SWITCHGEAR COMMITTEE

IEEE PES Switchgear committee
2012 Fall Meeting, San Diego

DS, ES, HSES/HSGS

On behalf of CIGRE WG A3.22/28

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HSES:High Speed Earthing Switch
HSGS:High Speed Grounding Switch

1. High Speed Earthing Switch (HSES) / High Speed Grounding Switch (HSGS)

1.1 Introduction
- Secondary arc and HSES / HSGS
- Four-legged reactor and HSES
- Operating sequence
- Possibility and Influence of successive faults on HSES interruption

1.2 Switching Requirements for HSES
- Categories of fault conditions
- Parametric study by model networks
- Proposed values of duties

2. Bus-transfer current switching by DS

3. Induced current switching by ES

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Secondary arc and HSES / HSGS

HSES (High Speed Earthing Switch) / HSGS (High Speed Grounding Switch) is

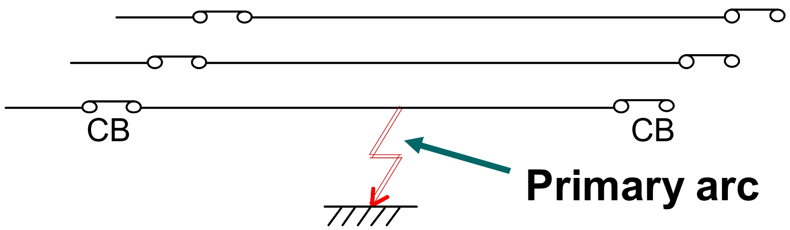
is used for secondary arc extinction.

"High speed earthing switches described in this standard are intended to extinguish the secondary arc remaining after clearing faults on transmission lines by the circuit-breakers." (CDV of IEC62271-112 [1])

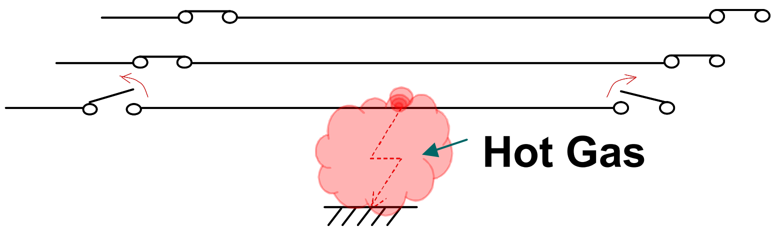
- ✓ High speed re-closing scheme when a ground fault occurred is one of key technologies for keeping the system stability.
- ✓ However, for UHV class high-voltage AC transmission lines, the secondary arc may not self-extinguish in a short time due to electro-static inductions from healthy phases. So the re-closing within due time will be difficult.
- ✓ As a countermeasure for these phenomena, High-Speed Earthing Switches (HSES) are applied for fast extinction of secondary arcs.

Secondary arc ?

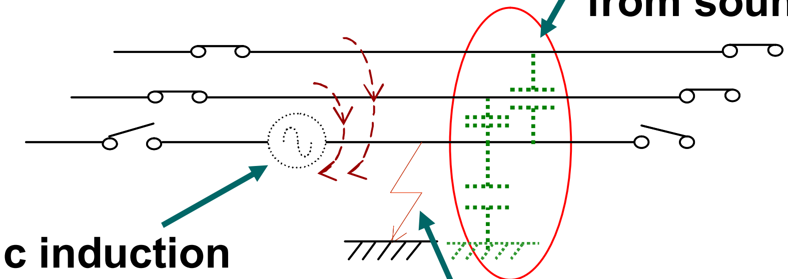
Transmission fault occurs



CBs clear the faulted phase



Secondary arc induced



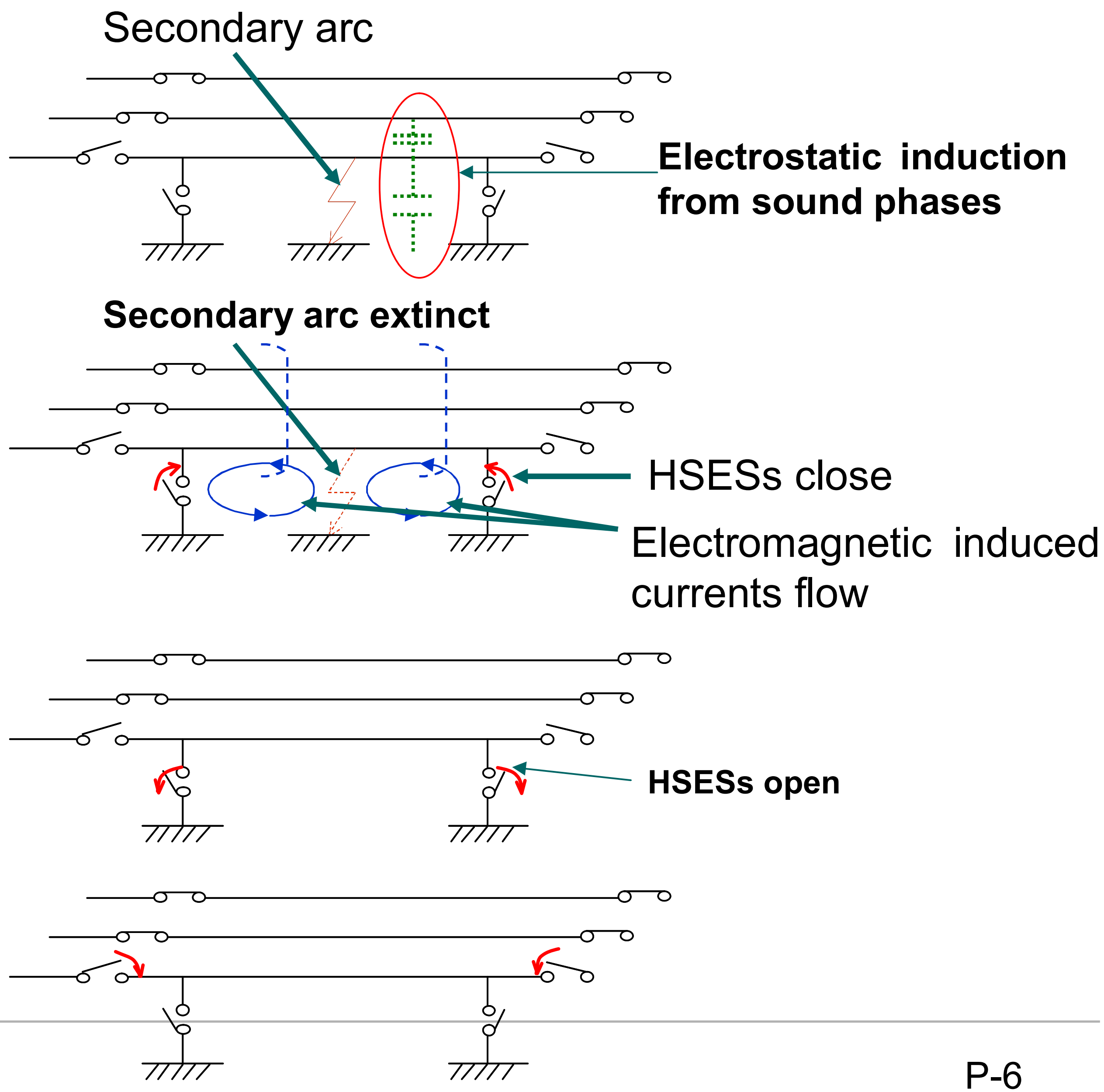
Secondary arc extinction by HSES

Secondary arc induced

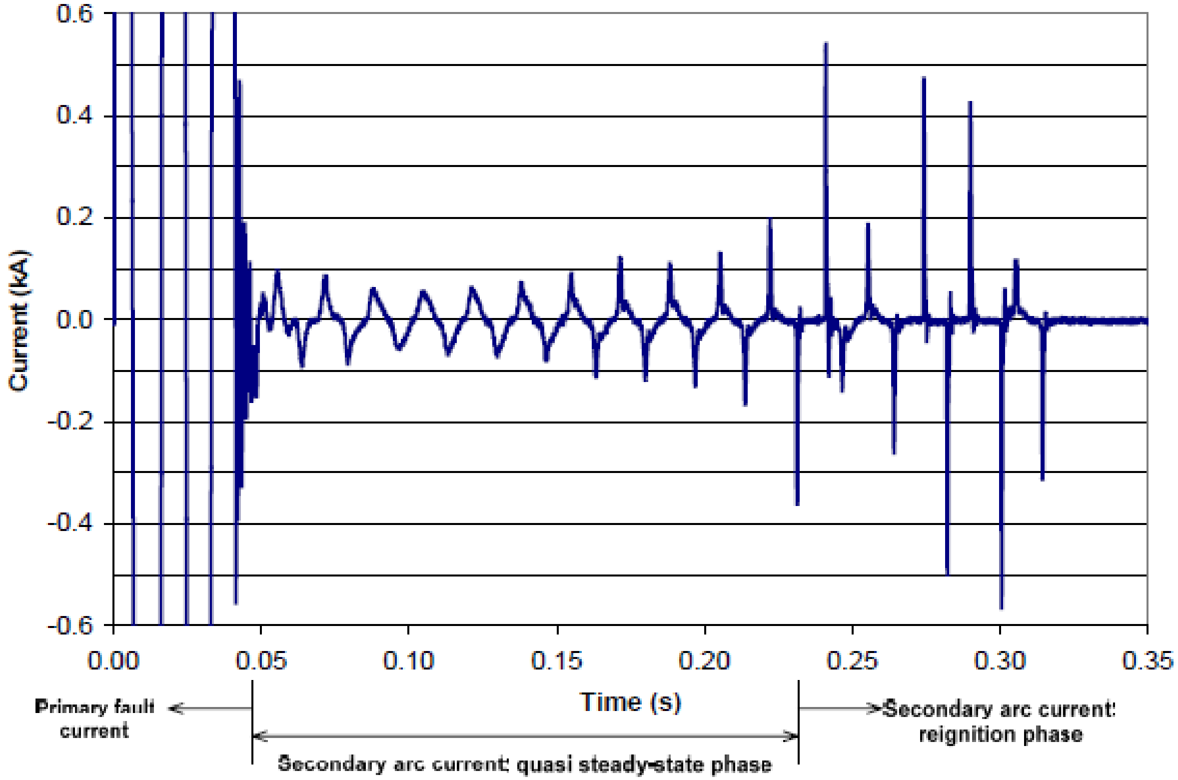
HSES at each end close to clear the secondary arc

HSES at each end open

CBs at each end reclose



Secondary arc



Measured primary arc (10 kA peak) followed by the secondary arc (BC Hydro, 2004) [2][3]

The current has two phases:

1) a quasi steady-state phase

2) a reignition phase (leading to arc extinction)

HSES / HSGS is

The HSES has been applied

From early 1980's in BPA (USA) systems for 500kV [4]

HSGS for 550kV system in BPA

HSES / HSGS is

The HSES has been applied

Since 2002 in KEPCO (Korea) 765kV systems [5] [6]

HSGS for 800kV system in KEPCO

HSES / HSGS is

For 1100/1200kV AC transmission systems HSES are envisaged to be used in certain cases.（Japan, China） [7] [8]

TEPCO UHV testing station

(CB) (HSES) (DS)

HSGS for TEPCO UHV testing station

Comparison of earthing switch, fast acting earthing switch and HSES [1]

Requirement	Earthing switch (Class E0 in IEC 62271-102)	Fast acting earthing switch (Class E1 (& E2) in IEC 62271-102)	High speed earthing switch for secondary arc extinction (HSES)
Closing	Slow motion e.g. Hand operated	Fast (High speed) closing operation	Fast (High speed) closing operation, controlled
Opening	Slow motion e.g. Hand operated	Slow motion May be hand operated	Fast opening, controlled
Making capability	None Must carry the full short circuit current	Must be able to make and to carry the full short circuit current	Must be able to make and to carry the full short circuit current
Clearing capability	none	none	Must be able to interrupt induced current and to withstand a TRV
Operating cycle	none	close	Close- open
endurance	Withstand capability against full short circuit current	2 (or 5) closings against full short circuit current	2 closings against full short circuit current

Four-legged reactor and HSES

- ✓ Four-legged reactors are also one of suitable measures for fast extinction of secondary arcs on the line.

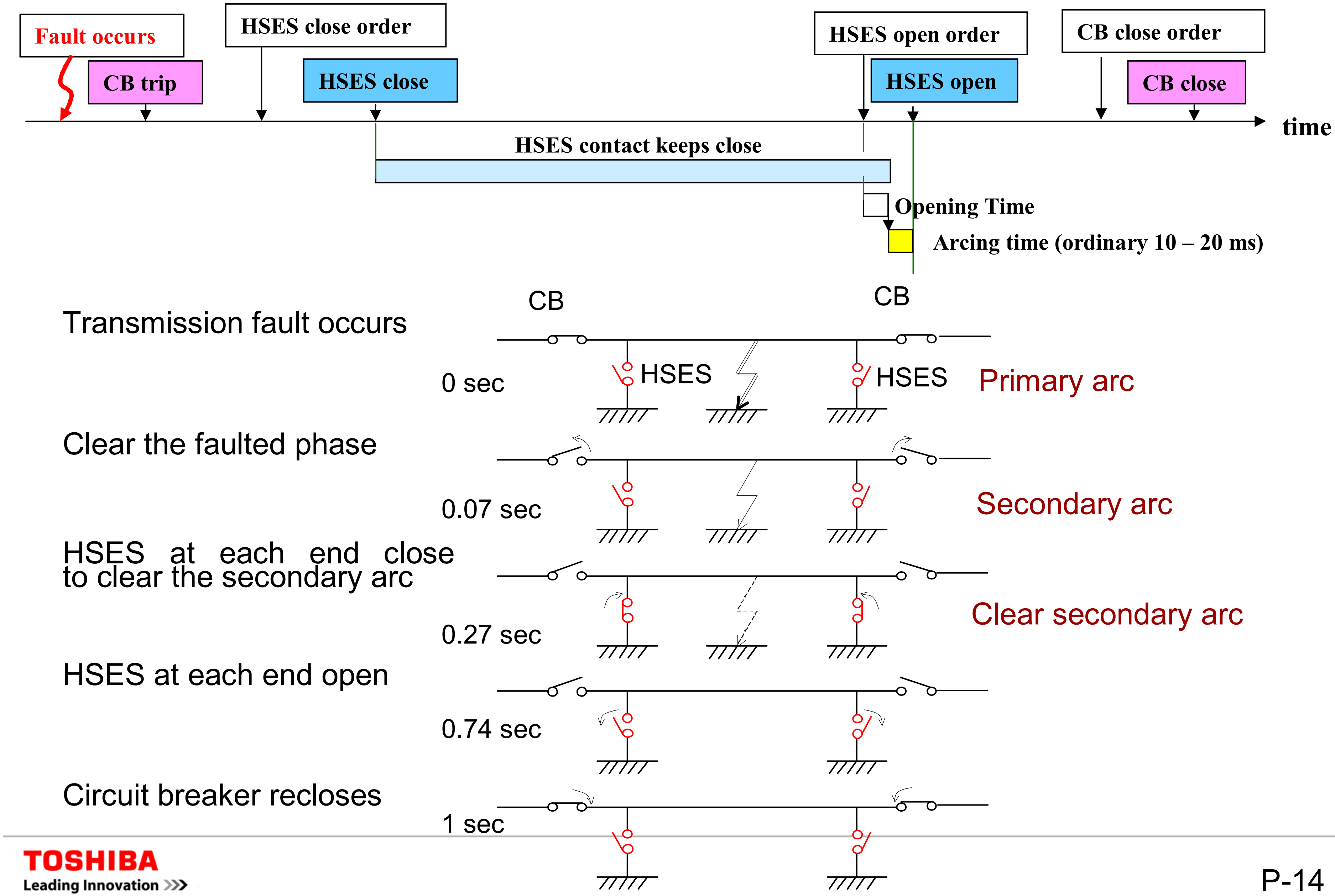
- ✓ Utilities can choose HSES solution when,
  - the reactive compensation by shunt reactors is not needed.
  or
  - they want to extinguish the secondary arc in the required time surely under various fault modes.

  - Especially for short distance lines without shunt reactors or for double circuit systems with multi-phase auto-reclosing scheme, where 4-legged reactors are not suitable, one of the useful and important means is to apply HSES for the purpose of secondary arc extinction.

Comparison between Four-legged reactor and HSES [1]

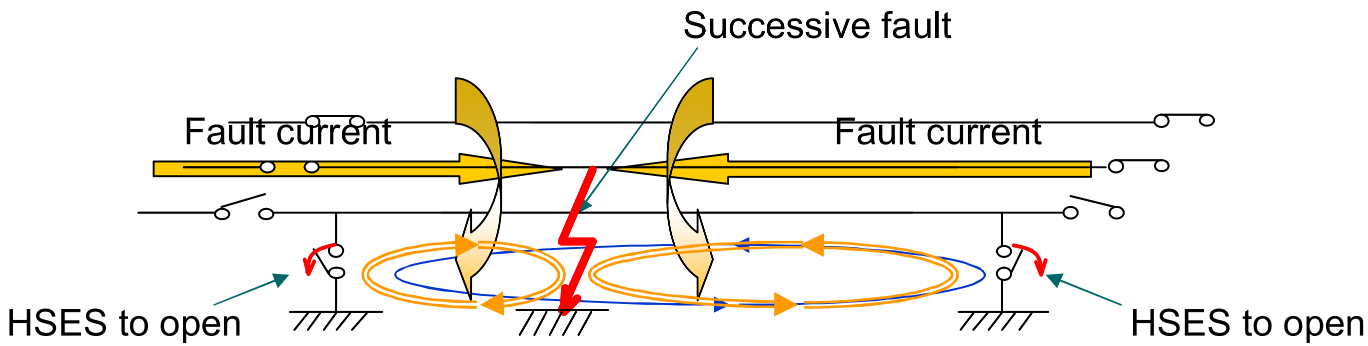
	4-legged reactor	HSES
Secondary arc extinction	- Effective especially for single-phase faults that hold the majority of the faults. - Difficult to choose a reactance value of reactors that effectively reduce the secondary arc current for all fault modes.	- Quick extinction for all fault modes.
Flexibility to the change of network	- In case a substation is constructed in the middle of a line, it might be required to substitute a reactor that has already installed.	- Not affect on the substation equipment that has already installed.
Control /Protection	- Special control is unnecessary for secondary arc extinction.	- Automatic sequential control such as "fault detection → CB open → HSES close → HSES open → CB close" is necessary in each phase, and it can be easily realized.
Economy	- Four-legged shunt reactor is appropriate for transmission lines which require shunt reactors for voltage control, while HSES would be economical for the lines without shunt reactors.	
Concern	- Detailed analysis is necessary so as not to cause resonance between shunt reactor inductance and line capacitance not only in power frequency of 50/60Hz but also in the high frequency band.	- Highly reliable control system is required since a mal-function leads to a ground fault.

