Switching phenomena and requirements of the capacitor bank circuit at the tertiary side of 1000kV transformer

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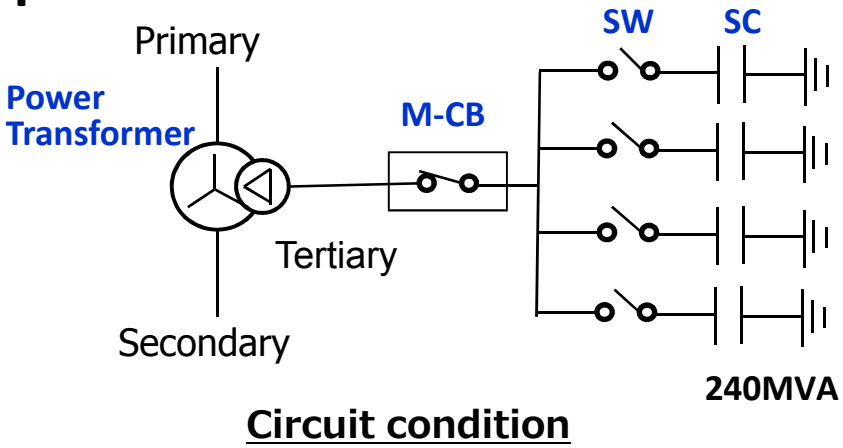
TOSHIBA
Leading Innovation

(Japan)

Features of UHV system

- **Large capacity of static capacitor (SC) at the tertiary side of transformer to supply reactive power**
- **Large capacity of power transformer in UHV systems**
- **Capacitance of circuit in UHV transformer itself is also large**



Circuit condition

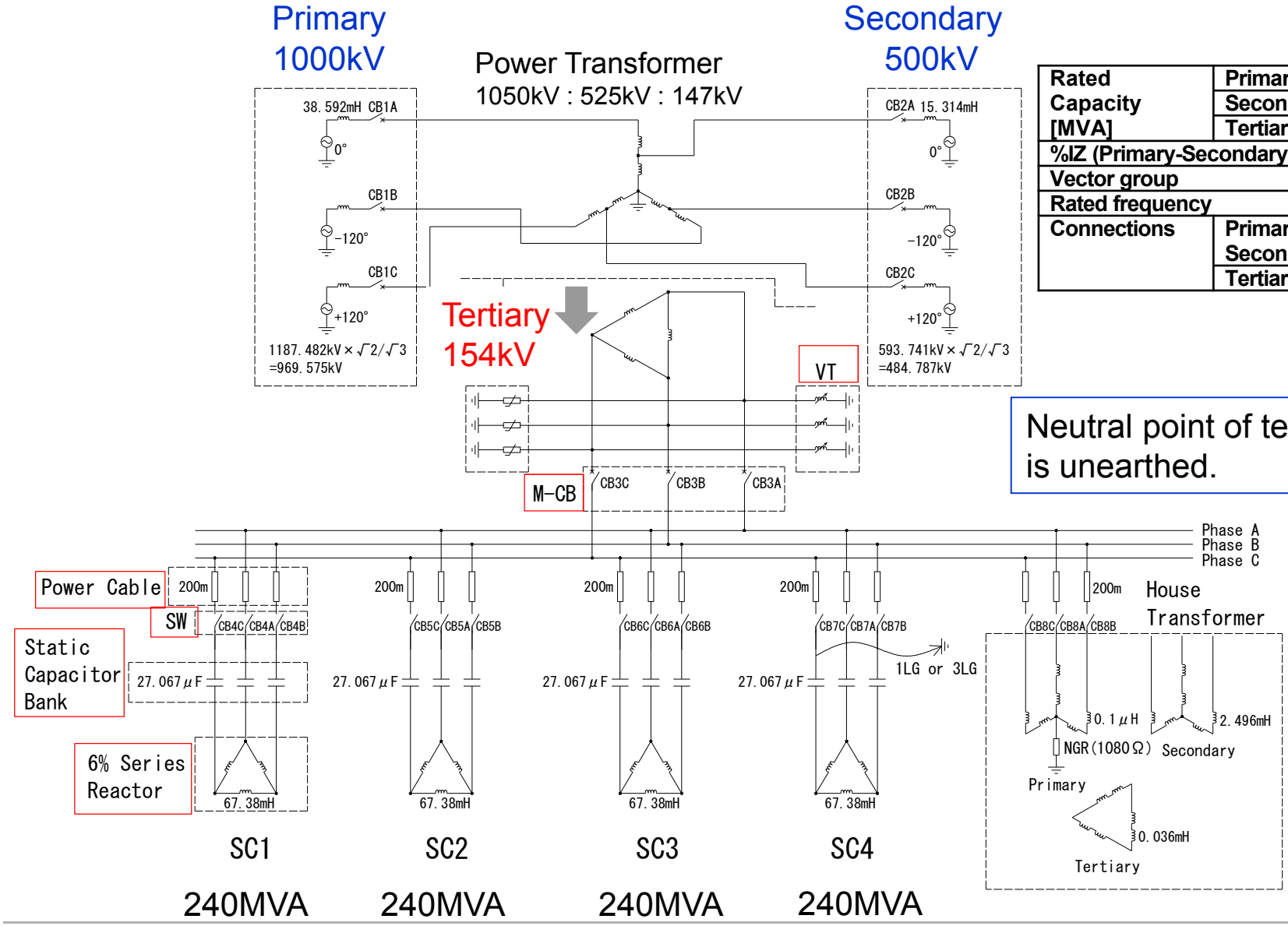
	System voltage	Rated Capacity of PTR
Primary	1000 kV	3000MVA
Secondary	500 kV	3000MVA
Tertiary	154 kV	1200MVA

