Application of HV VCB in Japan

Dr. Hiroki Ito, Mitsubishi Electric, Japan

VCB installations in Japanese utility as of November, 2009

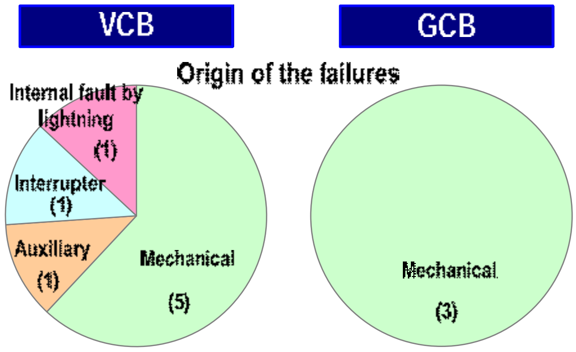
Questions	Utility A	Utility B	Utility C	Utility D	Utility E
Policy of VCB applications in transmission systems	Special applications for frequent interrupting operations	NO VCB applications in transmission lines Only for 24 kV and bellow	Special applications for frequent interrupting operations	NO VCB applications in transmission lines Only for 24 kV and bellow	VCB applications for 66 kV transmission systems & above
Number of VCB in service	170 kV: 66 units 72 kV: 630 units 24 kV: unknown	72 kV: None 24 kV: 1400 units	72 kV: 25 units 36 kV: 2 units for load switches 24 kV CB: 3 units		72 kV: 2629 units 36 kV: 171 units
Technical concerns for further applications to transmission	Overvoltage due to chopping & NSDD Long-term reliability such as vacuum leak and contact erosin	Overvoltage due to chopping & NSDD Long-term reliability	Overvoltage due to chopping & NSDD Long-term reliability		Long-term reliability Residual life evaluation
Requests to CIGRE investigation on VCB	Technical trend of VCB	Service experience Influence of NSDD & chopping to transmission systems Diagnostic technique	Service experience Solutions for NSDD & chopping Long-term reliability		Service experience

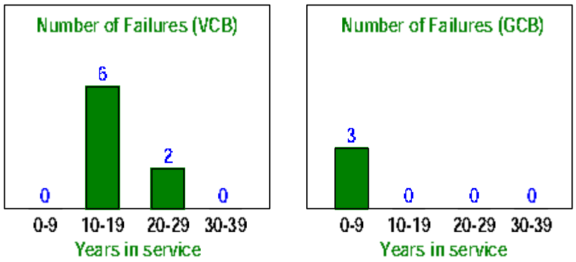
Presented at 2010 CIGRE Paris Session A3-303

Comparison of Failure rates between HV-VCB and GCB

	VCB	GCB
Rating	84 / 72 kV	84 / 72 kV
	12.5-31.5 kA	12.5-31.5 kA
	600-2000 A	600-3000 A
CB-year	24907 unit-year	12953 unit-year
Failure Rate	0.032	0.023

	VCB	GCB
Total Installations	2583	1454
Main Transformer	263	99
Distribution Transformer	814	199
Line Protection	1287	863
Shunt capacitor	117	30
Shunt reactor	0	15
Neutral point	3	147





Japanese utilities policies for HV-VCB acceptance

A significant factor in applying HV-VCB

Purchase price: 2 of 8 utilities

Life cycle cost: 7 of 8 utilities

VCB premium price

Acceptable: 5 of 8 utilities

Not acceptable: 4 of 8 utilities

Japanese Utility Anxieties on HV-VCB

Overvoltage due to chopping

- Chopping levels for 72.5 kV VCB and above
- Reignition overvoltage levels
- Consequence of chopping in transmission systems

NSDD (Non-Sustained Disruptive Discharge)

- Probability of NSDD, especially O-CO operations
- Consequence of NSDD in transmission systems
- Possible evolution to dielectric interruption failure including other phases

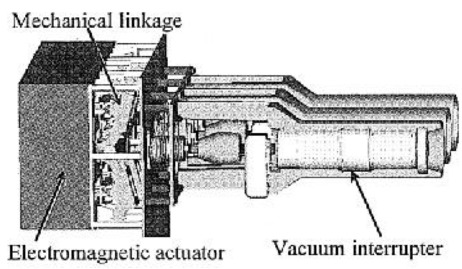
Long term reliability of VCB

Industrial applications in Japan as of November, 2009

Rating: 72 kV (52 kV and above)

