Inductive load switching
Standardization status

Rene Smeets

KEMA Testing, Inspections and Certification
The Netherlands
Member IEC MT 32 (inductive load switching)

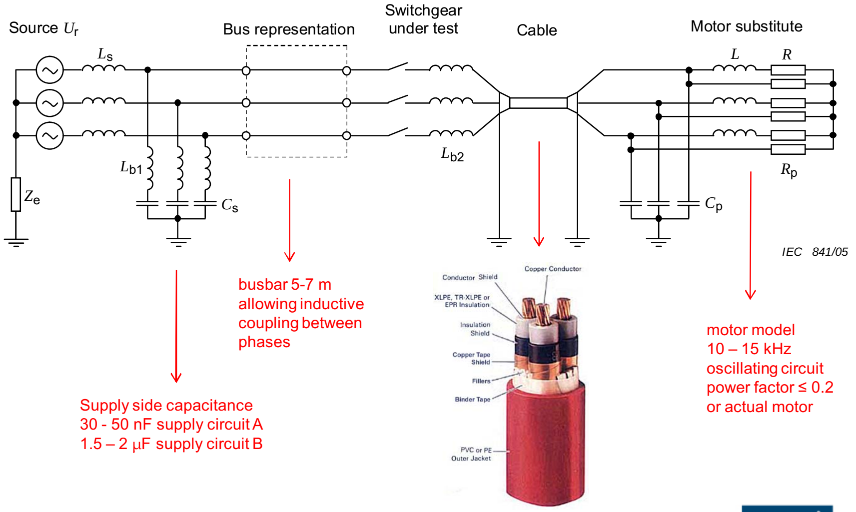
Experience you can trust.

IEC 62271-110: Inductive load switching (2005, 1st edition)

- Covers all voltage levels 1 – 800 kV
  - Unloaded transformer switching (no testing)
  - Motor switching ≤ 17.5 kV
  - Shunt reactor switching ≥ 52 kV

- Relevant for medium voltage: motor switching
  - Test-circuit defined in great detail
  - Three-phase interaction essential
  - High-frequency phenomena are represented

IEC Test circuit for motor switching



busbar 5-7 m
allowing inductive
coupling between
phases

Supply side capacitance
30 - 50 nF supply circuit A
1.5 – 2 μF supply circuit B

motor model
10 – 15 kHz
oscillating circuit
power factor ≤ 0.2
or actual motor

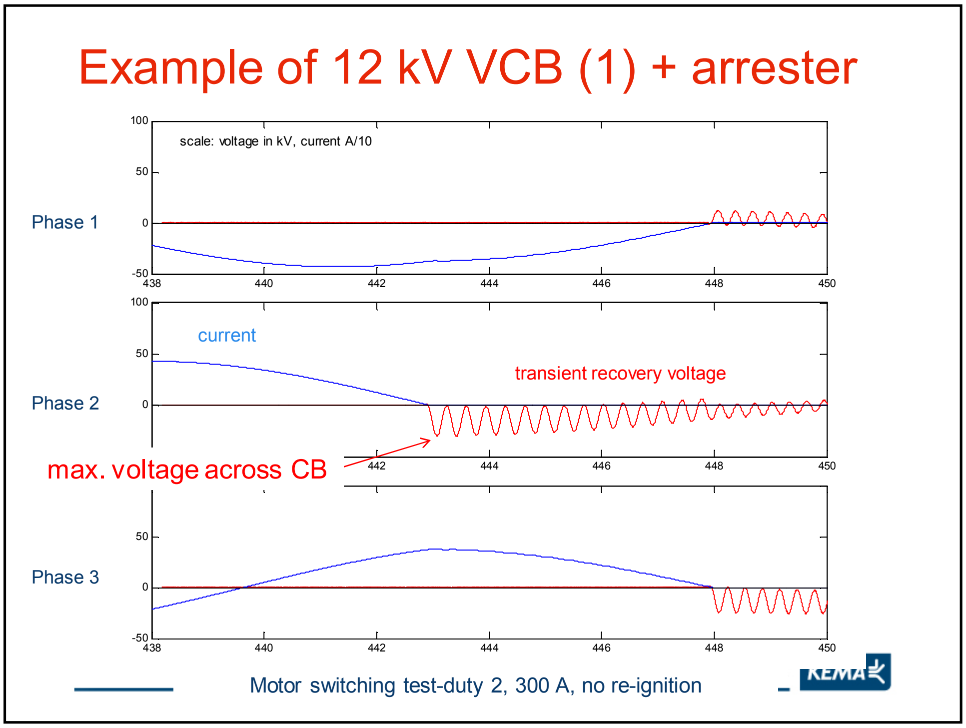
100 m screened cable

Required tests

Test duty	current	capacitance	Nr. of tests
1	100 A	30 - 50 nF	20
2	300 A	30 - 50 nF	20
3	100 A	1.5 – 2 μF	20
4	300 A	1.5 – 2 μF	20

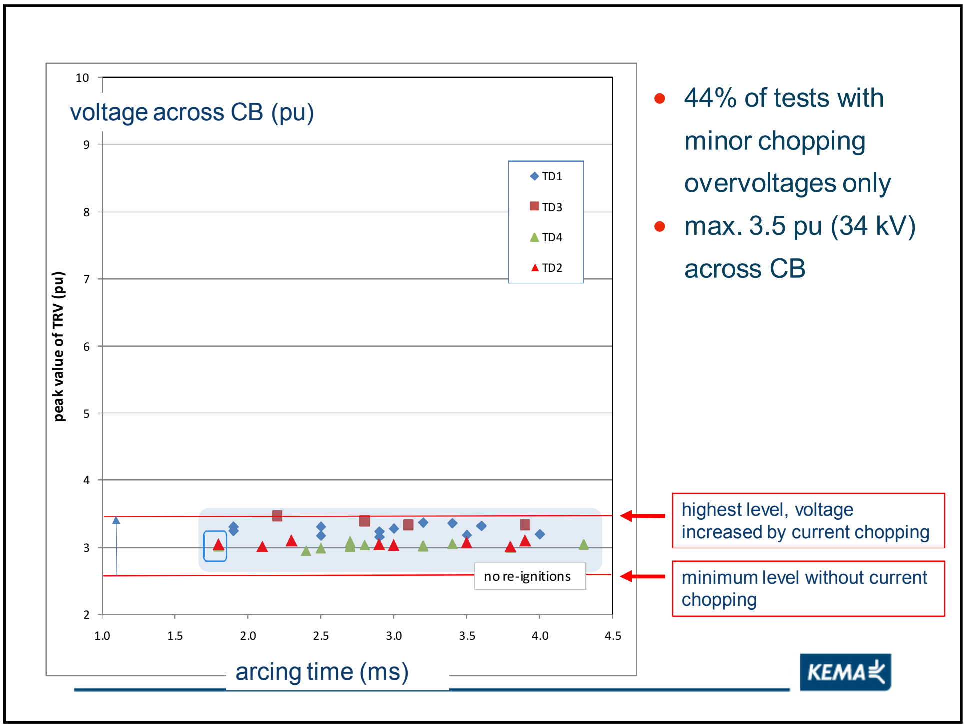
20 test at 0.5 ms steps of arcing time (at 50 Hz)

80 tests all together



Example of 12 kV VCB (1) + arrester

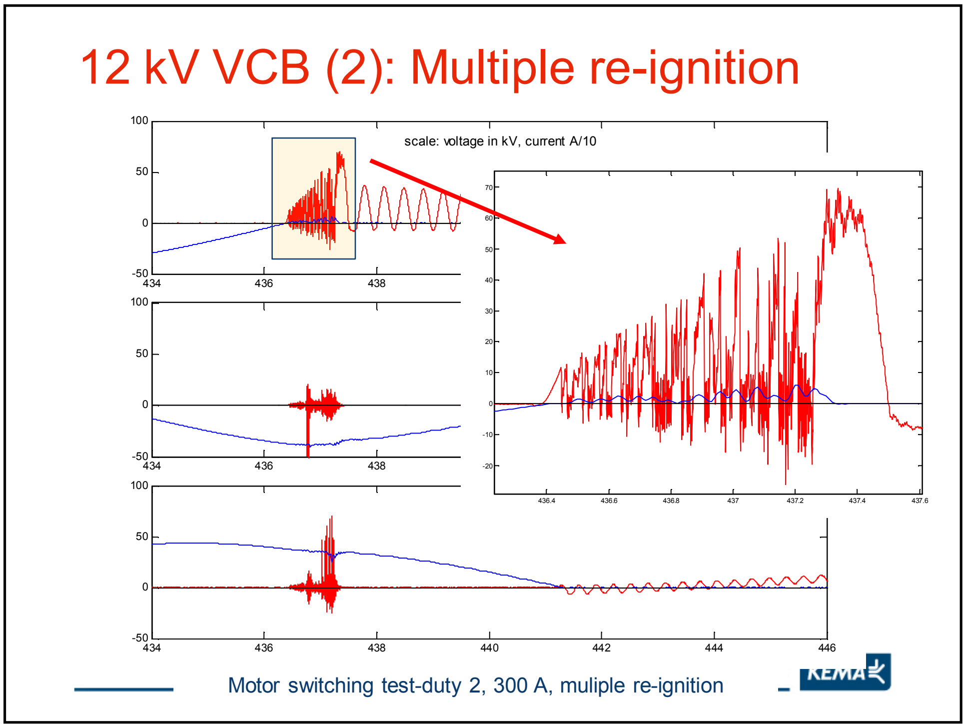
Motor switching test-duty 2, 300 A, no re-ignition



- 44% of tests with minor chopping overvoltages only
- max. 3.5 pu (34 kV) across CB