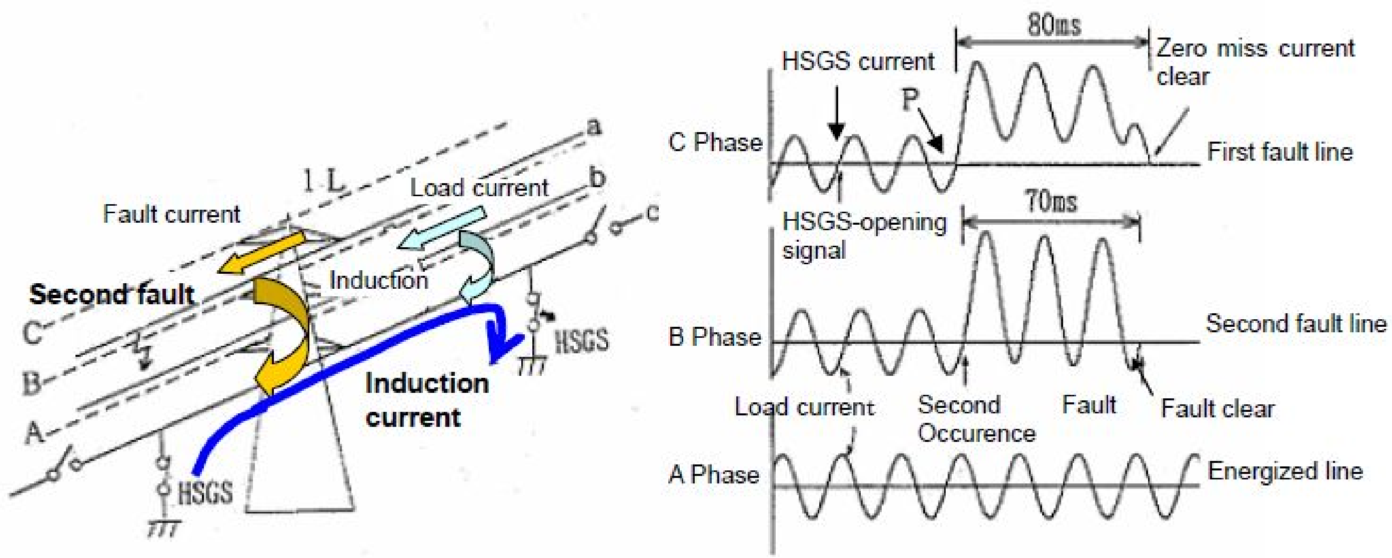
Typical operating sequence of HSES and CB



Possibility and Influence of successive faults on HSES interruption

Successive fault is Additional fault at the time of opening of HSES





The severest case for HSGS in which a second fault follows just before HSGS breaks the electromagnetic induction current at point P.

Possibility and Influence of successive faults on HSES interruption

Data provided by TEPCO, Japan

Field data in TEPCO (collaboration with CIGRE WG C4.306)

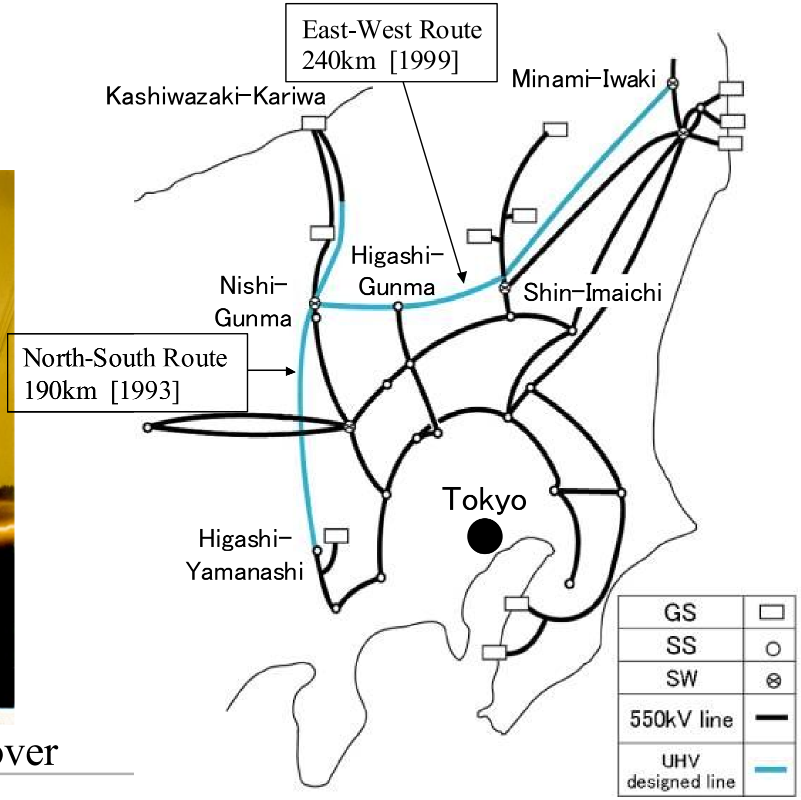
Fault rate of UHV designed transmission lines※ (cases / 100 km-year)			
Direct lightning strokes 1LG	Back- flashover 1LG	Direct or Back-flashover 2LG	Total of lightning fault
0.617	0.059	0.0294	0.705

※ now operating at 550kV.

Direct lightning stroke

to the upper phase line

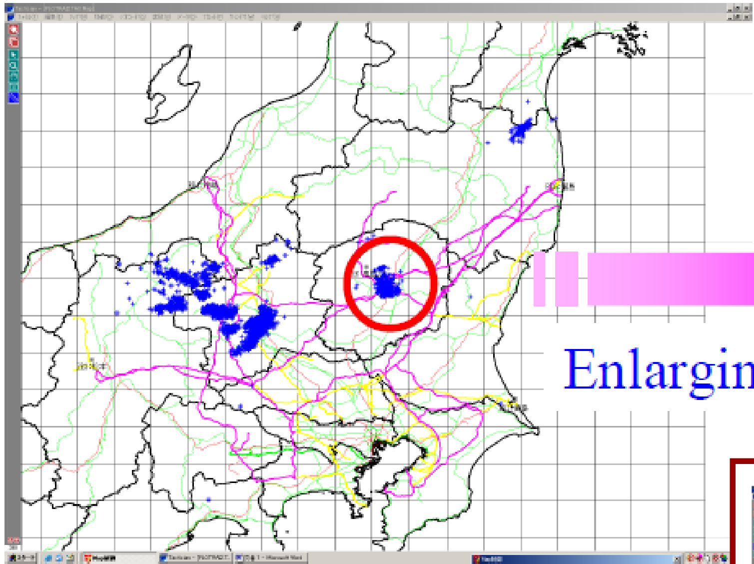
to the middle phase line and flashover



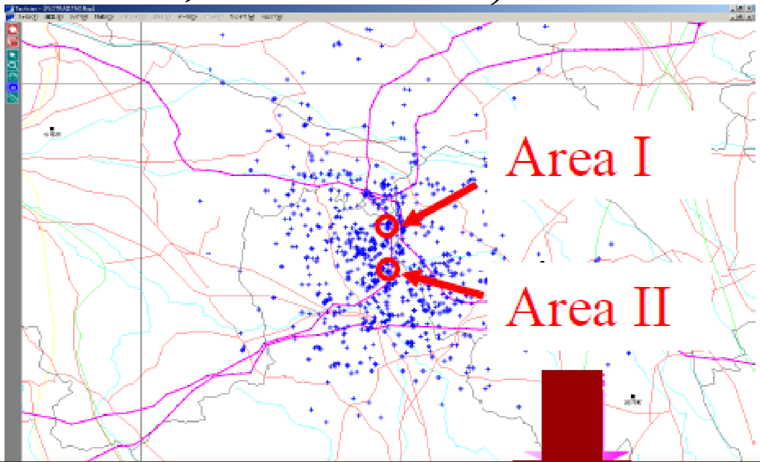
Location of the lightning strokes in TEPCO

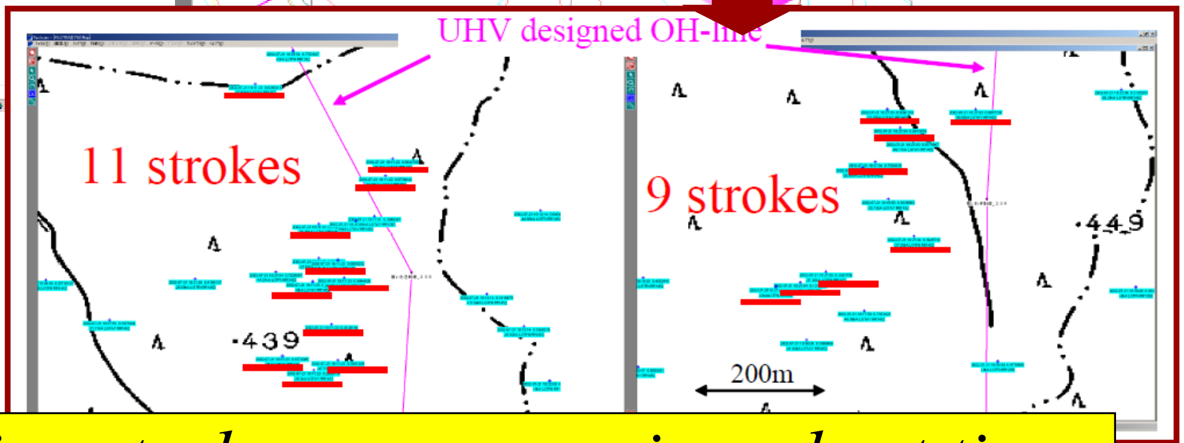
The location of the lightning strokes in summer observed by the lightning location system
（Observation time: 1 hour, 18:00-18:59, 2002/7/21)

Data provided by TEPCO, Japan



Enlarging





Red underline shows
the lightning strokes in 1 second.

Several lightning strokes can occur in a short time (less than 1 second) along the transmission lines.

Possibility and Influence of successive faults on HSES interruption

◆Probability of multiple & successive lightning (in coordination with WG C4.306)

Multiple lightning strokes within 1 second as well as successive direct lightning strokes were definitely observed along UHV OH line during 8 year measurements at the substations.

The possibility of the successive fault due to a direct lightning stroke cannot be disregarded. And then, successive fault as a study condition of HSES's specifications should be adopted.

◆Impact on network and user's policy on UHV / EHV line

UHV / EHV transmission lines carry huge bulk power and a fail of HSES interruption for a successive fault cause serious impact (ex. collapse of the stability) to the network.

Switching duties considering successive faults

Majority of HSES users adopt duty under successive faults.

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Switching Requirements for HSES

Technical requirements for HSES specified for UHV / EHV systems

	BPA (USA)	KEPCO (Korea)	TEPCO (Japan**)	SGCC (China)
Highest voltage	550	800	1100	1100
Interrupting current (kA)	700	8000	7000	TBA
TRV peak* (kV)	260	700	900	TBA
RRRV (kV/μs)	0.2	1.3	1.15	TBA

****TRV peak for Electro-statically induced current interruption***

***** Japan specify additional duty for delayed current zero interruption separately***

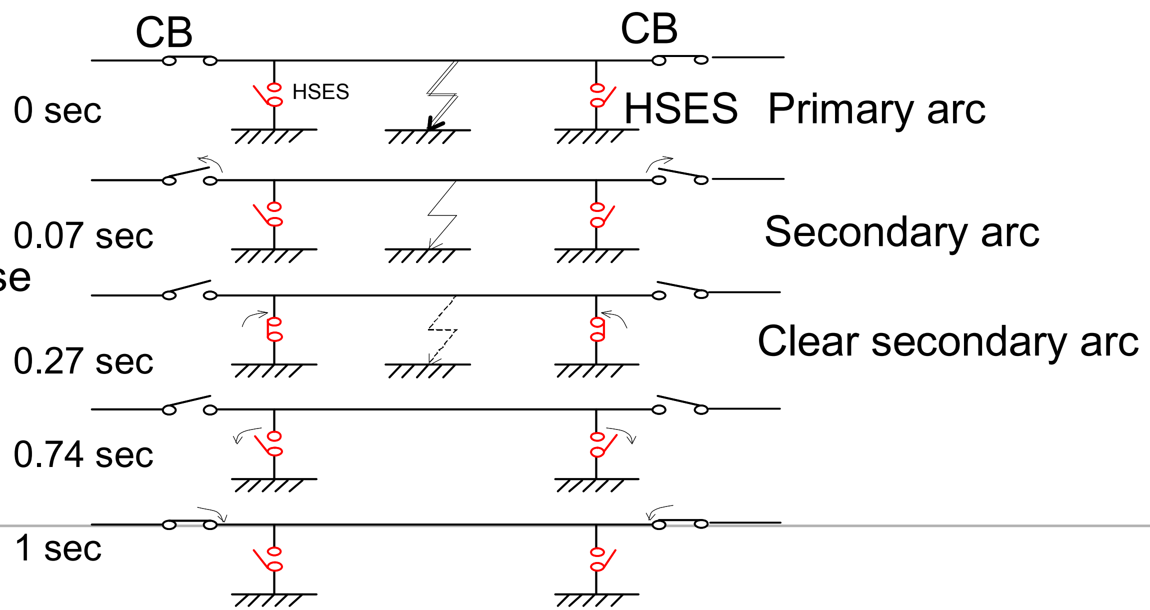
Transmission fault occurs

Clear the faulted phase

HSES at each end close to clear the secondary arc

HSES at each end open

Circuit breaker recloses



Categories of fault conditions

Depending on fault modes & operating sequence [1][10][11]

Category	Description
Category 0	This is a basic case. Only one single-line earth fault occurs within the transmission circuits. For both electromagnetic and electrostatic duties, the currents to be interrupted and recovery voltages are low. The values of category 0 are covered by those of Category 1.
Category 1	One single-phase earth fault plus another single-phase earth fault on different circuit without successive fault. This is the case that up to one single-phase earth fault within each circuit in a double-circuit system. This Category will be covered by class H1 in [3]
Category 2	This is the case that a successive single-phase earth fault occurs during HSES opening operation at the phase where the first single-phase earth fault occurs. Successive fault may occur in the same circuit or in the other circuit located in the vicinity of the circuit with a faulted line. This Category will be covered by class H2 in [3]
Category 3	This is the case that a single-phase earth faults with delayed current zero phenomena occurs in the presence of a successive single-phase earth fault. During the delayed current zero period HSES should be withstood against the stress caused by the arc generated between the contacts of HSES.
Category 4	This is the case that multi-phase faults occur within two or more phase circuits which are located in the vicinity each other. At least two different phases should be remained without fault condition.

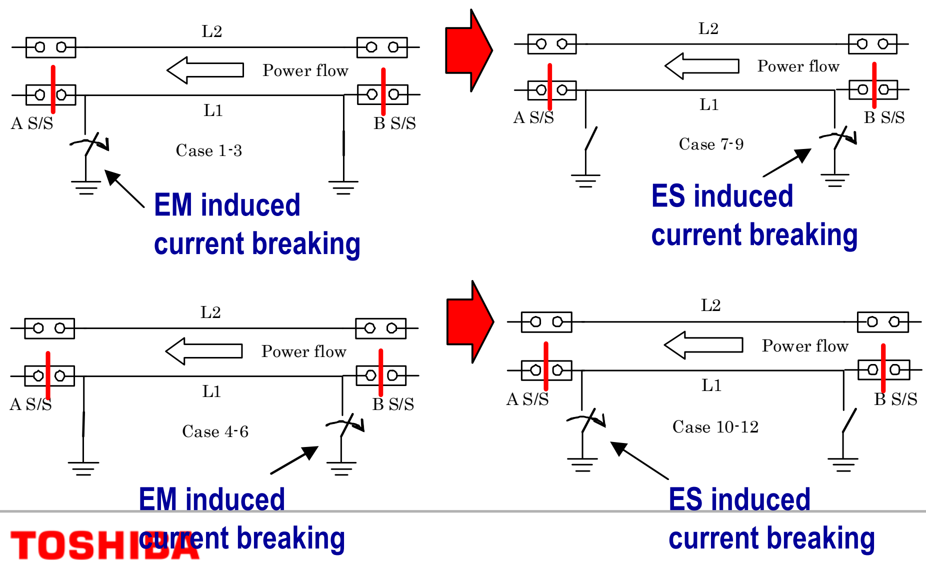
Calculations of duties

Categories depending on fault modes and operating sequence

Class	Category	Description
H1	0	Basic case : Only one single-line earth fault occurs within the transmission line.
	1	One single-phase earth fault plus another single-phase earth fault on different circuit without successive fault.
H2	2	One single-phase earth fault plus another single-phase earth fault on different circuit with successive fault.

