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Transmission and Distribution Equipment

Paper 10566_2022

Application of controlled switching for a 500 kV switchable line reactor connected to 600 MW solar power generating plant to reduce probability of unintentional re-ignitions and life cycle enhancement – A field case study

Urmil Parikh, Naveen Dubey, Tuan HoangNgoc, Nguyen Xuan Hong, Mirko Palazzo

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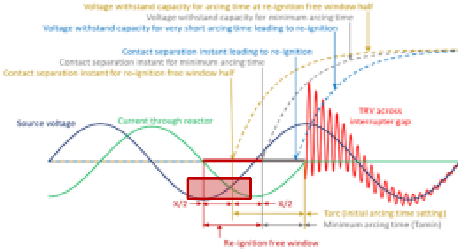
Motivation

Challenges with Shunt reactor switching

- During de-energization, shunt reactors experience severe over-voltage stresses with steep rise time due to interaction of high inductance of reactor and stray capacitance offered by bushing and winding to ground capacitance of the reactor.
- If the dielectric strength at current interruption instant when the said voltage stress will appear, not sufficient, may lead to re-breakdown known as ‘Re-ignitions’.
- The unintended re-ignitions accelerate aging of the CB internal component and the reactor insulation and may even lead to damage of the CB.

Line Reactors with NGRs

- Line reactors used for voltage profile management, are employed with NGRs, will further increase severity of the voltage stresses & re-ignitions probability.
- Nature of the over-voltages depends upon design of CB interrupting chamber, reactor specification, its design, connection configuration and reactor L & C.
- Hence, the over-voltage seen by the same CB will be different from site to site.
- Rating of the reactor plays a key role, as the chopping current depends upon the magnitude of the current.
- For small reactors, it becomes more severe due to higher chopping currents leading to steeper over-voltages with higher magnitude.
- Using controlled switching, the probability of re-ignitions can be reduced to a great extent by ensuring enough gap between arcing contacts when arc is expected to be quenched, which is generally in vicinity of natural current zero for SF6 circuit breakers.
- With Controlled switching device (CSD) this an be achieved: Starting arcing contact separation enough time before current zero, known as “Arcing time”.



- “Reignition free window.” The range of arcing time with min probability of un-intentional reignitions

Challenges for controlled switching of reactors

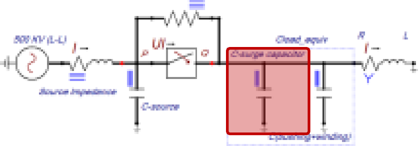
- Determine suitable arcing time for specific site cases due to reasons mentioned in this section previously.
- Ensure the right pre-commissioning (wiring & interlocking logic checks)
- Validation of controlled switching performance with live switching.
- External noise making errors in switching detection

The paper contains a case study for finding suitable arcing time settings and implementing controlled switching for a reactor installed on a line connected to solar power plant. The NGR of the reactor also has bypassing facility to avoid higher TRVs as discussed in previous section.

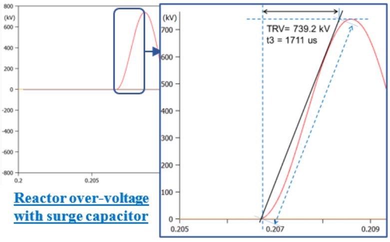
Right approach to find arcing time

a)Simulation study to determine TRV for specific reactor specifications and site conditions

Specifications of line reactor	
Source voltage	500 KV
KVAr rating	60 MVAr
Voltage rating (reactor)	500 KV
Current rating (reactor)	69.50 A
Z-reactor	7.75+ j4153.12 ohms
L-reactor	13.226 H
Bushing capacitance	525 pF/ph
Interwinding capacitance	3313.33 pF/ph
Surge suppressor	27000 pF/ph



- The surge capacitor has been adapted at site as per customer request to minimize risk of over-voltages especially in conjunction of shunt reactor switching.
- Moreover, the CB being capable to withstand the expected TRV without any additional over-voltage suppressing devices, the settings of the CSD has been considered without considering the surge capacitor to have better safely margin