highest level, voltage increased by current chopping

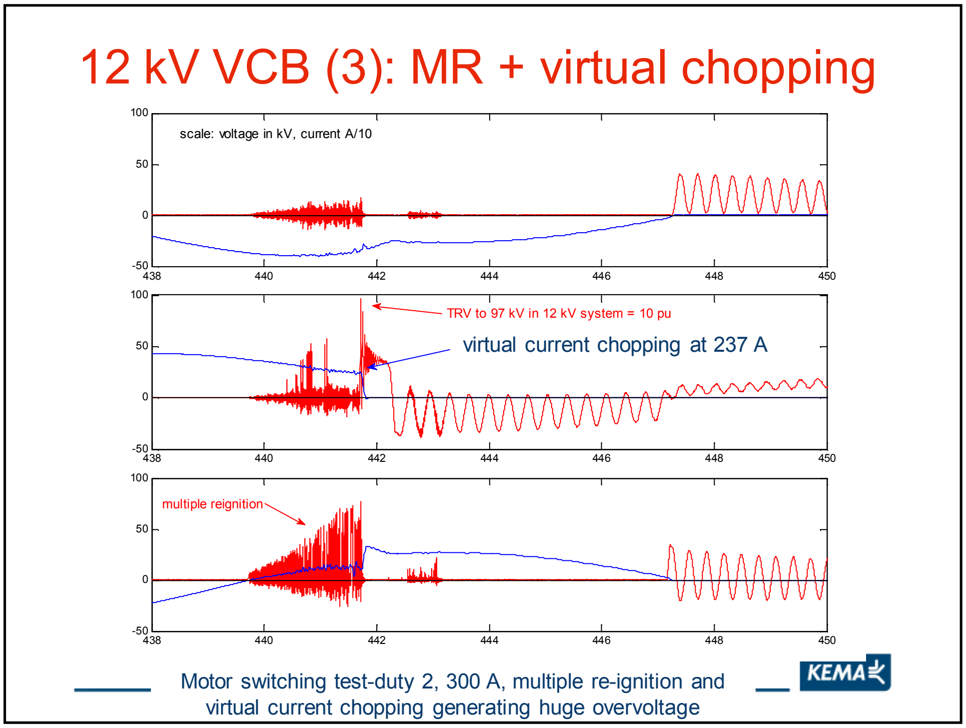
minimum level without current chopping



12 kV VCB (2): Multiple re-ignition

scale: voltage in kV, current A/10

Motor switching test-duty 2, 300 A, muliple re-ignition



12 kV VCB (3): MR + virtual chopping

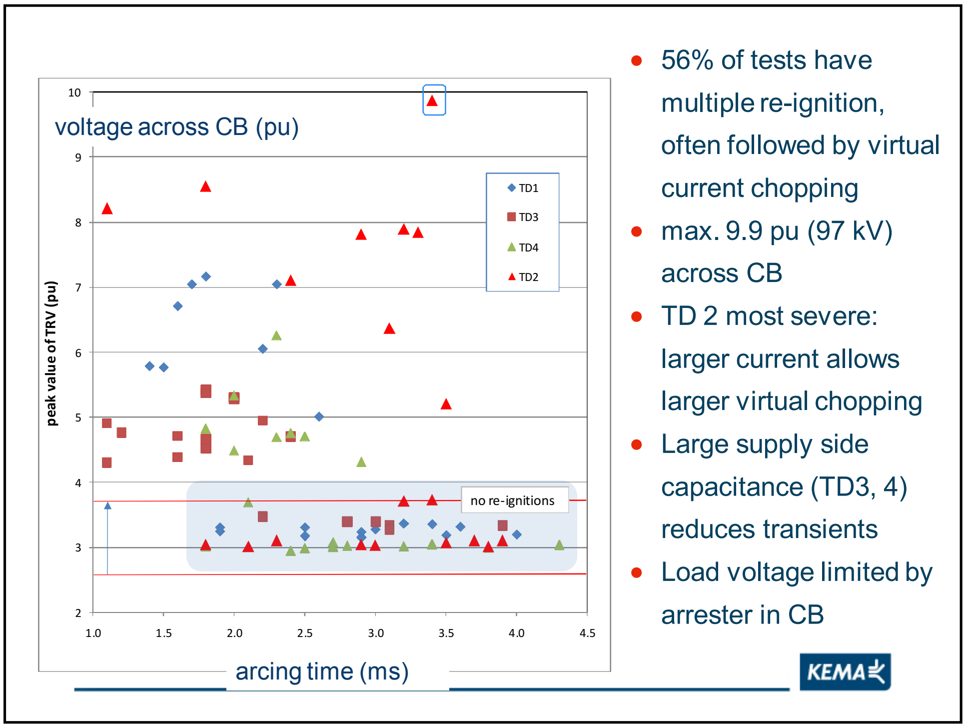
scale: voltage in kV, current A/10

TRV to 97 kV in 12 kV system = 10 pu

virtual current chopping at 237 A

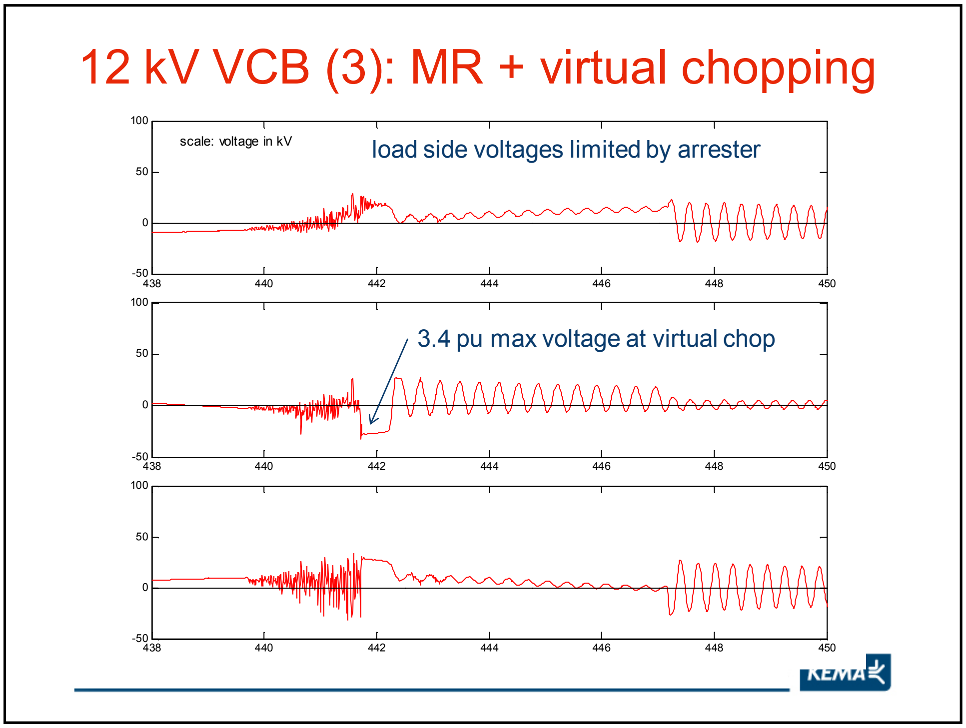
multiple reignition

Motor switching test-duty 2, 300 A, multiple re-ignition and virtual current chopping generating huge overvoltage



- 56% of tests have multiple re-ignition, often followed by virtual current chopping
- max. 9.9 pu (97 kV) across CB
- TD 2 most severe: larger current allows larger virtual chopping
- Large supply side capacitance (TD3, 4) reduces transients
- Load voltage limited by arrester in CB

12 kV VCB (3): MR + virtual chopping



scale: voltage in kV

load side voltages limited by arrester

3.4 pu max voltage at virtual chop

Conclusions / remarks

- Current chopping is no problem
- Multiple re-ignition generate steep surges that may endanger winding
- Virtual chopping is common but can be dealt with by arrester
- Overvoltages in test-circuits are expected to be higher than in service
- There is no limit of overvoltages set in the IEC standard
- Only outside flash-over would prevent VCB from passing motor switching test
- IEC standard not adapted to VCB application

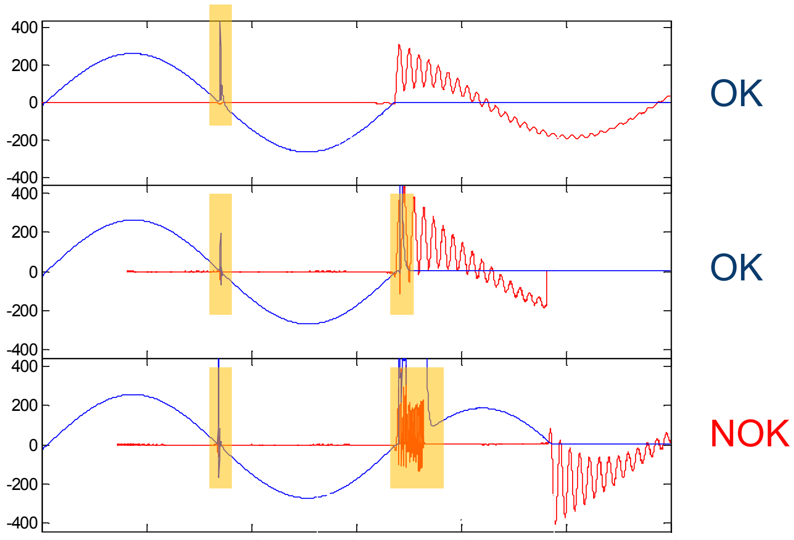
Future standardization in IEC

- New edition of IEC 62271-110 (inductive load switching) in 2013
- Shunt reactor switching re-introduced also in voltage range 12 – 52 kV

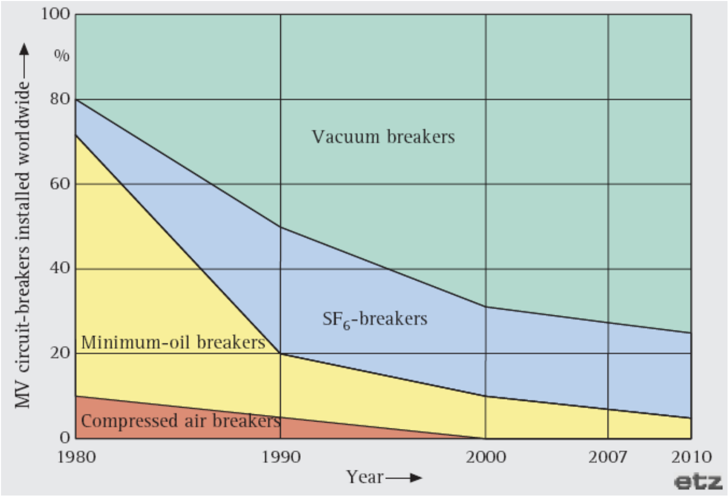
Test duty	Nr. of breaking operations		current
	3 phase	1 phase	
1	20	20	1600 A
2	20	20	500 A
3	-	18	500 A

- Short-circuit duties T10 & T30 will cover provided that their TRV covers inductive load TRV
- Criterion to pass: re-ignitions at one current zero only

frequent re-ignition no longer allowed



Market penetration of vacuum switchgear



End sheet

Thank you for your attention.

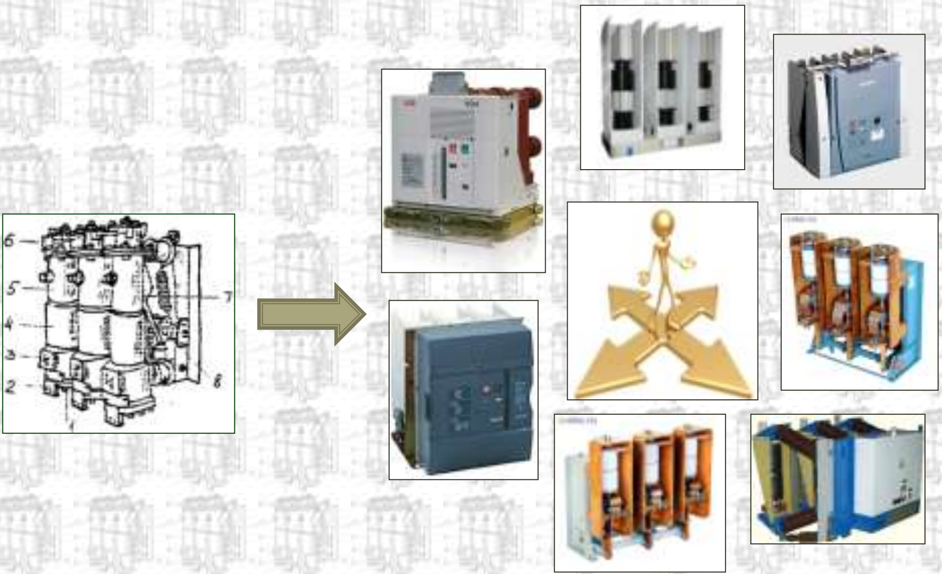
Experience you can trust.

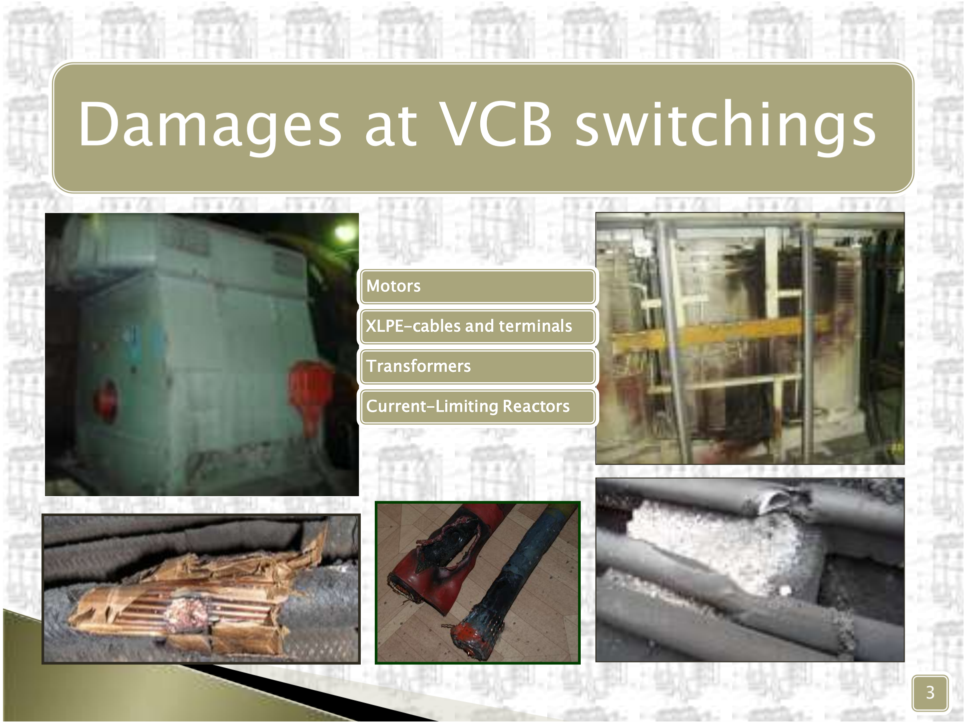
Transient Processes at Vacuum Circuit Breaker Switchings and Development of Technical Requirements for 6-35 kV Vacuum Circuit Breakers