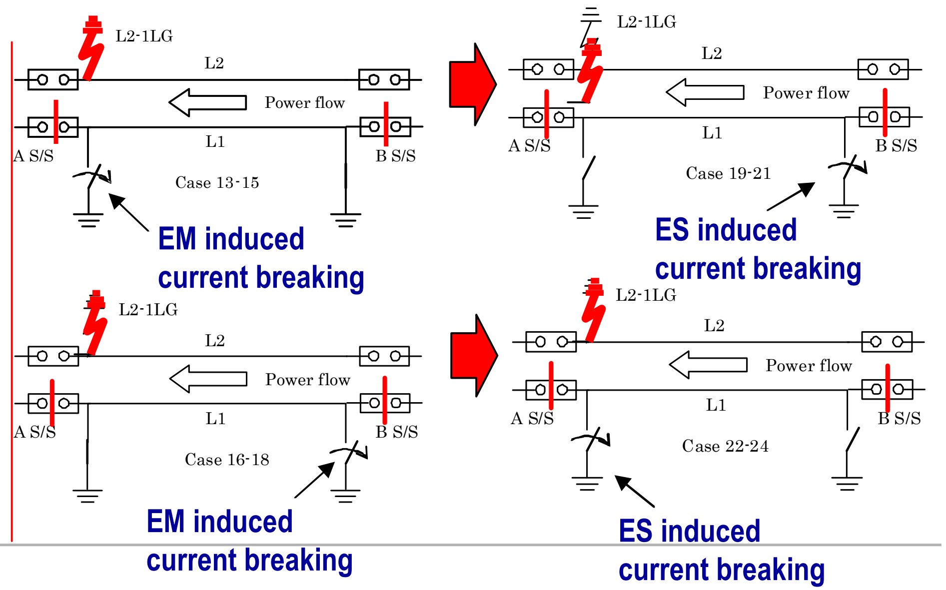
Analytical circuit for Category- 0 & 1

Electromagnetic (EM) **Electrostatic (ES)**



Analytical circuit for Category- 2

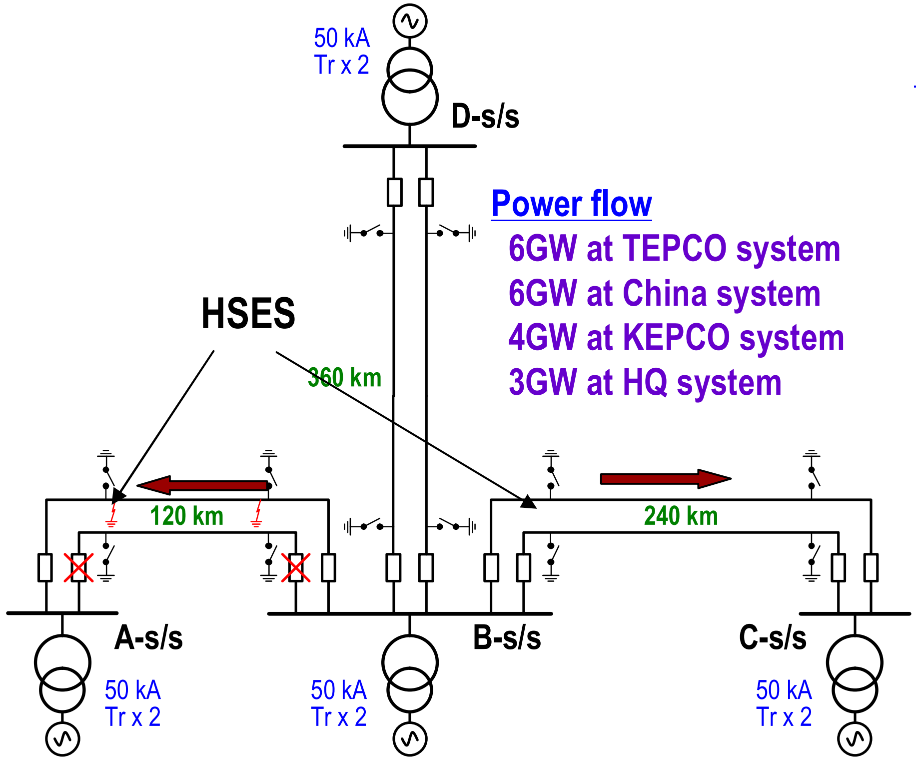
Electromagnetic (EM) **Electrostatic (ES)**



Parametric study with model network

Study on HSGS / HSES switching requirements in model networks is done by CIGRE WG A3.28

- ➢Effect of system voltage, line length, power flow, tower configuration
- ➢HSGS/HSES duties for different classifications proposed by IEC PT-48
- ➢Probability and effect of successive faults



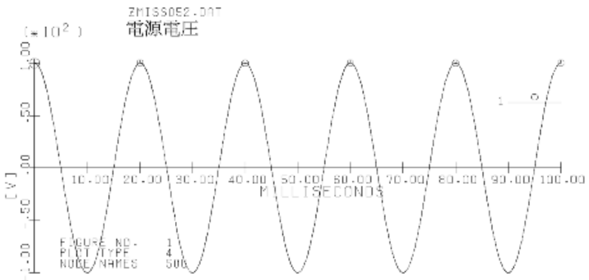
Analytical model and case for HSES

Tower configuration

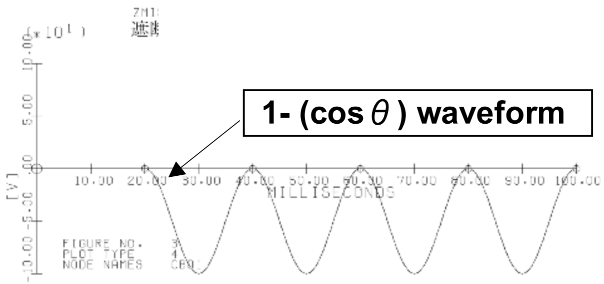
- •1100kV Double circuit tower of TEPCO (Japan)
- •1100kV Double circuit tower of SGCC (China)
- •800kV Double circuit tower of KEPCO (Korea)
- •2 x 800kV Single circuit tower of HQ (Canada)

Example of calculated waveforms

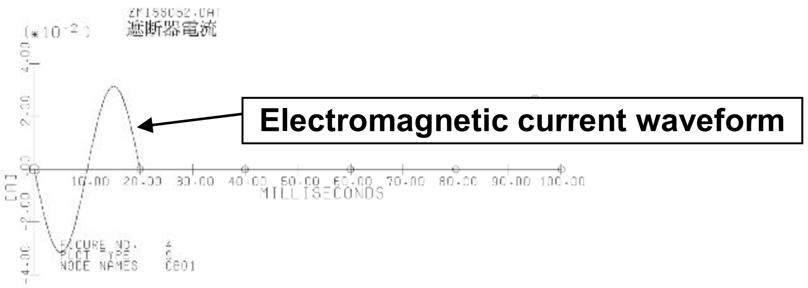
interrupted simultaneously



(a) Voltage wave form



(c) TRV waveform on HSESs

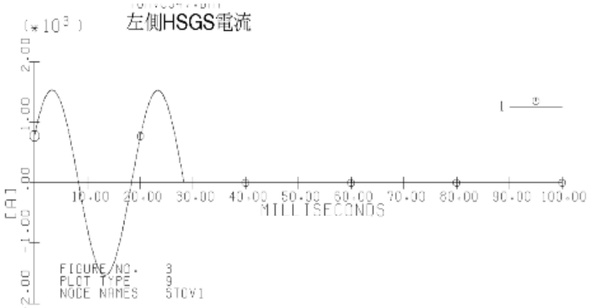


(b) Breaking current on HSESs

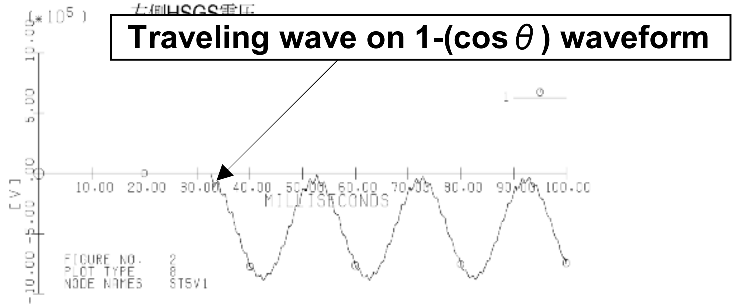
•interrupting current is of electromagnetic induced one and recovery voltage is of electrostatic

Example of calculated waveforms

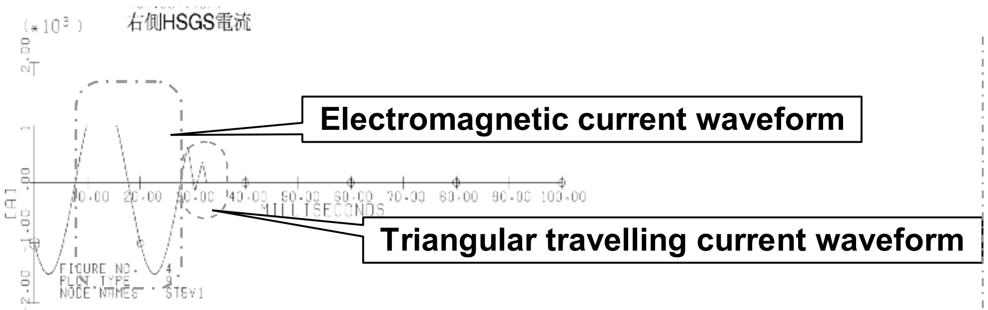
interrupted with small time difference



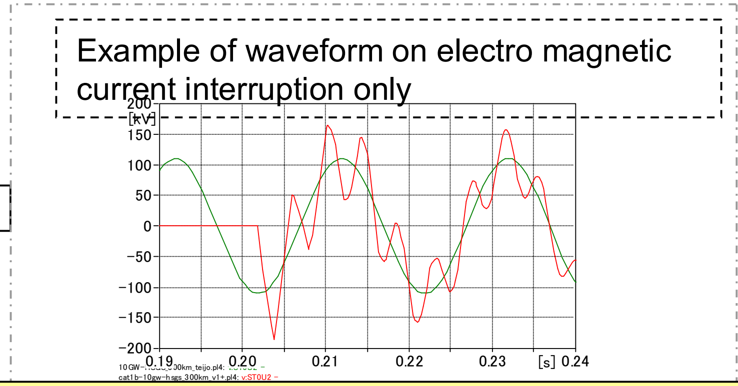
(a) Breaking current on 1st breaking HSES



(c) TRV waveform on HSES



(b) Breaking current on 2nd breaking HSES



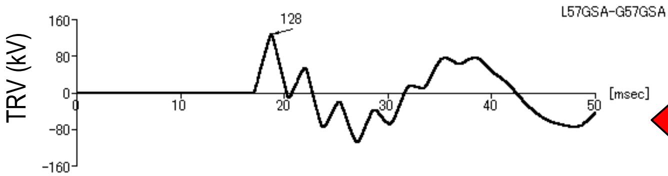
- **First HSES** interrupts electromagnetic induced current, and triangular travelling voltage & current wave appears on the transmission line.
- Recovery voltage for first HSES will be triangular wave. After last HSES interrupts recovery voltage will be of electrostatic.
- The current for **later HSES** changes from electromagnetic induced current to the triangular travelling current just before current zero.
- Recovery voltage for later HSES will be small triangular wave on the electrostatic recovery voltage.

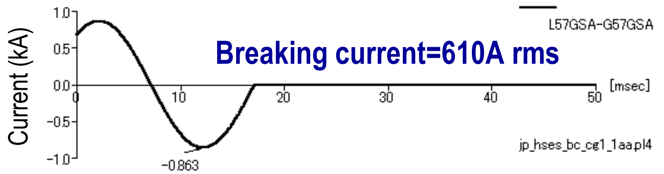
TEPCO and China 1100 kV model

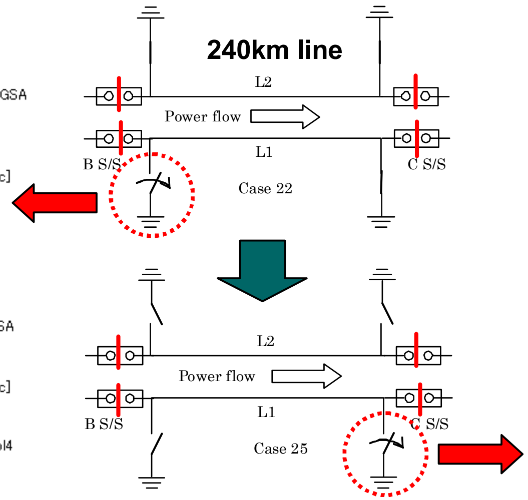
Typical waveforms

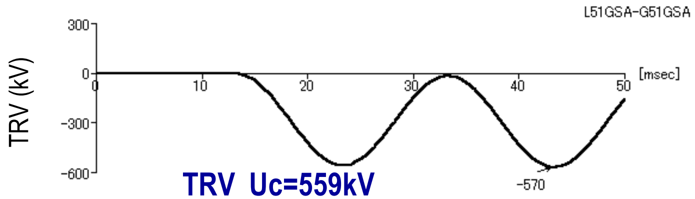
Electromagnetic (EM)	Category-1	Electrostatic (ES)

