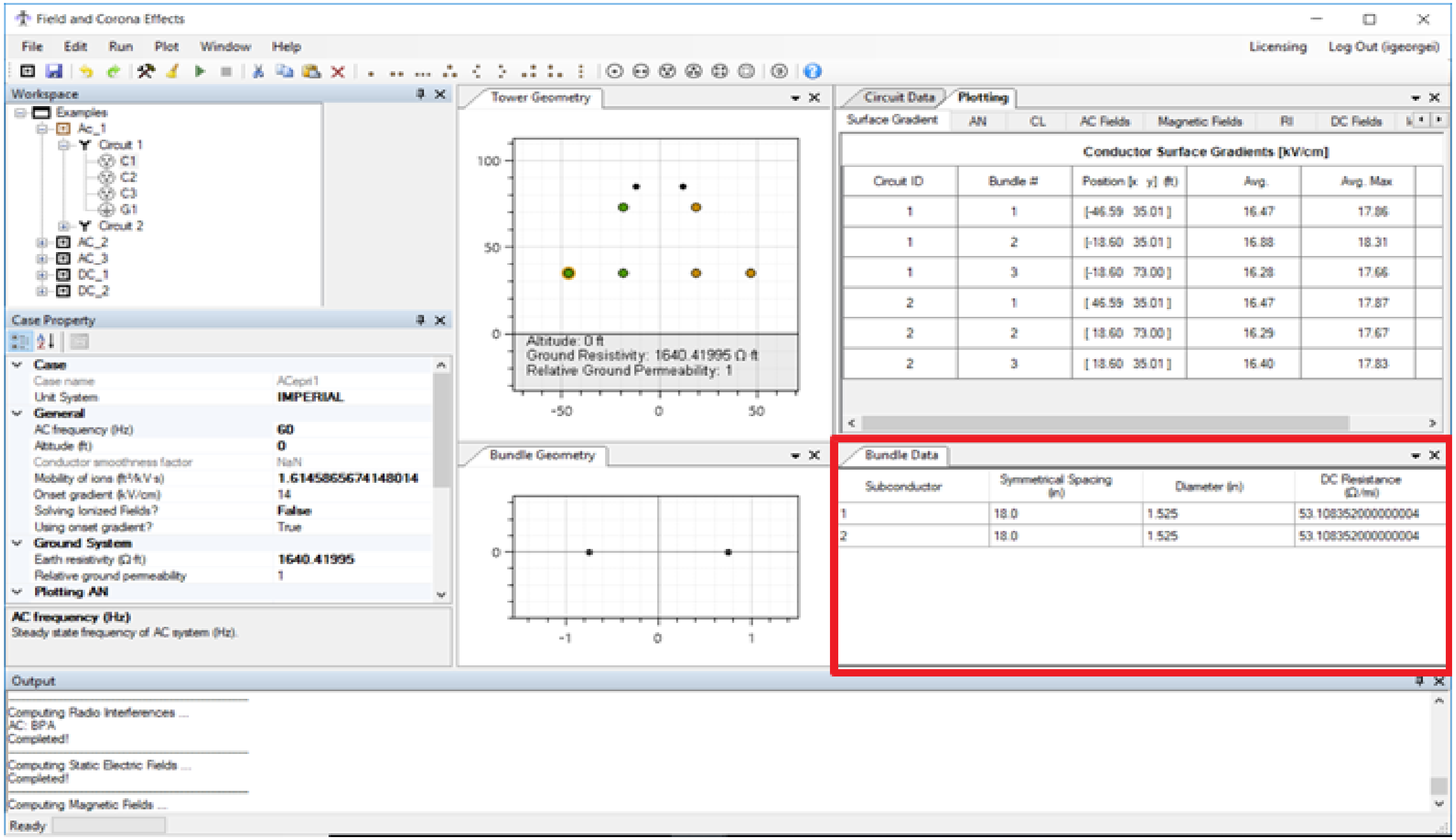
2. FACE GUI: Bundle Geometry Window

- Bundle Geometry Window show a cross-section that includes subconductor placement



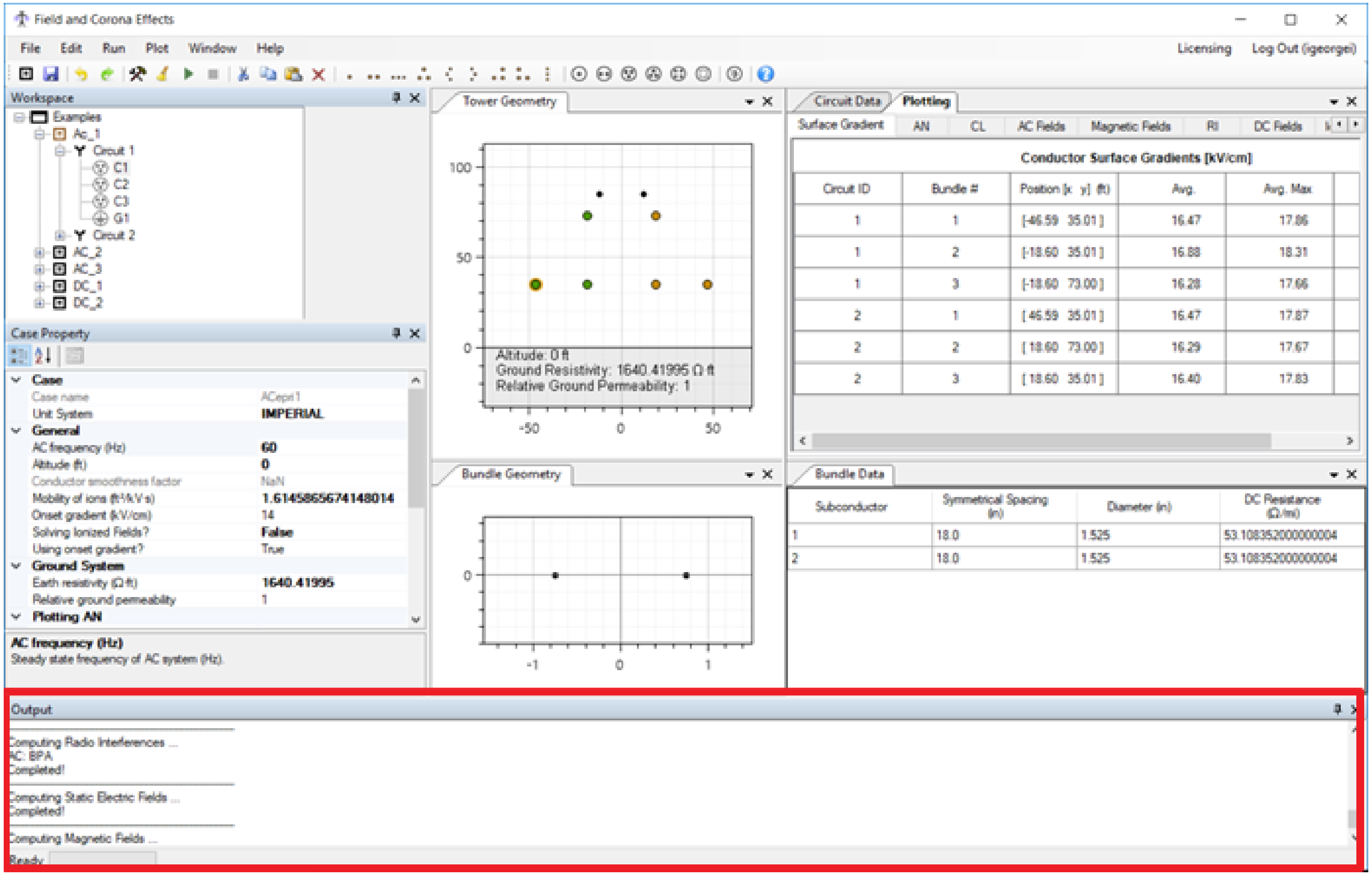
2. FACE GUI: Bundle Data Window

- Bundle Data Window shows the data for bundles and their individual sub conductors