Artem Bazavluk

Senior Engineer of Research Department

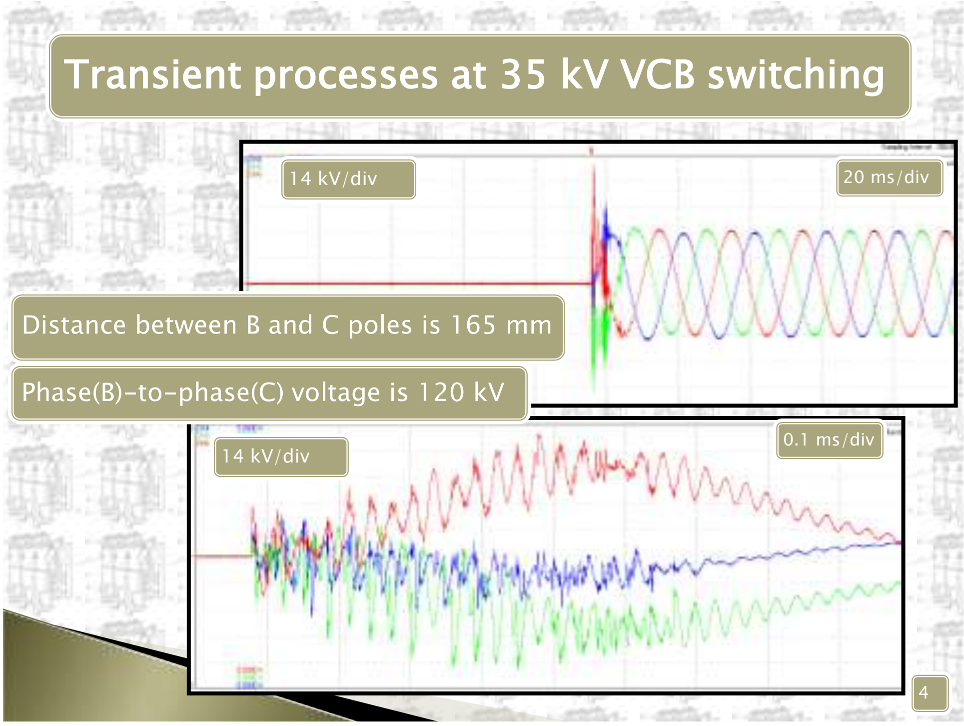
LLC BOLID, Novosibirsk, Russia





Damages at VCB switchings

- Motors
- XLPE-cables and terminals
- Transformers
- Current-Limiting Reactors



Transient processes at 35 kV VCB switching

14 kV/div

20 ms/div

Distance between B and C poles is 165 mm

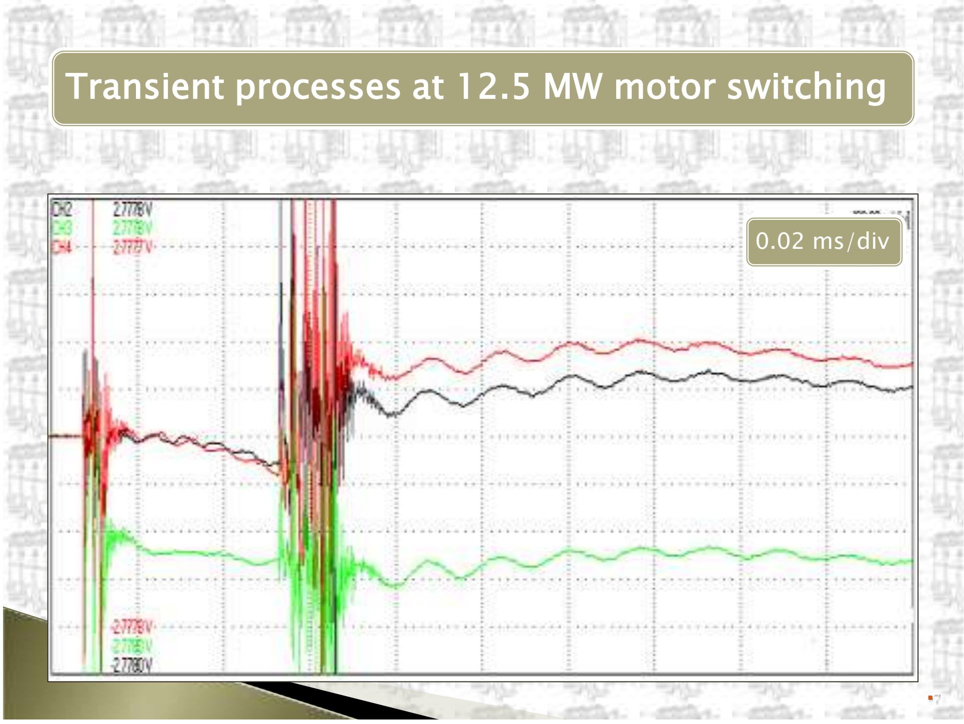
Phase(B)-to-phase(C) voltage is 120 kV

14 kV/div

0.1 ms/div

Damage of 35 kV VCB (Koksovaya Substation, Nizhny Tagil Steel Plant)

Damage of cable terminal at 35 kV VCB switching (Koksovaya Substation, Nizhny Tagil Steel Plant)



Transient processes at 12.5 MW motor switching

0.02 ms/div

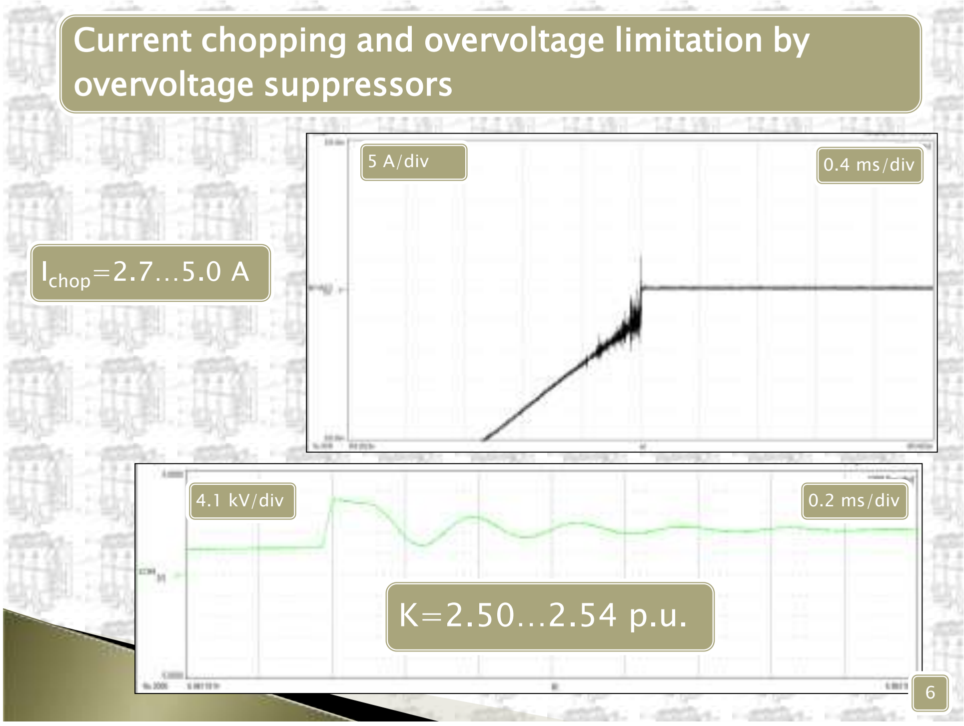
Damage of current limiting reactor at VCB closing

Measuring Equipment of LLC BOLID

Up-to-date measuring equipment and own-constructed devices allow recording transient processes with high sampling rate in the broad range of time

Overvoltages at VCB switchings

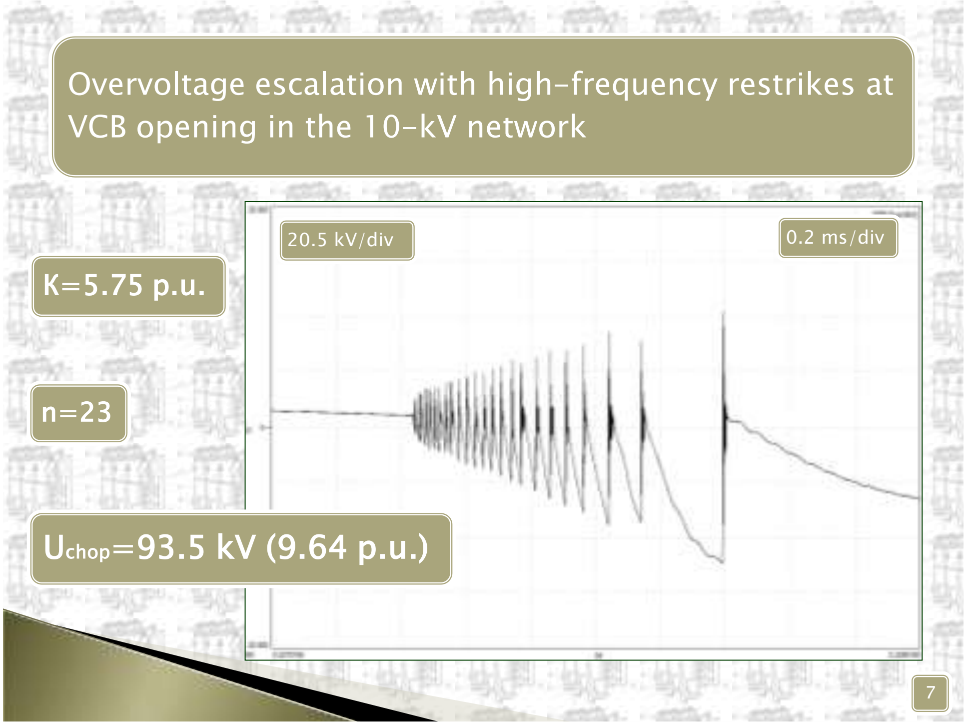
Overvoltages due to current chopping	Overvoltage escalation with high-frequency restrikes at VCB opening
Overvoltage escalation with high-frequency prestrikes at VCB closing	Overvoltages due to virtual current chopping



Current chopping and overvoltage limitation by overvoltage suppressors

I_{chop}=2.7…5.0 A

K=2.50…2.54 p.u.

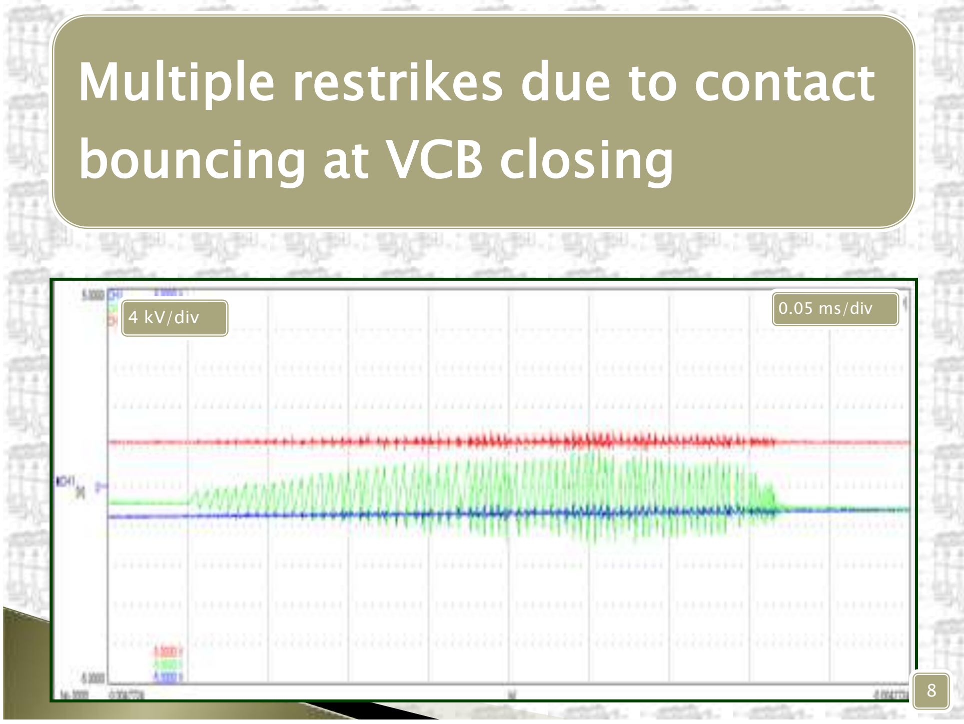


Overvoltage escalation with high-frequency restrikes at VCB opening in the 10-kV network

K=5.75 p.u.

n=23

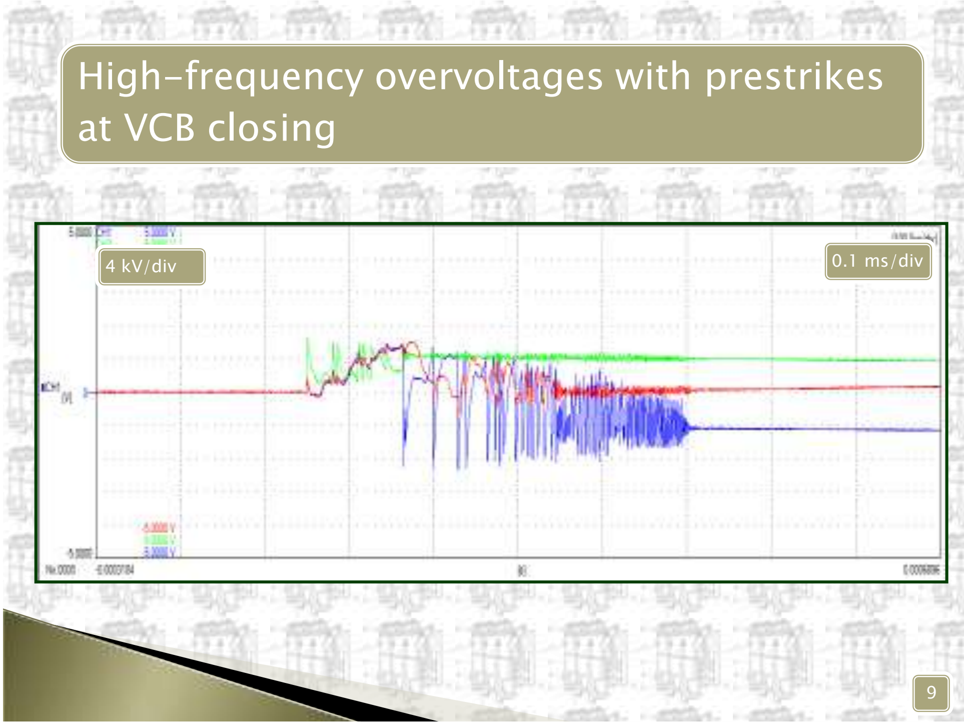
U_{chop}=93.5 kV (9.64 p.u.)