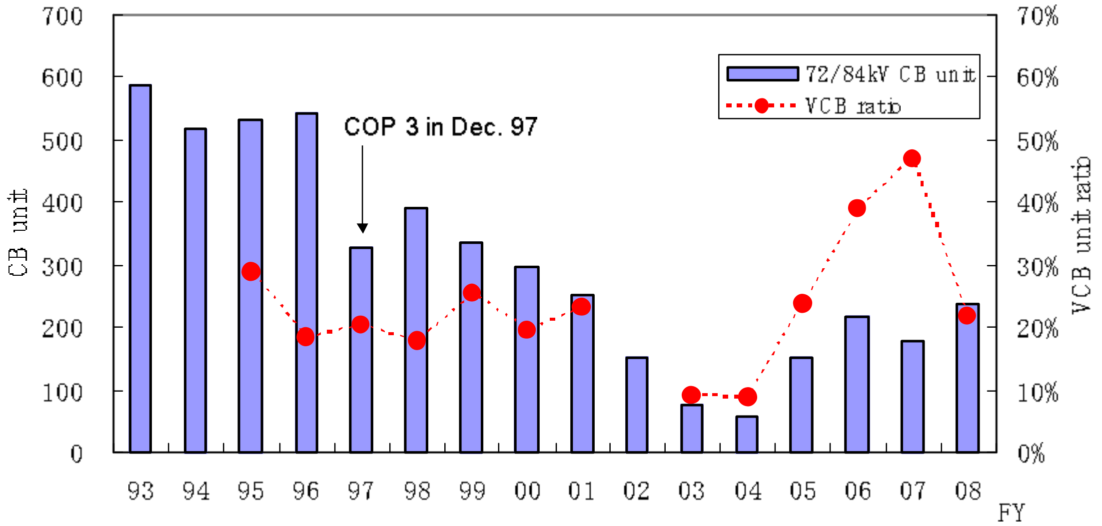
Applications	Manufacturer A	Manufacturer B	Manufacturer C
Factory	713 units	827 units	667 units
Railway	456 units	253 units	245 units
Office	333 units	744 units	450 units
Others	179 units	135 units	
Total	1681 units	1959 units	1362 units

120 kV dead tank 1-break VCB



72 kV VCB with electromagnetic operating mechanism

Installation number of VCB in JAPAN



Annual circuit breaker backlog and the ratio of vacuum circuit breaker

- High voltage VCB was developed in the 1970's
- High voltage VCBs have been installed in the 1980's and 1990's.
- SF6 was defined as the global warming gas in 1997.

Motivations for VCB developments & installations in JAPAN

A large number of VCBs are put in service since 1970's, because of

Advantages of VCB

Utilities
- Less maintenance work
- Frequent switching capability

Industrial system
- Non-flammability
- Low operating energy

The reduction of SF6 gas usage seems not to be a primary factor of utilities' policy to VCB installations starting in 1970s. High voltage VCBs have been installed to special requirements mostly in the 1980's and 1990's before 1997 when COP3 conference was defined as SF6 gas to be one of the global warming gas.

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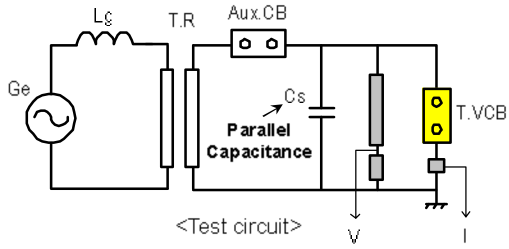
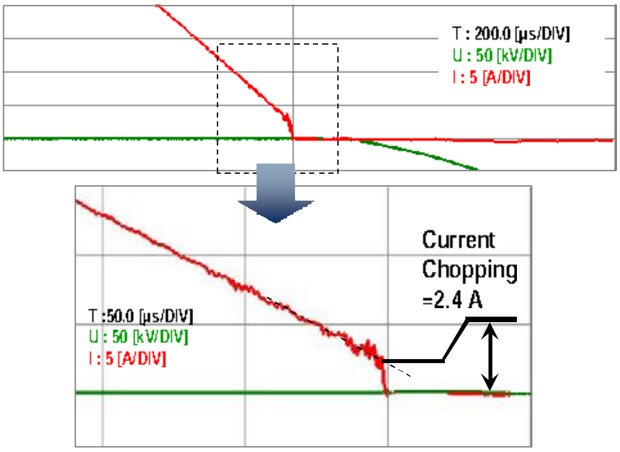
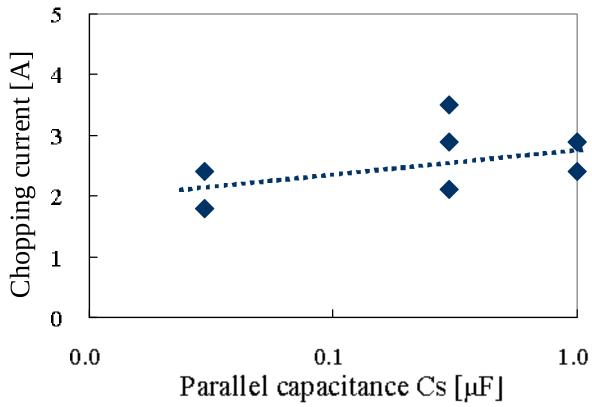
Current chopping behaviour of VCB

Current chopping of HV-VCB during inductive current switching can be reduced to 2-3 A levels with new contact materials.