Switching phenomena in the tertiary side of UHV class power transformer were studied by using EMTP to find the practical requirements for switching devices at the tertiary side in normal and 1LG condition

Example of UHV Transformer and GIS

1000kV Transformer and GIS
(Shin-Haruna substation : TEPCO Power Grid Inc.)

Circuit configuration for EMTP analysis



Rated Capacity [MVA]	Primary	3000MVA
	Secondary	3000MVA
	Tertiary	1200MVA
%IZ (Primary-Secondary)		18 %
Vector group		Y-y-d
Rated frequency		50Hz
Connections	Primary,/ Secondary	GIB
	Tertiary	Cable

Neutral point of tertiary circuit is unearthed.

Parameters for EMTP analysis

Parameter	Condition for analysis
Voltage transformer	With / Without
Fault condition	Normal / 1LG / 3LG
Switching device	M-CB/ SW
The first phase to clear in 1LG	Sound phase/ Fault phase
Number of static capacitor banks before and after operation	1 bank to 0 bank/ 4banks to 3 banks/ 4banks to 0 banks/ etc.
Location of 1LG	Cable side / SC side
Capacity of VT	100VA / 15VA
Cable length	200m /50m

Note: Calculations are conducted at 187kV basis at tertiary side, taking the actual planned maximum operating condition in Japan.

Typical Cases for study

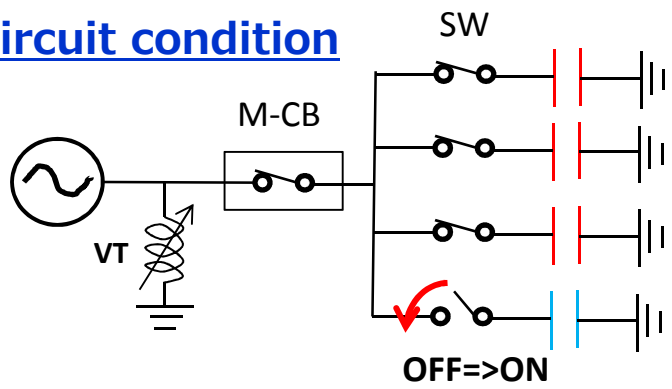
	Case I	Case II	Case III	Case IV
Operation	Making by SW *	Breaking by SW	Breaking by M-CB	Breaking by M-CB
Number of SCs before switching	3 (720MVA)	1 (240MVA)	4 (960 MVA)	4 (960 MVA)
Number of SCs after switching	4 (960MVA)	0 (0 MVA)	0 (0 MVA)	0 (0 MVA)
Fault condition	No fault	No fault	1 LG (phase A)	1 LG (phase A)
First pole to clear	NA	not specified	Fault phase	Fault phase
VT	With	With	With	Without
NGR	Without	Without	Without	Without