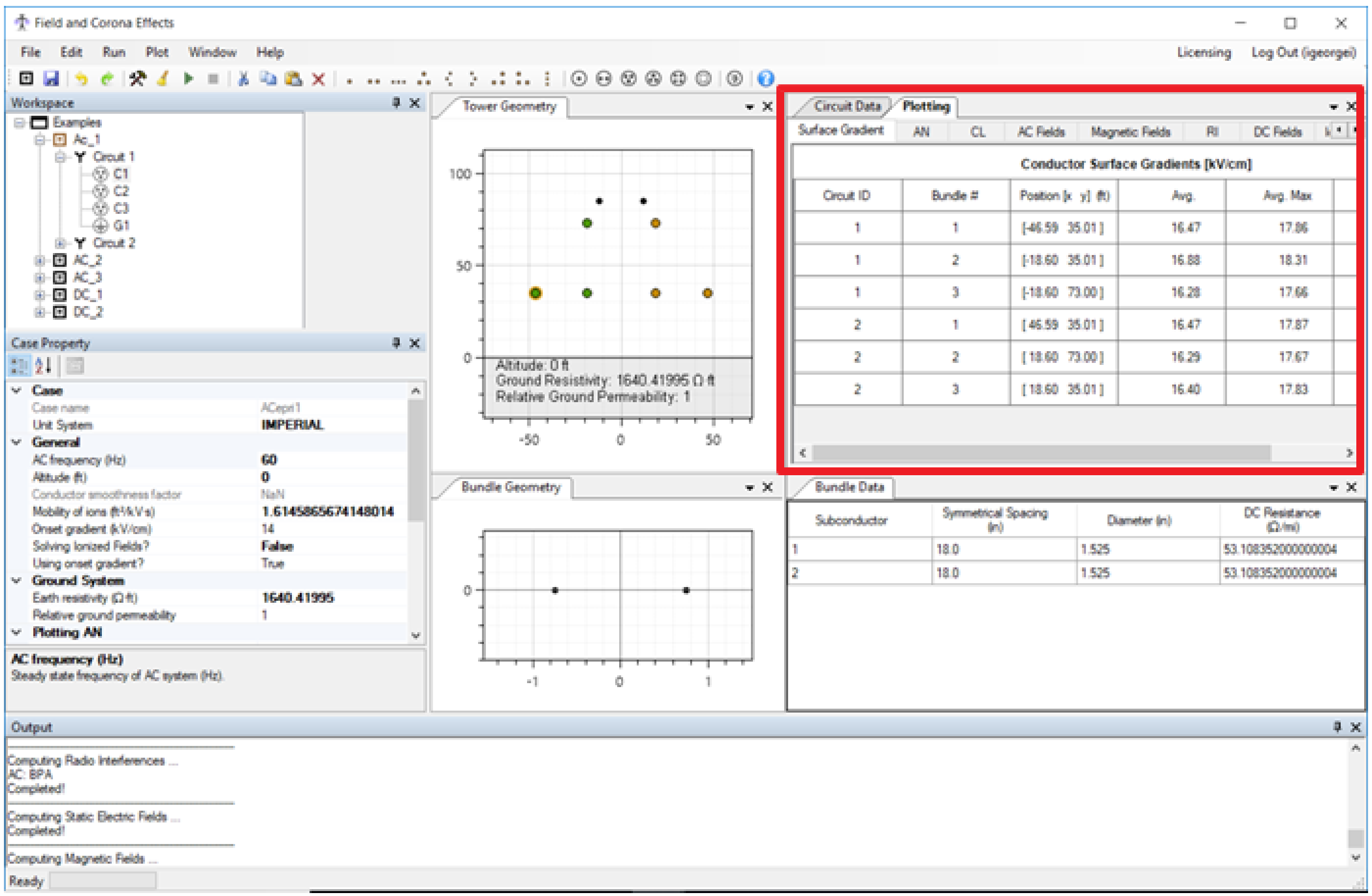
2. FACE GUI: Output Window

- Output Window shows code, simulation results, and error messages



2. FACE GUI: Plotting Window

- Plotting Window where simulation results are displayed and navigated



3. Examples & Validations

- Surface Gradient
- AN
- RI
- CL
- Static Electric Fields
- Static Magnetic Fields
- Ionized Fields

3. Examples & Validations: Surface Gradients

- IEEE Committee Paper: "A Survey of Methods for Calculating Transmission Line Conductor Surface Voltage Gradients," IEEE Trans., PAS, vol. 98, 1979. Total 13 Cases
- IEEE Committee Paper, “A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines,” IEEE Trans., PAS, vol.101, no.10, pp. 4090-4099, Oct. 1982. 20 AC and 4 DC Cases
- Robert G. Olsen, Steven D. Schennum and Vernon L. Chartier, “Comparison of Several Methods for Calculating Power line Electromagnetic Interference levels and Calibration with Long Term Data,” IEEE Transactions on Power Delivery, Vol. 7, No. 2, **April** 1992. Total 9 AC Cases

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3. Examples & Validations: Surface Gradients

[28] IEEE Committee Paper, "A Survey of Methods for Calculating Transmission Line Conductor Surface Voltage Gradients," IEEE Trans., PAS, vol. 98, pp. 1996-2014, 1979.