Breaking Current I_{rms} = 200A





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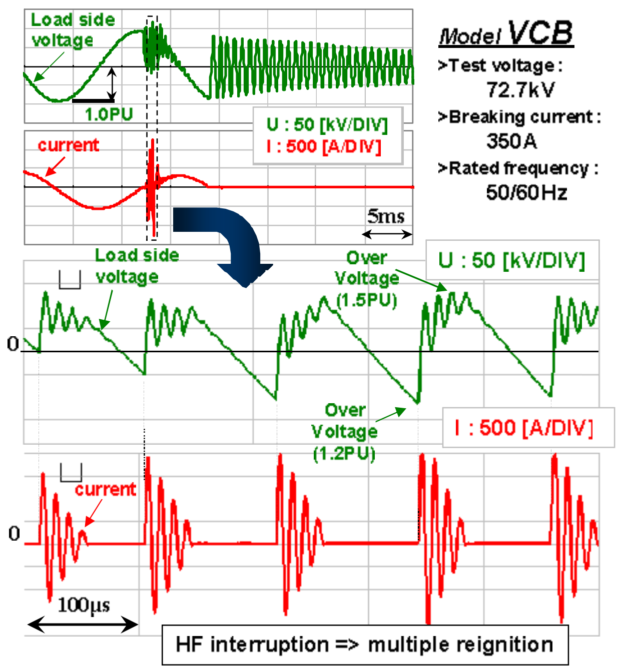
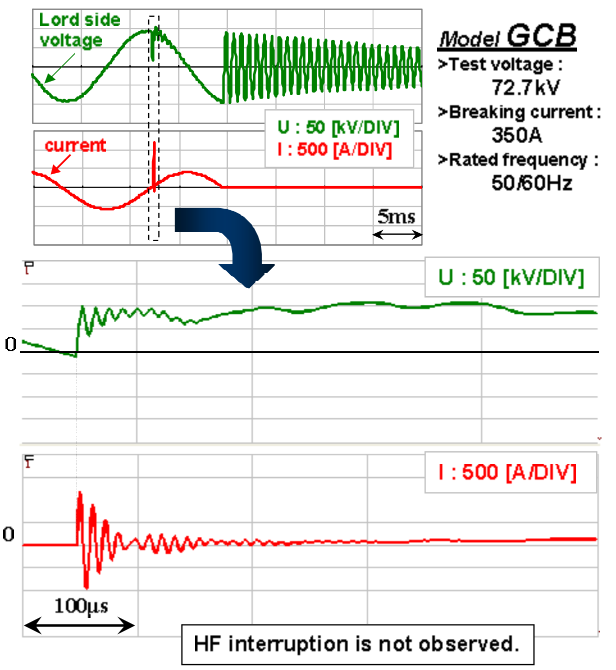
High frequency interruption during inductive load switching