Multiple restrikes due to contact bouncing at VCB closing

4 kV/div

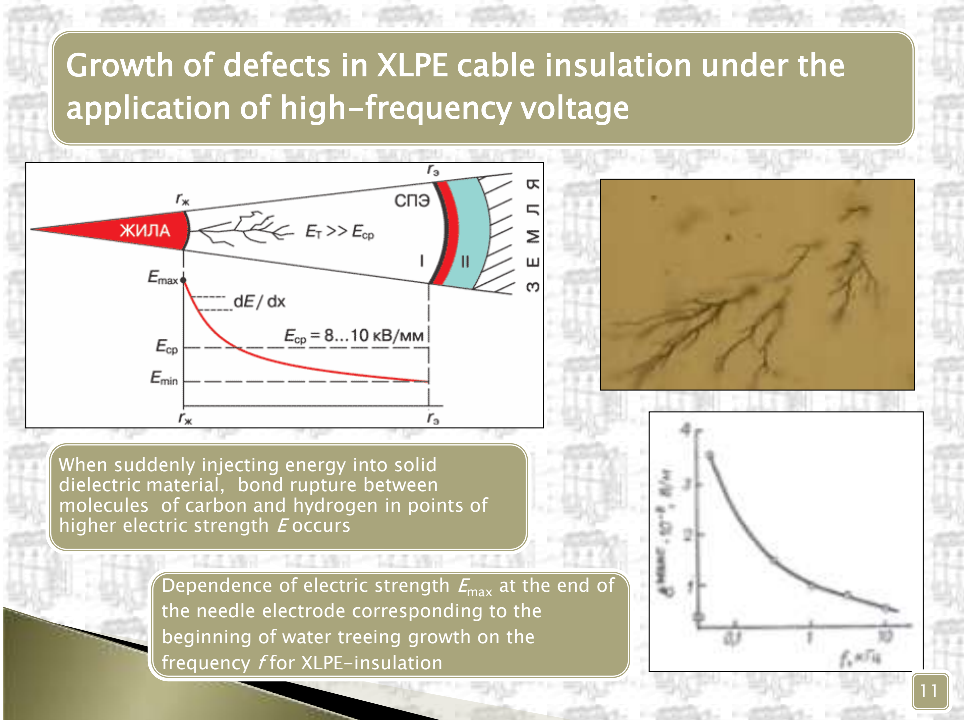
0.05 ms/div



High-frequency overvoltages with prestrikes at VCB closing

4 kV/div

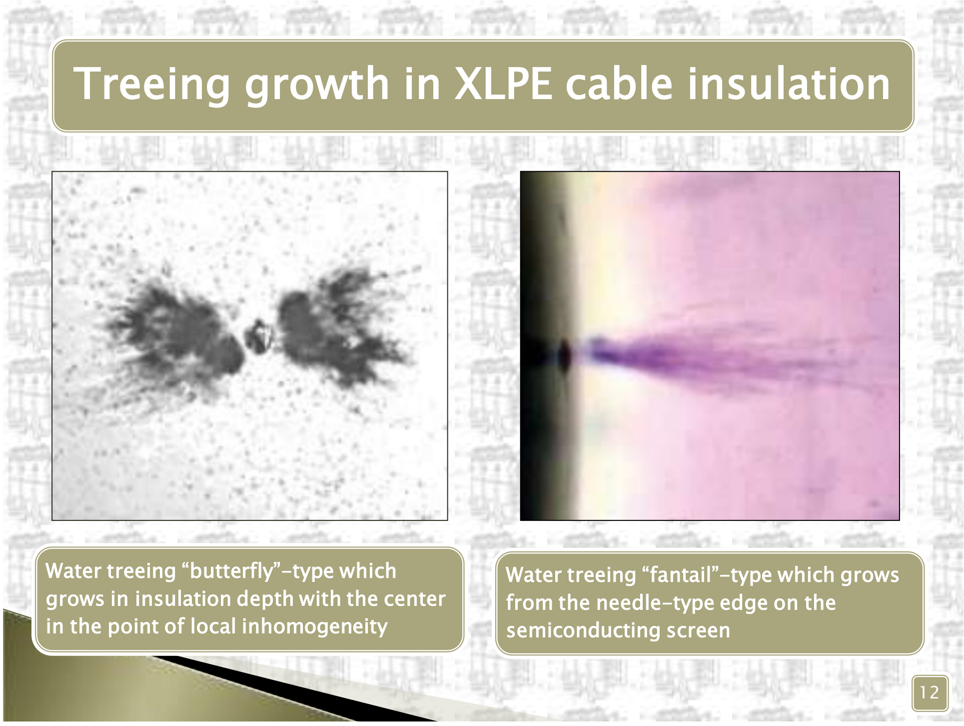
0.1 ms/div



Growth of defects in XLPE cable insulation under the application of high-frequency voltage

When suddenly injecting energy into solid dielectric material, bond rupture between molecules of carbon and hydrogen in points of higher electric strength *E* occurs

Dependence of electric strength E_{max} at the end of the needle electrode corresponding to the beginning of water treeing growth on the frequency *f* for XLPE-insulation



Treeing growth in XLPE cable insulation

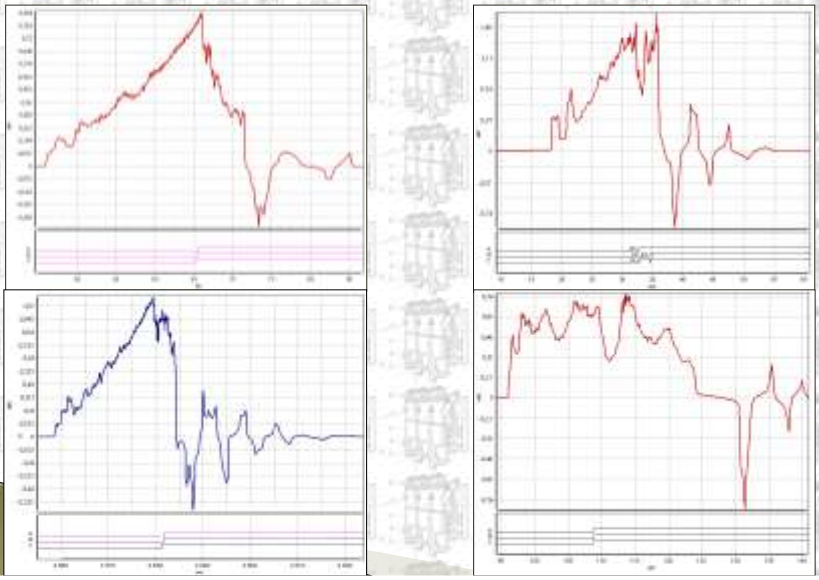
Water treeing "butterfly"-type which grows in insulation depth with the center in the point of local inhomogeneity

Water treeing "fantail"-type which grows from the needle-type edge on the semiconducting screen

Contact closure velocity versus time for various VCBs

Russian circuit breakers

Foreign circuit breakers



Vacuum Interrupter characteristics:

- Chopping current
- Material of contacts
- Degree of purity for contact surface
- Electric strength of contact gap
- Geometrical parameters of contacts
- Vacuum level
- Transient resistance of contacts

+

VCB Mechanism characteristics:

- Travel velocity of moving contact in the vacuum interrupter at closing/opening
- Contact bouncing
- Nonsimultaneous contact closing/opening

Technical characteristics for VCB to revise and introduce into normative documents

The rate of breakdown voltage (at VCB closing/opening)

Travel velocity of moving contact (at VCB closing/opening);

Electric strength at the distance of 2mm between contacts

(Corona discharges inside a vacuum interrupter are inadmissible)

Contact bouncing

Chopping current

Nonsimultaneous closing/opening

Pressure inside a vacuum interrupter

Transient resistance for vacuum interrupter contacts

Conclusions

- Vacuum circuit breakers should be carefully verified and monitored by both manufacturers and operating companies
- Vacuum circuit breakers should be equipped with a special device for controlling and checking of their mechanical characteristics
- VCB characteristics should be periodically checked during their operation
- Switched equipment should be protected by overvoltage suppressors and RC-circuits (i.e. valid choice of VCB and devices for their protection depending on consumer loads)
- XLPE cables, motors and transformers should switched by vacuum circuit breakers with higher technical requirements
- GOST requirements **should not** be applied for all types of vacuum circuit breakers. New power engineering equipment calls for additional requirements and strengthens existing requirements

Thank you for your attention!

Recovering of electric strength in different mediums

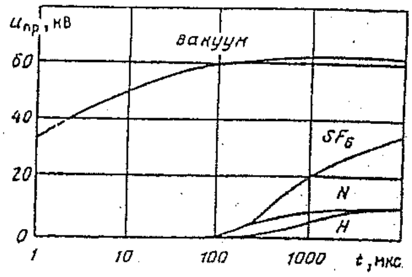
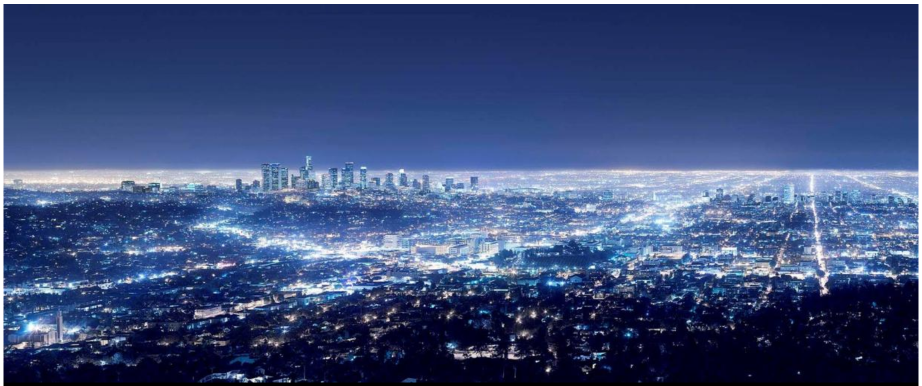


Рис. 4. Восстанавливающаяся электрическая прочность промежутка длиной 6 мм после отключения тока 1600 А в вакууме и различных газах при атмосферном давлении

Recovering of electric strength for 6mm gap after 1600 A interruption in vacuum and various gases under atmospheric pressure



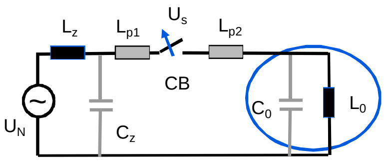
Edgar Dullni, DECMS-ET, 2012-09-04

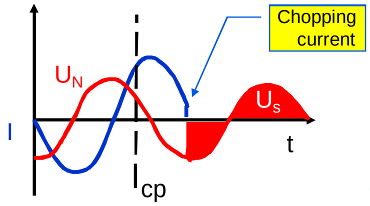
Overvoltages generated by VCBs
Basics of Inductive Switching

Overview

- Breaking of inductive currents
  - Chopping of current and associated over-voltage
  - Over-voltage produced by multiple re-ignitions
- Making of inductive currents
  - High-frequency making current
  - Pre-ignitions and associated over-voltage
- Virtual chopping
- Mitigation means

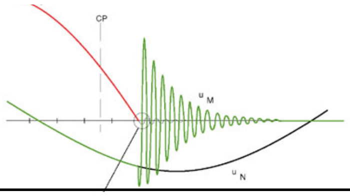
Chopping of inductive currents
Transient recovery voltage (TRV)



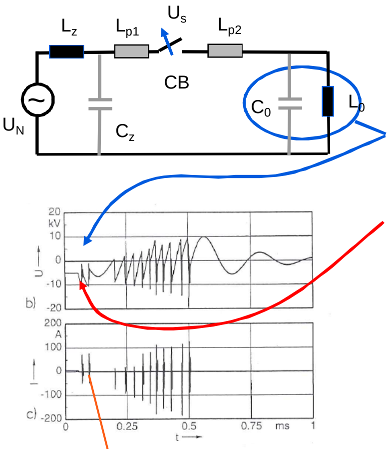


- After opening, current ceases just before current-zero at a level of 2 - 3 A (CuCr) (Chopping)
- Trapped current through L_0 charges C_0 >> I_{chop} determines over-voltage
- This effect exites an oscillation of L_0 and C_0
  - Frequency > 500 Hz depending on L_0 and C_0
  - Determines the TRV steepness
- After current-zero, the charge in C_0 still can only discharge through L_0

$$U_{\max} = \sqrt{\frac{L_0}{C_0}} \cdot i_{chop} \qquad f = \frac{1}{2\pi\sqrt{L_0 C_0}}$$