Note *: at peak voltage of phase A

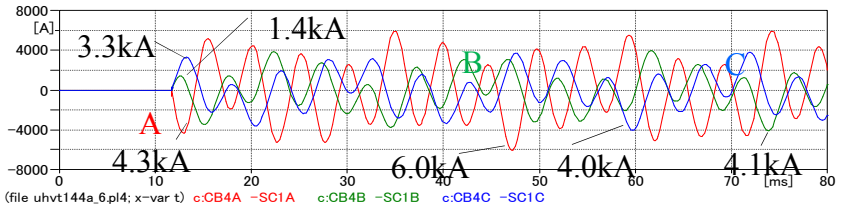
Making operation in normal condition by SW

(Case I)

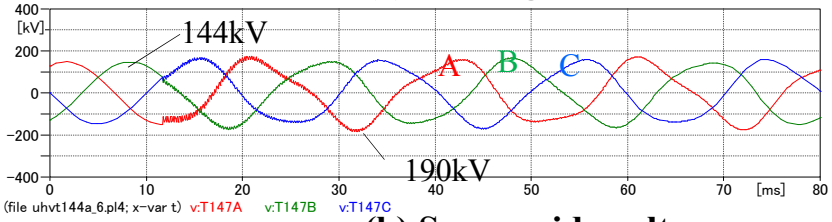
Circuit condition



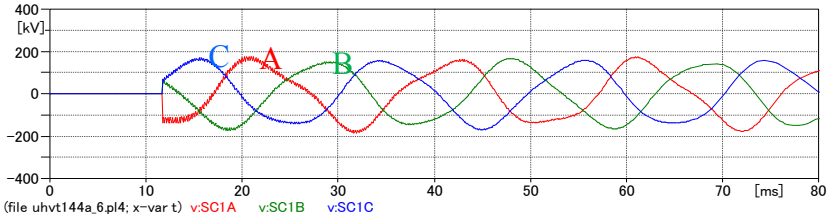
*:Making at peak voltage of phase A



(a) Making Current



(b) Source side voltage



(c) SC side voltage

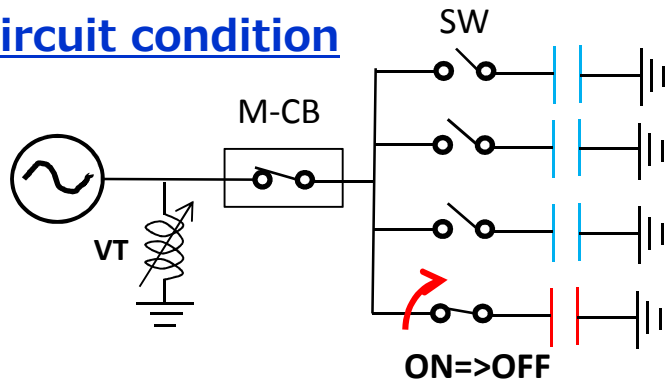
Analysis Results

- **Current:**
  Inrush current : 200Hz superimposed 50Hz
  Initial peak current : 4.3kA
  (Steady current : 1.3kA)
  Maximum current: 6.0kA around 30ms after making
- **Voltage**
  Waveform : Slightly deformed
  Peak voltage: 190kV , no critical level