High frequency reiginition of VCB

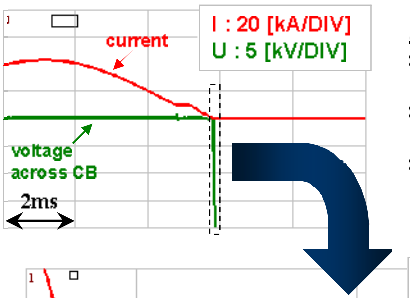


High frequency reignition of GCB

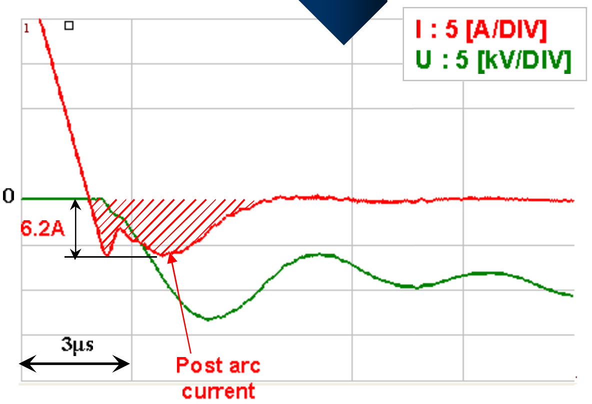


Post arc current after SLF interruption

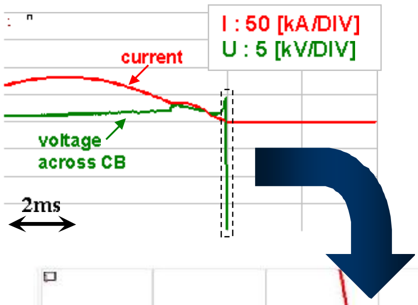
SLF(L90) interruption of VCB



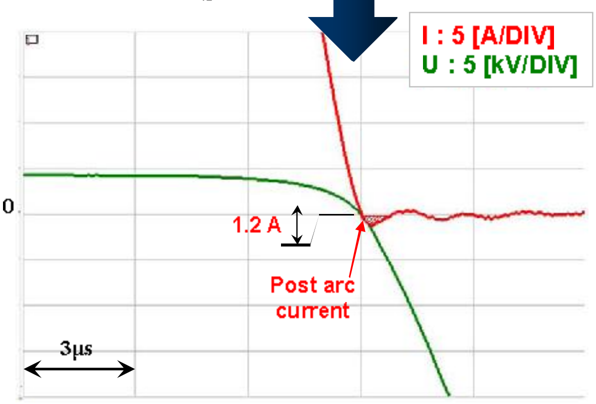
Model **VCB**
>Rated voltage : 72/84kV
>Breaking current : 31.5kA x 0.9
>Rated frequency : 50/60Hz



SLF(L90) interruption of GCB



Model **GCB**
>Rated voltage : 420kV
>Breaking current : 63kA x 0.9
>Rated frequency : 60Hz



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Experiences with HV vacuum switchgear in the USA

Dr. Mietek Glinkowski, ABB, USA

Experience with HV Vacuum switchgear in the USA

- US market is **different**
  - Ratings (ANSI), requirements (60 Hz, high SCC), substation practices (**D**ead**T**ank**B**reaker vs **L**ive**T**ank**B**reaker), system architecture, traditions (outdoor vs indoor), business drivers, …
- Historically vacuum technology was conceived and developed in the US
  - Feb. 1890 – US Patent for vacuum switching
  - Sept 1926 – first successful HV vacuum switching experiment

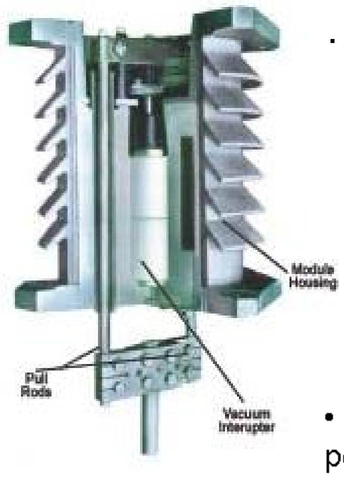
Application of vacuum in the US

- Starting in late 1950s vacuum was commercially applied in MV Circuit breakers (15 kV)
- Vacuum has virtually eliminated gas CBs for Medium Voltages (5kV-38 kV) for both indoor and outdoor with the exception of some special cases
- Starting in late 1960s vacuum interrupters were also applied in load break switches (LBS)
  - First in MV applications – up to 38 kV
  - Then in HV applications – gradually up to 242 kV

HV Vacuum Switches in US

- For HV applications vacuum was introduced mainly for capacitor and reactor switching
  - Vacuum was recognized as "ideal" for repetitive switching
  - Good interruption for any power factors (cap./ind.) and all levels of load currents
- For capacitor bank switching either CLR (Current Limiting Reactors) or synchronizing POW (Point On Wave) was practiced for inrush current mitigation
- For reactor switching low current chopping was needed for preventing restrikes and voltage escalation

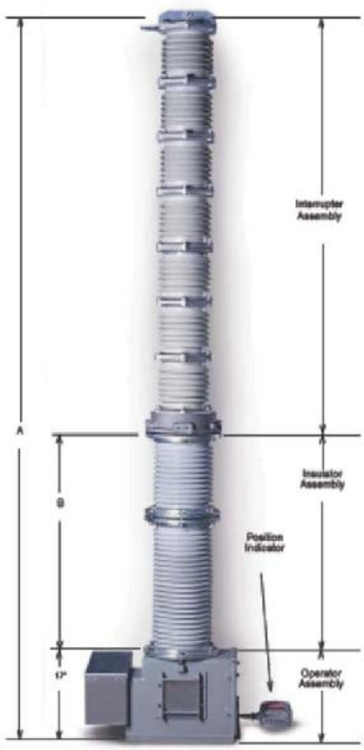
Concept of construction of HV vacuum switches