Case	SF	FACE Results		Successive Images(17) IEEE Results		Successive Images(18) IEEE Results		Error			
		C.P	O.P	C.P	O.P	C.P	O.P	C.P	O.P	C.P	O.P
1	A	15.51	14.67	15.51	14.66	15.51	14.62	0	0.01	0	0.05
	AM	15.51	14.67	15.51	14.79	15.51	14.68	0	-0.12	0	-0.01
	MB	15.51	14.67	15.51	14.79	15.51	14.68	0	-0.12	0	-0.01
2	A	14.69	13.59	14.69	13.59	14.69	13.53	0	0	0	0.06
	AM	15.67	14.49	15.64	14.46	15.64	14.4	0.03	0.03	0.03	0.09
	MB	15.67	14.65	15.64	14.47	15.64	14.59	0.03	0.18	0.03	0.06
3a	A	14.49	14.21	14.49	14.17	14.49	14.17	0	0.04	0	0.04
	AM	15.5	15.2	15.46	15.12	15.46	15.12	0.04	0.08	0.04	0.08
	MB	15.58	15.2	15.56	15.12	15.56	15.12	0.02	0.08	0.02	0.08
3b	A	14.57	14.2	14.57	14.2	14.57	14.16	0	0	0	0.04
	AM	15.58	15.18	15.56	15.24	15.54	15.1	0.02	-0.06	0.04	0.08
	MB	15.67	15.18	15.68	15.32	15.65	15.1	-0.01	-0.14	0.02	0.08
4a	A	15.37	15.27	15.37	15.27	15.36	15.26	0	0	0.01	0.01
	AM	16.74	16.63	16.68	16.59	16.67	16.56	0.06	0.04	0.07	0.07
	MB	16.74	16.77	16.68	16.63	16.67	16.75	0.06	0.14	0.07	0.02
4b	A	14.98	15.35	14.98	15.35	14.97	15.33	0	0	0.01	0.02
	AM	16.31	16.72	16.26	16.68	16.25	16.64	0.05	0.04	0.06	0.08
	MB	16.31	16.86	16.26	16.81	16.25	16.83	0.05	0.05	0.06	0.03
5	A	14.43	13.51	15.23	14.21	15.22	14.15	-0.8	-0.7	-0.79	-0.64
	AM	16.04	15.03	16.91	15.77	16.89	15.71	-0.87	-0.74	-0.85	-0.68
	MB	17.12	16.19	17.03	15.92	16.9	15.87	0.09	0.27	0.22	0.32
6a	A	18.54	17.23	18.54	17.23	18.53	17.15	0	0	0.01	0.08
	AM	21.08	19.6	21.06	19.58	21.05	19.48	0.02	0.02	0.03	0.12
	MB	21.08	19.83	21.18	19.75	21.05	19.48	-0.1	0.08	0.03	0.35
6b	A	18.54	17.05	18.54	16.95	18.53	16.95	0	0.1	0.01	0.1
	AM	21.09	19.39	21.06	19.26	21.05	19.26	0.03	0.13	0.04	0.13
	MB	21.09	19.64	21.17	19.54	21.05	19.54	-0.08	0.1	0.04	0.1
7	A	13.72	12.41	13.72	12.31	13.7	12.31	0	0.1	0.02	0.1
	AM	16.58	14.99	16.62	15.04	16.59	14.91	-0.04	-0.05	-0.01	0.08
	MB	16.62	15.58	16.84	15.37	16.63	15.5	-0.22	0.21	-0.01	0.08
8	A	11.43	10.4	11.43	10.4	11.41	10.33	0	0	0.02	0.07
	AM	14.22	12.94	14.29	13.01	14.28	12.92	-0.07	-0.07	-0.06	0.02
	MB	14.26	13.44	14.48	13.3	14.3	13.39	-0.22	0.14	-0.04	0.05
9 (DC)	A	17.47		17.46		17.46		0.01		0.01	
	AM	19.21		19.13		19.13		0.08		0.08	
	MB	19.42		19.18		19.4		0.24		0.02	
10 (DC)	A	16.16		16.16		16.15		0		0.01	
	AM	20.49		20.59		20.55		-0.1		-0.06	
	MB	21.39		21.13		21.58		0.26		-0.19	

A:Average AM:Average Maximum C.P: Center Phase
MB: Maximum Bundle Gradient O.P.: Outer Phase

3. Examples & Validations: Surface Gradients

[31] IEEE Committee Paper, "A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines," IEEE Trans., PAS, vol.101, no.10, pp. 4090-4099, Oct. 1982.

			AC Cases																				DC Cases			
Cases			1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	18	19	20	21	22
													a	b	c											
n=			1	2	3	4	3	4	4	4	4	4	6	10	8	8	7	6	8	8	12	16	4	6	6	4
Ref 1	Phase A	Max	15.8	16.9	15.8	17.6	18.3	18.4	16.2	19.8	17.4	22.6	21.80	-	-	14.9	15.9	12.8	14.9	12.5	13.8	13	28.2	25.9	24	21.7
		Avg-Max	15.8	16.7	15.6	16.6	17.8	18.2	16	19.6	17.1	22.3	21.60	-	-	14.5	15.5	12.4	14.5	12.2	13.5	12.5	27.6	25	23.5	21.1
	Phase B	Max	16.8	17.9	16.8	16.9	17.2	19.8	17.3	21.1	18.4	24.5	-	15.9	-	15.5	14.9	13.4	15.5	13	14.6	13.4				
		Avg-Max	16.8	17.9	16.8	16.1	16.6	19.8	17.3	21.1	18.4	24.5	-	15.7	-	15.4	14.6	13.1	15.4	12.9	14.4	13.3				
	Phase C	Max	15.8	16.9	15.8	17.6	17.1	18.4	16.2	19.8	17.4	22.6	-	-	18.3	14.9	15.9	12.8	14.9	12.5	13.8	13				
		Avg-Max	15.8	16.7	15.8	16.5	16.4	18.2	16	19.6	17.1	22.3	-	-	-	14.5	15.5	12.4	14.5	12.1	13.5	12.5				
FACE Results	Phase A	Max	15.82	16.94	15.87	17.46	18.22	18.53	16.24	19.9	17.44	22.55	21.49			14.84	15.72	12.68	14.83	12.48	14.03	12.91	27.84	25.86	23.96	21.65
		Avg-Max	15.82	16.8	15.7	16.5	17.8	18.3	16.05	19.67	17.22	22.27	21.2			14.54	15.48	12.41	14.46	12.15	13.59	12.44	27.37	25.01	23.44	21.28
	Phase B	Max	16.84	17.92	16.88	16.83	17.11	19.83	17.3	21.12	18.44	24.55		16.02		15.41	14.81	13.1	15.01	12.93	14.44	13.31				
		Avg-Max	16.84	17.92	16.87	16.09	16.69	19.83	17.3	21.11	18.43	24.53		15.86		15.38	14.6	13.09	14.73	12.9	14.39	13.26				
	Phase C	Max	15.82	16.94	15.87	17.46	17.03	18.53	16.24	19.9	17.44	22.55			17.83	14.84	15.72	12.68	14.83	12.48	14.03	12.91				
		Avg-Max	15.82	16.8	15.7	16.5	16.42	18.3	16.05	19.67	17.22	22.27			17.51	14.54	15.48	12.41	14.46	12.15	13.59	12.44				
Errors			0.02	0.04	0.07	0.14	0.08	0.13	0.04	0.1	0.04	0.05	0.31			0.06	0.18	0.12	0.07	0.02	0.23	0.09	0.36	0.04	0.04	0.05
			0.02	0.1	0.1	0.1	0	0.1	0.05	0.07	0.12	0.03	0.40			0.04	0.02	0.01	0.04	0.05	0.09	0.06	0.23	0.01	0.06	0.18
			0.04	0.02	0.08	0.07	0.09	0.03	0	0.02	0.04	0.05		0.12		0.09	0.09	0.3	0.49	0.07	0.16	0.09				
			0.04	0.02	0.07	0.01	0.09	0.03	0	0.01	0.03	0.03		0.16		0.02	0	0.01	0.67	0	0.01	0.04				
			0.02	0.04	0.07	0.14	0.07	0.13	0.04	0.1	0.04	0.05			0.47	0.06	0.18	0.12	0.07	0.02	0.23	0.09				
			0.02	0.1	0.1	0	0.02	0.1	0.05	0.07	0.12	0.03				0.04	0.02	0.01	0.04	0.05	0.09	0.06				
Max. error			0.04	0.1	0.1	0.14	0.09	0.13	0.05	0.1	0.12	0.05	0.40	0.16	0.47	0.09	0.18	0.3	0.67	0.07	0.23	0.09	0.36	0.04	0.06	0.18

