Study Committee B2

Overheda lines

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Electrical environment evaluation of HVAC/HVDC hybrid overhead transmission line using a reduced-scale model

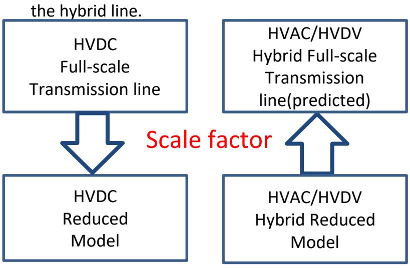
Koo Yong SHIN[1], Joon Arm OH[1], S.W. Lee[1], T.W. Kim[1], Mun No JU[2], Jeong Min WOO[2*]
[1]Korea Electric Power Research Institute (KEPRI), Korea Electric Power Corporation (KEPCO), Daejeon 34056, Korea
[2]Electrical Environment Research Center, Korea Electrotechnology Research Institute, Changwon 51543, Korea
*woojm@keri.re.kr

Motivation

- Securing a path for the construction of a new HVDC transmission line has been difficult worldwide due to civil complaints related to environmental issues
- A method that involves installing AC and DC lines in the same transmission tower and operating AC and DC lines in parallel within the same site area is being considered

Method/Approach

- The electrical environmental characteristics of a hybrid line were evaluated in a short period using a reduced-scale model that simulates the scale down of the hybrid line.



Objects of investigation

- The scale factor of the reduced-scale model is determined by the applied voltage, the experimental space, and the size of the conductor

$$K_V = \frac{V_{reduced}}{V_{full}}$$

$$\rho = \varepsilon E X A / V$$

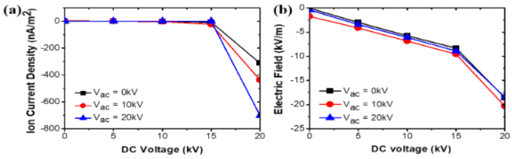
where ρ is the charge density at the ground surface, ε is the permittivity, E is the electric field strength at the ground surface, A is the area, and V is the volume.

Experimental setup & test results

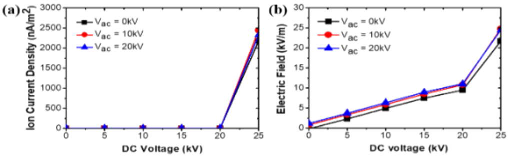
- The hybrid reduced-scale model was designed with the standard electric tower shape of an AC 765 kV transmission line as the basic target to simulate the parallel operation of ±500 kV DC with a 765 kV AC two circuit transmission line

<Photograph of the reduced-scale model>

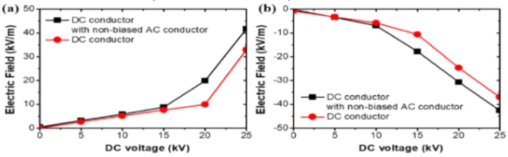
Discussion



(a) Ion current density by DC voltage (b) Ground electric field by DC voltage
<Negative pole with negative pole at the bottom>



(a) Ion current density by DC voltage (b) Ground electric field by DC voltage
<Positive pole with Positive pole at the bottom>



(a) Positive pole at the bottom (b) Negative pole at the bottom
DC electric field effect depending upon the presence of AC conductor

Conclusion

- A reduced-scale model was designed to reduce AC 765 kV/DC ±500 kV by a reduction factor of 1/40
- In the hybrid test, an electric field of -13.44 kV/m was measured at the bottom of the negative pole when a reduction factor 1.6 was applied, whereas an electric field of -11 kV/m was calculated in the simulation.
- The AC electric field was unaffected by the DC electric field. However, the DC electric field changed with variation in AC voltage. The corona onset voltage of the DC conductor was affected by the presence of the AC conductor even without AC voltage bias.

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Simulation(electric flux line method)

- The mobility of ions is constant regardless of field strength
- Thermal diffusion of ions is neglected
- The space charge affects the magnitude of the electric field. It does not affect the direction of the electric field (Deutsch assumption)
- The electric field on the surface of the conductor where the corona discharge is occurring is constant at the value at the beginning of the corona discharge

Reduced model parameter

<Pole configuration of reduced-scale model according to reduction factor>

Reduction factor		765kV full-scale line	Reduced-scale model	Note
0.04	Pole Spacing	27 ~ 29 m	1.08 ~ 1.16 m	1/25
	Pole Height	23 ~ 72 m	0.92 ~ 2.88 m	
0.03	Pole Spacing	27 ~ 29 m	0.82 ~ 0.88 m	1/33
	Pole Height	23 ~ 72 m	0.70 ~ 2.18 m	
0.025	Pole Spacing	27 ~ 29 m	0.68 ~ 0.73 m	1/40
	Pole Height	23 ~ 72 m	0.56 ~ 1.8 m	

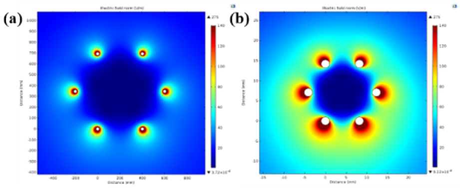
<Design parameters of reduced-scale model>