TRV
Uc=128kV, dv/dt=0.088kV/us

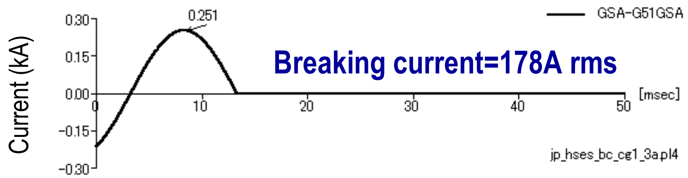






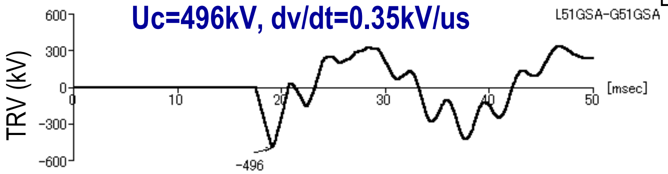


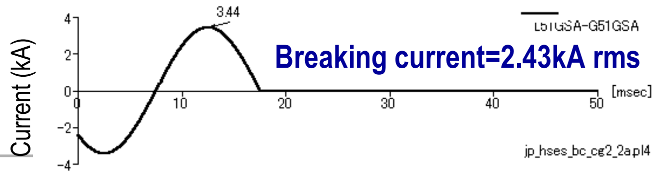
TRV Uc=559kV

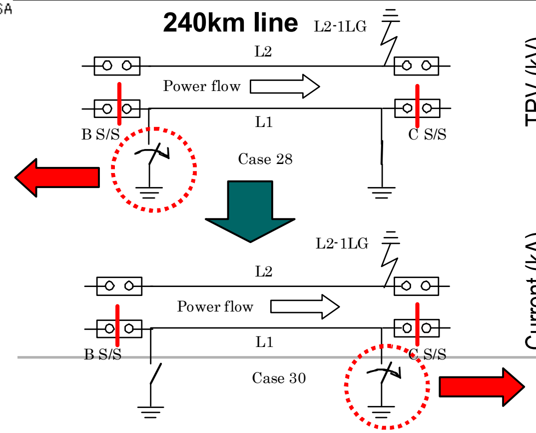


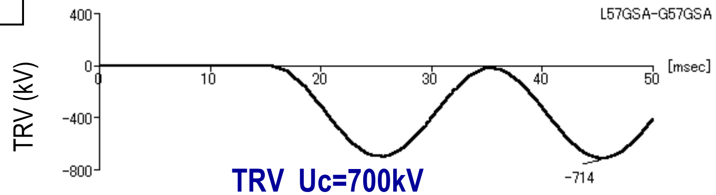
Category-2

TRV
Uc=496kV, dv/dt=0.35kV/us

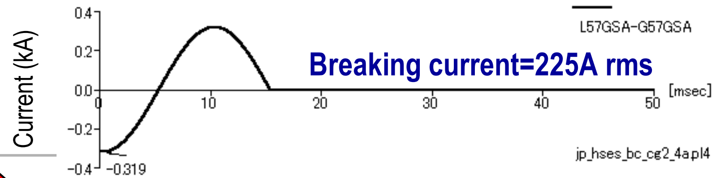






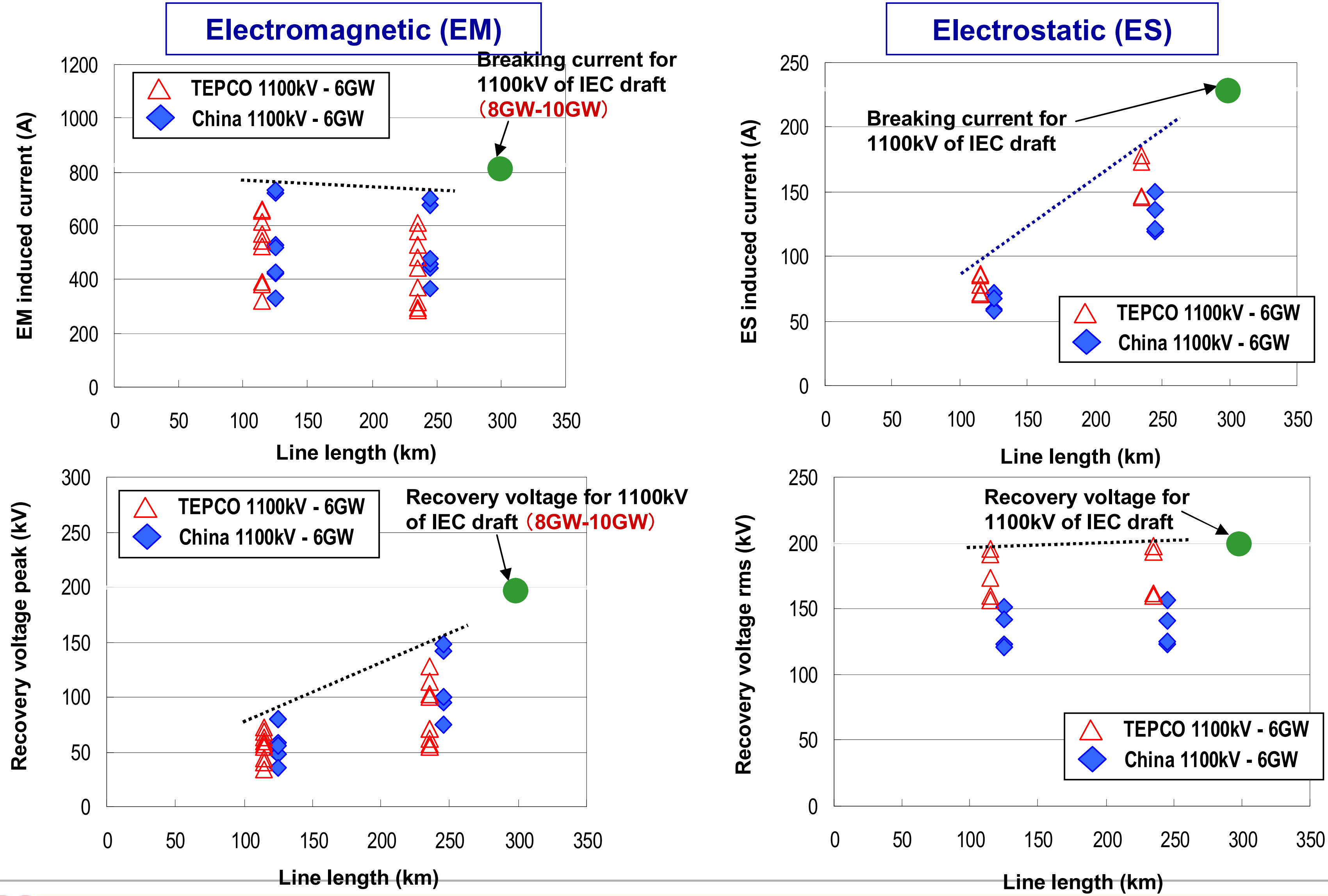


TRV Uc=700kV



TEPCO and China 1100 kV model

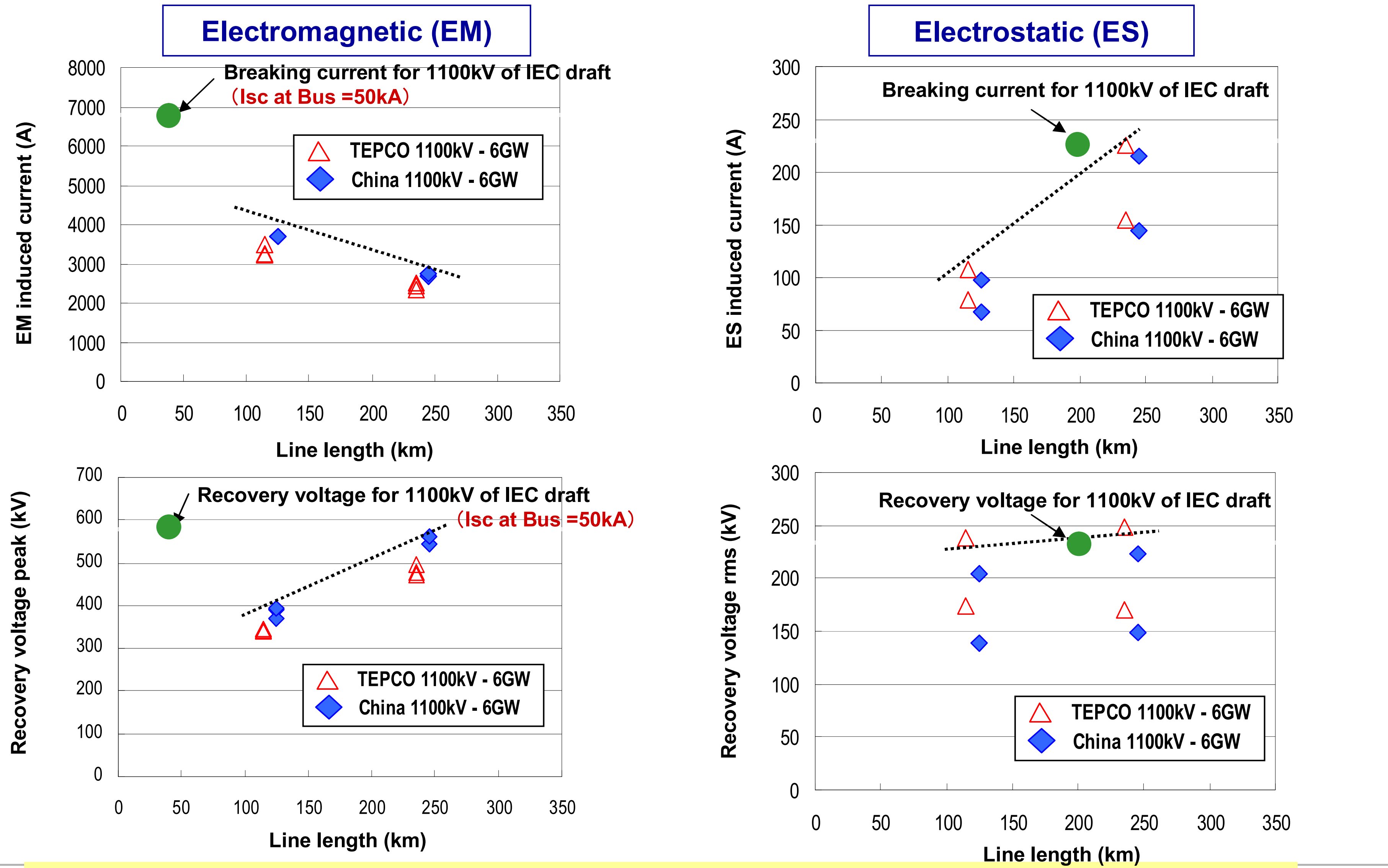
Induced current breaking results for class H1 (category 0 & 1)



Induced currents and recovery voltages of category 0 and 1 are covered by IEC draft.

TEPCO and China 1100 kV model

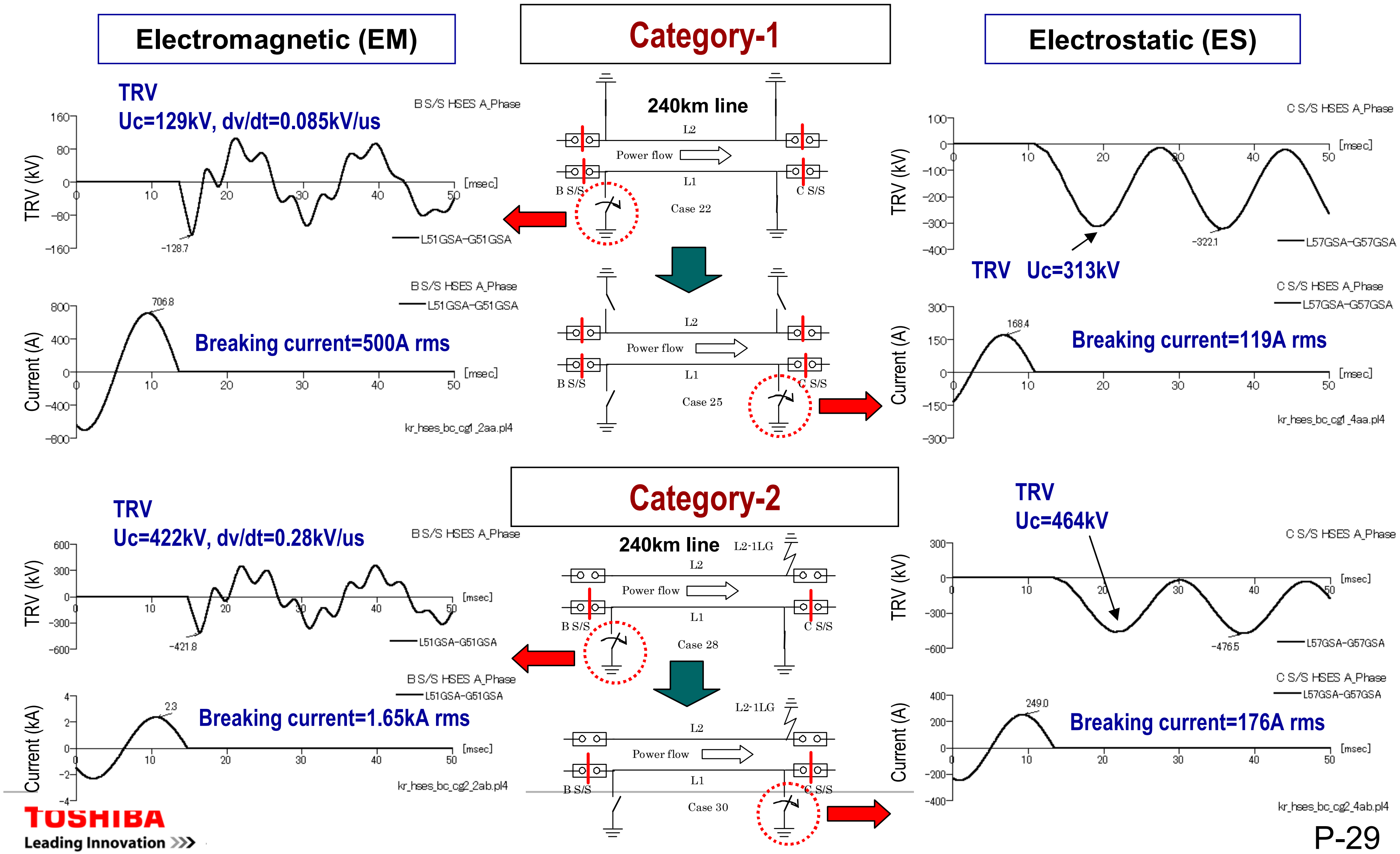
Induced current breaking results for class H2 (category 2)



Induced currents and recovery voltages of category 2 are also covered by IEC draft.

KEPCO and HQ 800 kV model

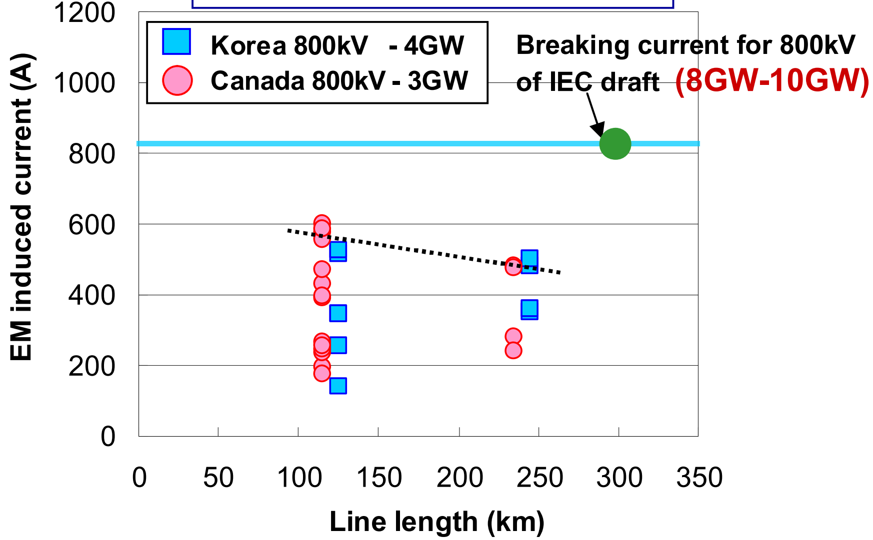
Typical waveforms



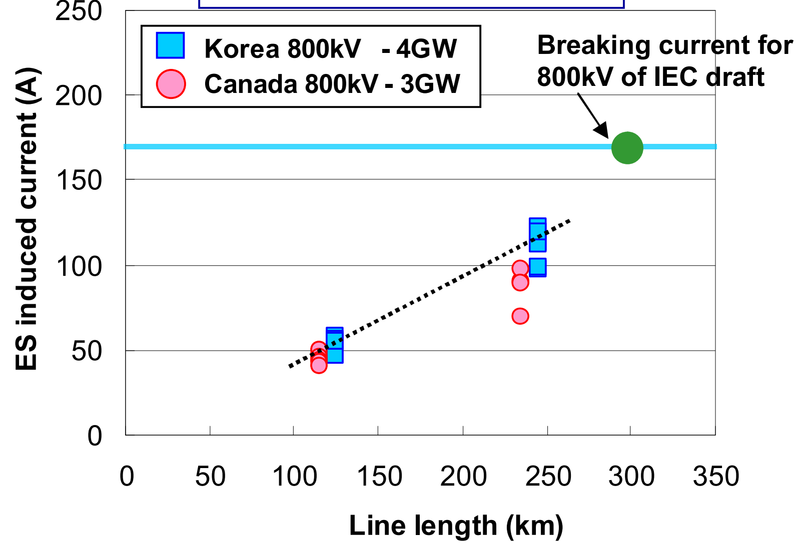
KEPCO and HQ 800 kV model

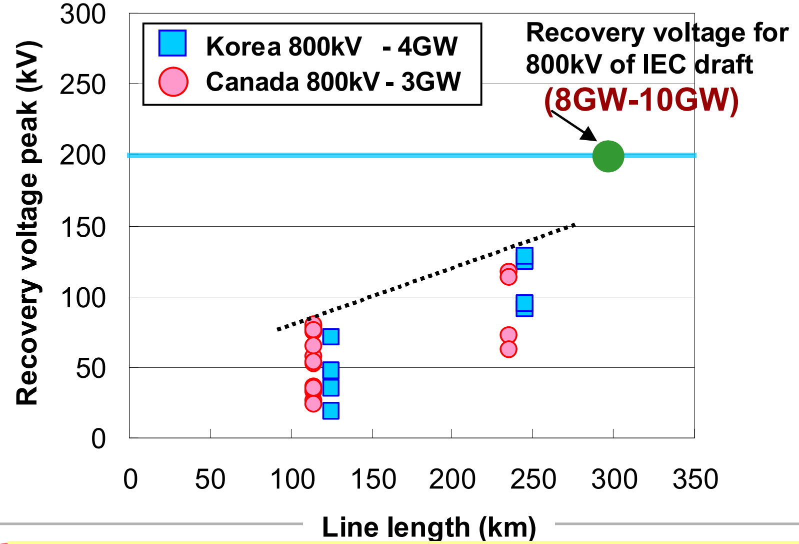
Induced current breaking results for class H1 (category 0 & 1)

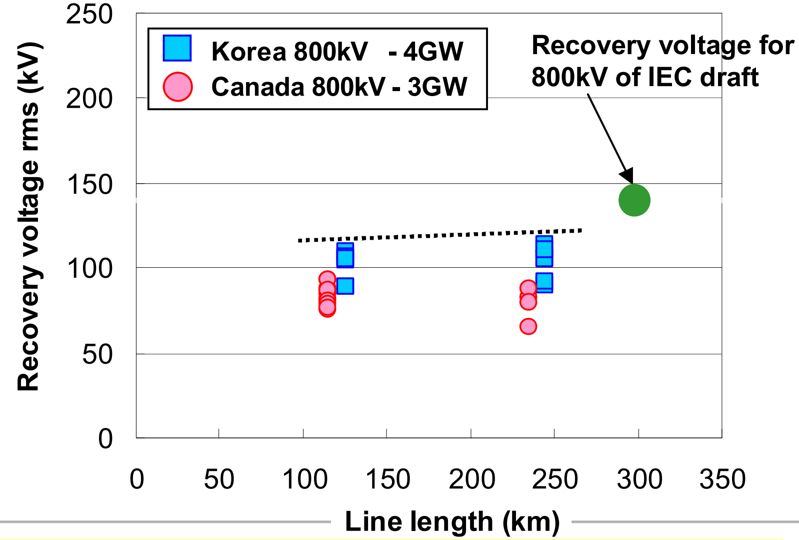
Electromagnetic (EM)



Electrostatic (ES)



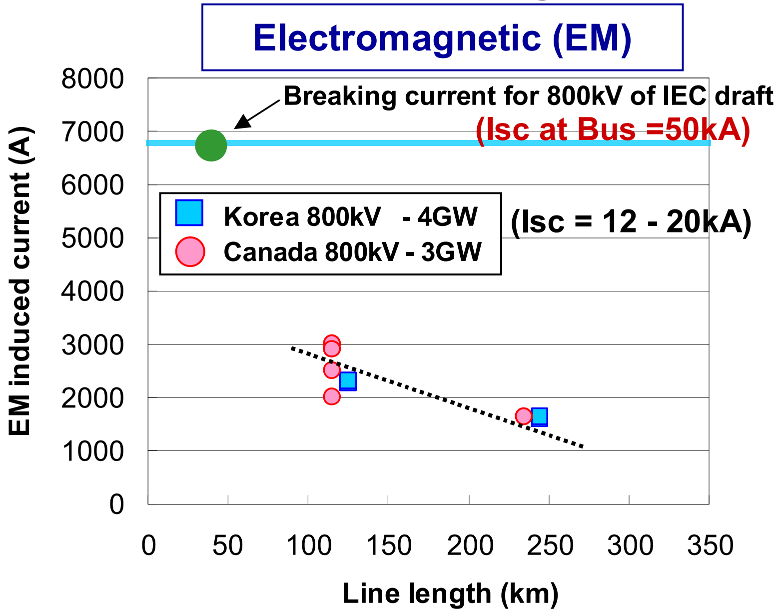


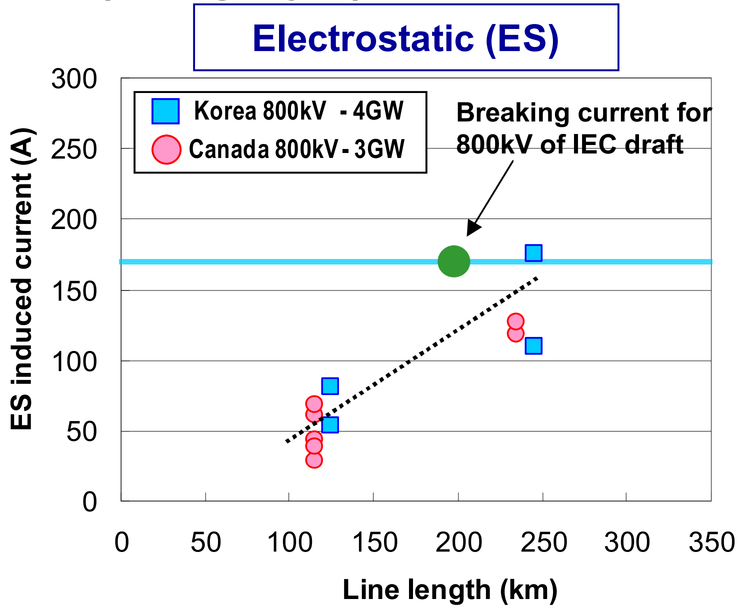


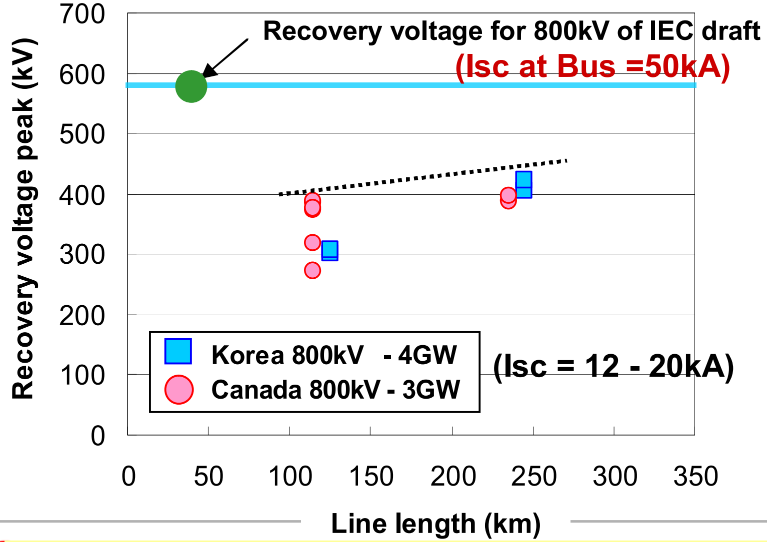
Induced currents and recovery voltages of category 0 and 1 are covered by IEC draft.

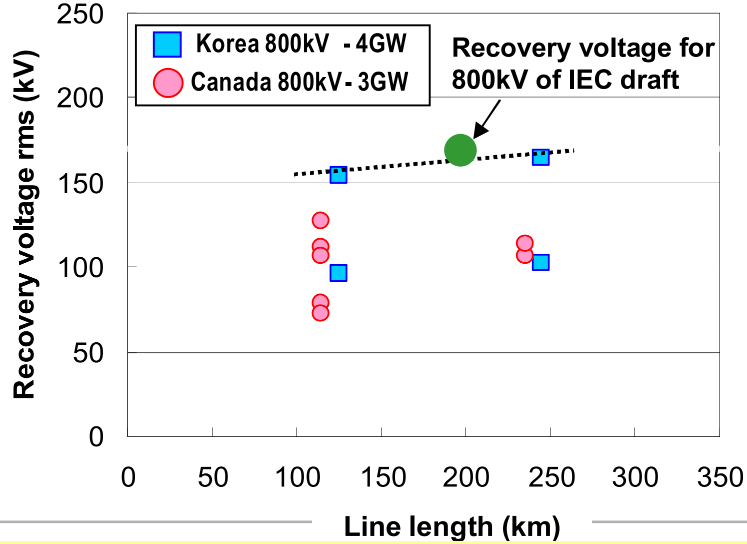
KEPCO and HQ 800 kV model

Induced current breaking results for class H2 (category 2)









Induced currents and recovery voltages of category 2 are also covered by IEC draft.