- Vacuum module
  - can be stacked up for higher voltage ratings
  - can handle up to 600 A cont current

Up to 5.8 m

- Up to 9 interrupter modules per phase could be used
- Common mechanism



Typical HV Switch ratings used

- Voltage from 15 kV – 242 kV
- Cont. Current up to 600 A
- SC Current up to 4000 A
- Momentary current up to 40 kA asym
- ST Current up to 10 kA 2 sec
- Number of modules

Rated Voltage	BIL (term-term)	No. of VIs
72	400	4
121	750	7
145	850	8
242	950	9

Field experience with HV vacuum switches

- Reputation not so good due to variety of issues
  - Specific designs
  - Technology related
  - Non-vacuum-related
  - Non-technology-related
  - Quality, service
- Some additional effort would be required to overcome the historical biases

World Wide acceptance/hesitation towards future HV Vacuum Circuit breaker applications

Feedback from the global survey

Worldwide survey

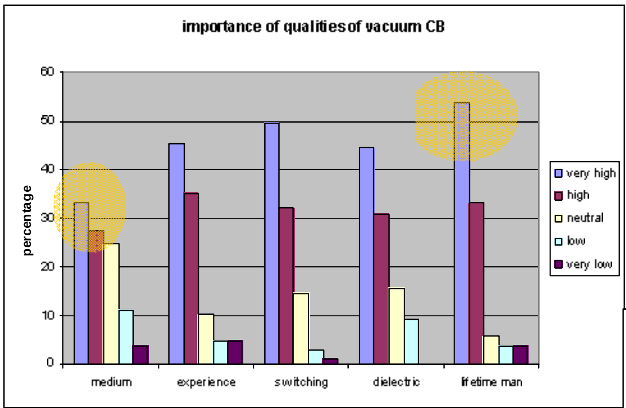
- WG has sent a 5-question survey to utilities worldwide based on 5 categories:
  A: Interrupting medium: SF6 vs. vacuum
  B: Service experience: known reliability data
  C: Switching performance: interruption capability, switching overvoltages
  D: Dielectric performance: breakdown statistics
  E: Life-time management: maintainability, monitoring of medium, electrical life, low temperature issues
  F: Other
- In favor of or against vacuum and SF6 including sensitivity to pricing, acceptance issues, and potential concerns
- The same categories and questions used for vacuum and for SF6
- WG is still analyzing the data
  (please see blank survey for details)

Brief summary of survey results

- 113 respondents from 27 countries
  USA = 22, China = 14, Germany = 10, Korea = 9, Japan = 8, Australia = 8, etc.
- Some missing countries –Russia

Brief summary of survey results

Vacuum



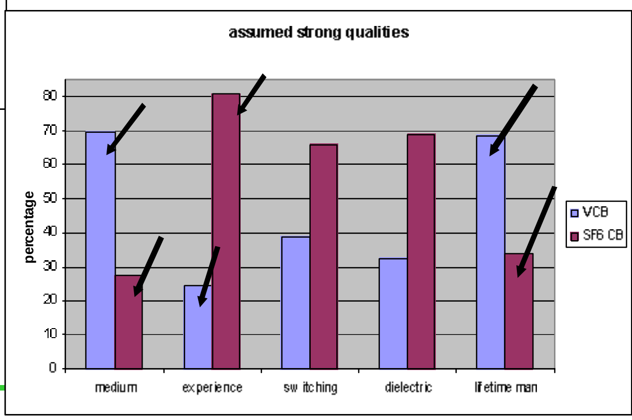
What qualities are important?

- **Vacuum as medium not so important**
- **Lifetime most important**

Explain

What are strong qualities of vacuum?

- **Vacuum as medium is considered strong quality**
- **Experience (lack of) is the weakest for vacuum**