Breaking operation in normal condition by SW

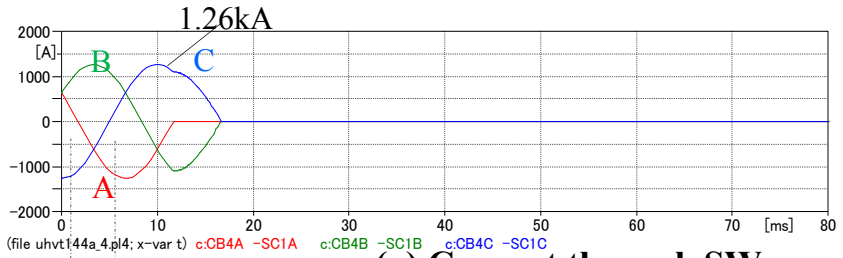
(Case II)

Circuit condition

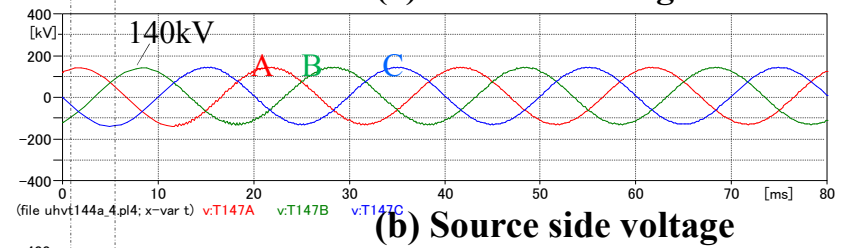


Analysis Results

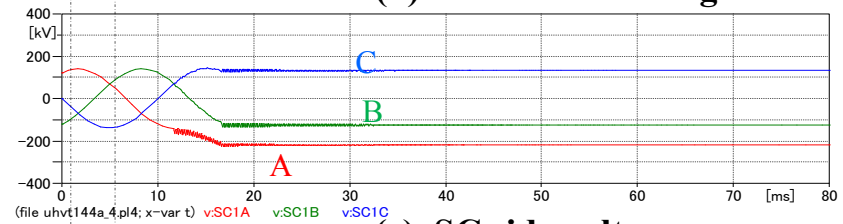
- **Source side voltage :**
  Keep same voltage wave shape as before breaking
- **SC side Voltage :**
  Each phase keeps DC value after breaking
- **Voltage across the SW contacts :**
  Wave shape is (1-cosθ)
  Maximum value is 362kV on first pole to clear at first peak



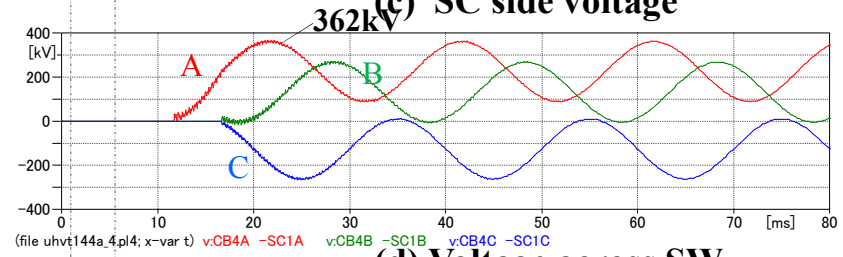
(a) Current through SW



(b) Source side voltage



(c) SC side voltage

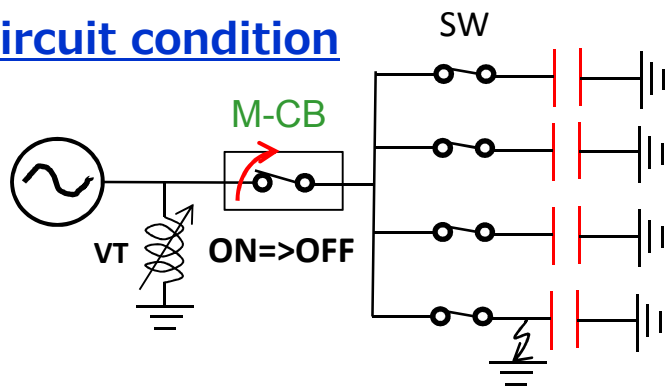


(d) Voltage across SW

Breaking operation in 1LG by M-CB with VT

(Case III)