3. Examples & Validations: Surface Gradients

Robert G. Olsen, Steven D. Schennum and Vernon L. Chartier, "Comparison of Several Methods for Calculating Power line Electromagnetic Interference levels and Calibration with Long Term Data," IEEE Transactions on Power Delivery, Vol. 7, No. 2, April 1992

Case #	Paper			FACE Avg. Max			Error		
	A	B	C	A	B	C	A	B	C
1	14.97	14.25	15.06	14.94	14.2	14.94	-0.03	-0.05	-0.12
	14.98	14.13	14.88	15.03	14.2	14.94	0.05	0.07	0.06
2	15.07	15.93	15.07	15.07	15.93	15.07	0	0	0
3	15.42	16.21	15.42	15.42	16.21	15.42	0	0	0
4	16.19	17.29	16.19	16.2	17.3	16.2	0.01	0.01	0.01
5	13.36	15.16	14.92	13.36	15.17	14.94	0	0.01	0.02
	11.69	13.95	12.5	11.67	13.82	12.5	-0.02	-0.13	0
6	19.5	20.95	19.5	19.51	20.96	19.51	0.01	0.01	0.01
7	17.42	16.95	17.7	17.4	16.96	17.72	-0.02	0.01	0.02
	17.74	16.95	17.37	17.72	16.96	17.4	-0.02	0.01	0.03
8	17.24	17.45	16.13	17.25	17.45	16.13	0.01	0	0
	16.7	18.14	17.62	16.71	18.15	17.63	0.01	0.01	0.01
9	18.37	19.8	18.37	18.38	19.81	18.38	0.01	0.01	0.01

3. Examples & Validations: AN (audible noise)

- IEEE Committee Paper, “A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines,” IEEE Trans., PAS, vol.101, no.10, pp. 4090-4099, Oct. 1982.
  - 20 AC and 4 DC Cases

- Comparison to BPA free software (From Teshmont)
  - 8 DC Cases

3. Examples & Validations: AN (audible noise)

[31] IEEE Committee Paper, "A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines," IEEE Trans., PAS, vol.101, no.10, pp. 4090-4099, Oct. 1982.

AC Cases																						
Case #			1	2	3	4	5	6	7	8	9	10	11a	11b	11c	12	13	14	15	16	17	18
n			1	2	3	4	3	4	4	4	4	4	6	10	8	8	7	6	8	8	12	16
ref 1	BPA	L50	61.2	54.3	45.6	50.5	51.5	54.8	50.9	57.7	55.1	61.1	61.2	54.6	58.1	52	57.1	52.2	55.2	54.5	52.4	51.4
	GE	L5	65.7	61.2	51.2	55.8	56.5	58.1	56	59.8	59.3	60.5	61.6	59	61.2	58.1	62.3	58.2	61.3	60.9	59	58.8
		L50	60.3	55.1	46.6	51.9	52.8	55.7	54.4	58.2	56.6	59.9	61.2	54.7	58.6	52.9	58.4	52.8	56.7	55.4	54.1	53.9
	IREQ	L5	53.5	53.9	51.7	55.8	57.6	57.7	56	59.3	58.9	60.2	60.5	59.7	60.6	58.5	62.3	60.3	62	63.2	59	59.8
FACE	BPA	L5	63.55	56.1	47.42	52.56	53.74	57.3	53.48	60.05	57.18	63.64	62.63	54.54	59.86	54.69	59.49	54.99	58.5	57.36	55.26	54.1
		L50	60.05	52.6	43.92	49.06	50.24	53.8	49.98	56.55	53.68	60.14	59.13	51.04	56.36	51.19	55.99	51.49	55	53.86	51.76	50.6
	GE	L5	64.45	59.48	49.48	54.34	55.12	57.08	55.05	58.68	57.88	59.49	59.83	55.4	59.67	57.2	61.19	57.45	61.11	60.04	58.35	58
		L50	59.01	53.39	44.91	50.4	51.42	54.67	51.34	57.03	55.17	58.96	59.22	51.22	56.88	51.97	57.28	52.02	56.64	54.67	53.42	53.15
	IREQ	L5	52.3	52.34	50.26	56	56.05	56.74	55.17	58.23	57.51	59.48	59.24	56.28	59.81	58.05	61.66	60.06	61.77	62.43	59.57	59.84
		L50	48.8	48.84	46.76	52.5	52.55	53.24	51.67	54.73	54.01	55.98	55.74	52.78	56.31	54.55	58.16	56.56	58.27	58.93	56.07	56.34
ERROR	BPA		1.15	1.7	1.68	1.44	1.26	1	0.92	1.15	1.42	0.96	2.07	3.56	1.74	0.81	1.11	0.71	0.2	0.64	0.64	0.8
	GE L5		1.25	1.72	1.72	1.46	1.38	1.02	0.95	1.12	1.42	1.01	1.77	3.6	1.53	0.9	1.11	0.75	0.19	0.86	0.65	0.8
	GE L50		1.29	1.71	1.69	1.5	1.38	1.03	3.06	1.17	1.43	0.94	1.98	3.48	1.72	0.93	1.12	0.78	0.06	0.73	0.68	0.75
	IREQ		1.2	1.56	1.44	0.2	1.55	0.96	0.83	1.07	1.39	0.72	1.26	3.42	0.79	0.45	0.64	0.24	0.23	0.77	-0.57	-0.04

3. Examples & Validations: RI (Radio Interference)

- Robert G. Olsen, Steven D. Schennum and Vernon L. Chartier, "Comparison of Several Methods for Calculating Power line Electromagnetic Interference levels and Calibration with Long Term Data," IEEE Transactions on Power Delivery, Vol. 7, No. 2, **April** 1992. Total 9 AC Cases
- Comparison to BPA Software results (provided by Teshmont)
  - 8 DC Cases

3. Validations: Static Electric & Magnetic Fields

- Comparison to BPA Software Results (provided by Teshmont)
  - Static Electric Fields: 8 DC cases
  - Magnetic Fields: 8 DC Cases