Breaking of inductive currents with short arcing time
Multiple reignitions during opening



High-frequency current peaks determined by L_{p1} and C_0

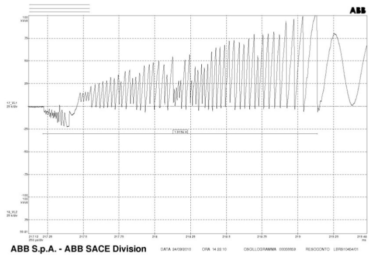
1. After seapration of contacts, current chops
2. Energy is trapped in the oscillatory circuit of the load (L_0 - C_0)

   The voltage at the transformer builds up
3. When TRV voltage across the contacts exceeds the dielectric withstand (short gap), the arc re-ignites
4. Vacuum interrupters are able to interrupt these high frequency currents with a steepness of up to 200 A/µs !
5. TRV builds up again, until the next breakdown occurs
6. The process continues, until the dielectric withstand between the contacts exceeds the TRV >>> multiple re-ignitions

Points 1 – 3 occur for every switching device, points 4 - 6 are specific for vacuum interrupters

Range of inductive currents and TRV values

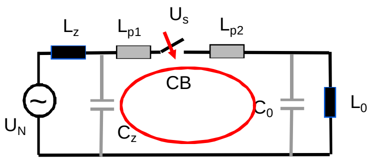
Transformer power	Primary inductance	Inductive current	Rate of voltage rise	TRV frequency
0.2 – 2 MVA no-load	50 – 1000 H	0.1 - 1 A	< 50 V/µs	< 0.5 kHz
5 – 20 MVA no-load	5 – 20 H	2 - 10 A	> 100 V/µs	> 1 kHz
400 kVA induct. load	~ 1 H	~ 20 A	0.5 - 2 kV/µs	4 kHz
10 MVA short-circuit	3 mH	6 kA	4 kV/µs	40 kHz



Voltage rise with VI contact stroke: 30 to 60 V/µs

Voltage withstand at small strokes: 20 to 40 kV/mm

Making of inductive currents
High-frequency inrush currents



$$\hat{I}_{re} = \Delta\hat{U}_s \cdot \sqrt{\frac{C_0}{L_{p1}}}$$

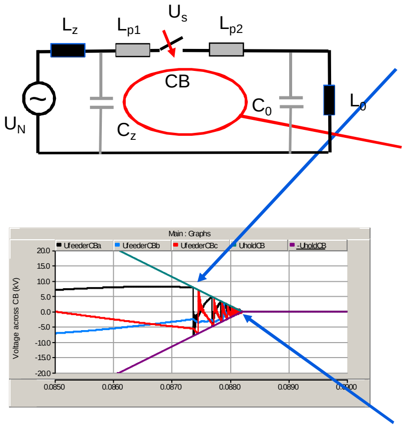
$$f_{re} \approx \frac{1}{2\pi}\cdot\sqrt{\frac{1}{C_0 \cdot L_{p1}}}$$

for $C_z >> C_0$ and $L_{p1} >> L_{p2}$

- After contact making, the charge on the cable capacitance C_z discharges into C_0 via the cable inductances L_{p1} and L_{p2}
  - Frequency of > 400 kHz
  - similar to the switching of very small back-to-back capacitors
- In addition the inrush current of the transformer flows, however, on a 50 Hz time scale (10 – 12 x rated current)

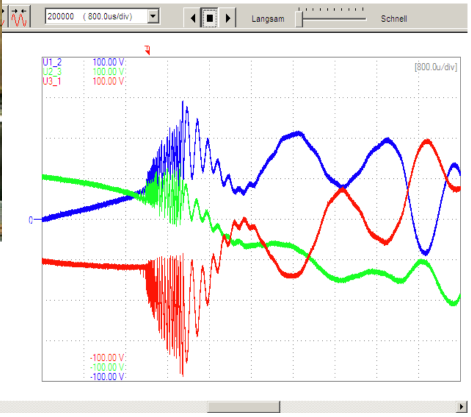
C_0 consists of the capacitance of the load-side connection, but also of any earth capacitance of the transformer

Making of inductive currents
Multiple re-ignitions during closing



1. Before mechanical touch of contacts, a pre-ignition occurs at small contact gap
2. The source-side cable capacitance instantaneously charges the load–side capacitance C_0 and a high-frequency current flows
3. Vacuum interrupters are able to interrupt these high frequency currents with a steepness of up to 200 A/µs !
4. As during the breaking process, a TRV builds up at the transformer terminals.
5. When the TRV exceeds the dielectric withstand of the gap, an arc ignites
6. The process continues until the contacts mate

Breaking of inductive currents in 3-phase networks
Virtual chopping

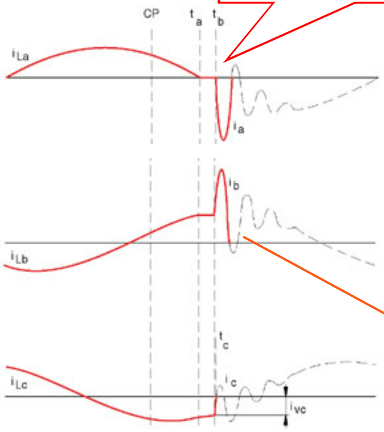


Load breaking:	400 kW
Current:	20 A
Voltage peak:	97 kV
du/dt (breakdown)	250 kV/**µs**

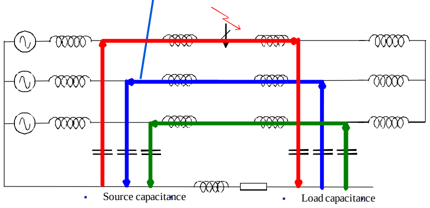
Virtual chopping through capacitive coupling

Exacerbates over-voltages

At re-ignition of TRV, the source-side capacitance charges the load–side cable



Re-ignition current takes return path through other phases



Return current forces current-zero of 50Hz currents in other phases >>> virtual chopping

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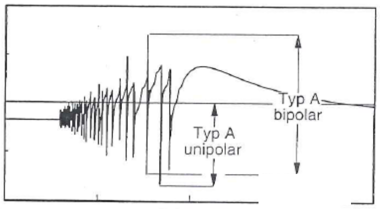
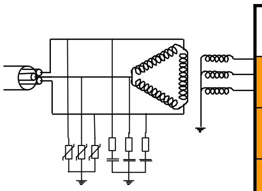
Over-voltage probability and mitigation

Thesis Helmer, 1996 TU Brunswick



- Type A over-voltage in p.u. under different conditions (7.5 p.u. equals BIL)
- Tests on an 11kV / 1 MVA dry type transformer
- Figures in brackets give the probability of occurrance of multiple re-ignitions for an arcing time of < 0.5 ms.



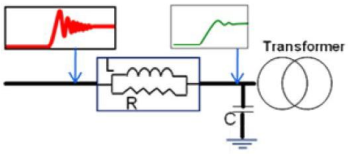
ZORC snubber circuit

Damping by resistor

	Breaking of	Stationary no-load current	Inrush current
Without cable	without ZnO	7.2 pu (80%)	8 pu (30%)
	with ZnO	7.5 pu (70%)	7.6 pu (50%)
	with ZORC	(0 %)	(0 %)
80m cable	with ZnO	(0 %)	6.2 pu (30%)

Surge arresters can limit the peak voltage but cannot prevent multiple re-ignitions

Mitigation means for inductive loads



- Surge arresters
  - limit the over-voltage peak values,
  - Have to be adapted to the anticipated „safe“ voltage levels and anticipated discharge energies
  - but cannot avoid the fast transients, which give uneven voltage distribution on windings
- RC - components
  - Reduce the du/dt of the recovery voltage and peak voltage
  - Have to be adapted to the network by numerical calculations (EMTP) in order to avoid resonance oscillations
- Filter chokes
  - Reduce the voltage rise for low current loads

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Recommended protection for medium voltage motors used with vacuum interrupters

Dr. Erik Taylor

Infrastructure & Cities Sector

SIEMENS

General recommendations for motor switching

- B.K. Gupta (Ontario Hydro), N.E. Nilsson (Ohio Edison), D.K. Sharma (EPRI), "Protection of Motors Against High Voltage Switching Surges," IEEE Trans. Energy Conversion, vol. 7, no. 1, pg. 139, March 1992.
- "This paper reviews the results from an extensive EPRI project on turn insulation capability of motors and other publications in order to quantify the surge environment and the surge strength of typical utility motors…"
- "The risetimes and magnitudes of surges produced by vacuum and air-magnetic switchgear are similar…"
- "Inadequate quality control appears to be the real cause for low surge strength of poor motors…"
- "Experimental and analytical investigations indicate that modern vacuum switchgear, when used as recommended by the manufacturers, are as benign as air-magnetic switchgear for typical utility applications. In most motor applications with well designed motor supply systems, surge capacitors are not necessary; they may be required only under special circumstances…"
- "As part of the EPRI project, surges at 39 motors in 16 plants of 11 North American utilities were measured over a period of 3 years."

Protection strategy for MV motors

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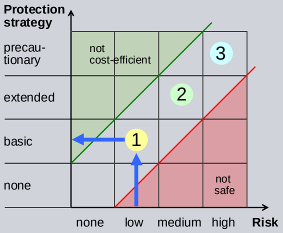
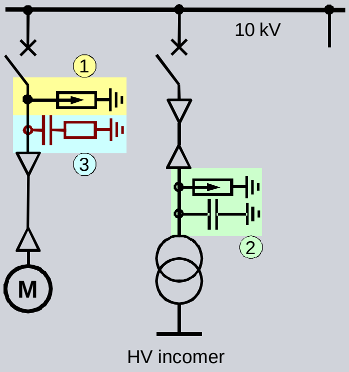


① Motor I_{start} < 600 A
⇨ surge arrester at motor feeder

② Surges from feeding net
⇨ add surge capacitor + arrester at the incoming feeder

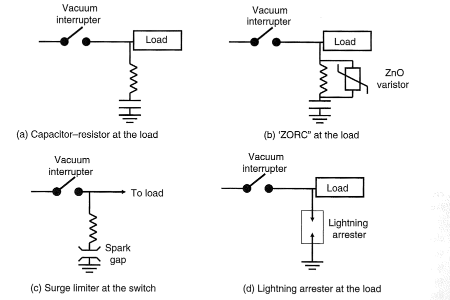
③ Old motor, frequent starting or insulation not acc. IEC 60034-15
⇨ add RC circuit at motor feeder



From A. Müller (Siemens), D. Sämann (Siemens), "Switching Phenomena in Medium Voltage Systems – Good Engineering Practice on the Application of Vacuum Circuit-Breakers and Contactors," PCIC Europe Conf., 2011

Range of options for surge protection

SIEMENS



(a) Capacitor–resistor at the load (b) 'ZORC" at the load (c) Surge limiter at the switch (d) Lightning arrester at the load

FIGURE 5.19 Possible surge protection schemes to be used at the terminals of a large inductance such as a motor or a transformer.

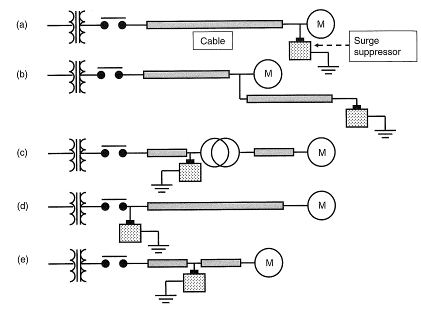
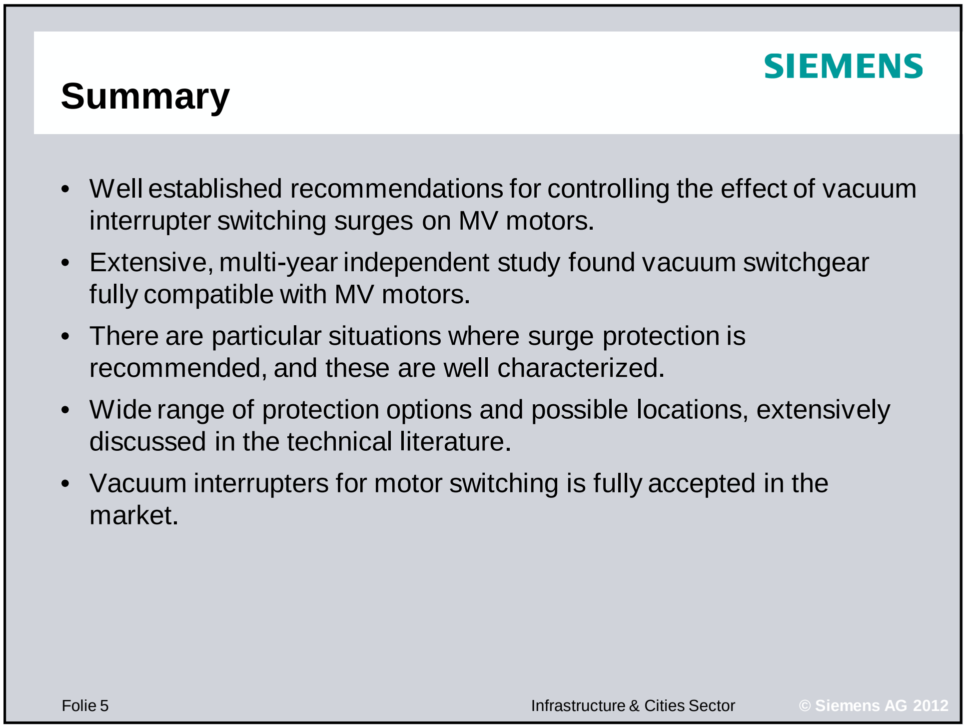


FIGURE 5.20 How to position the surge arrester with respect to the inductive element [15].