Proposed values of duties

Calculation results and proposed values (1100 and 1200kV)

Comparison between calculated value and proposed value	Electromagnetic coupling				Electrostatic coupling	
	Rated induced current A(rms)	Rated power frequency recovery voltage kV(rms)	First TRV peak kV	Time to first peak ms	Rated induced current A(rms)	Rated induced voltage kV(rms)
Category 1(1)	744 (832)(3)	76	189	1,92 (1.0)(4)	228	196
Class H1	830	80	200	1,0	230	200
Category 2(2)	6832	232	576	0,6	177	235
Class H2	6800	240	580	0,6	230	235

One set of duties is proposed for the standard [9]

17A/998/CDV (committee draft for vote [1]) is approved, and now at the stage for FDIS.

Rated voltage *Ur* kV	Electromagnetic coupling				Electrostatic coupling	
	Rated induced current A(rms)	Rated power frequency recovery voltage kV(rms)	First TRV peak kV	Time to first peak ms	Rated induced current A(rms)	Rated induced voltage kV(rms)
550	6800	240	580	0,6	120	115
800	6800	240	580	0,6	170	170
1100-1200	6800	240	580	0,6	230	235

IEC 62271-112 Ed 1.0: High-voltage switchgear and controlgear - Part 112:
Alternating current high-speed earthing switches for secondary arc extinction on transmission lines

1. High Speed Earthing Switch (HSES) / High Speed Grounding Switch (HSGS)

1.1 Introduction
- Secondary arc and HSES / HSGS
- Four-legged reactor and HSES
- Operating sequence
- Possibility and Influence of successive faults on HSES interruption

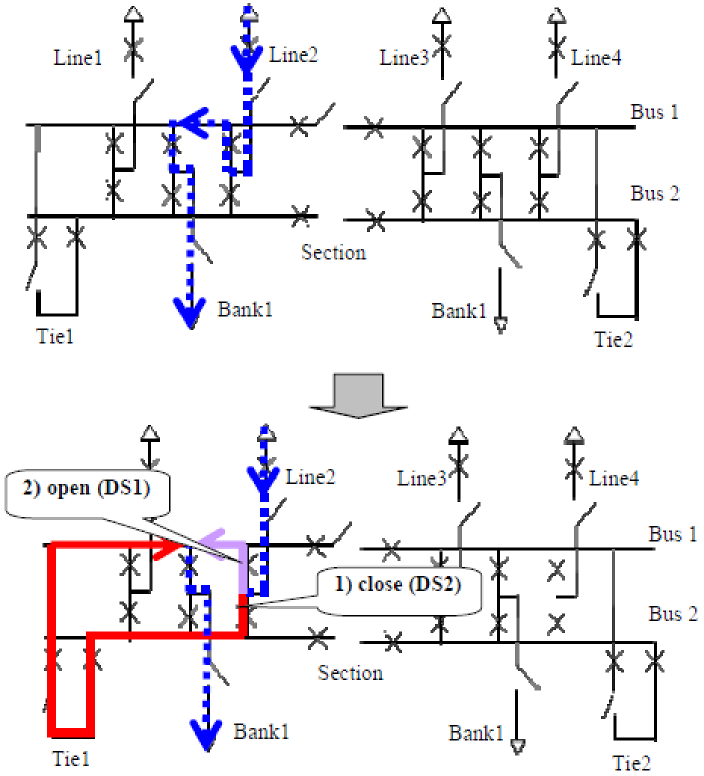
1.2 Switching Requirements for HSES
- Categories of fault conditions
- Parametric study by model networks
- Proposed values of duties

2. Bus-transfer current switching by DS

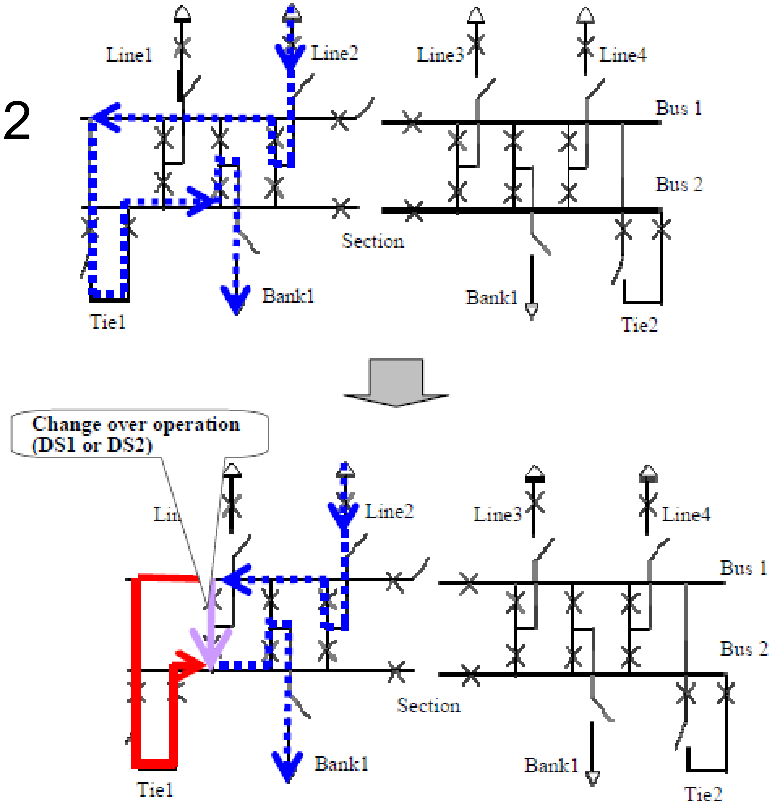
3. Induced current switching by ES

2. Bus-transfer current switching by DS

Case 1



Case 2



Specification for the UHV projects [2]

	IEC62271-102	Japan (GIS)	China pilot (GIS or MTS)
Interrupting current	80% of rated normal current, not exceeded 1600 A	8000 A for 1100 kV Maximum rated normal current	1600 A for 1100 kV In accordance with existing standard
Voltage	AIS: 300 V rms GIS: 40 V rms	300 V rms 400 V/μs	400 V rms

Bus-transfer current switching by DS

IEC62271-102 Annex B (normative) [12]

Applied to AC disconnectors, with rated voltages of 52 kV and above, capable of switching bus-transfer currents.

B.4.106.1 Rated -transfer current

The value of the rated bus-transfer current for both air-insulated and gas-insulated disconnectors shall be 80 % of the rated normal current. It will normally not exceed 1 600 A, irrespective of the rated normal current of the disconnector.

NOTE A maximum rated bus-transfer current of 1 600 A was chosen as being typically the highest current which can be switched even though the rated normal current of the disconnector may be substantially greater. It is common practice to select disconnectors based on the short-time current ratings as well as the rated normal current. The maximum continuous current carried by the disconnector, therefore, may be considerably less than the rated normal current. Rated bus-transfer currents greater than 80 % of the rated normal current or greater than 1 600 A may be assigned by the manufacturer.

B.4.106.2 Rated bus-transfer voltage

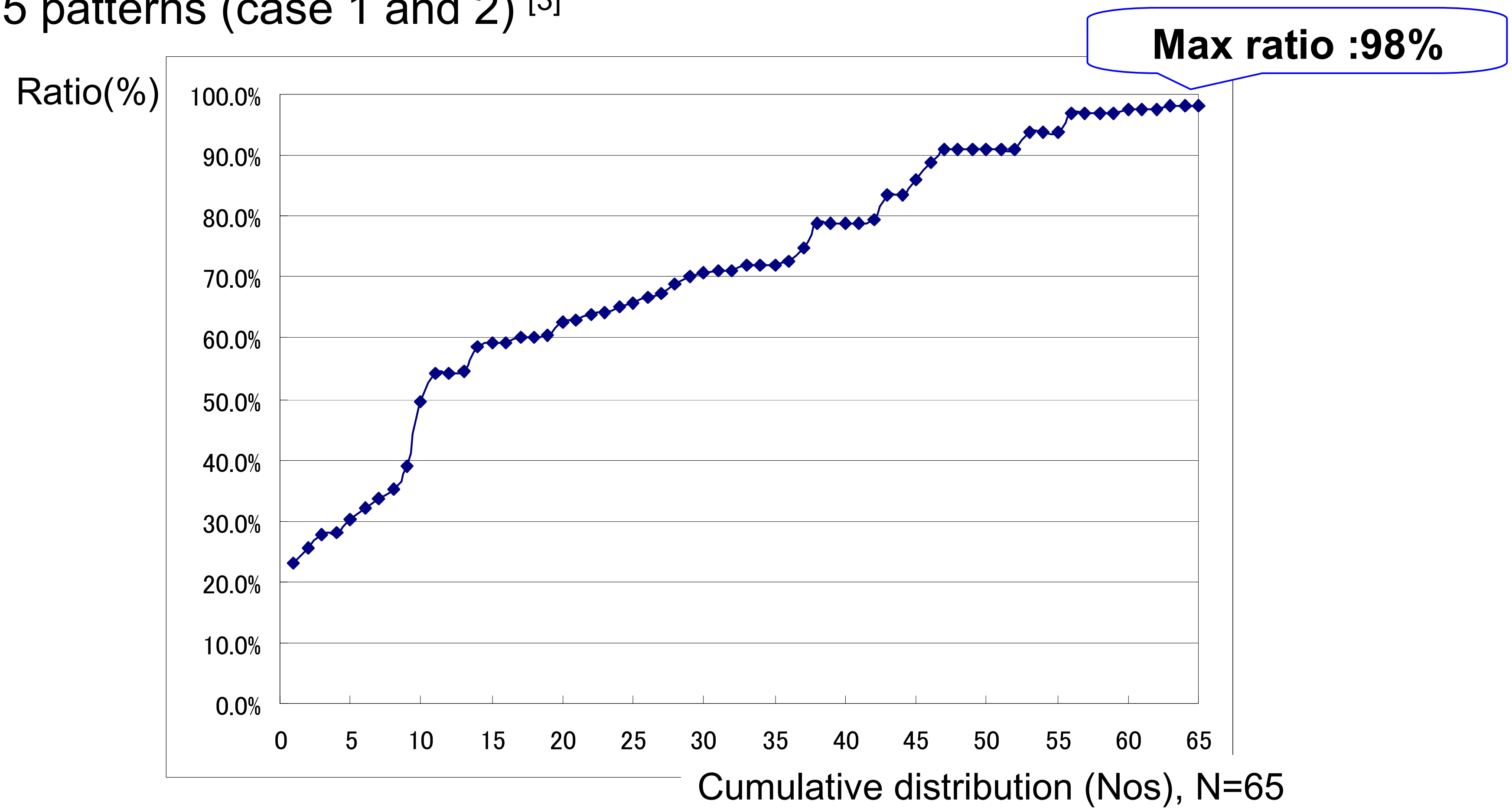
Table B.1 – Rated bus-transfer voltages for disconnectors

Rated voltage (kV)	Air-insulated disconnectors (V_{rms})	Gas-insulated disconnectors (V_{rms})
245	200	20
300		
362		
420	300	
550		40
800		

Bus-transfer current

Theoretical calculation

Calculated loop length and current distribution ratio for realistic 65 patterns (case 1 and 2) [3]

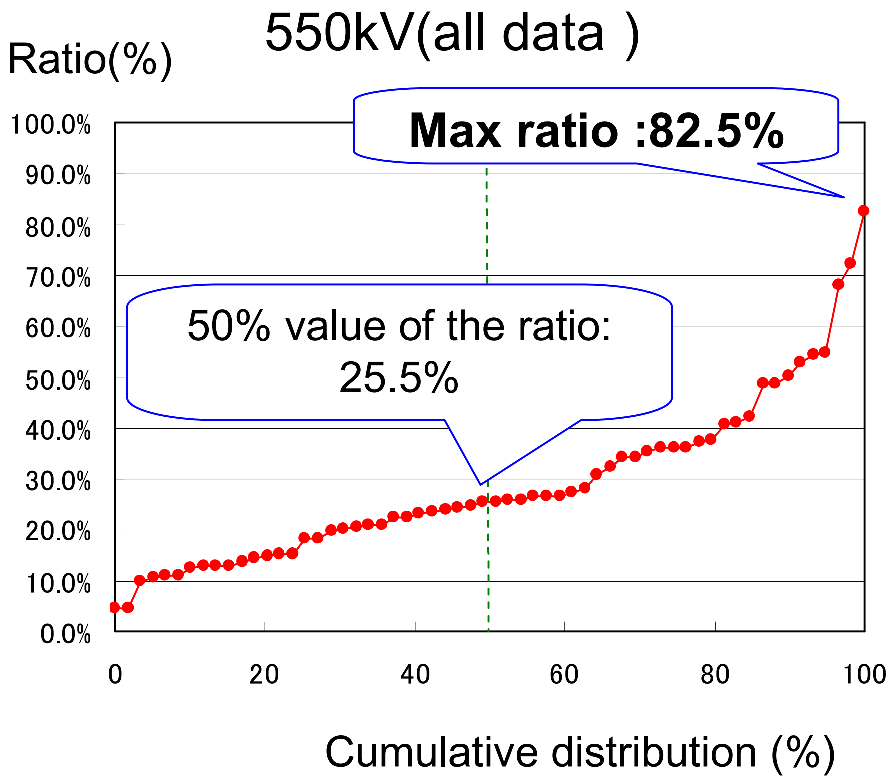


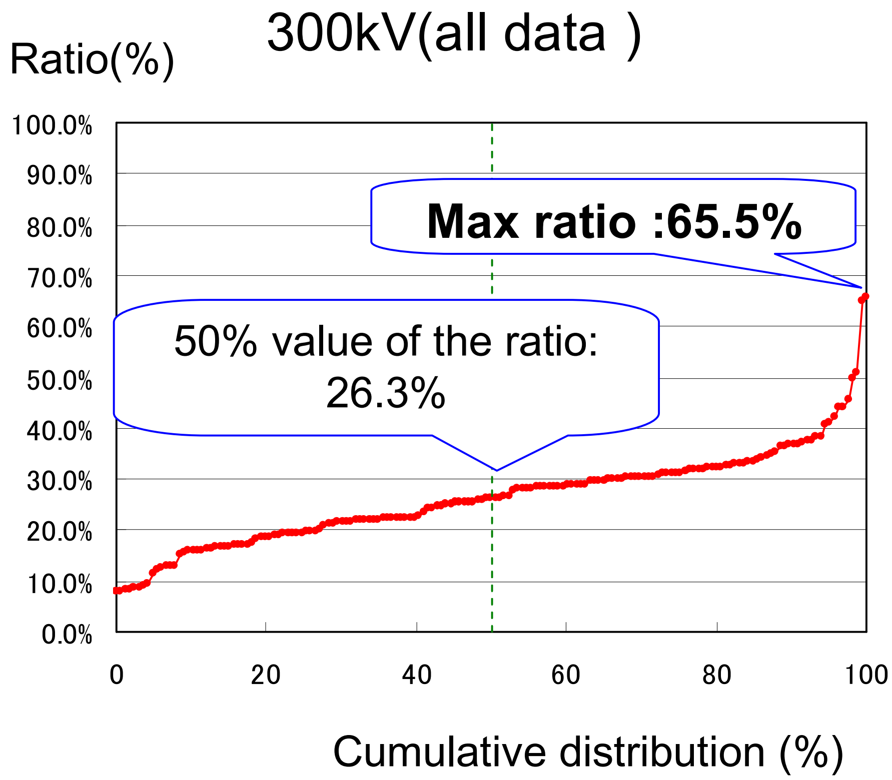
The highest ratio of current distribution is 98 %.

Bus-transfer current

Field data Field data in TEPCO from April 2008 to March 2009.

- 550 kV 11 substations – 60 bays (40 line bays and 20 transformer bay)
- 300kV 23 substations – 167 bays (93 line bays and 74 transformer bay)





- **The maximum ratio of the maximum load current to the rated current of the 550kV bay was 82.5% , 50% value of the ratio was 25.5%**
- **As for 275kV, the maximum ratio was 65.6%, 50% value was 26.3% (Feeder bay 28.8%, bank bay 22.6%)**

Bus-transfer current

Recommendations for Specification

Since the maximum rated current is now increased to 3150A and 4000A or more in the EHV/UHV systems,
the bus-transfer current should be revised by reflecting the rated current specified for the UHV systems.

17A/994/CDV（Amendment 2 to IEC 62271-102:
Highvoltage switchgear and controlgear - Part 102:
Alternating current disconnectors and earthingswitches (Addition of 1100 kV and 1200 kV), circulated on 2011-12-23）is approved. [13]

For rated voltages of 1 100 kV and 1 200 kV the rated bus-transfer current for both air insulated and gas insulated disconnectors shall be 80 % of the rated normal current, without any upper limit.

NOTE 2 Rated bus-transfer currents greater than 80 % of the rated normal current may be assigned by the manufacturer.