3. Validations: Static Electric & Magnetic Fields

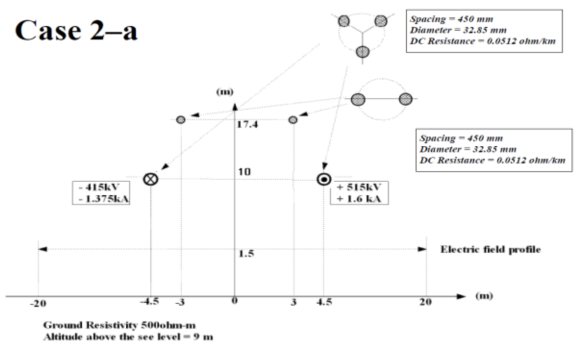
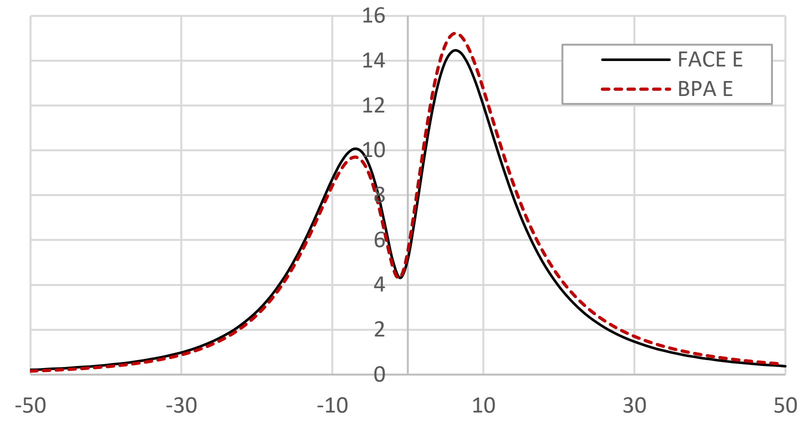
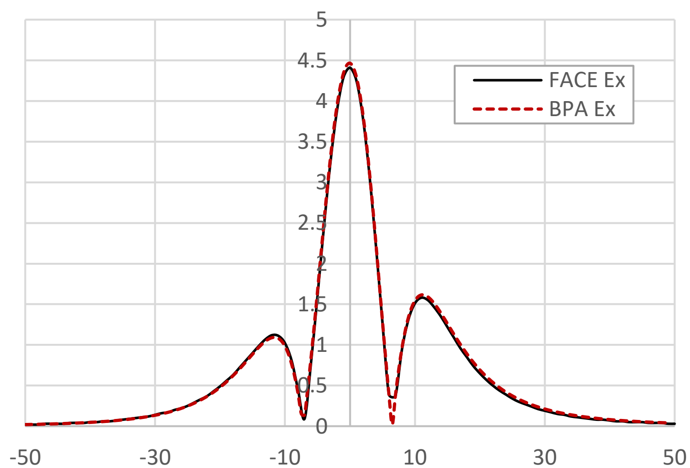
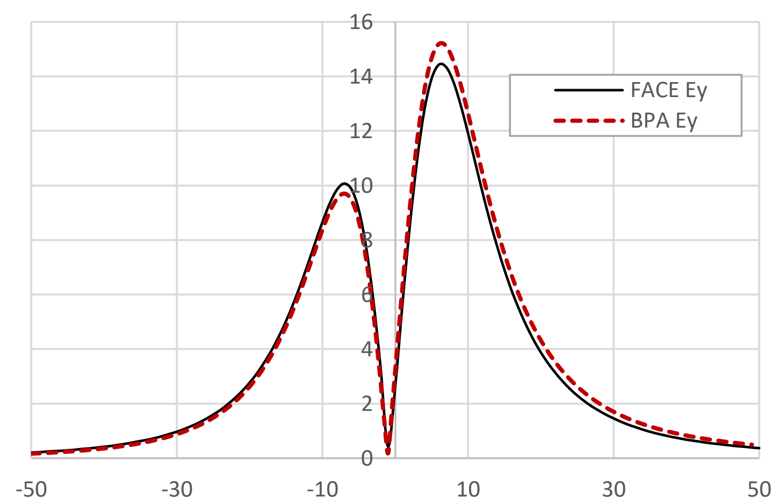


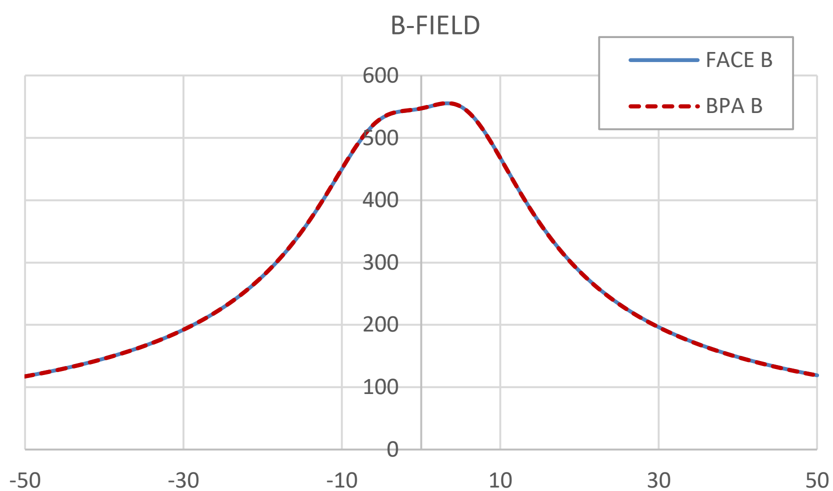
Figure 1.5. Case 2-a diagram, one possible upgrade to a bipolar scheme.