Conductor type	CARDINAL 480 mm²			
Number of Sub-conductors	6			
Line	Full-scale	Reduced-scale		
Sub-conductor diameter, mm	30.42	2.01	2.01	2.01
Sub-conductor spacing, mm	400	14.4	10.37	8.23
Equivalent diameter, mm	625.35	24.9	18.95	15.62
Reduction factor	1	1/25	1/33	1/40
Conductor type	CARDINAL 480 mm²			
Number of Sub-conductors	4			
Line	Full-scale		Reduced-scale	
Sub-conductor diameter, mm	30.42	2.01	2.01	2.01
Sub-conductor spacing, mm	400	13.5	9.34	7.23
Equivalent diameter, mm	385.24	15.38	11.67	9.63
Reduction factor	1	1/25	1/33	1/40
Conductor type	CARDINAL 480 mm²			
Number of Sub-conductors	2			
Line	Full-scale	Reduced-scale		
Sub-conductor diameter, mm	30.42	2.01	2.01	2.01
Sub-conductor spacing, mm	400	9.68	5.55	3.78
Equivalent diameter, mm	156	6.24	4.72	3.90
Reduction factor	1	1/25	1/33	1/40

- If the diameter of the cardinal (483 mm²) wire, which is a sub-conductor mainly used in the current transmission line, is reduced to 1/40, it is difficult to develop a new wire with a thickness of 0.76 mm. Therefore, the smallest wire produced according to the current Korea Industrial Standard (2.01 mm) was applied to the reduced-scale model.

$$d_{eq} = D\sqrt[n]{\frac{nd}{D}}$$

where d_{eq} is the equivalent diameter of a single conductor, D is the bundle diameter, n is the number of sub-conductors, and d is the diameter of the sub-conductor



(a) Full-scale model (b) Reduced-scale model

<Conductor surface electric field intensity distribution of full-scale and reduced-scale models>

<Applied voltage in reduced-scale model >

	Full-scale	Reduced-scale #1	Reduced-scale #2 (Equivalent diameter application)
Pole Height (%)	(100)	(2.5)	(2.5)
Sub-conductor diameter, mm (%)	30.42 (100)	0.76 (2.5)	2.01 (6.6)
Sub-conductor spacing, mm (%)	400 (100)	10 (2.5)	8.2 (2.1)
Equivalent diameter, mm (%)	625.4 (100)	15.6 (2.5)	15.6 (2.5)
Voltage (%)	(100)	(2.5)	(4.6)
Conductor surface electric field (%)	(100)	(100)	(100)

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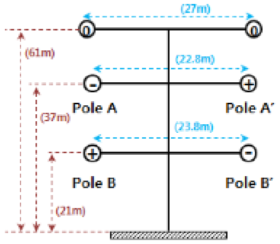
Hardware

<Specifications of the DC power supply>

	Specification	Note
Input voltage	AC220V, 50~60 Hz	
Output voltage	0~±120kV	Variable
Output current	0~±10mA	Variable
Ripple	0.1%	RMS at max. output
Line Regulation	0.01% at±10% input change	
Load Regulation	0.01% at full load	
Efficiency	80% or more at max. output	

<Specifications of the AC power supply>

	Specification	Note
Input voltage	3-phase AC380V, 60Hz	
Output voltage	3-phase 0~30kV	Variable
Output current	580mA	Rating
Rated capacity	3-phase 30kVA	



<HVDC double-bipole in the full-scale line>

Results

- Comparison between converted and measured values of AC 765 kV/±500 kV hybrid transmission line

* The maximum point of the full-scale line ±14m, **Evaluation point of reduced-scale line ±0.4m

		Simulation value* (full-scale)	1/40 Reduced -scale**
Voltage (converted value)		DC500kV with AC765kV	DC20kV(500) with AC30kV
Number of sub-conductor		6	6
Sub-conductor diameter, mm		30.48	2.01
Sub-conductor spacing, mm		400	8.23
Equivalent diameter, mm		625.35	15.62
Lower part ground height, m		23	0.58
Middle part ground height, m		40	1.01
Upper part ground height, m		56	1.40
Lower part pole spacing, m		28.8	0.72
Middle part pole spacing, m		28.4	0.71
Upper part pole spacing, m		27.2	0.68
Electric field reduction factor K_e		1	1.6
Ion current density reduction factor K_p		1	64
Negative pole /Positive pole (converted value)	Electric field L50, kV/m	-11/-3.35	-8.4(-13.44) /-1.9(-3.04)
	Ion current density, nA/m^2	-5.2/-0.5	-1(0)/0(0)

<Comparison between converted and measured values of ±500 kV double-bipole full-scale transmission line>

* The maximum point of the full-scale line ±14m, **Evaluation point of reduced-scale line ±0.4m

		Full-scale*	1/40 Reduced-scale**		
DC Voltage, kV (converted value)		500	20(500)	24.4(500)	30(500)
Number of sub-conductor		6	6		
Sub-conductor diameter, mm		30.48	2.01		
Sub-conductor spacing, mm		400	8.23		
Equivalent diameter, mm		625.35	15.62		
Lower part pole height, m		21	0.525		
Upper part pole height, m		37	0.925		
Lower part pole spacing, m		23.8	0.595		
Upper part pole spacing, m		22.8	0.57		
Conductor surface electric field, kV/cm		17.42 /17.61	14.26 /14.42	17.43 /17.62	21.39 /21.63
Electric field reduction factor K_e		1	1.6	1.95	2.4
Ion current density reduction factor K_p		1	64	78	96
Measured value Negative pole/Positive pole (converted value)	Electric field L50, kV/m	-7.2/6.9	-7.3(-4.6) /7.1(4.4)	-9.0(-4.6) /8.8(4.5)	-11.1(-4.6) /10.8(4.5)
	Ion current density, nA/m^2	-7.0/2.8	-2(0)/2(0)	-3(0)/2(0)	-7(0)/2(0)
Simulation value Negative pole/Positive pole (converted value)	Electric field L50, kV/m	-9.85/7.45	-13.01(-8.1)/13.01(8.1)	-15.88(-8.1)/15.88(8.1)	-20.66(-8.6)/19.52(8.1)
	Ion current density, nA/m^2	-3.53/1.57	0(0)/0(0)	0(0)/0(0)	-77.73(-0.8)/0(0)