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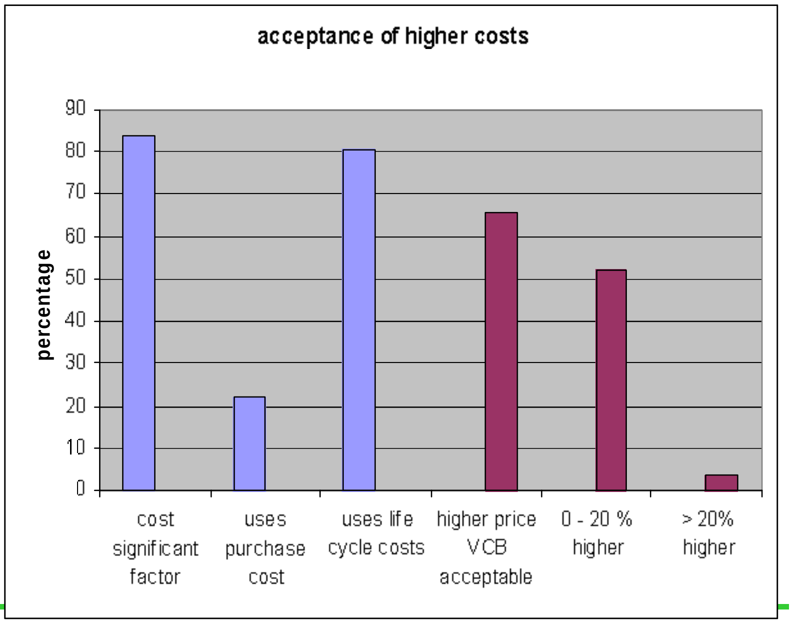
Brief summary of survey results

- Although the survey was directed towards engineering/technology experts a question on cost sensitivity was asked

• Cost is a significant decision factor
• but higher price would be acceptable mostly from 0-20%



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Brief summary of survey results

- Many additional comments received (written in)
- Grouped in several generic categories
- Categories could overlap
  - Leaks versus maintenance vs. low temp behavior etc.

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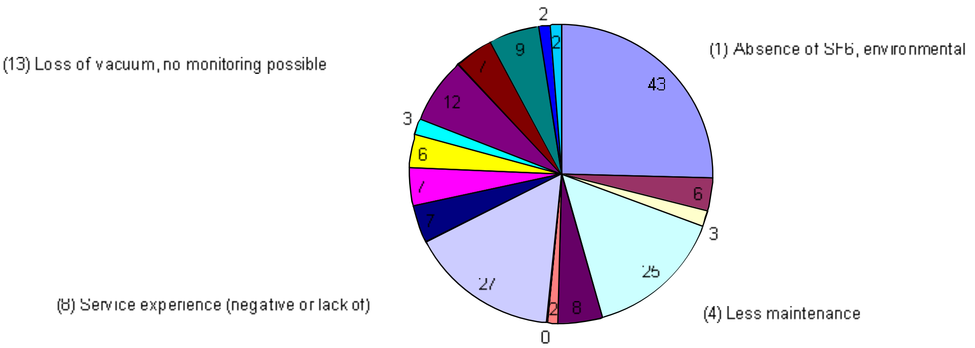
Brief summary of survey results

Summary of written comments to Q1 and Q2



- (1) Absence of SF6, environmental
- (2) Low temperature behaviour
- (3) Fast recovery
- (4) Less maintenance,
- (5) leaks very rare (existing leaks issues in SF6)
- (6) High nr. of operations
- (7) High altitude
- (8) Service experience (negative or lack of)
- (9) Gaps in series with grading capacitors, multiple gaps
- (10) Capacitive current switching
- (11) Switching overvoltages
- (12) X-ray
- (13) Loss of vacuum, no monitoring possible
- (14) Chopping, interaction with transformers, switching transients
- (15) Nominal current capability, ratings
- (16) Size
- (17) High-pressure air for external insulation

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Lifetime Management of Vacuum Circuit Breakers

Prof. Leslie Falkingham, VIL, UK

Introduction

Since their introduction in the late 1960's Vacuum Circuit Breakers have become the dominant technology for Medium Voltage applications

Today over a million MV VCB are manufactured each year. This success is due to their high performance, good environmental profile, extremely high reliability, low maintenance and low cost

It is expected that most or all of these attributes will also be applicable when applied to higher voltages

Subjects

- Vacuum Circuit Breaker Experience at Medium Voltage
- Maintenance
- End of Life Disposal
- High Voltage Vacuum Circuit Breaker Experience

Vacuum Circuit Breaker Experience at Medium Voltage

Service experience over the past 40 years has shown MV Vacuum Circuit Breakers to be extremely reliable. This is due to a number of factors:

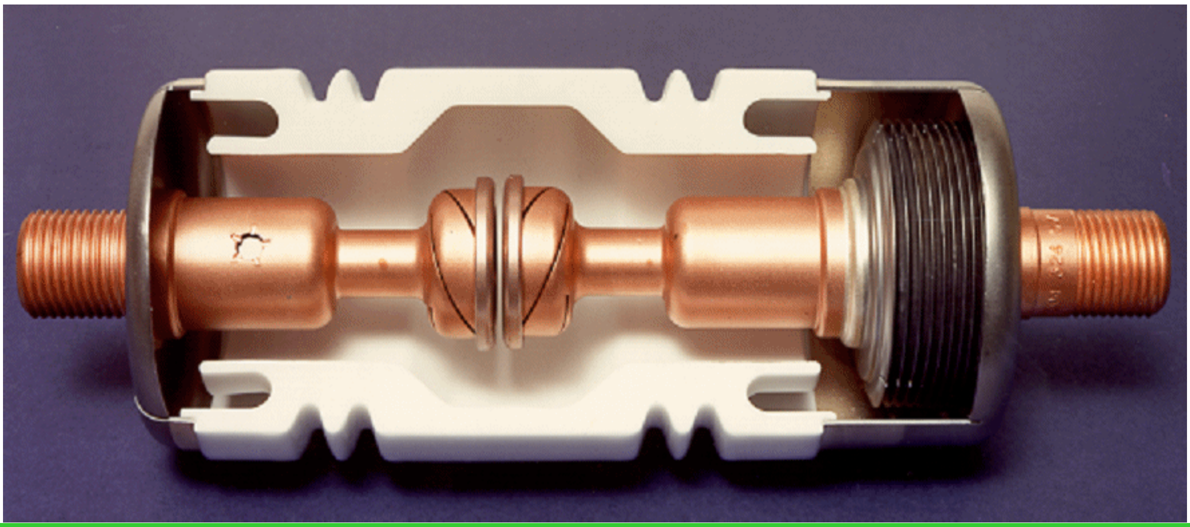
- The vacuum interrupters are zero maintenance and are very reliable, with MTTF of the order of 44,000 Interrupter years
- The operating stroke and mechanism energies are very low resulting in simple reliable mechanisms
- for air insulated equipment there are no gas or liquid leak possibilities

Vacuum Circuit Breaker Experience at Medium Voltage

Vacuum circuit breakers are relatively simple with the interrupter having only one moving component which moves linearly over a very short stroke 6-8 mm for 12 kV

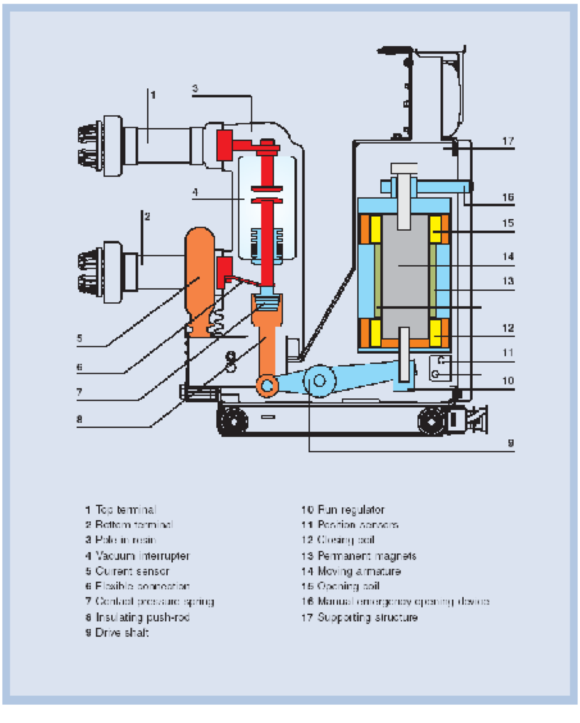
Vacuum Circuit Breaker Experience at Medium Voltage

Vacuum interrupters, although high technology devices are made in a special factory under controlled conditions giving very high levels of product quality and reliability



Vacuum Circuit Breaker Experience at Medium Voltage

Vacuum circuit breakers are very simple devices with a very simple mechanism providing a short linear movement to the moving contact



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Maintenance

- The principle of operation of the Vacuum Interrupter means that there is no gas compression and this coupled with very low mass contacts means that mechanism energies are very low. Thus the mechanism is low energy resulting in lower wear, less maintenance, and higher reliability
- Although spring mechanisms are common, the very short stroke of the interrupters also helps with mechanism design and in conjunction with the low energy requirement has allowed the use of a unique mechanism based on permanent magnets. This Permanent Magnetic Actuator has only one moving part and is capable of millions of operations with little or no maintenance

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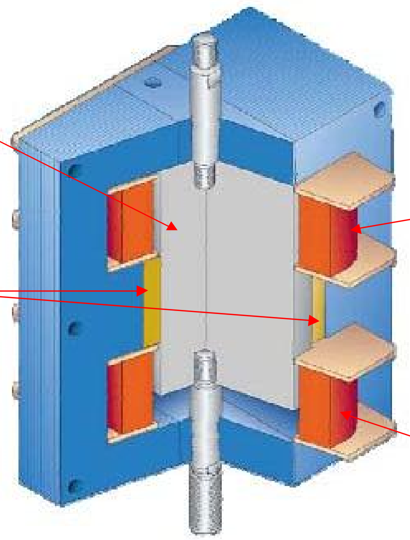
Maintenance