Reactor over-voltage with surge capacitor

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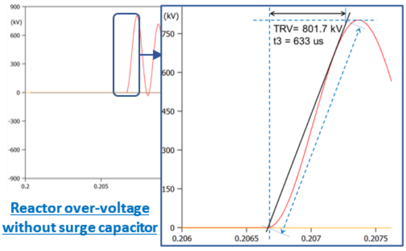
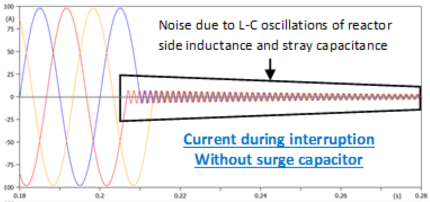


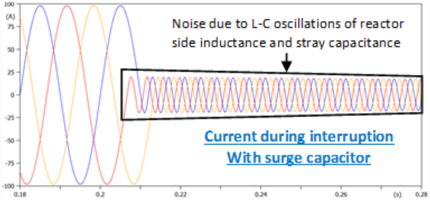
Reactor over-voltage without surge capacitor

- *Noise due to LC oscillations of reactor L & capacitance*



Noise due to L-C oscillations of reactor side inductance and stray capacitance

Current during interruption Without surge capacitor



Noise due to L-C oscillations of reactor side inductance and stray capacitance

Current during interruption With surge capacitor

Maximum over-voltage vs different chopping currents

Sr. No	Chopping current (A)	With surge capacitor		Without surge capacitor	
		Over-voltage peak (kV)	Rise time (t3) (μs)	Over-voltage peak (kV)	Rise time (t3) (μs)
1	0	739.19	1710.9	801.70	633.00
2	3	743.56	1608.0	839.55	525.00
3	5	751.83	1527.6	899.83	460.51
4	10	793.91	1350.4	1100.9	369.95

b) Chopping number (λ) calculation for CB model (As per IEC 62271-306 and IEEE C37.015)

Find λ_{max} with statistical distribution, T_{amax} & minimum RRDS from reactor type test results (IEC62271-110)

$$\lambda = A + Bt_{arc} + 2Se.\ Where,\ A = \frac{1}{n}\sum_{i=1}^{n}\lambda_i - \left(\frac{B}{n}\right)\left(\sum_{i}^{n} t_{ai}\right)\ \&\ B = \frac{S_{xy}}{S_{xx}}$$

$$Sxx = n\sum_{i=1}^{n} {t_{ai}}^2 - \left(\sum_{i=1}^{n} t_{ai}\right)^2, Syy = n\sum_{i=1}^{n} {\lambda_i}^2 - \left(\sum_{i=1}^{n} \lambda_i\right)^2$$

$$Sxy = n\sum_{i=1}^{n} t_{ai}\lambda_i - \left(\sum_{i=1}^{n} t_{ai}\right)\left(\sum_{i=1}^{n} \lambda_i\right)\ \&\ Se^2 = \frac{1}{n(n-2)}\left(S_{yy} - B^2 S_{xx}\right)$$

Consequently, parameter values are found as *A = -4823, B = 9270, Se = 21555.34,* t_{amax} *= 13 and RDDS = 0.38 pu*

t_{amax} *is max. arcing time observed in all four test duties*

↓

↓

With λ_{max} find over-voltage parameters k_{a_uc} (*pu*) & k_{rv_uc} (*pu*), arcing time *(*t_{arc_uc}*) using calculated RDDS*

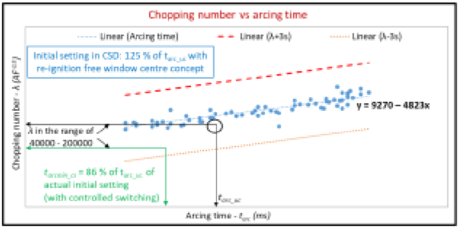
t_{arc_uc} = 7.2 ms

*(Corresponds to n*o over-voltage mitigation technique)

↓

For evaluated t_{arc_uc}, find λ_{cs}, k_{a_cs} (*pu*), k_{rv_cs} (*pu*) and min. arcing time t_{arcmin_cs} with controlled switching as mitigation technique using CB chopping characteristics :

t_{arcmin_cs} = 0.86 t_{arc_uc}



Chopping characteristics of CB

↓

Find initial arcing time setting for CSD: t_{arc_cs} using reignition free window center concept:

$t_{arc\_cs} = t_{arcmin\_cs}$*+(Half cycle -* t_{arcmin_cs} *)/ 2*

t_{arc_cs} = 1.25 t_{arc_uc} = 9 ms

Field experience & Test results

Follow proper procedure as described below…

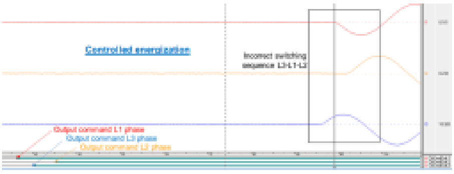
a) Pre-commissioning checks

- Check wiring schemes & bypass circuits if present
- Perform interlocking logic checks.
- Perform offload operations to validate command routes.

b) Live switching to validate performance

- Perform first live switching operation and check for expected behavior.