Bus-transfer voltage

- Recovery voltage $V = I \cdot s\sqrt{[R'^2 + (\omega L')^2]}$

Where, I (A) = Bus-transfer current,
s (m) = Length of current carrying loop,
R' (Ω/m) = Resistance,
ωL' (Ω/m) = Reactance,
ω (s^{-1}) = $2 \pi f$,
f (Hz) = power frequency

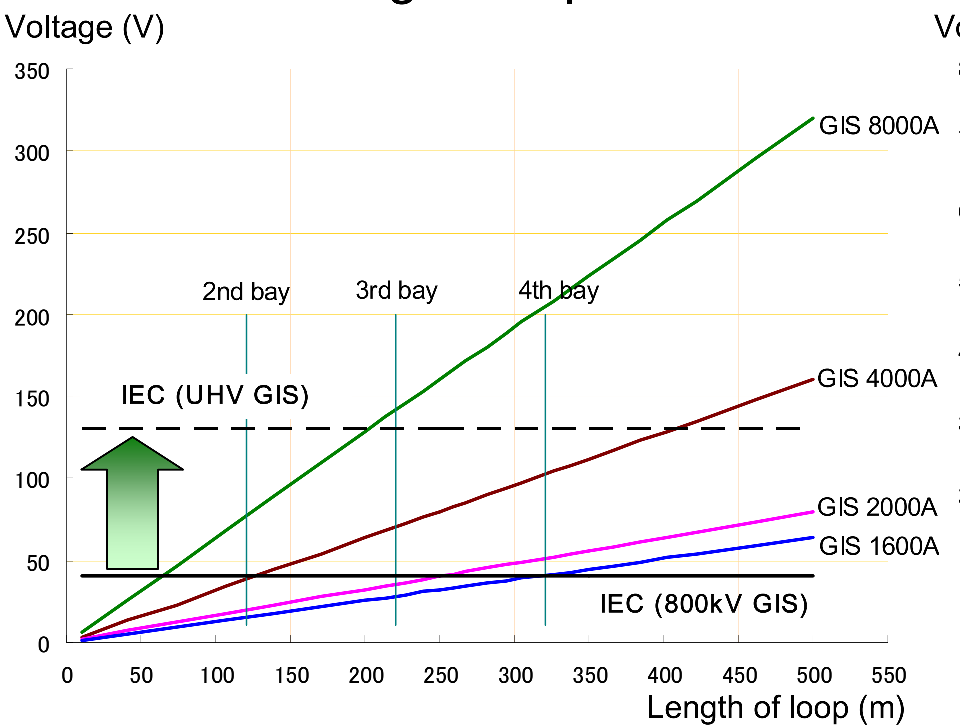
- $rrrV = 2 \cdot \omega \cdot Z \cdot I$

Where, I (A) = Bus-transfer current,
Z (Ω) = Surge impedance,
ω (s^{-1}) = $2 \pi f$

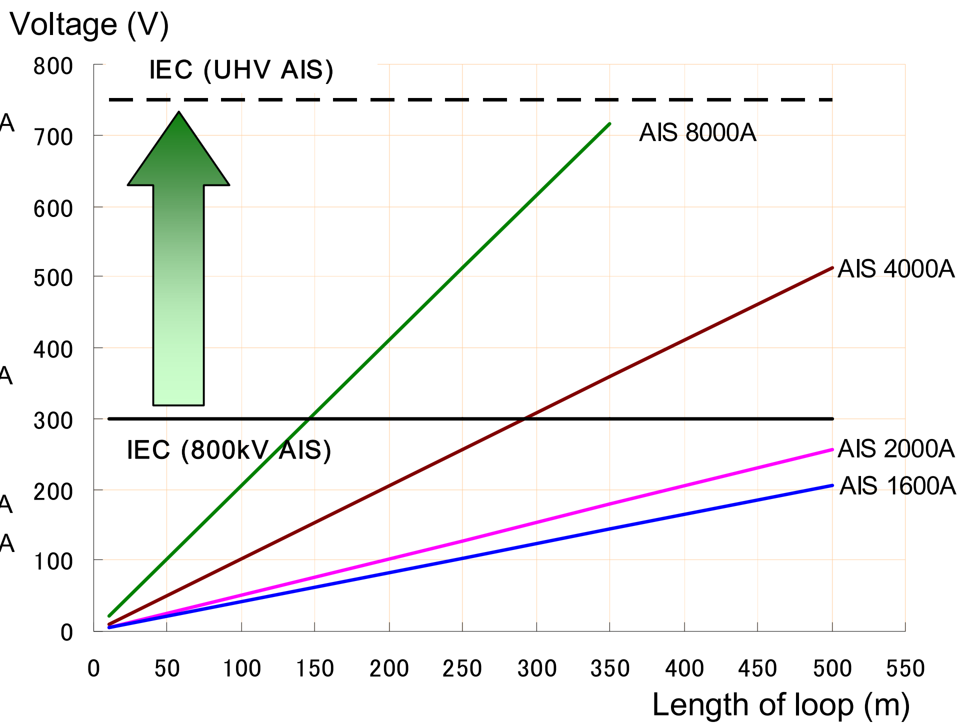
Bus-transfer voltage

Theoretical calculation [3]

- Bus transfer voltage for GIS and AIS/Hybrid GIS applications by using typical values for resistance and reactance.
- The bus-transfer voltage linearly increase with length of loop.
  The vertical lines indicate loop length between bays with typical distances (20 m x 50 m).
- AIS and Hybrid- GIS have higher impedance values and yield higher bus transfer voltage compared to GIS.



Bus-transfer voltage of GIS



Bus-transfer voltage of AIS / Hybrid-GIS

2. Bus-transfer current switching by DS

17A/994/CDV（Amendment 2 to IEC 62271-102: Highvoltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthingswitches (Addition of 1100 kV and 1200 kV), circulated on 2011-12-23）is approved [13] and now at the stage for FDIS.

Table B.1 – Rated bus-transfer voltages for disconnectors

Rated voltage U_r kV	Air insulated disconnectors V r.m.s.	Gas insulated disconnectors V r.m.s.
420	300	
550 800		40

Add the following lines to Table B.1:

1 100 1 200	750	130

1. High Speed Earthing Switch (HSES) / High Speed Grounding Switch (HSGS)

1.1 Introduction
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- Four-legged reactor and HSES
- Operating sequence
- Possibility and Influence of successive faults on HSES interruption

1.2 Switching Requirements for HSES
- Categories of fault conditions
- Parametric study by model networks
- Proposed values of duties

2. Bus-transfer current switching by DS

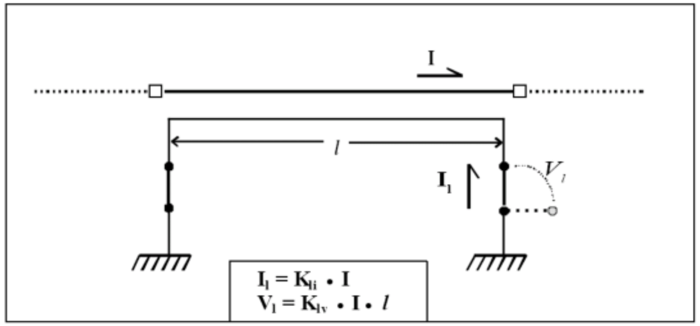
3. Induced current switching by ES

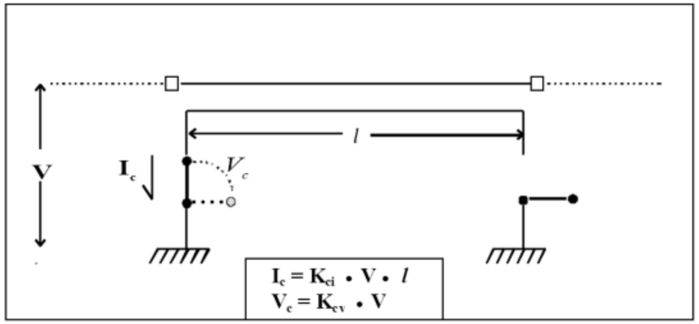
3. Induced current switching by Earthing Switches

IEC62271-102 Annex C (normative) [12]

Table C.1 – Standardized values of rated induced currents and voltages for earthing switches

Rated voltage (kV)	Electromagnetic coupling		Electrostatic coupling	
	Rated induced current (A_{rms})	Rated induced voltage (kV_{rms})	Rated induced current (A_{rms})	Rated induced voltage (kV_{rms})
550	160	20	25	25
800	160	20	25	32





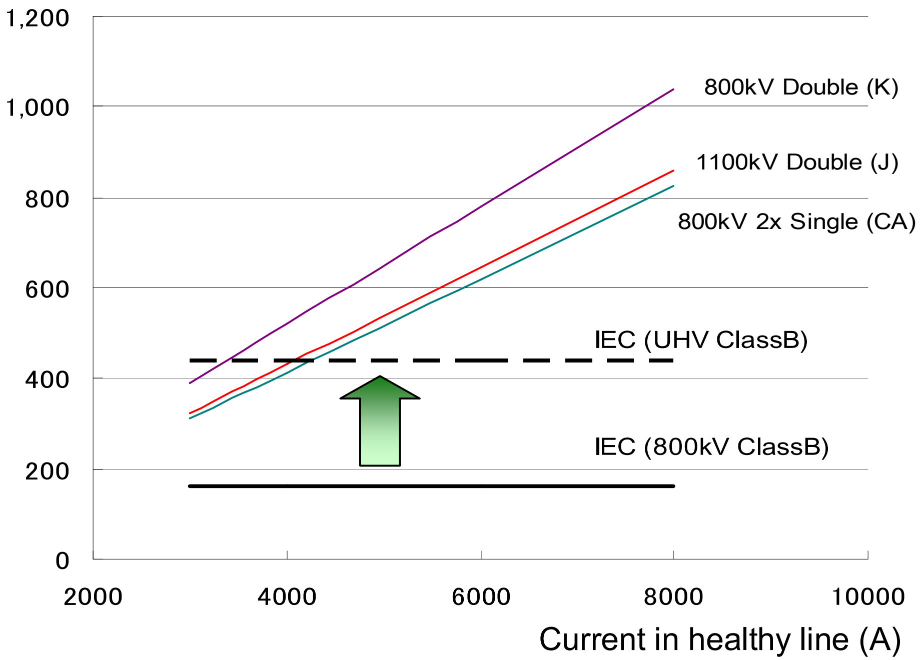
Specification for the UHV and 800kV projects [2]

	Rated voltage (kV)	Line length (km)	Circulating current I (A_{rms})	Electromagnetic coupling		Electrostatic coupling	
				Rated induced current (A_{rms})	Rated induced voltage (kV_{rms})	Rated induced current (A_{rms})	Rated induced voltage (kV_{rms})
HQ	765	335	3000	78	10.0	16.3	10.6
KEPCO	800	155	8000	1560	122	25	38
TEPCO	1100	*n/a*	8000	1000	70	40	50
CHINA (Future)	1100	327	4000	1134	156	82	63
IEC Class B 62271-102		*n/a*	*n/a*	*160*	*20.0*	*25.0*	*32.0*

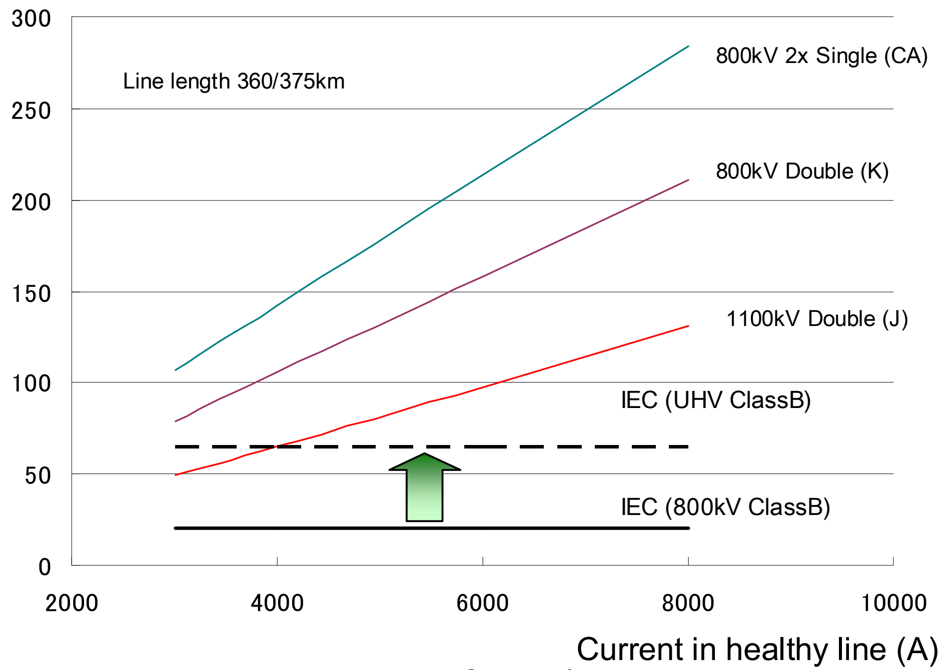
Induced current switching by Earthing Switches

Electromagnetically (EM) induced and Electrostatically (ES) induced current switching duty on Earthing Switches are calculated by using EMTP-ATP.

- For Line length from 120km to 375km
- the load current from 4 to 8kA
- Tower configuration of Japan, Korea, and Canada



EM induced current

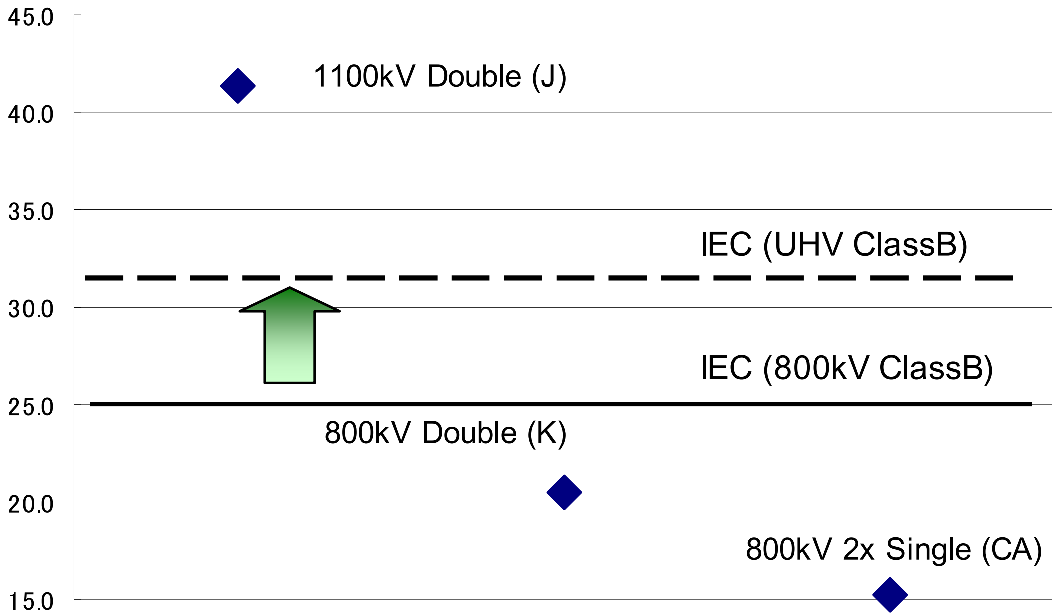


Recovery voltage of EM induced current interruption

Induced current switching by Earthing Switches

Electromagnetically (EM) induced and Electrostatically (ES) induced current switching duty on Earthing Switches are calculated by using EMTP-ATP.

- For Line length from 120km to 375km
- the load current from 4 to 8kA
- Tower configuration of Japan, Korea, and Canada



Recovery voltage of ES induced current interruption

Induced current switching by Earthing Switches

17A/994/CDV（Amendment 2 to IEC 62271-102: Highvoltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthingswitches (Addition of 1100 kV and 1200 kV), circulated on 2011-12-23）is approved [13] and now at the stage for FDIS.

Rated voltage U_r kV	Electromagnetic coupling				Electrostatic coupling			
	Rated induced current A (r.m.s.)		Rated induced voltage kV (r.m.s.)		Rated induced current A (r.m.s.)		Rated induced voltage kV (r.m.s.)	
	Class		Class		Class		Class	
	A	B	A	B	A	B	A	B
1 100	110	440	5	65	7,5	50	20	40
1 200	110	440	5	65	7,5	50	20	40

References

[1] IEC 17A/998/CDV dated 2012-03-23 (IEC 62271-112 Ed 1.0: High-voltage switchgear and controlgear - Part 112: Alternating current high-speed earthing switches for secondary arc extinction on transmission lines)

[2] CIGRE Technical Brochure 362 - Technical requirements for substation equipment exceeding 800kV (2008-12)

[3] CIGRE Technical Brochure 456 - Background of Technical Specifications for Substation Equipment exceeding 800 kV AC (2011)

[4] R. M. Hasibar, et al, “The application of high-speed grounding switches for single-pole reclosing on 500 kV power systems”, IEEE Tr. on PAS, Vol. PAS-100, No. 4, April 1981

[5] G.E. Agafonovet al., “High Speed Grounding Switch for Extra-high Voltage Lines”CIGRE 2004, A3-308

[6] S. P. Ahn,et al.,”The Investigation for adaptation of High Speed Grounding Switches on the Korean 765kV Single Transmission Line”,IPST 05-096 Montreal 2005

[7] Y. Yamagata et al., “Development of 1,100kV GIS - Gas Circuit Breakers, Disconnectors and High-speed Grounding Switches –”, CIGRE 1996, 13-304

[8] LI Zhen-qiang et al., “Effect of UHV Ground Wire Disposition and HSGS on Second Arc Current”, UHV transmission technology in 2009 an international conference CP0282

[9] Y.Goda et al, “Insulation Recovery Time after Fault Arc Interruption for Rapid Auto-reclosing on UHV (1000kV class) Transmission lines” , IEEE Transmission on Power Delivery, Vol. 10, No.2, April 1995

[10] M. Toyoda, et al., “Considerations for the standardization of high-speed earthing switches for secondary arc extinction on transmission lines”, CIGRE 2011 Bologna 2011, 295

[11] M. Toyoda, et al., “Considerations for the Standardization of High-speed earthing switches for secondary arc extinction on transmission lines (part 2)”, CIGRE 2011 SC A3 Technical Colloquium, A3-103 2011

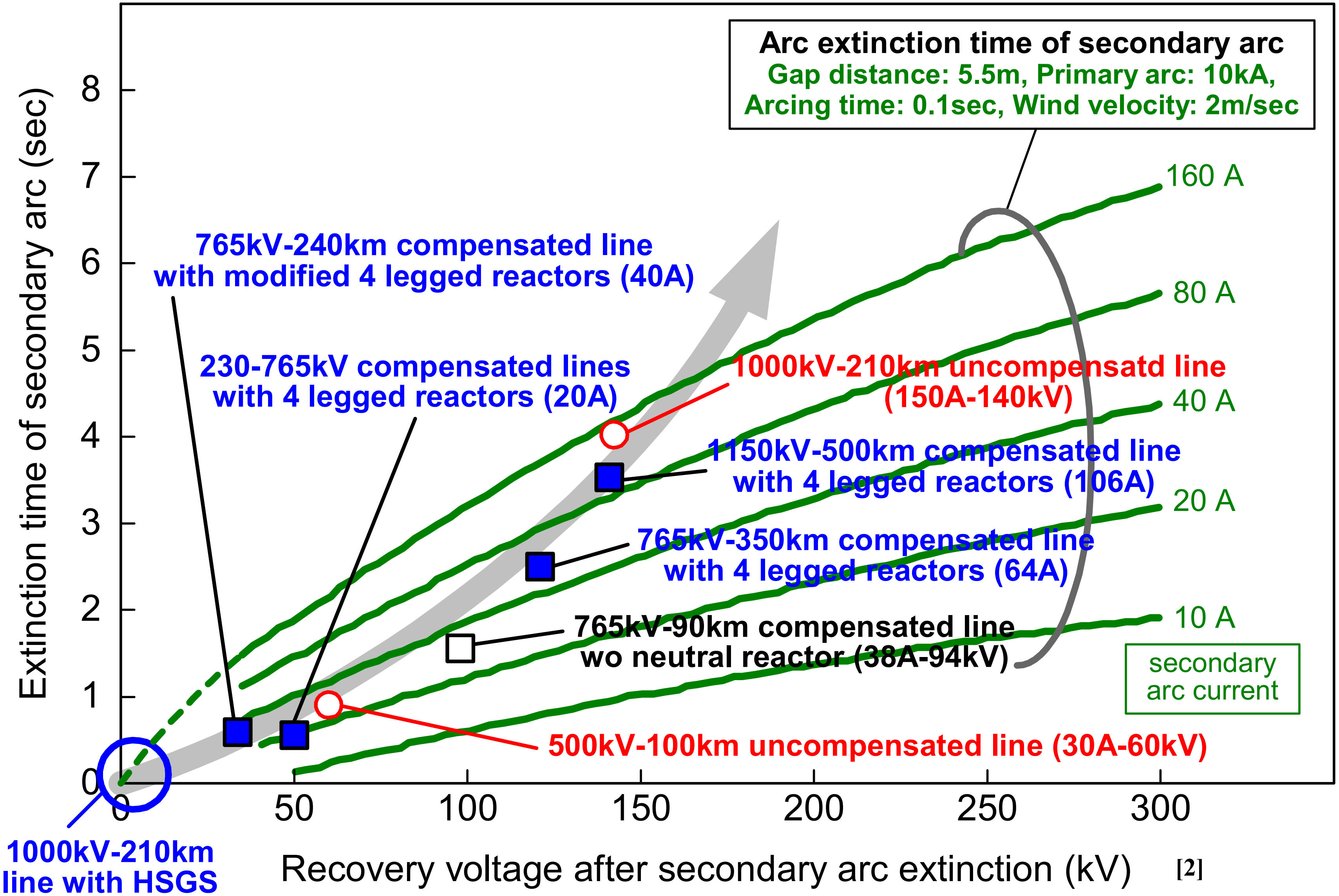
[12] IEC 62271-102: High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches

[13] IEC 17A/994/CDV dated 2012-12-23 (Amendment 2 to IEC 62271-102: Highvoltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthing switches (Addition of 1100 kV and 1200 kV))

Thank you !