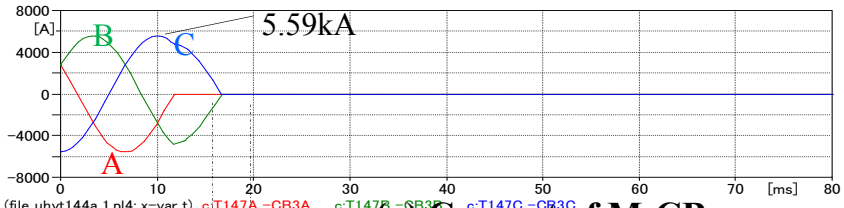
Circuit condition



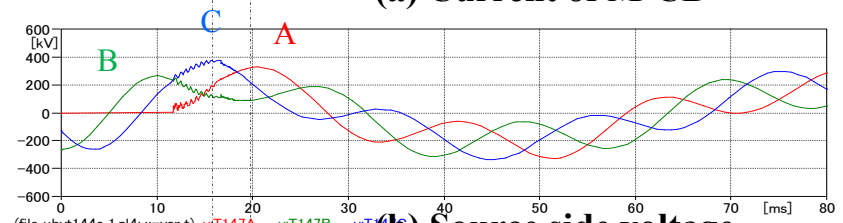
*: Earth fault phase is the first phase to clear, and it is phase A in the study

Analysis Results

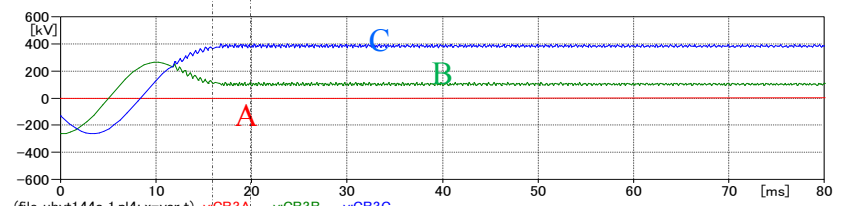
- Source side voltage after breaking : DC plus 50Hz AC component on about 15 Hz oscillations appear on three phases.
- SC side voltage after breaking : Sound phase keeps DC value.
- Voltage across the M-CB contacts : Maximum value is 730kV on second pole to clear and It appears at second peak.
- Zero sequence voltage : Maximum value is 244kV, including oscillating component of about 15Hz



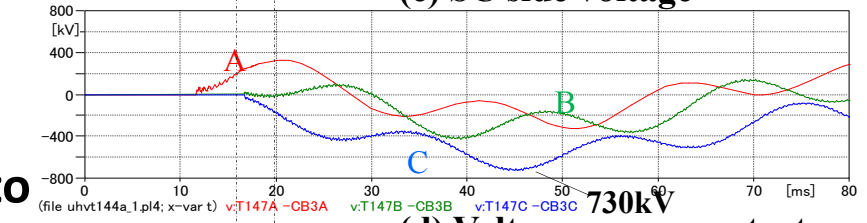
(a) Current of M-CB



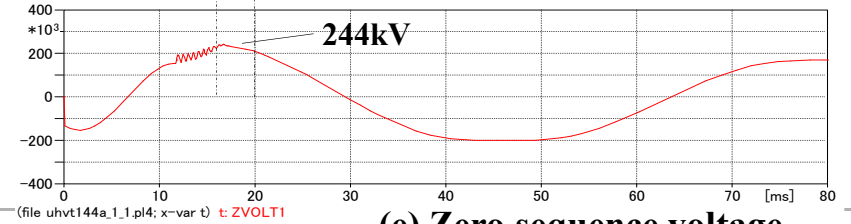
(b) Source side voltage



(c) SC side voltage



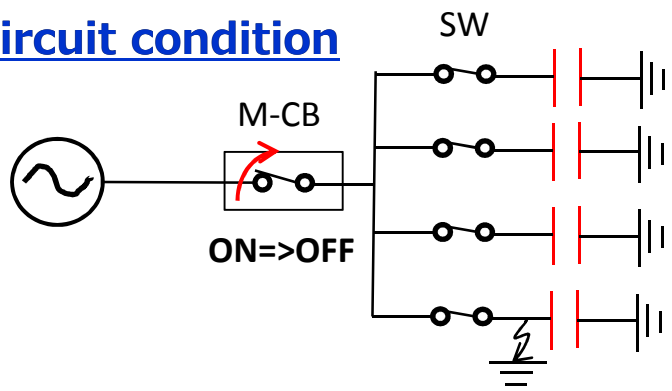
(d) Voltage across contacts



(e) Zero sequence voltage

Breaking operation in 1LG by M-CB without VT (Case IV)