Issue 1: wiring issue found during first live switching



Operation with incorrect switching sequence L3-L1-L2 cigre | PARIS 2022

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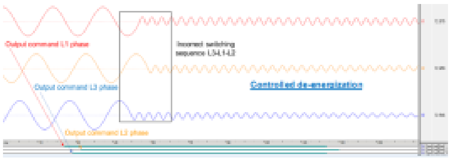
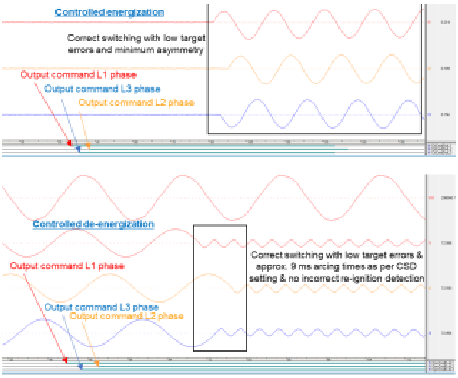


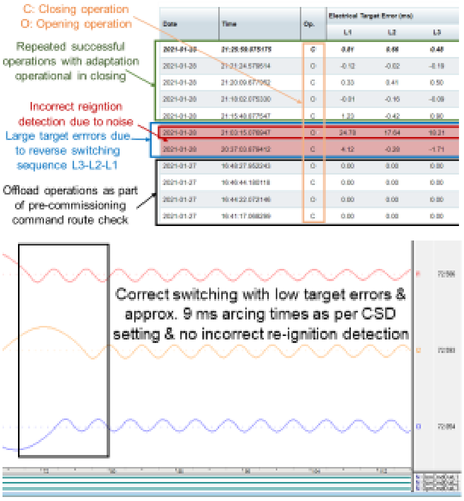
Operation with incorrect switching sequence L3-L1-L2

Correction: CTs for L1 & L3 phases were found swapped in first live switching operation. This was corrected.



Operation with correct switching sequence L1-L3-L2

Issue 2: Troubleshooting for incorrect reignition detection due to noise using Digital filtering



Date	Time	Op.	Electrical Target Error (ms)		
			L1	L2	L3
2021-01-28	21:25:58.875178	C	0.81	0.68	0.48
2021-01-28	21:21:24.578514	O	-0.12	-0.02	-0.18
2021-01-28	21:20:09.677082	C	0.33	0.41	0.50
2021-01-28	21:18:02.075330	O	-0.01	-0.16	-0.08
2021-01-28	21:15:48.877547	C	1.23	-0.42	0.90
2021-01-28	21:03:15.078947	O	24.78	17.64	10.21
2021-01-28	20:37:03.679412	C	4.12	-0.28	-1.71
2021-01-27	16:49:27.952243	O	0.00	0.00	0.00
2021-01-27	16:46:44.180118	C	0.00	0.00	0.00
2021-01-27	16:44:22.072146	O	0.00	0.00	0.00
2021-01-27	16:41:17.068299	C	0.00	0.00	0.00

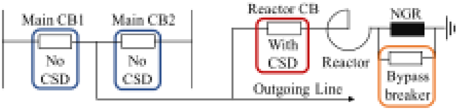
Operation records including offload, incorrect and successful repeated operations

- After all issues resolved, repeat operations to check performance in successive operations.