Secondary arc

For reference



[2]

Four-legged reactor

For reference

Suppression of secondary arc by reactor

- Figure A shows three phase circuit with single line ground fault at phase C. If the circuit is fully transposed, three capacitances between phases (Cij) and three capacitances between each phase to ground (Cii) are respectively equal.
- By adding three reactors (Lij) so as to cancel the coupling between phases, electro-statically induced voltage on phase C will also be cancelled, and therefore the secondary arc by the electro-statically induced current by capacitances (Cij), is not generated theoretically. For un-transposed single circuit line, unbalanced reactors effectively contribute to this cancellation.

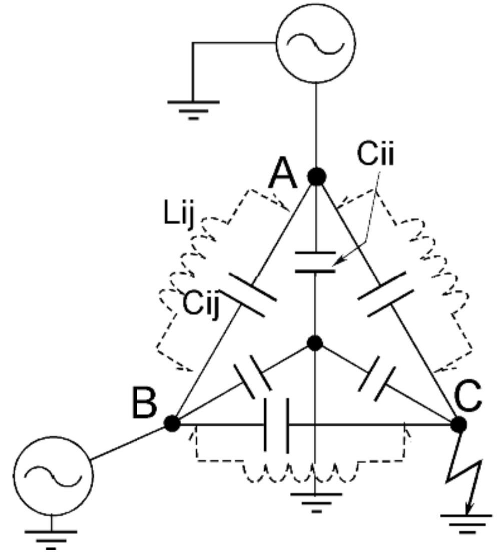


Fig A. Three phase circuit (fully transposed) with single line ground fault

Four-legged reactor

- In case of single circuit line, reactors with delta or un-earthed star are to be connected to the three phase. Theoretically, for un-transposed single circuit line, unbalanced reactors have to be connected, in case of un-transposed double circuits' line, 15 (=6C2) reactors between phases are necessary.
- On the other hand, when the reactive compensation of lines is needed shunt reactors are installed in the order of 40-50% compensation. The reactors are often installed at the both ends of the circuit by dividing into two.
- In case of single circuit, combination of earthed (for compensation) and un-earthed reactors (for secondary arc extinction) is generally replaced by four-legged reactors. (See Figure B)

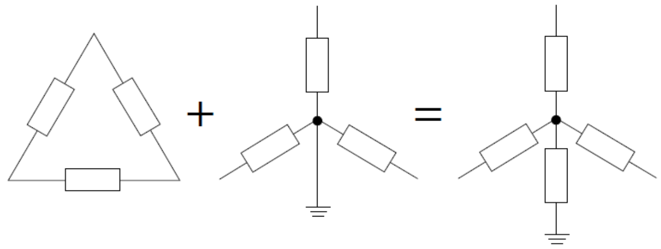
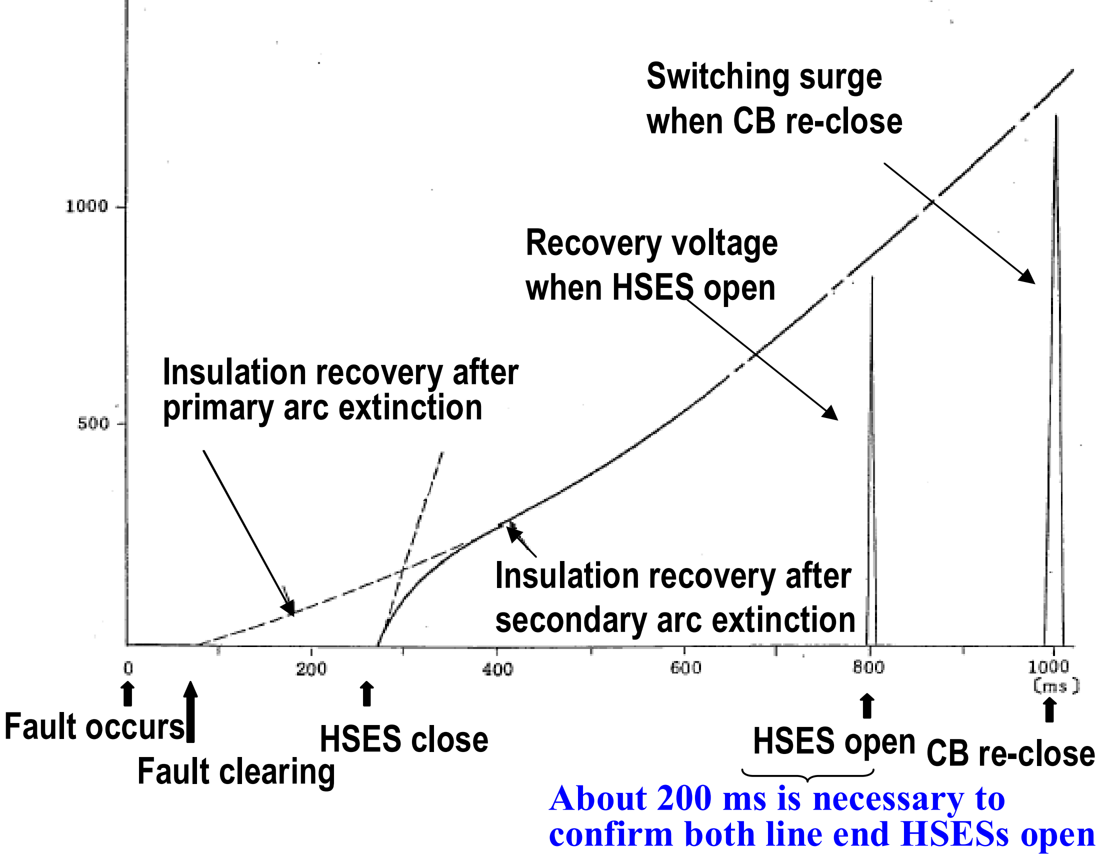
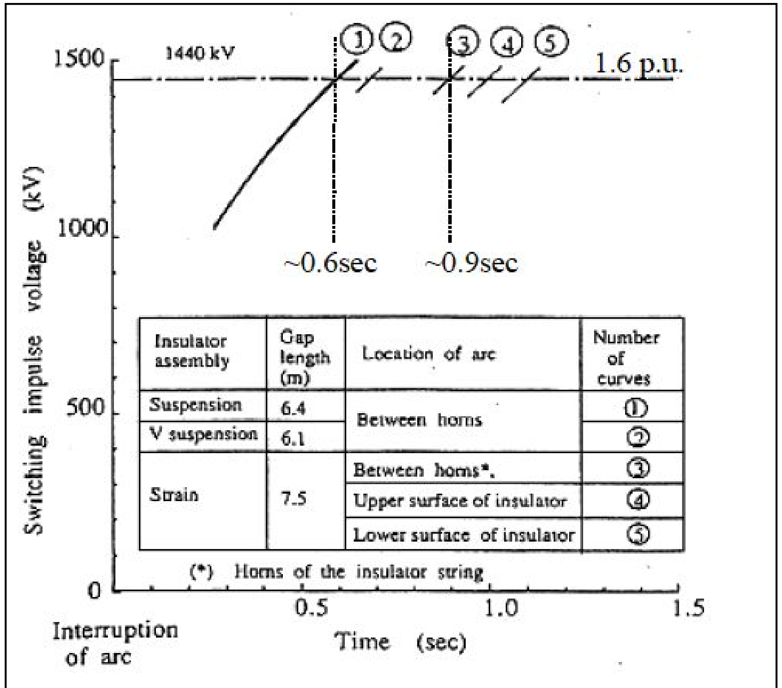


Fig B. principle of 4-legged reactor

Operating sequence

Relation between dielectric recovery of insulation at fault point and operating sequence of HSES (1100kV Systems)





Insulator assembly	Gap length (m)	Location of arc	Number of curves
Suspension	6.4	Between horns	①
V suspension	6.1		②
Strain	7.5	Between horns*.	③
		Upper surface of insulator	④
		Lower surface of insulator	⑤

(*) Horns of the insulator string

Recovery characteristics after primary arc extinction [2][9]

It takes around 0.6-0.9 sec for the dielectric recovery of the insulation enough to withstand 1.6 pu, which is switching overvoltage level of UHV transmission lines.

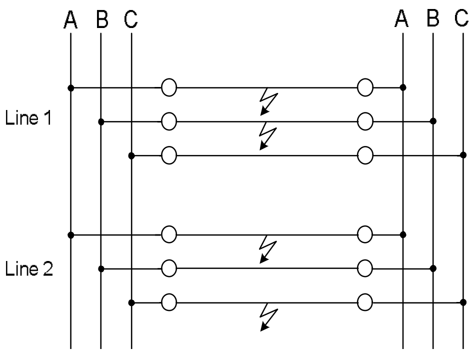
→ Around 1 sec is required as the dead time of re-closing.

Multi-phase auto-reclosing scheme

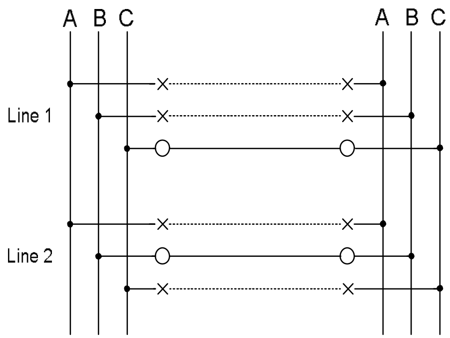
For reference

Definition:

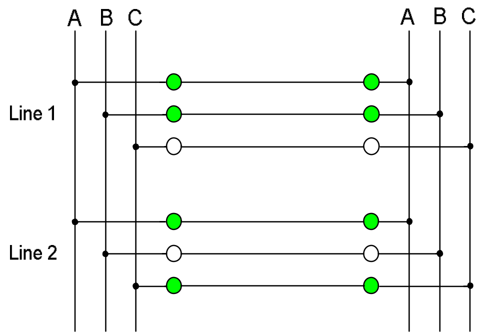
Auto-reclosing scheme applied to double circuit overhead lines in which all faulted phase circuits are tripped and re-closed independently provided that at least two, different phase circuits remain un-faulted.



Up to four phases faults out of six phases
(2 circuits × 3 phases)



Only faulted phases cleared



Both terminals reclosed simultaneously

NOTE: At least two different electrical phases must be remaining

Remarks
○ : Closed CB
● : Reclosed CB
× : Opened CB

Observation result showing possibility of successive fault

Data provided by TEPCO, Japan

Measurement data of the direct lightning surges at substations

	Transmission line	date	No.	time	Phase of lightning
①	Higashi-gunma	2000/05/08	1	02:14:06.895	1L-Middle
			2	02:14:07.077	1L-Middle
②	Minami-iwaki	2000/07/04	1	12:41:17.850	1L-Upper
			2	12:41:18.028	1L-Lower
			3	12:41:18.missed	1L-Lower
③	Minami-niigata	2004/08/07	1	11:29:14.957	2L-Upper
			2	11:29:15.449	2L-Upper
			Cf.	11:29:35.600	2L-Upper

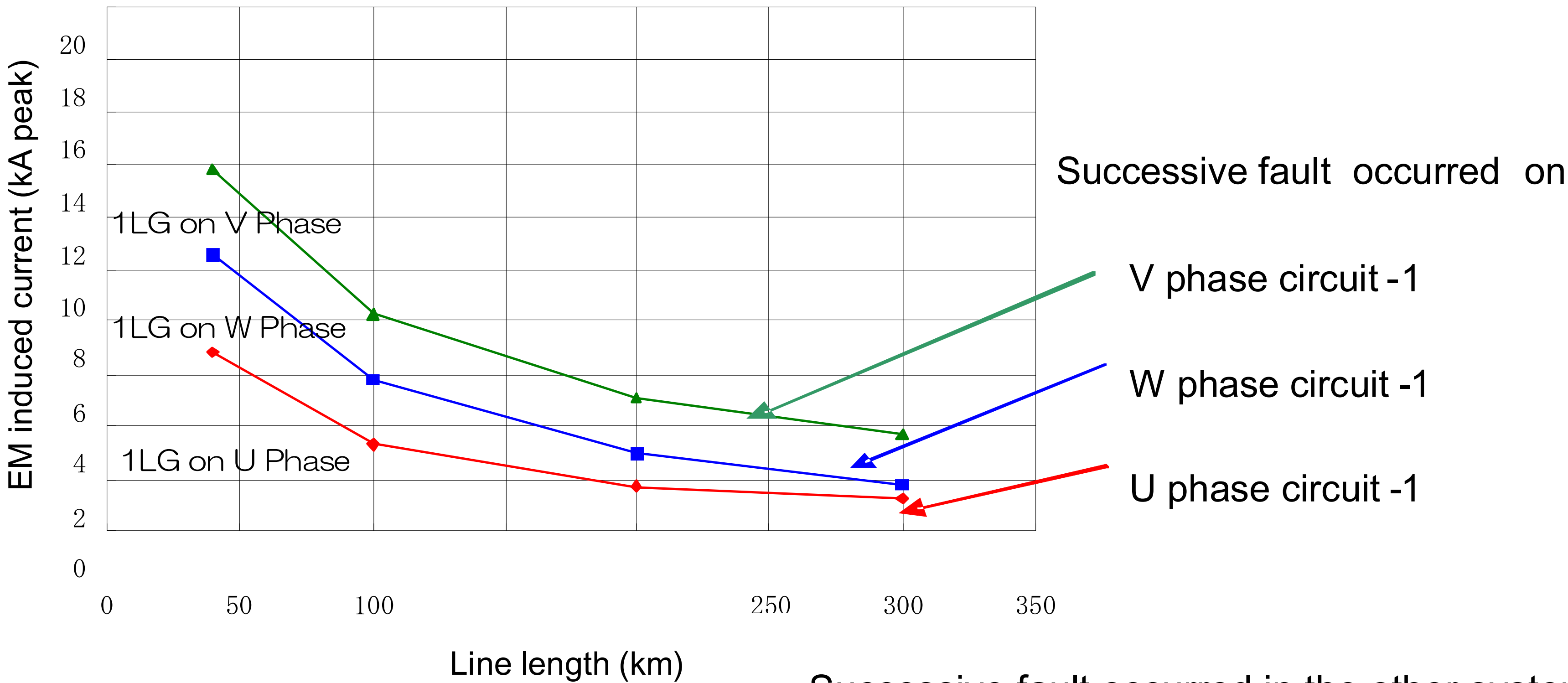
※ Yellow cells show 1LG occurrence

Calculation results of interruption on HSES for 1LG with successive fault on the line

For reference

HSES interruption current becomes almost 10 times Higher

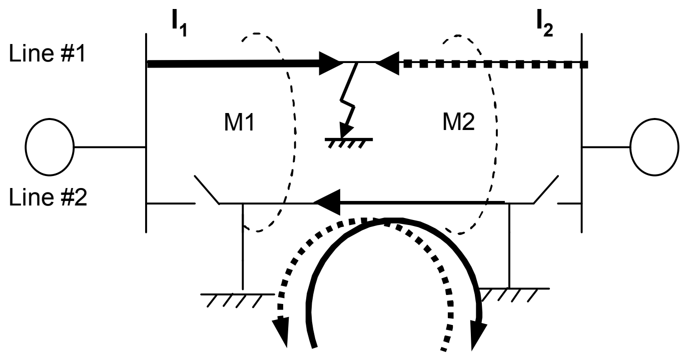
The EM current decreases with increasing line length.



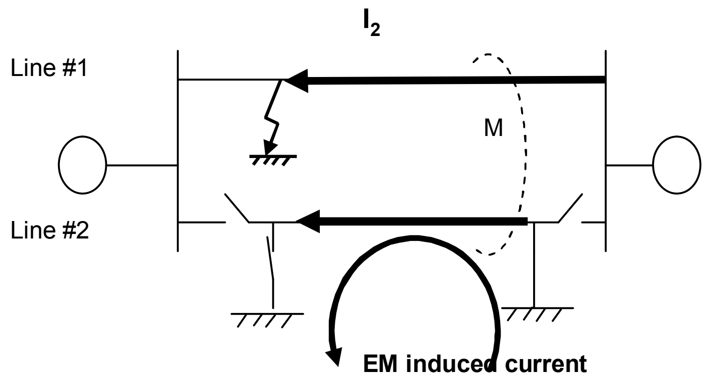
Successive fault occurred in the other system on the same tower than first 1LG system.

Successive fault location of the transmission line

For reference



I_1 and I_2 are in the opposite direction



Short circuit current depends on the line impedance, which corresponds to line length.