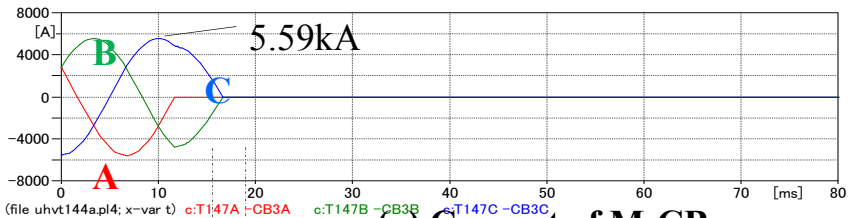
Circuit condition



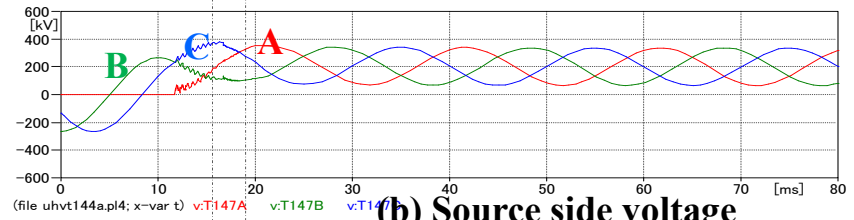
*: Earth fault phase is the first phase to clear, and it is phase A in the study

Analysis Results

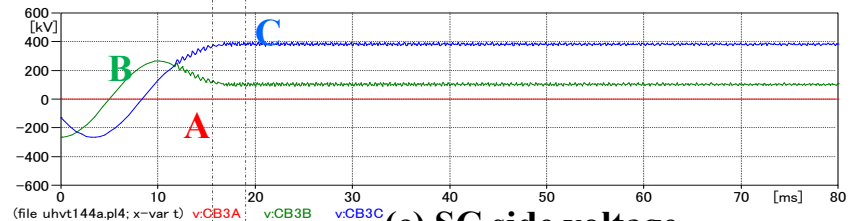
- Source side voltage after breaking : DC plus 50Hz AC component appear on three phases.
- SC side Voltage after breaking : Sound phase keeps DC value, same as Case III (with VT).
- Voltage across the M-CB contacts : Maximum value is 353kV on first pole to clear. It appears at first peak.
- Zero sequence voltage : Maximum value is 244kV, and keeps the DC component after breaking.