Permanent Magnetic Actuator mechanism

Maintenance



Magnetic Actuator

Maintenance

Comparison of 145kV VCB with 145kV GCB
(Same manufacturer)

Operation	GCB	VCB
• General inspection	3- 6 years	3-6 years
• Gas monitoring or refilling	Required	Not required
• Maintenance (wearing parts)	12 years	12 years
• Overhaul of CB Chamber	Required	Not required
• SF_6 emission data report	Required	Not required
• Electrical cost for tank heater	Required	Not required

Maintenance

Vacuum Interrupter Life may be an issue. Vacuum Interrupters are sealed for life devices. However the vacuum life is generally time based and is not significantly affected by the operational duties.

Historically a "shelf life" of 20 years was widely used by the industry for MV VCB with the intention of replacing the VI at 20 years as a mid life service of the VCB which had an intended life of 40 years. This would be equivalent to the overhaul of the Breaker Chamber for GCB, and may be necessary at 20 or 30 years for HV VCB.

Maintenance

Vacuum Interrupters in SF_6 or high pressure gas may also be an issue. The condition of vacuum in a VI is normally verified by a simple power frequency voltage test, however if the VI is inside an insulating gas container, the insulating gas may enter the VI and allow a failed device to pass the voltage test, giving a false reading.

IEC have recognised this by requiring that Gas Insulated VCB must interrupt a high current arc to verify condition after short circuit tests.

End of Life Disposal

- VCB have no restrictions on end of life disposal
- For air or solid insulated breakers there is no requirement to degas or decontaminate the equipment
- There are no toxic arc products within the equipment
- There are no specific environmental issues

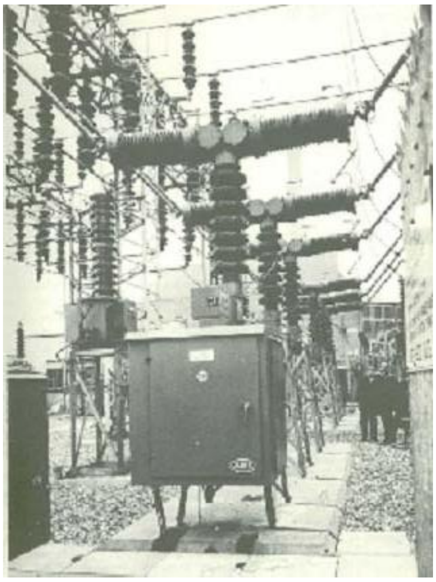
High Voltage Vacuum Circuit Breakers

- High Voltage VCB include much of the technology inherited from MV VCB
- Some VCB use SF_6 gas as a dielectric medium, but the latest VCB no longer do this, and are completely SF_6 free

72.5kV Dry Air insulated Dead Tank Vacuum Circuit Breaker

High Voltage Vacuum Circuit Breakers

There is some long term experience with HV VCB. A small number of multi break 132 kV VCB were installed in the UK in 1967.
Although these were expensive and had complex mechanisms due to the requirement for 6 breaks per phase, the field experience was good, with no problems reported over 30 years of service



132kV Live Tank Vacuum Circuit Breaker

High Voltage Vacuum Circuit Breakers

More recently there is extensive experience with HV VCB mainly from Japan, where several thousand HV VCB have been in service for up to 20 years.

There have been a small number of problems, but overall the experience has been extremely good

145kV Live Tank Vacuum Circuit Breaker

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High Voltage Vacuum Circuit Breakers

Comparison of HV VCB with HV GCB (Same rating)

Attribute	GCB	VCB
• Mechanical Life	10,000	10,000
• Electrical Life (Load current)	6,000	10,000
• Short Circuit Life (40kA)	6-10 @100%	30 @ 100%

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High Voltage Vacuum Circuit Breakers

Modern HV VCB can use one VI per phase up to 145kV and have very simple, low energy mechanisms.
The VI are relatively small and as they are sealed for life have no maintainable components.

72.5kV and 145kV Vacuum Interrupters Hannover Fair 2011

High Voltage Vacuum Circuit Breakers

- One vacuum interrupter per phase coupled with very simple, low energy mechanisms

- This means that they are very similar in construction to the MV VCB and so it is believed that the excellent service experience and very high reliability of VCB in Medium Voltage can be replicated in the HV applications

72.5kV Live Tank Vacuum Circuit Breaker