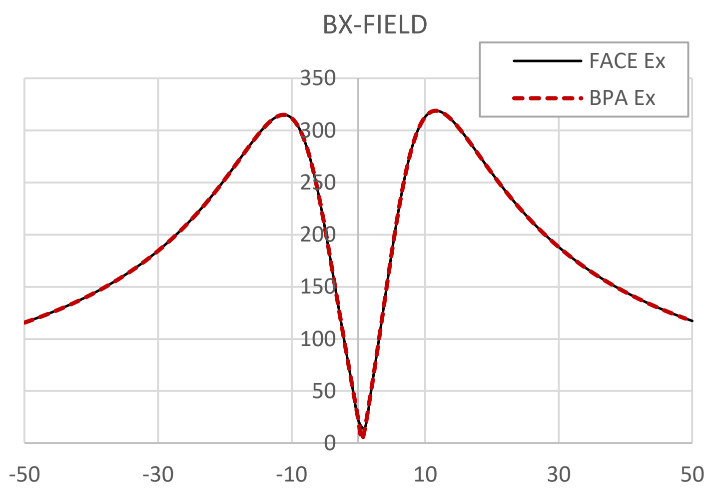


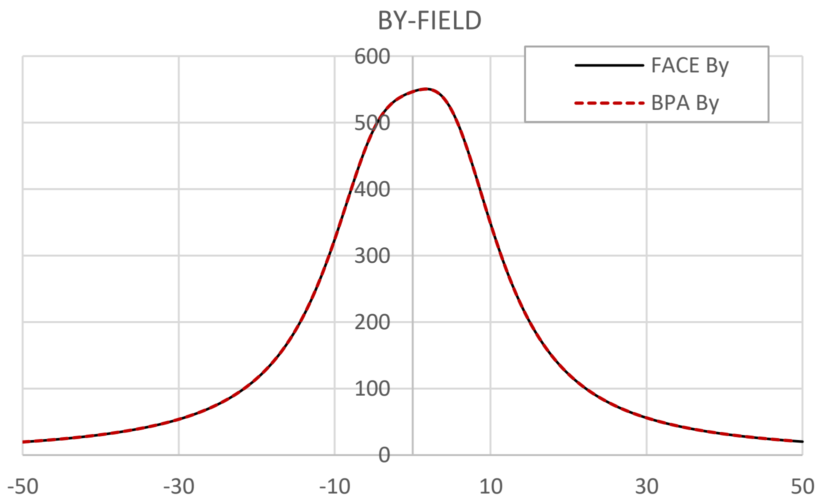




3. Validations: Static Electric & Magnetic Fields







3. Validations: Ionized Field Computation

- Theory & Solutions: Online help
- Validation Examples: MH Bipole 1 & 2

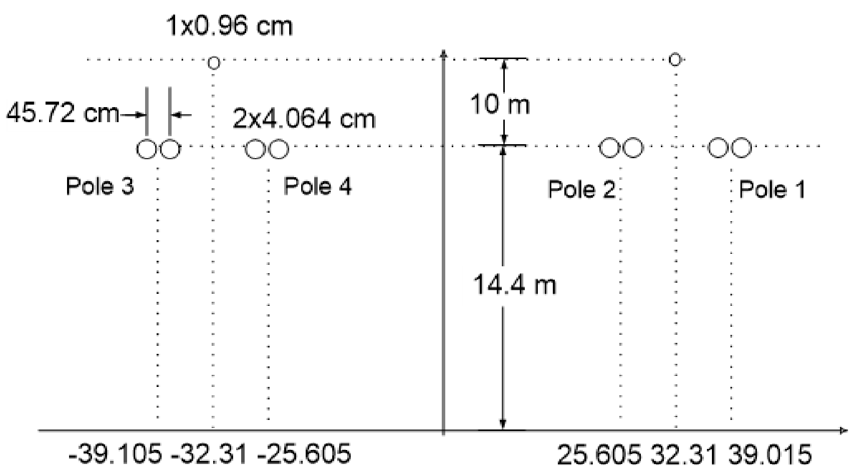


Fig. 1. Geometry of the Manitoba Nelson River

TABLE 1. OPERATING VOLTAGES IN *kV* FOR TWO CASES CONSIDERED

	Pole 1	Pole 2	Pole 3	Pole 4
Case 1	-450	450	-450	0
Case 2	-440	440	-470	470

3. Validations: Case 1, Ion trajectories

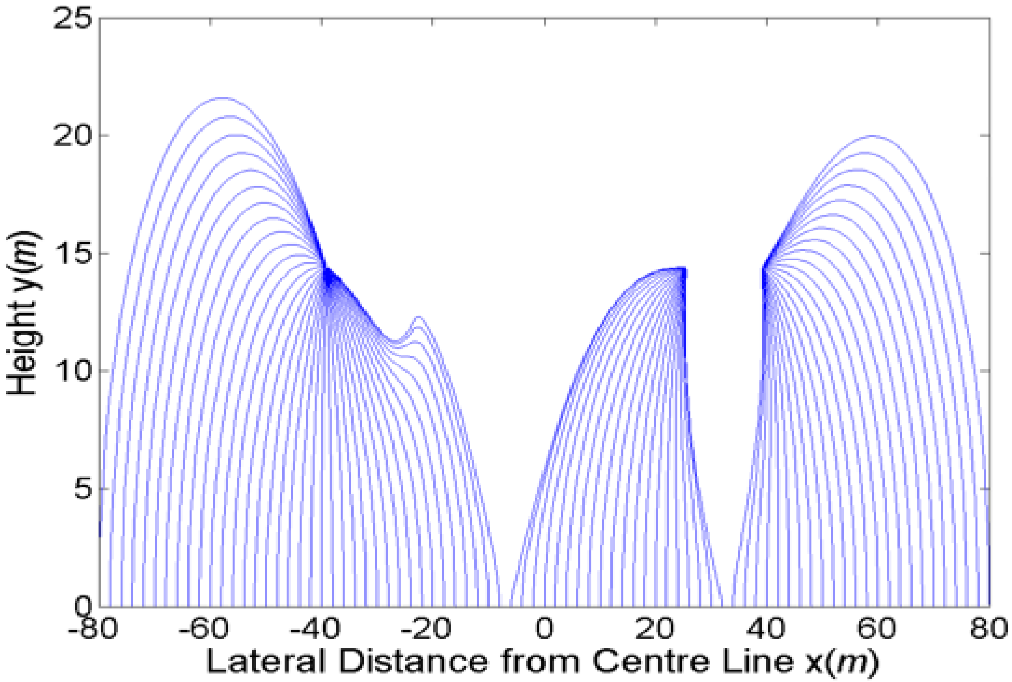


Fig. 4a. Ion trajectories at Ground Level in Case 1.

3. Validations: Case 1, Simulation Results

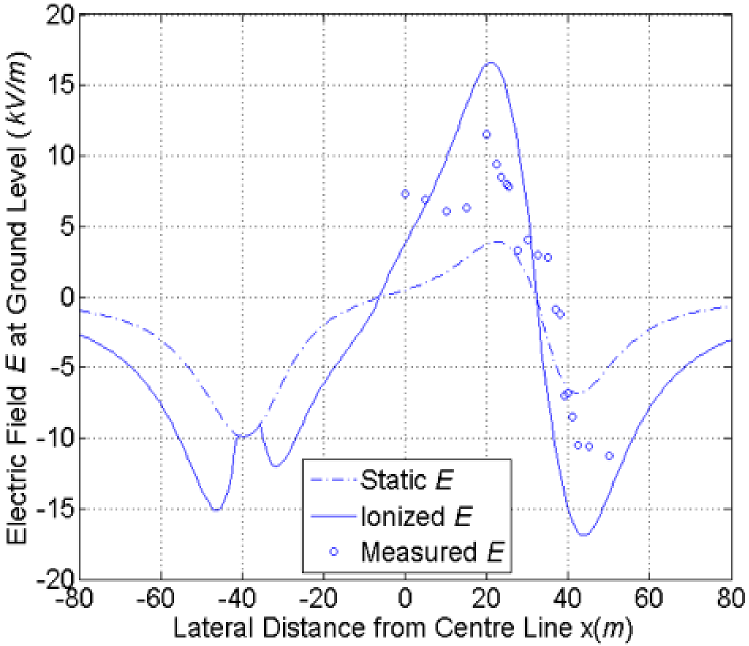


Fig. 4b. Electric Field Profile at Ground Level for Case 1.

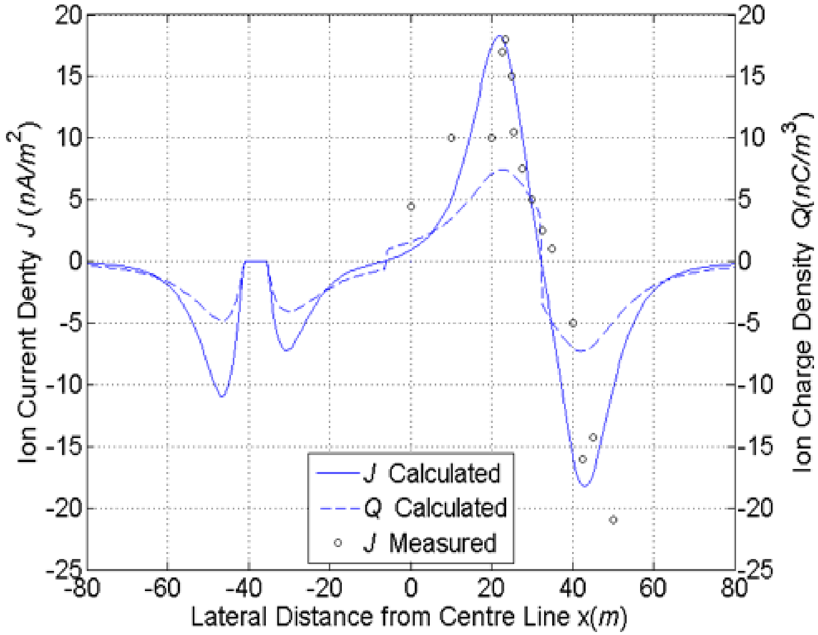


Fig. 5. Ion Current and Charge Densities at Ground Level for Case 1.