From P. G. Slade, *The Vacuum Interrupter: Theory, Design, and Application*, New York: CRC Press, 2008, Sec. 5.3.3.



Summary

- Well established recommendations for controlling the effect of vacuum interrupter switching surges on MV motors.
- Extensive, multi-year independent study found vacuum switchgear fully compatible with MV motors.
- There are particular situations where surge protection is recommended, and these are well characterized.
- Wide range of protection options and possible locations, extensively discussed in the technical literature.
- Vacuum interrupters for motor switching is fully accepted in the market.

VCB's in Cable Networks

Dr. Hans Schellekens
ISDEIV Tomsk
2 – 7 September 2012

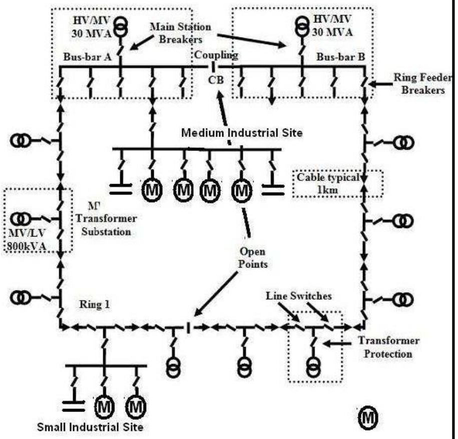
This paper is a reaction on

"Vacuum circuit breakers in distribution networks.
Mechanical characteristics and overvoltages during switching"
By Dr. Sarin

Conclusion : ***In particular, use of VCB's of certain types in medium voltage networks (especially in city distribution networks), where CLP insulation cables are used, is unreasonable due to increased insulation degradation of such cables.***

Typical Mixed MV Distribution Network

- 30 MVA / HV-MV substation / cos(phi)=0.95
- 5 ring feeders
- Each ring 15 km cable
- Each substation 37.5 km of cable
- Each ring 15 RMU of 800kVA
- Small industrial site : 3 per public network
- Medium size industrial site : 1 per public network



Typical Mixed MV Distribution Network 2

Network	Type of operation	Number of units	Switching Frequency	Switching Voltage in [pu]		Cable Length in [km]	
Public			Per year	Source side	Load side	Source side	Load side
Substation	Load	5	0.1	1.05	1.05	30	7.5
	Earth Fault		0.25 (*)	1.73	1.73		
	3Φ Fault		0.25	2.25	0		
RMU	Load	37	0.2	1	1	37.5	0.02
	Over current		0.03(**)	1	1.8		
	3Φ Fault		0.03	1.9	0		
3 Small Industrial Sites 2MVA	Load	6	1000	1	1	37.5	0.1
	Inrush Current	6	10	1	3 / 5.5 (***)		
	Cap. Bank	3	250	1	1.5		
	Fault	9	0.06 (**)	1.9	0		
Medium Size Industrial site 10 MVA	Load	10	1000	1	1	30	0.1
	Inrush Current	8	10	1	3 / 5.5		
	Cap. Bank	2	500	1	1.5		
	Fault	10	0.06 (*)	1.9	0		

VCB
+
protection

Duration of Switching Voltage : 5 msec
Duration of Earth Fault : 1 sec – 1 hou
Duration of Cap. Bank : 1 minute

XLPE Cable Ageing

Water Treeing

- Electro – Chemical
- Depends weakly on Electric Field
- Depends strongly on water adsorption
- Depends on frequency

Electric Treeing

- Depends strongly on Electric Field
  - Follows CRINE's model

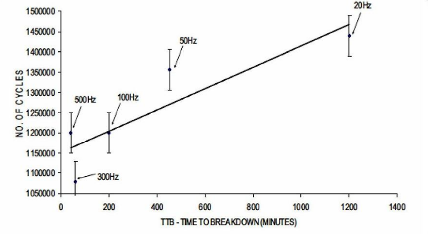


Figure 12. The number of cycles experienced by tree before breakdown.

Electrical Treeing Characteristics in XLPE Power Cable Insulation in Frequency Range between 20 and 500 Hz

G. Chen
School of Electronics and Computer Science
University of Southampton, Southampton SO17 1BJ, UK

and C. H. Tham
SP Powergrid Ltd, Singapore

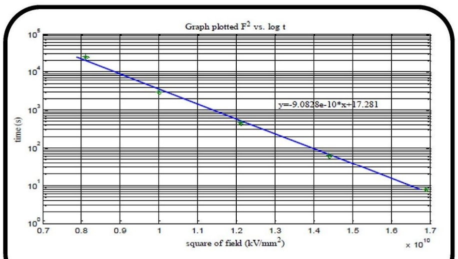
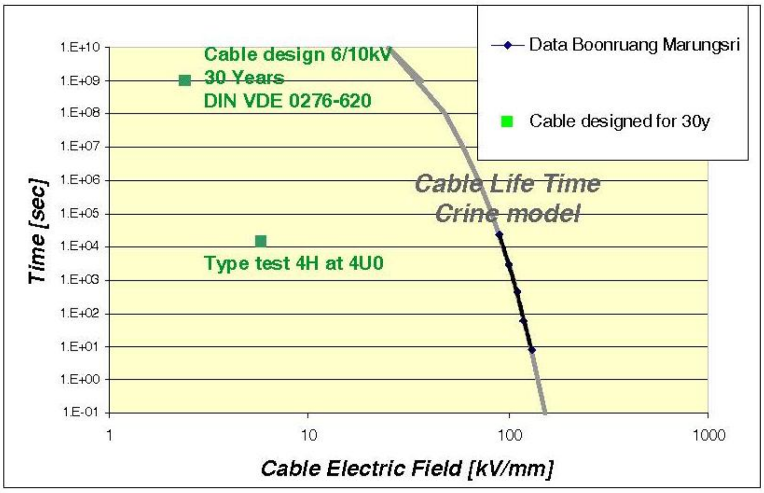


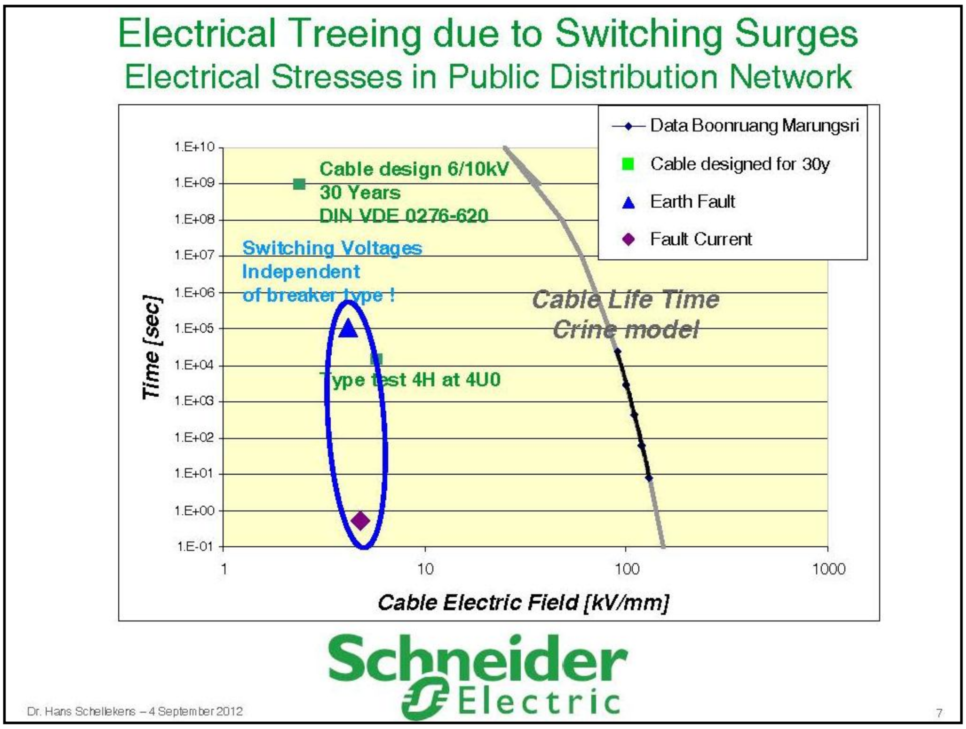
Fig. 5 A Linear Relationship Between F^2 and log t at 23 ℃

Investigation Life Time Model of 22 kV XLPE Cable for Distribution System Applications in Thailand

BOONRUANG MARUNGSRI, ANUCHA RAWANGPAI and NIMIT CHOMNAWANG

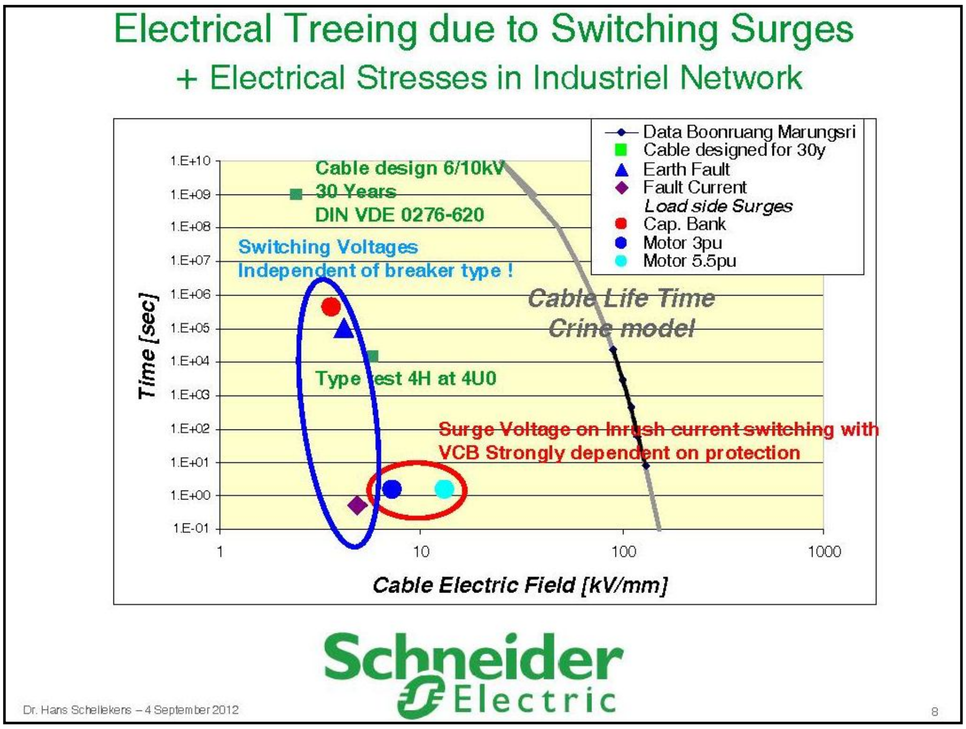
Electrical Treeing due to Switching Surges





Electrical Treeing due to Switching Surges
Electrical Stresses in Public Distribution Network

Schneider Electric

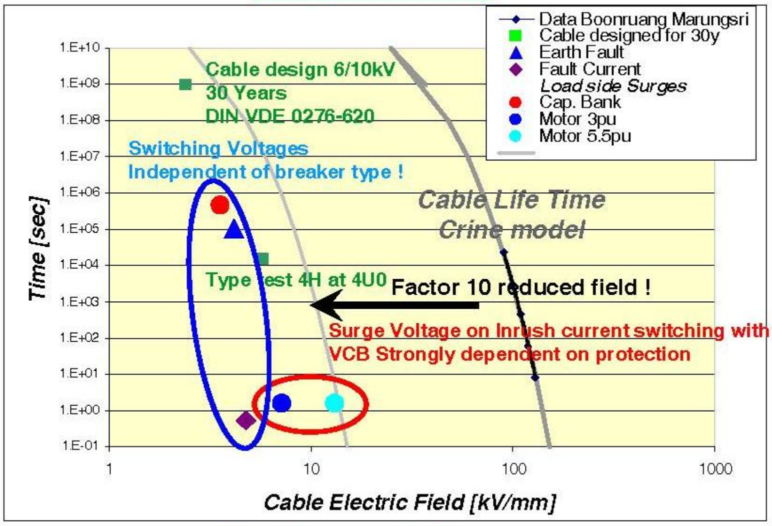


Electrical Treeing due to Switching Surges
+ Electrical Stresses in Industriel Network