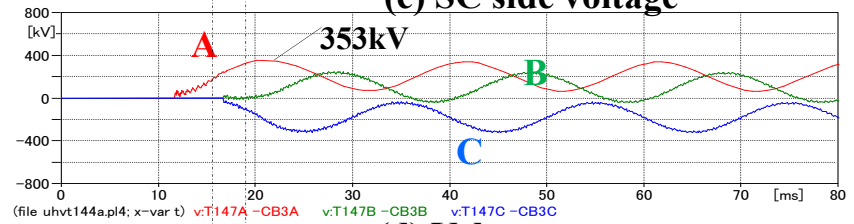
(a) Current of M-CB



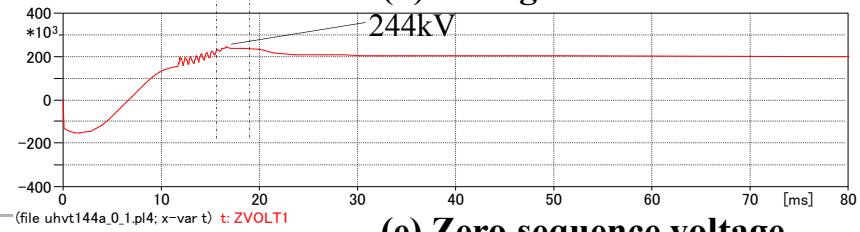
(b) Source side voltage



(c) SC side voltage

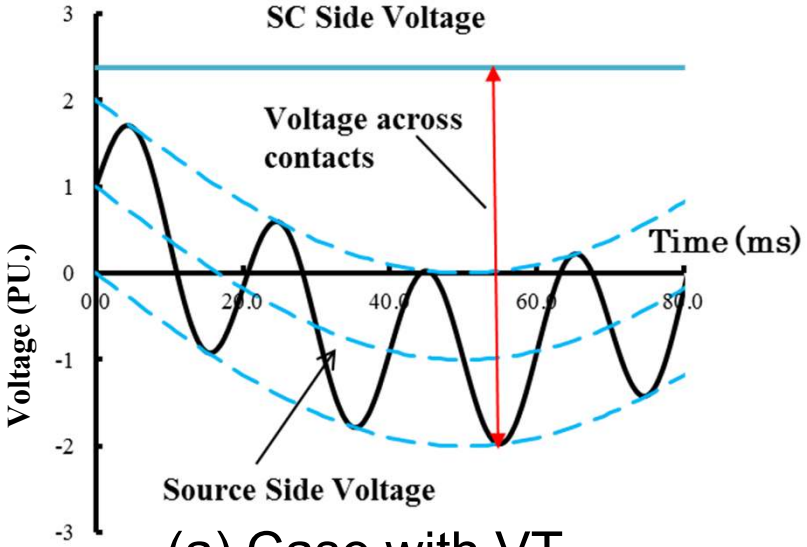


(d) Voltage across contacts

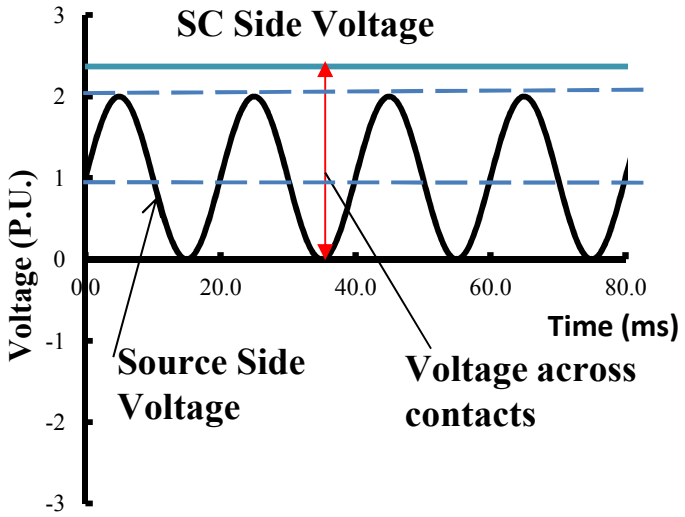


(e) Zero sequence voltage

Reason of voltage escalation in 1LG with VT



(a) Case with VT



(b) Case without VT

1) Source side voltage rise in sound phases due to voltage shift of neutral point by 1LG in unearthed circuit.
2) When this DC voltage discharges via VT excitation inductance, so the source side voltages start to oscillate at lower frequency with DC component .

1) Source side voltage rise in sound phases due to voltage shift of neutral point by 1LG in unearthed circuit.
2) DC voltage of source side keeps constant value, since there is no path for current flow.