3. Validations: Case 2, Ion Trajectories

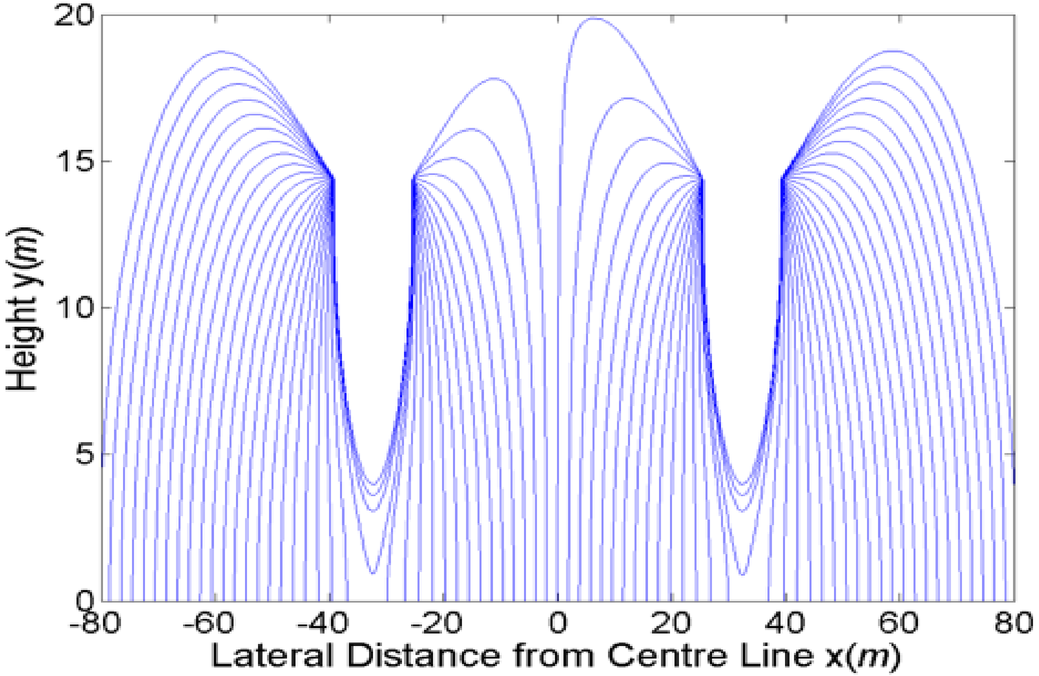


Fig. 11(a). Ion Trajectories *h = 1.5 m for case 2*.

3. Validations: Case 2, Simulation Results

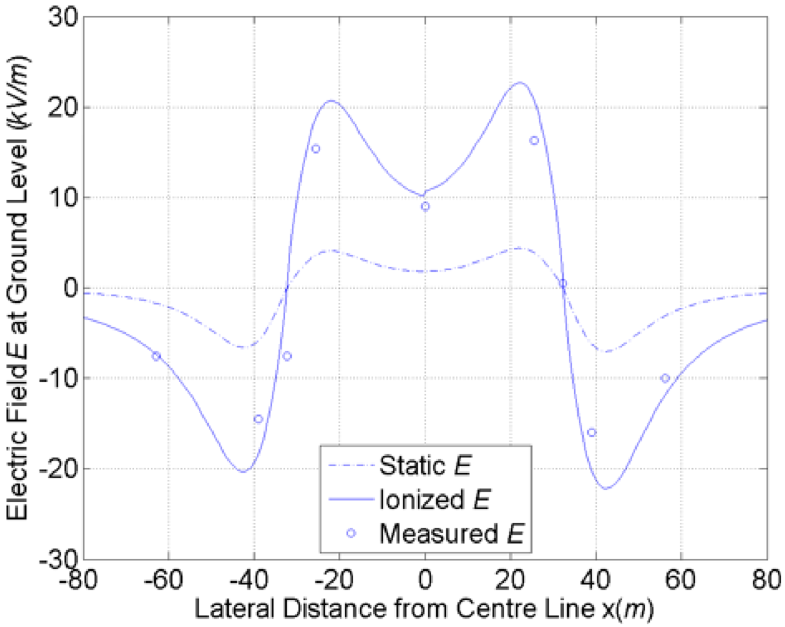


Fig. 9. Electric Field Profile at Ground Level for Case 2

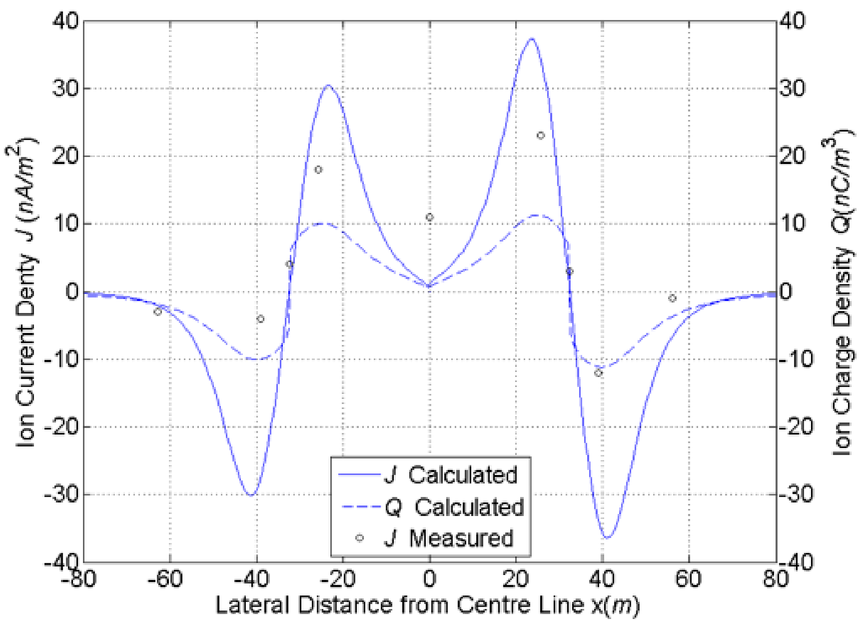


Fig. 10. Ion Current and Charge Densities at Ground Level for Case 2.