Schneider Electric

Electrical Treeing due to Switching Surges

very unlikely



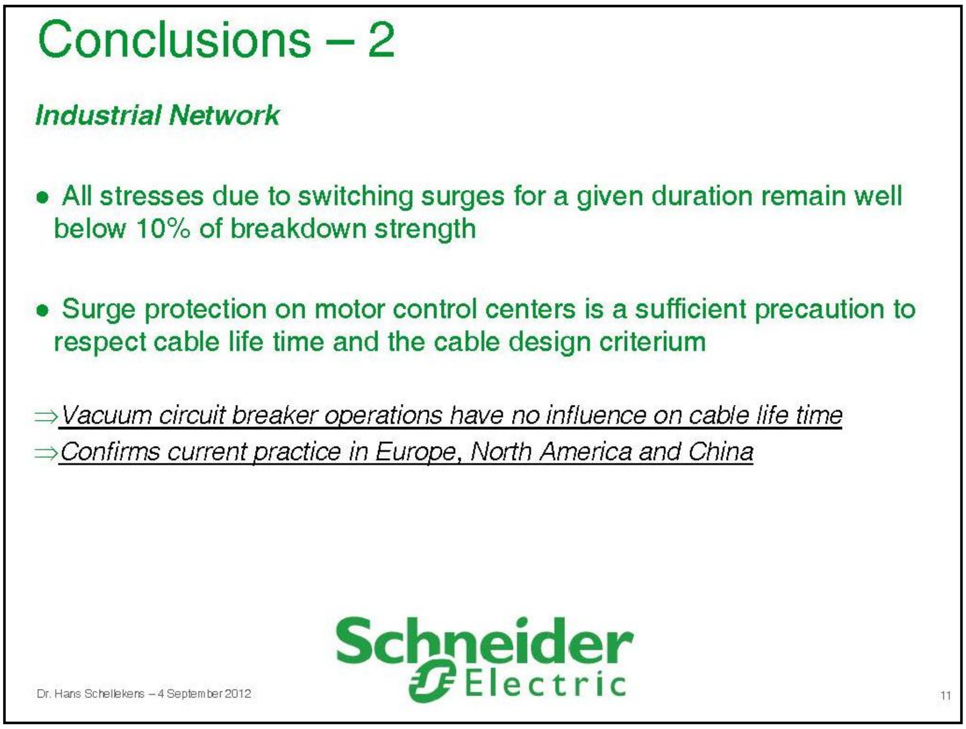
Conclusions – 1

Public Distribution Network

- Switching operations don’t influence the cable life time
  - True for all CB’s; air, oil, SF6 and vacuum

- Switching surges in connected Industrial sites don’t propagate into the public network and are of no concern.

⇒*(Vacuum) Circuit Breaker operations can not explain the increased failure rate in Russian cable networks*



Conclusions – 2

Industrial Network

- All stresses due to switching surges for a given duration remain well below 10% of breakdown strength

- Surge protection on motor control centers is a sufficient precaution to respect cable life time and the cable design criterium

⇒*Vacuum circuit breaker operations have no influence on cable life time*

⇒*Confirms current practice in Europe, North America and China*

TAVRIDA ELECTRIC
Excellence in engineering

Panel Discussion

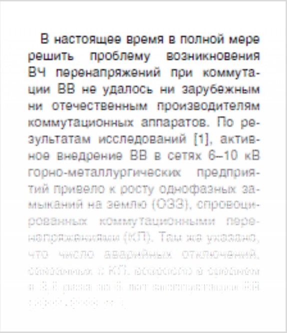
“Overvoltages generated by VCB at switching of inductive loads”

Dr. Alexey Chaly

ISDEIV Tomsk · 2—7 September 2012

Statement №1

“Deployment of VCB into electrical networks of ore factories resulted in growth of earth faults stimulated by switching overvoltages” [1]



В настоящее время в полной мере решить проблему возникновения ВЧ перенапряжений при коммутации ВВ не удалось ни зарубежным ни отечественным производителям коммутационных аппаратов. По результатам исследований [1], активное внедрение ВВ в сетях 6–10 кВ горно-металлургических предприятий привело к росту однофазных замыканий на землю (ОЗЗ), спровоцированных коммутационными перенапряжениями (КП). Там же указано, что число аварийных отключений,

[1] “Overvoltages at vacuum circuit breakers switching”, EnergoExpert, vol. 2, 2011

Investigation of the only available reference [2] shown the following:

- author claims that percentage of earth faults due to switching overvoltages increased

This claim is not supported with any primary data

This claim is not supported with any methodology:

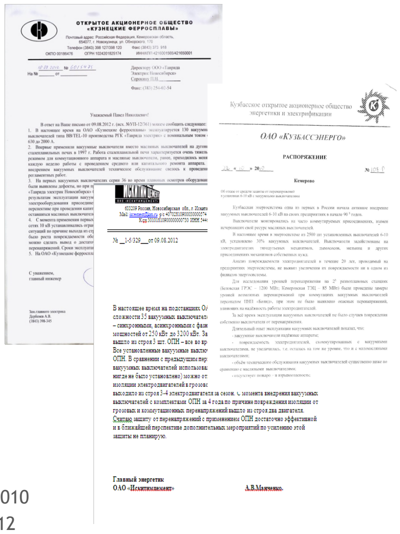
- What type of VCB was used?
- Was overvoltage protection applied?
- How different reasons of overvoltages have been discriminated?

[2] Faults Investigations at electrical network of ore factories, News of Electrical Technology, vol. 5 (60), 2010

Percentage of failure cause

Failure cause	Weight, %	
	before 2002	2002–2008
Lightning overvoltages	5	4
Earth fault overvoltages	25	33
Switching overvoltages	10	38
Aging of the insulation	54	20
Mechanical stress	2	3
Other cause	4	2

Our direct inquiry to ore factories revealed the opposite situation. Chief power engineers of the factories do not notice increase of damages of insulation due to switching overvoltages after deployment VCB into their network [3, 4, 5]


ОТКРЫТОЕ АКЦИОНЕРНОЕ ОБЩЕСТВО
«КУЗНЕЦКИЕ ФЕРРОСПЛАВЫ»
Почтовый адрес: Российская Федерация, Кемеровская область,
654077, г. Новокузнецк, ул. Обнорского, 170
Телефон (3843) 398 127/398 120 Факс (3843) 373 918
ОКПО 00186476 ОГРН 1024201825174 ИНН/КПП 4216001565/421650001

10.08.2012 № 6015475
На № ______ от __________

Директору ООО «Таврида
Электрик Новосибирск»
Сорокину П.Н.

Факс: (383) 254-02-54

Уважаемый Павел Николаевич!

В ответ на Ваше письмо от 09.08.2012 г. (исх. №УП-12/361) можем сообщить следующее:
1. В настоящее время на ОАО «Кузнецкие ферросплавы» эксплуатируется 130 вакуумн
выключателей типа BB/TEL-10 производства РГК «Таврида электрик» с номинальным током
630 до 2000 А.
2. Впервые применили вакуумные выключатели вместо масляных выключателей на дугов
сталеплавильных печах в 1997 г. Работа сталеплавильной печи характеризуется очень тяжел
режимом для коммутационного аппарата и масляные выключатели, ранее, приходилось меня
каждую неделю работы с проведением среднего или капитального ремонта аппарата.
внедрением вакуумных выключателей техническое обслуживание свелось к проведен
регламентных работ.
3. На первых вакуумных выключателях серии 36 во время плановых осмотров оборудован
были выявлены дефекты, но при п
«Таврида электрик Новосибирск»
результатам эксплуатации вакуум
электрооборудования присоедине
перспективе при проведении капит
оставшихся масляных выключател
4. С момента применения первых
сетях 10 кВ устанавливались огра
ситуаций по причине выхода из ст
было роста повреждаемости об
можно сделать вывод о достато
перенапряжений. Сроки эксплуата
5. На ОАО «Кузнецкие ферроспла

С уважением,
главный инженер

Зам.главного электрика
Дербенев А.В.
(3843) 398-345

ИСКИТИМЦЕМЕНТ
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633209 Россия, Новосибирская обл., г. Искит
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К/сч 30101810900000000730 ИНН 544

№ 1-5/329 от 09.08.2012

В настоящее время на подстанциях О
сложности 35 вакуумных выключате
– синхронными, асинхронными с фаз
мощностей от 250 кВт до 3200 кВт. За
вышло из строя 3 шт. ОПН – все во вр
Все установленные вакуумные выклю
ОПН. В сравнении с предыдущим пер
вакуумных выключателей использова
нигде не было установлено) можно от
изоляции электродвигателей в грозов
выходило из строя 3-4 электродвигателя за сезон. С момента внедрения вакуумных выключателей с комплектами ОПН за 4 года по причине повреждения изоляции от грозовых и коммутационных перенапряжений вышло из строя два двигателя.
Считаю защиту от перенапряжений с применением ОПН достаточно эффективной и в ближайшей перспективе дополнительных мероприятий по усилению этой защиты не планирую.

Главный энергетик
ОАО «Искитимцемент» А.В.Манченко.

Кузбасское открытое акционерное общество
энергетики и электрификации

ОАО «КУЗБАССЭНЕРГО»

РАСПОРЯЖЕНИЕ

22 « 10 » 2010 № 108-Р

Кемерово

Об отказе от средств защиты от перенапряжений
в установках 6-10 кВ с вакуумными выключателями

Кузбасская энергосистема одна из первых в России начала активное внедрение вакуумных выключателей 6-10 кВ на своих предприятиях в начале 90-х годов.

Выключатели монтировались на часто коммутируемых присоединениях, взамен исчерпавших свой ресурс масляных выключателей.

В настоящее время в энергосистеме из 2500 шт установленных выключателей 6-10 кВ, установлено 30% вакуумных выключателей. Выключатели задействованы на электродвигателях тягодутьевых механизмов, дымососов, мельниц и других присоединениях механизмов собственных нужд.

Анализ повреждаемости электродвигателей в течение 20 лет, проводимый на предприятиях энергосистемы, не выявил увеличения их повреждаемости ни в одном из филиалов энергосистемы.

Для исследования уровней перенапряжения на 2-х разноплановых станциях (Беловская ГРЭС – 1200 МВт; Кемеровская ТЭЦ – 85 МВт) были проведены замеры уровней возможных перенапряжений при коммутациях вакуумных выключателей персоналом ННП «Болид», при этом не было выявлено опасных перенапряжений, влияющих на надёжность работы электродвигателей.

За всё время эксплуатации вакуумных выключателей не было случаев повреждения собственно выключателя от перенапряжения.

Длительный опыт эксплуатации вакуумных выключателей показал, что:
- вакуумные выключатели надёжные аппараты;
- повреждаемость электродвигателей, скоммутированных с вакуумными выключателями, не увеличилась, т.е. осталась на том же уровне, что и с маломасляными выключателями;
- объём технического обслуживания вакуумных выключателей существенно ниже по сравнению с масляными выключателями;
- отсутствует пожаро – и взрывоопасность;

[3] Decree from JSC "Kuzbassenergo" from 22.10.2010
[4] Response from JSC "Kuznetskiy ferroalloy", 2012
[5] Response from JSC "Iskitimcement", 2012

Conclusion №1

Reliable field data proving that deployment of VCB into ore factories resulted in increase of insulation damages due to switching overvoltages has not been presented in the only available reference.

Statement №2

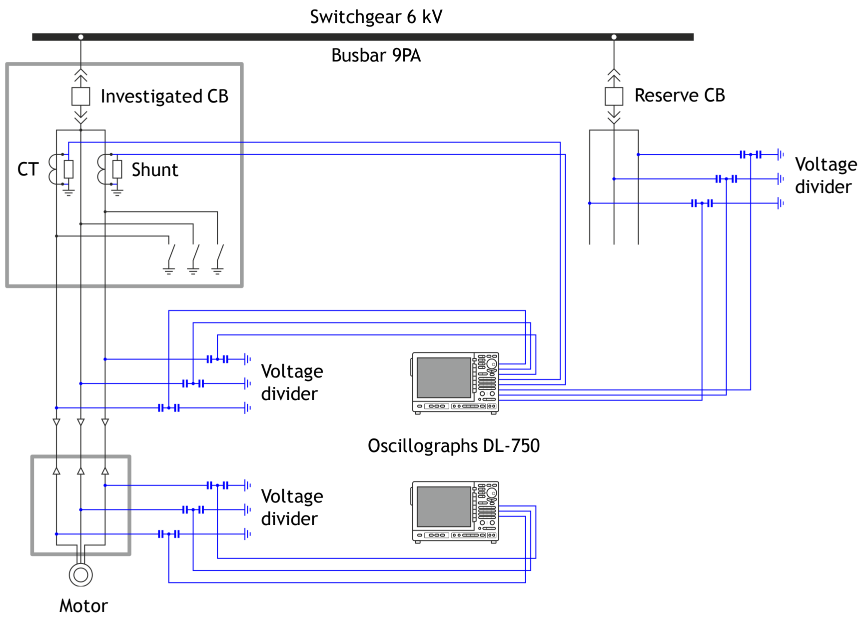
“VCB creates higher overvoltages than OCB at motor closing” [2, 6]

This was stated on the basis of experimental investigation conducted in [6] at which 3 types of VCB and 1 OCB were closed 10 times each for motor 800kW connected with approximately 100 m cable.