Breaking duty of M-CB and SW

Table 7 Summary of capacitive switching duty for M-CB and SW

Switching device	Fault condition	VT installation	NGR installation	Current (Arms)	Maximum voltage across contacts (kV)
M-CB	1LG	With	Without	4000	730 kV* (Case III)
		Without	Without	4000	353 kV** (Case IV)
SW	1LG	With	Without	1000	649 kV*
		Without	Without	1000	373 kV**
	No fault	With	Without	1000	393kV**

*: Maximum voltage may appear on second phase to clear at the second or later AC peak.
**: Standard capacitive current switching recovery voltage; (1- cosθ) type waveform

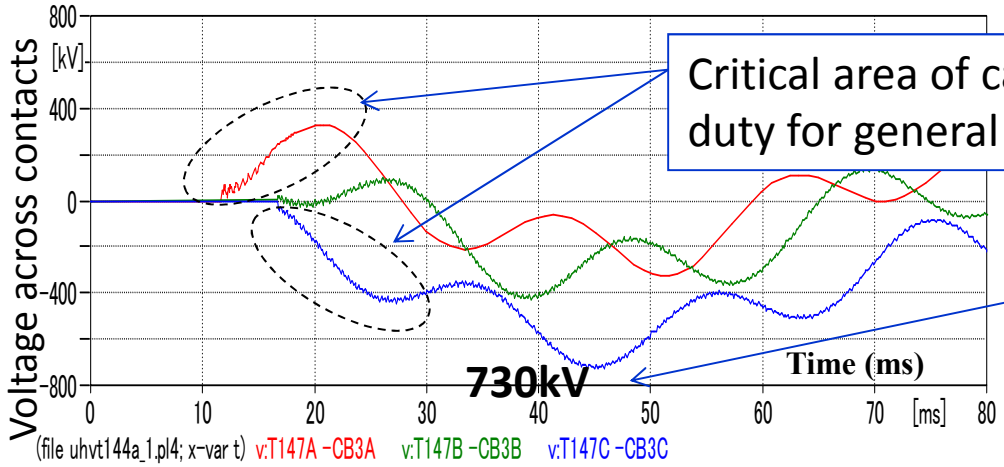
Table 8 Capacitive current switching test condition according to IEC62271-100

Rated voltage	Rated current for BC1 /BC2	Peak Recovery voltage
170 kV	400 Arms	384 kV
245 kV	400 Arms	555 kV
420 kV	400 Arms	950 kV

Conclusion (1/2)

Breaking Operation

- **Very high recovery voltage is caused under 1LG with VT condition.**
  - **The recovery voltage waveform is not (1 - cosθ) shape**
  - **It appears on second phase to clear after one cycle later comparing to normal capacitive switching duty. At this time insulating strength between contacts is relatively high.**
  - **The breaking current is higher than that of IEC standard value . This high breaking current may reduce the contact lifetime, thus requiring frequent maintenance.**



Critical area of capacitive switching duty for general design GCB

At this time GCB contacts are completely open, and insulating strength between contacts are high.

Conclusion (2/2)

Breaking Operation (Continued)

- **The required duties could not be covered by 170kV /245kV rating circuit breaker for 1LG condition.**
- **It's not easy to evaluate the suitable switching device which covers the requirements.**
- **Special attention should be paid, while selecting switchgear of capacitor bank in a tertiary circuit.**
- **Special capacitive switching test may be necessary.**

Making Operation

- **Making current is rather high, but it is not critical, because it appears after mechanically closed for most breakers.**

Insulation level

- **Required Insulation level to earth in tertiary circuit is high. Special consideration should be taken to.**

➢ **One of tentative proposal is using non-magnetic voltage measuring device in tertiary circuit, such as optical voltage transducers.**

➢ **The other option is to review carefully about the requirements and dielectric performance of M-CB and SW based on the study results.**

Influence of parameters

Influence of other parameters on Recovery

Parameter	Severe condition (Higher RV peak)		Relaxed condition
Circuit condition	1LG	>>	normal
VT	With VT	>>	Without VT
Number of connected SCs before breaking(M-CB/SW)	4 SCs	>	1 SC
Number of SCs for breaking operation(M-CB)	4 SCs	>	1 SCs
First phase to clear in 1LG with VT	Earthed phase	>	Sound phase
Location of 1LG (SW only)	Cable side	>	SC side
Capacity of VT	100VA	=	15VA
Cable length for M-CB	200m	=	50m
Cable length for SW with VT	50m	>	200m

Thank you very much

for your kind attention