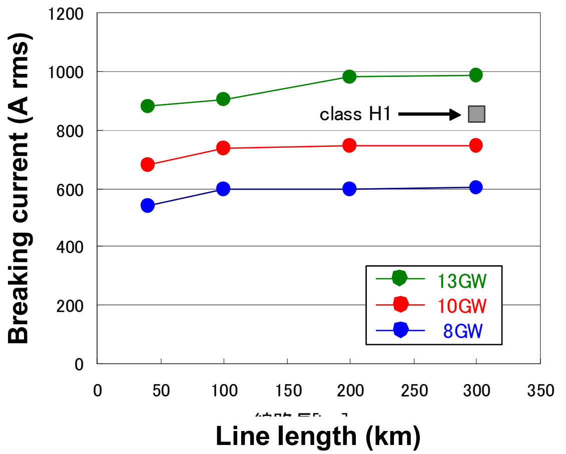
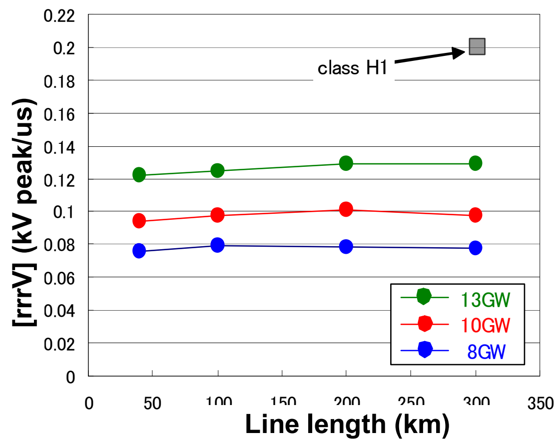
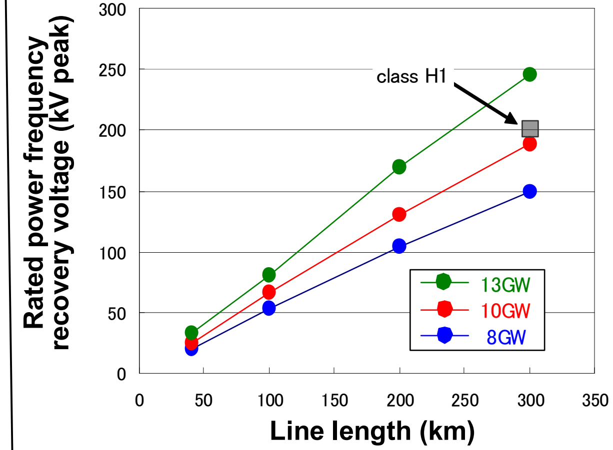
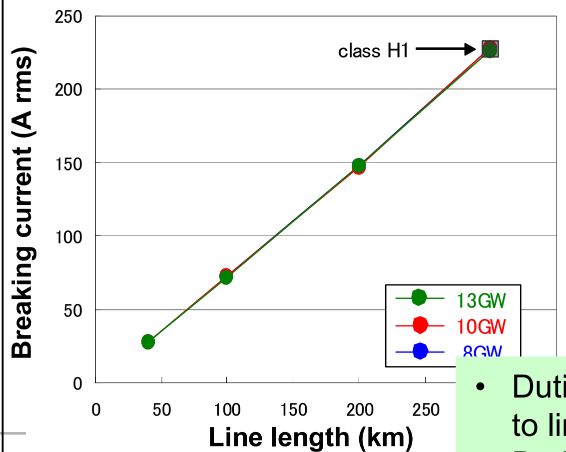
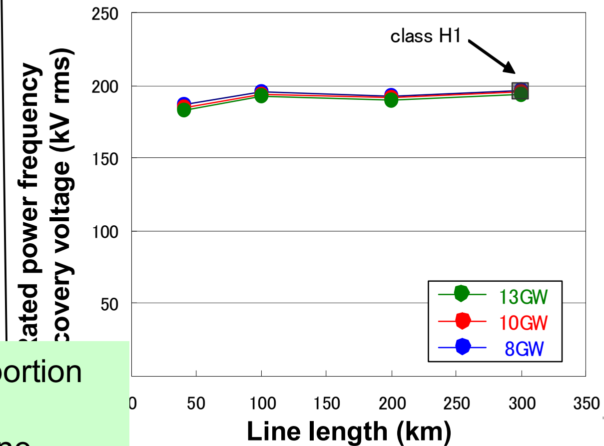
fault location at the centre of the line
⇒the EM current will be smaller

fault location near the line end
⇒the EM current will be larger

Parametric study

For reference

Categories 0 & 1

	Breaking current (Arms)	RRRV (kV peak/us)	Rated PF recovery voltage (kV rms) or (kV peak)
Electro-magnetically (EM)			
Electro-statically (ES)			

- Duties for EM; Recovery voltage increases in proportion to line length though current and RRRV stays.
- Duties for ES; Current increases in proportion to line length though recovery voltage stays.

TOSHIBA
Leading Innovation

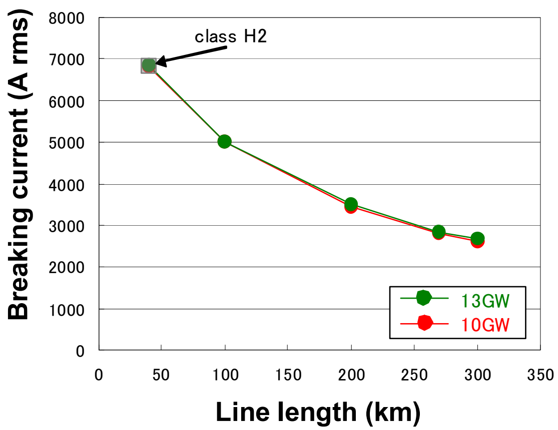
Parametric study

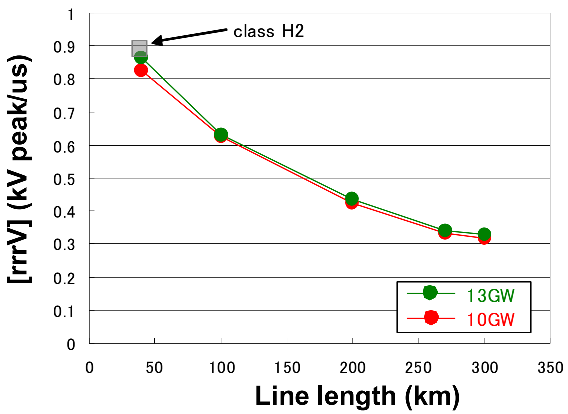
For reference

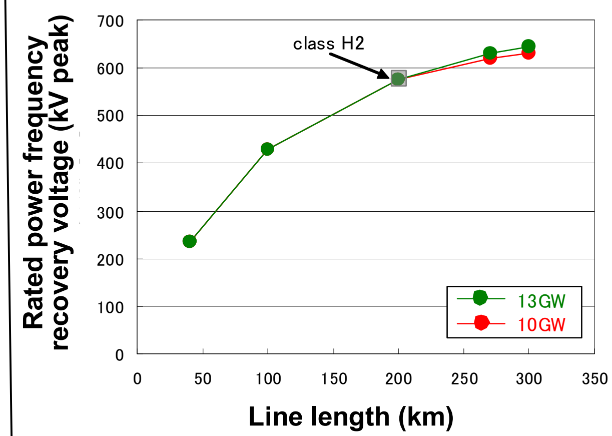
Categories 2

Breaking current (Arms) | RRRV (kV peak/us) | Rated PF recovery voltage (kV rms) or (kV peak)

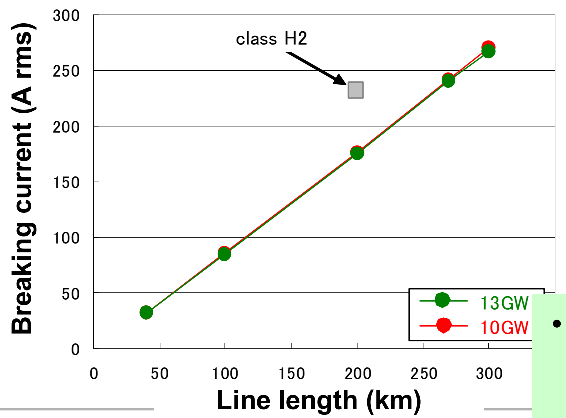
Electro-magnetically (EM)

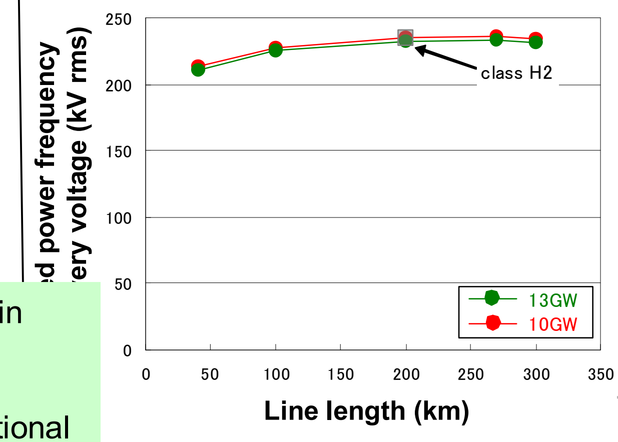






Electro-statically (ES)

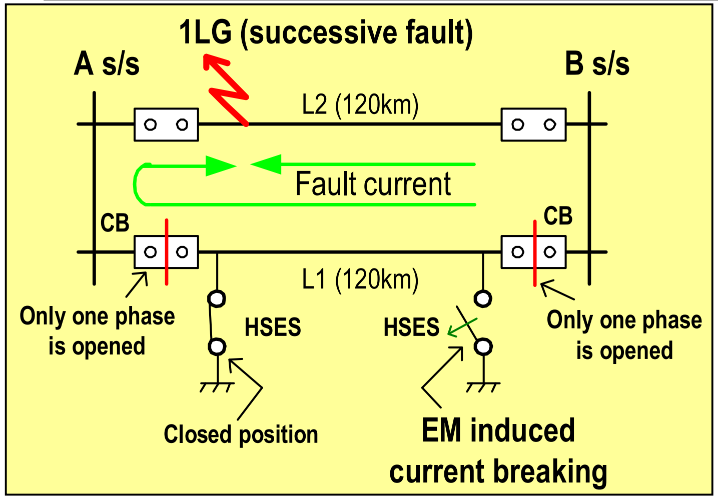




- Duties for EM; Current & RRRV decrease in proportional to line length though recovery voltage increases.
- Duties for ES; Current increases in proportional to line length though recovery voltage stays.

Comparison of the HSES breaking duties for HQ- and KEPCO-800kV system , China-1100kV system
(EM induced current breaking of class H2 ; category 2)

For reference



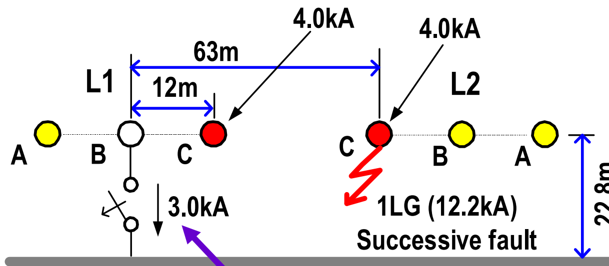
● : Fault phase (Current based on the 1LG is flowing)

● : Healthy phase (Current based on the power flow is flowing)

○ : HSES closed phase (EM induced current is flowing)

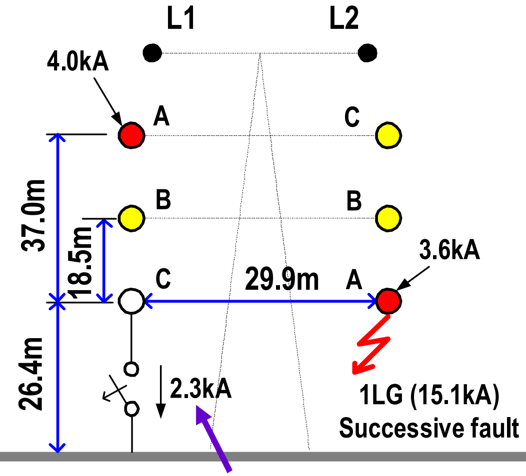
Power flow : 6GW (China),
4GW (KEPCO),
3GW (HQ)

HQ 800kV system (single circuit tower)



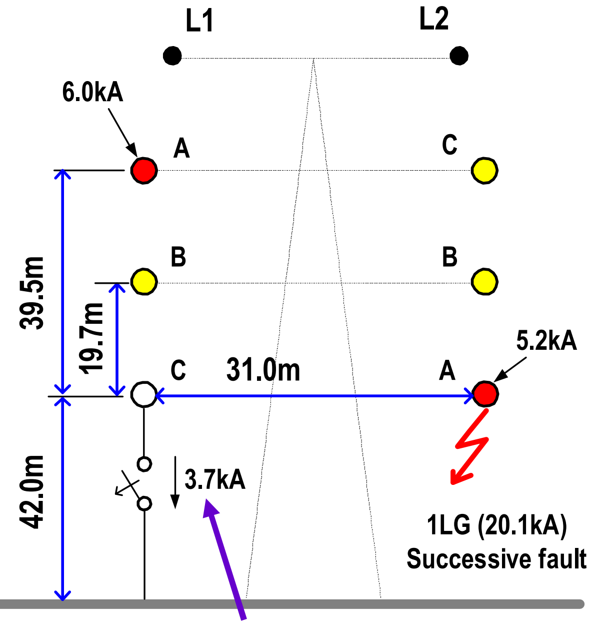
EM breaking duties of HSES
I=3.0kA, Uc=387kV, 3rV=0.53kV/μs
(Z= dv/dt / di/dt = 331ohm)

KEPCO 800kV system (double circuit tower)



EM breaking duties of HSES
I=2.3kA, Uc=307kV, 3rV=0.38kV/μs
(Z= dv/dt / di/dt = 310ohm)

China 1100kV system (double circuit tower)



EM breaking duties of HSES
I=3.7kA, Uc=394kV, 3rV=0.49kV/μs
(Z= dv/dt / di/dt = 298ohm)

他回線(上記では2L側)で継続している地絡事故(1LG)電流は、当該回線(上記では1L側で1LG事故を遮断した回線)にも流れているため、同じ系統電圧であれば、2回線鉄塔の送電線路に比べて、相間距離の短い1回線鉄塔(電力線水平位置)の方が、HSESに流れる電磁誘導電流は大きくなる。その結果、TRV上昇率、波高値も高くなる。

For reference

Table B.1 - Preferred values for single-phase earth faults with delayed current zero phenomena in the presence of a successive fault

Rated voltage U_r kV	Electromagnetic coupling				Electrostatic coupling	
	Rated induced current ($^{+10}_{-0}$ %) A(rms)	Rated power frequency recovery voltage rms ($^{+10}_{-0}$ %) (kV)	First TRV peak ($^{+10}_{-0}$ %) kV(peak)	Time to first peak ($^{+10}_{-0}$ %) (ms)	Rated induced current ($^{+10}_{-0}$ %) A(rms)	Rated induced voltage ($^{+10}_{-0}$ %) kV(rms)
550	7800	70	170	0,4	7800	100
800	7800	70	170	0,4	7800	150
1100-1200	7800	70	170	0,4	7800	200

NOTE 1 A typical delayed current zero period is 80ms, considering relay time, break time of the circuit-breaker and the time between current zeros. This period should be specified by the users. During this period current zero should not occur.

NOTE 2 This duty is the case considering the interruption occurs after the delayed current zero phenomena have disappeared and the interruption duty is not severe as the case of Table 1 caused by low di/dt.

- Type tests for HSES indicated in Table B.1 should be included to verify the arcing time of more than 80 ms with the condition specified in Table B.1.
- Table B.1 indicates the duty corresponding to single-phase earth fault with delayed current zero phenomena in the presence of successive single-phase earth fault. A HSES will interrupt the current at current zero. The first prospective current zero crossing should come after 80 ms, whereas the d.c. time constant of the fault current is 120 ms.
- The duty during the delayed current zero phenomena is to confirm that the HSES can withstand such stress during that period. Only after the delayed current zero period finishes, interruption should be conducted.

Category 4

For reference

Table B.2 — Preferred values for multi-phase earth faults in a double-circuit system

Rated voltage U_r kV	Electromagnetic coupling				Electrostatic coupling	
	Rated induced current ($^{+10}_{-0}$ %) A(rms)	Rated power frequency recovery voltage rms ($^{+10}_{-0}$ %) (kV)	First TRV peak ($^{+10}_{-0}$ %) kV(peak)	Time to first peak ($^{+10}_{-0}$ %) (ms)	Rated induced current ($^{+10}_{-0}$ %) A(rms)	Rated induced voltage ($^{+10}_{-0}$ %) kV(rms)
550	1400	100	250	1,25	150	125
800	1400	100	250	1,25	210	180
1100-1200	1400	100	250	1,25	290	245

•Table B.2 indicates the duty for HSES corresponding to up to four-phase earth faults where a multi-phase auto-reclosing scheme is applied.

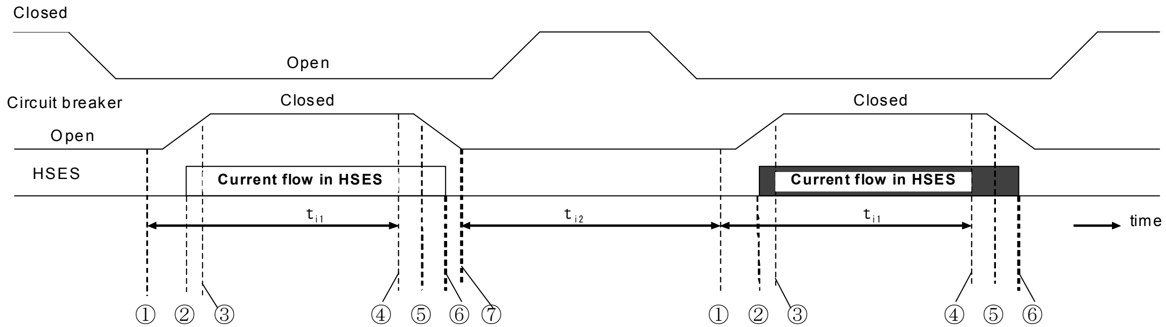
Operating sequence (1)

For reference

- **Rated operating sequence**

C – *t*i1 – O or C - *t*i1 – O - *t*i2 – C - *t*i1 – O.

- *t*i1 is a time that is longer than the time required for secondary arc extinction and for dielectric recovery of air insulation at the faulted point. *t*i1 is determined by users considering system stability;
- *t*i2 is the intermediate time that is given by the system protection. *t*i2 covers the time of closing of the circuit-breakers after the HSESs open, a fault is detected on the line, the circuit-breakers open again and HSESs are released to close.
- In this case the HSES shall be able to operate without intentional time delay.



Circuit-breaker	Transmission line circuit-breakers that interrupts the fault	3	Contact touch of HSESs
HSES	High-speed earthing switches	4	Energizing of the opening release of the HSESs
1	Energizing of the closing circuit of the HSESs	5	Contact separation of HSESs
2	Current start in HSESs	6	Arc extinction in HSESs
*t*i1, *t*i2	Times defined in 4.102	7	Fully open position of HSESs

Operating sequence (2)

For reference

- **Number of operation of HSES**
  (considering the coordination with CBs)

  2 classes:

  – Class M0: 1000 operations (for normal application);

  – Class M1: 2000 operations (for special requirement where frequent lightning strokes occur).

For other items such as design, test conditions, condition after test, etc. will be somewhat in between of CBs and Earthing switches. Therefore new standard for HSES will refer often to IEC 62271-100, -102, and -1.