---

[2] Faults Investigations at electrical network of ore factories, News of Electrical Technology, vol. 5 (60), 2010

[6] Scientific and technical report: experimental research of vacuum circuit breakers characteristics during motor switching at Novosibirskaya CHPP №4, 2010



Experimental results

Circuit breaker	Average source side phase-to-earth per unit overvoltage, p.u.		Average motor side phase-to-earth per unit overvoltage, p.u.	
	closing	opening	closing	opening
VCB1	1,64	1,62	2,97	1,68
VCB2	1,54	1,54	1,89	1,60
VCB3	1,57	1,86	3,34	1,86
OCB	1,53	1,39	2,55	1,56

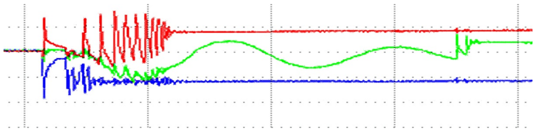
During investigation substantial error at measurements was committed.

Voltage detection from motor side had unstable contact resulted in noise.

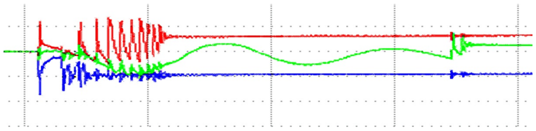
Voltage detection from source side was OK.

Compare the oscillograms

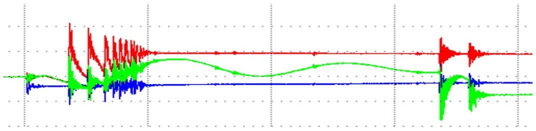
Source side Test



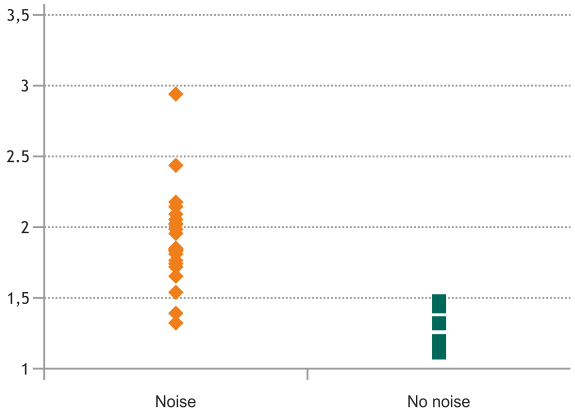
Motor side Test 1



Motor side Test 2



Ratio of the maximum motor side overvoltages to the source side overvoltages



What is average overvoltage for this oscillogram?

Then why average is so important for insulation?

For insulation we would expect maximum overvoltage to be more important.

If we lined up maximum *(maximum maximoro)* overvoltages recorded for each CB at these ten closing operations, we would get the following:

Circuit breaker	Maximum overvoltage on the source side, kV	Maximum overvoltage on the motor side (all oscillograms), kV	Maximum overvoltage on the motor side (noise-free oscillograms), kV
VCB1	10,6	17	12,3
VCB2	9,2	13,3	13,3
VCB3	13,3	21,2	NA
OCB	10,0	19,6	NA

Conclusion №2

Experimental investigation presented in [6] has been conducted with substantial measurement and treatment errors.

At the same time it has not provided any evidence that VCB generates higher overvoltages than OCB at motor closing.

[6] Overvoltages at vacuum circuit breakers switching”, EnergoExpert, vol. 2, 2011

Statement №3

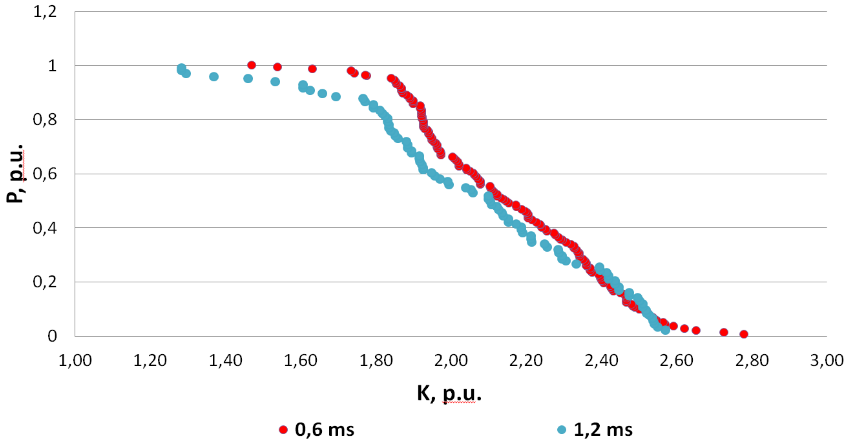
“To ensure safe VCB operation *(from overvoltage generation standpoint)* the following additional requirements shall be applied for VCB. Foreign VCB can meet all these requirements but none of the local manufacturers can meet all of them” [1]

[1] Overvoltages at vacuum circuit breakers switching”, EnergoExpert, vol.2, 2011

Additional VCB requirements

Parameter	Value
Non-simultaneity of main contacts closing, milliseconds, not more	1
Non-simultaneity of main contacts opening, milliseconds, not more	1
Contact velocity at closing, m/s, not less	1,2
Contact velocity at opening, m/s, not less	1,5
Contact bounce duration, ms, not more	0
Contact resistance, micro Ohm, not more	40
Current chopping, A	3,5-5
VI pressure, Pa, not more	10e-4
Duration of repeatable breakdowns, microseconds, not more	50
VI dielectric strength at 2mm contact gap, kV/mm, not less	35
Breakdown voltage reduction rate at closing, kV/ms, not less	60
Breakdown voltage increment rate at opening, kV/ms, not less	75

Probability function for overvoltage (p.u.) at motor depending on non-simultaneity of main contacts closing



Conclusion №3

Introduction of new requirements for VCB is not properly motivated.

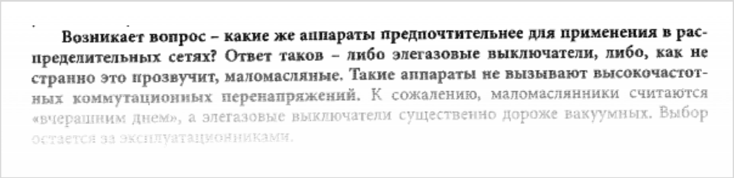
None of the key VCB manufacturers today is prepared to claim compliance with these requirements.

Test methods for many of these requirements do not exist.

Compliance with the requirements may have opposite effect with regard to generation of switching overvoltages.

Statement №4

“Preferable CB for distribution networks are oil or SF6 circuit breakers” [7]



Возникает вопрос – какие же аппараты предпочтительнее для применения в распределительных сетях? Ответ таков – либо элегазовые выключатели, либо, как не странно это прозвучит, маломасляные. Такие аппараты не вызывают высокочастотных коммутационных перенапряжений. К сожалению, маломасляники считаются «вчерашним днем», а элегазовые выключатели существенно дороже вакуумных. Выбор остается за эксплуатационниками.

[7] Vacuum circuit breakers in distribution networks.
Mechanical characteristics and overvoltages during switching, Progress electro, 2010

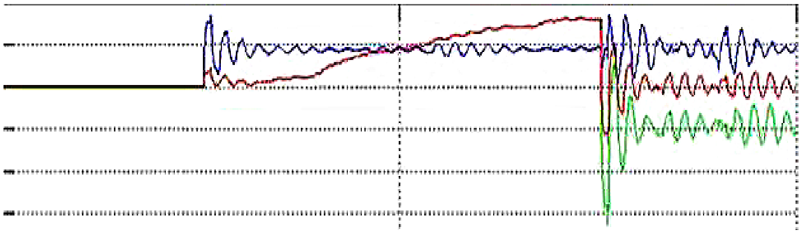
Conclusion №4

This statement is false as authors have not presented any proof that VCB being properly protected in accordance with the manufacturers recommendation generates more dangerous overvoltages than oil or SF6 circuit breakers.

Tavrida vision related to VCB application for motor closing

Closing of motors for any breaker results in switching overvoltages.

The most dangerous regime is associated with the closure of the first CB pole at voltage maximum followed by closure of the second and third poles in the opposite maximum of the motor natural frequency oscillation.



Maximum switching-on overvoltage mode for ideal CB
(0,8 MVA motor, 100 m cable, 5 kV/div, 100 us/div)

In this regime for ideal CB *(not capable of interrupting HF currents)* maximum overvoltages may reach 3.3 p.u. unipolar [8] *(at motor terminals)* that is below requirements of IEC 60034-15 *(4.9 p.u for 6kV motors)* with safety margin 33%.

At the same time bipolar voltage may reach 4.9 p.u. that will result for typical motor in 3.2 *(65%)* p.u. interturn voltage [9]. This is still below insulation level prescribed in IEC 60034-15 *(3.9 p.u. for 6 kV motors)* with safety margin 18%.

Closing of vacuum circuit breakers is associated with the multiple restrikes that is not advantageous for insulation. From the other hand these restrikes have positive effect of limiting maximum overvoltages to lower level than for ideal breaker *(<2.8 p.u. with 99% probability)* [8]

[8] Numerical Simulation of Overvoltage Generated at Switching on Medium-voltage Motors with the aid of Different Circuit Breakers, ISDEIV Paper, 2012

[9] Switching phenomena in medium voltage systems good engineering practice on the application of vacuum circuit breakers and contactors, PCIM Europe Paper RO-47, 2011

Conclusion for motor closing

We consider overvoltage effect of different CB at motor closing as approximately equal and not dangerous from IEC 60034-15 standpoint.

At the same time we cannot claim that closing of CB (of any type) is 100% safe for Russian market as GOST does not prescribe any requirements related to motor impulse withstand capability.

Tavrida vision related to VCB application for motor interruption

It seems that today there is a common vision that the most dangerous regime is interruption of starting motor that is rare or irrelevant for majority of applications.

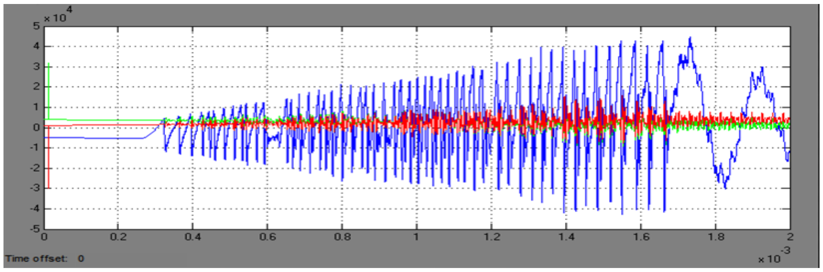
On the other hand in this regime if VCB starts departing contacts close to natural current zero dangerous overvoltages may be generated for a wide range of motor powers and cable lengths [10].

This process first discovered in early 70-s and called «Voltage escalation» [11] is relevant only for breakers having high HF interrupting performance, i.e. VCB.

[10] The influence of a vacuum circuit breaker and circuit parameters of switching overvoltages generated during interruption of starting motors, ISDEIV Paper, 1996

[11] Voltage escalation in the switching of the motor control circuit by the vacuum contactor, IEEE TRANS. PAS Vol. 91, 1972

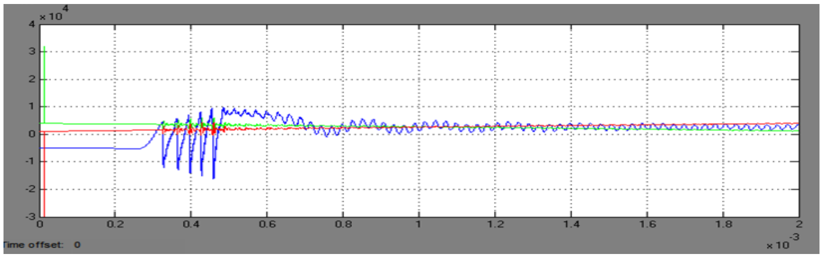
Voltage escalation



Interruption of 800kW motor in the least favorable phase
without overvoltage protection

Maximum overvoltage on motor terminals reaches 8.3 p.u. exceeding insulations level prescribed in IEC 60034-15.

To avoid possible negative effect of VCB *(though having very low probability)* on motor Tavrida offers application of SA in parallel to main VCB contacts. In this case voltage escalation stops at relatively early stage.



Interruption of 800kW motor in the least favorable phase with
SA being installed in parallel to main VCB contacts

Maximum overvoltages does not exceed 3.0 p.u. that is less than insulations level prescribed in IEC60034-15 with safety margin 39%.

Conclusion for motor interruption

To avoid dangerous overvoltages at interruption of starting motors we recommended installation of SA in parallel to main VCB contacts. This limits overvoltages to safe level *(from IEC60034-15 standpoint)*.

Resulting maximum overvoltages are also lower than the ones that may be generated by ideal CB at motor closing and by transient earth faults.

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Thank you

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