FACE
Field and Corona Effects

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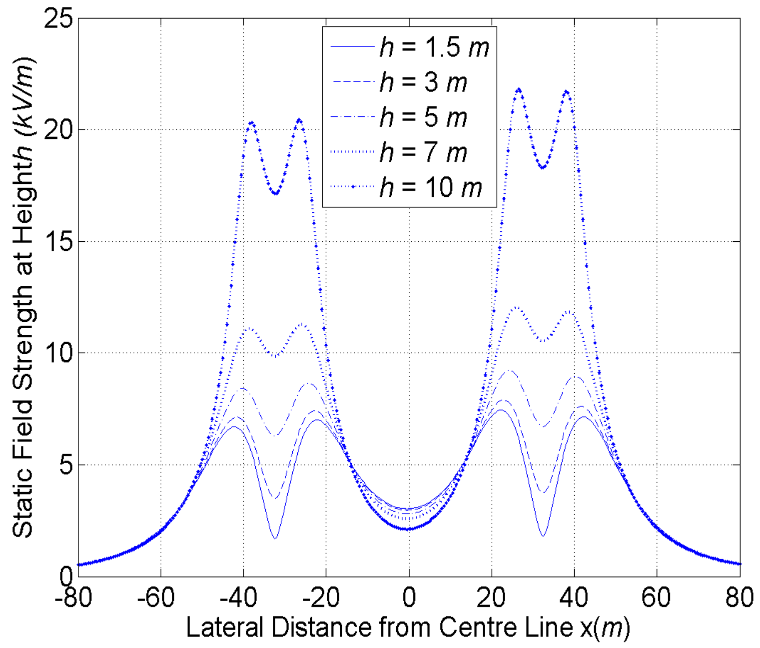
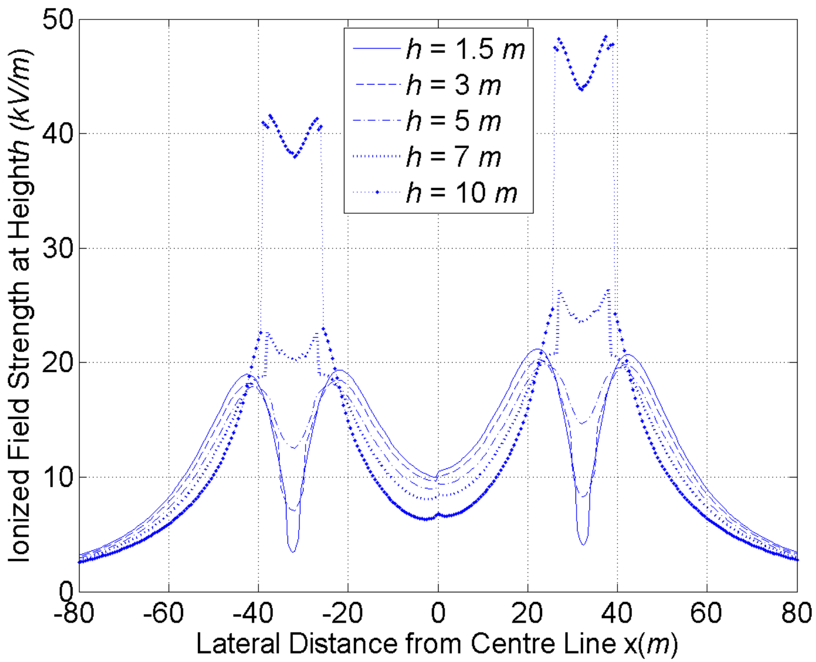
3. Validations: Case 2, at various meas. height *h*

- Demonstrate Robustness & Efficiency





Field and Corona Effects

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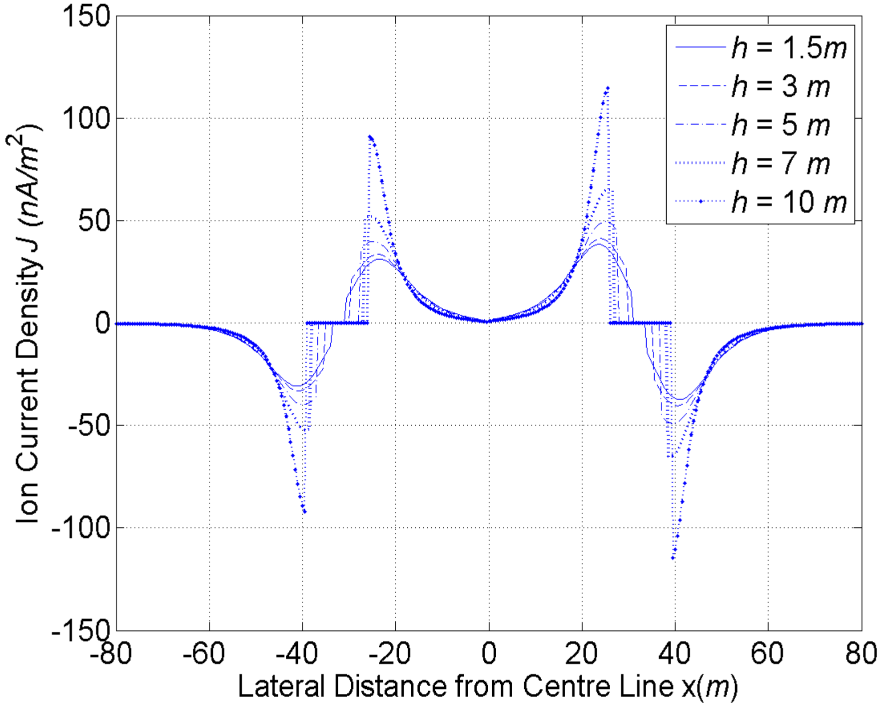
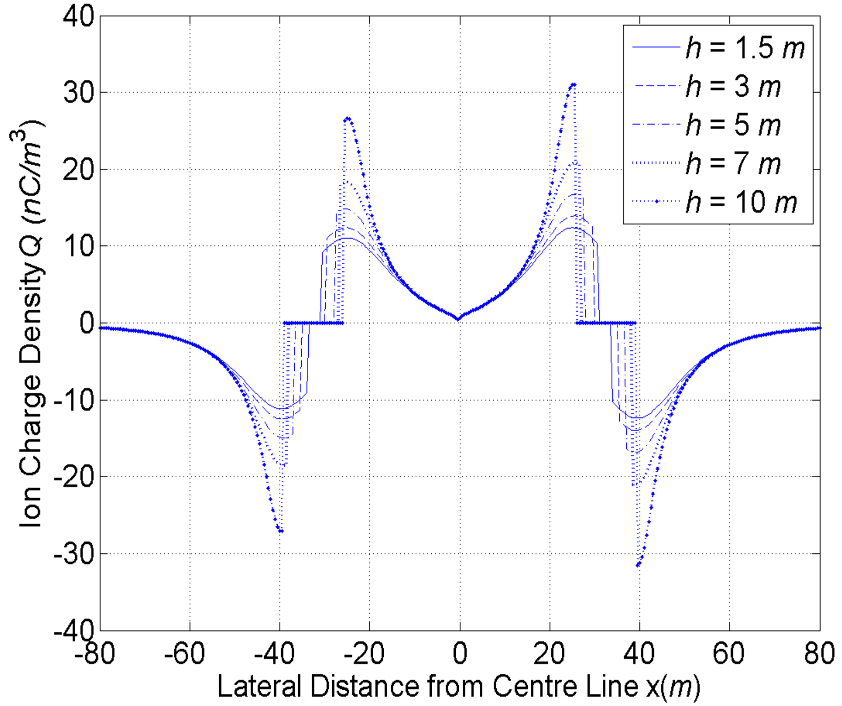
3. Validations: Case 2, at various meas. height *h*

- Demonstrate Robustness & Efficiency





Questions & Answers

Thank you

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