Controlled switching performance	Type	DR No	Phase 1	Phase 2	Phase 3
Achieved arcing times (ms) Target: 9.0 ms (for each phase)	Open	35	8.88	8.98	8.81
		33	8.99	8.84	8.91
Achieved making angles (deg°) Target: 90° (for each phase)	Close	36	102.26°	99.64°	96.63°
		34	93.67°	95.13°	96.43°

Switching performance: Successful operations after commissioning

c) Proposed interlocking logics



SLD of line with reactor bay

i. NGR Bypass CB shall be closed to have CSD in circuit

ii. When reactor CB closed together line being dead, it shouldn't be possible to open Main CB1/Main CB2

Conclusion

Controlled switching success factors

- Determination of right settings for based on load specifications and CB model. For reactor application:
  - ○ Perform simulations for expected TRV (especially for reactors with NGR or small size)
  - ○ Calculation as per IEC 62271-306 & IEEE C37.015 using reactor switching type test results as per IEC62271-110
- Perform pre-commissioning checks, includes…
  - ○ Wiring checks
  - ○ Interlocking logic checks
  - ○ Offload operations to check command routes prior to live switching operations.
- Perform live switching to validatee performance
  - ○ If needed, use digital filtering to avoid incorrect monitoring of operations.
  - ○ For reactors , this is important to ensure this to avoid incorrect reignition detection.
- Implementing bypass arrangement for NGR assists in reducing extra over-voltages imposed on CB due to higher first pole-to-clear factor.

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Transmission and Distribution Equipment

Paper 10660_2022

Field application of controlled switching & advanced digital monitoring techniques to mitigate switching transients for various power equipment connected with CBs with different drive technologies

Urmil Parikh, Michael Stanek, Mirko Palazzo, Davide Zanon, Sebastiano Scarpaci, Patrik Lindfors-Dahlin, Mehulbhai Sonagra

Hitachi Energy Sweden AB, Hitachi Energy Switzerland Limited, Hitachi Energy Italy Limited, Hitachi Energy India Limited,

Motivation

Applications of controlled switching

- De-energization of reactors to avoid unintentional re-ignitions which otherwise may lead to high chopping over-voltages and consequently faster aging of internal CB components as well as insulation of the reactor. Sometimes, it can lead to permanent damage of CB as well as reactor insulation.
- Energization of capacitor banks, long cables and transformers to mitigate energization inrush currents. This intern reduces Temporary over-voltages because of high inrush currents for cables and transformer applications.
- Reduction in switching over-voltages during energization and re-energization during auto-reclosures for long EHV & UHV transmission lines.

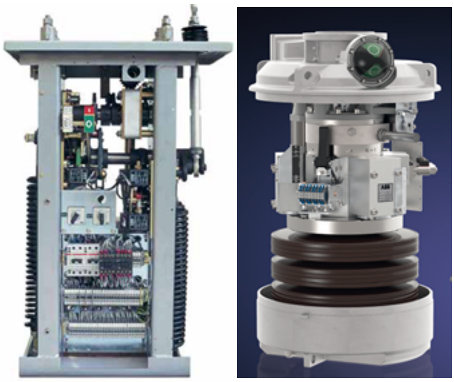
Applications for different drive technologies

a) Spring operating mechanism

- ○ Separate springs for opening & closing
- ○ Closing spring generates driving force perform closing, together it charges the opening spring
- ○ Opening spring is placed underneath the mechanism housing and is part of CB’s mechanical linkage, makes already closed CB ready for immediate opening
- ○ After closing operation, a motor charges the closing spring, making it ready for next closing operation
- ○ Consistent operating times under all environmental conditions make it suitable for controlled switching applications

b) Spring operating mechanism with hydraulic power transmission

- ○ Single disc spring stores energy for performing opening and closing operations
- ○ The energy of the spring is sufficient to perform operating sequence *O-t-CO-t’-CO*
- ○ Storage pistons mechanical energy of spring is converted to hydraulic energy
- ○ Fluid between high pressure system & operating cylinder serves as flexible linkage
- ○ A fast-acting control valve positioned in flow path controls closing and opening operations
- ○ Provides consistent operating times and hence, is suitable for controlled switching



c) Motor drive

- ○ Digitally controlled motor directly moving CB contacts as per stored contact travel program
- ○ Energy charging, buffering, release & transmission being electrical reduces moving parts
- ○ Simple & reliable with elimination of wearing components, reduced operating forces & min noise
- ○ Being digital, provides consistent operating time; hence, is best suitable for controlled switching
- ○ Provides advanced online monitoring & improved asset management

Motor based operating mechanism

Regardless of the CB & drive technologies, a Controlled Switching Device (CSD) typically evaluates actual CB operating times from configured feedback signals & provides intrinsic condition monitoring of the CB’s switching behavior.

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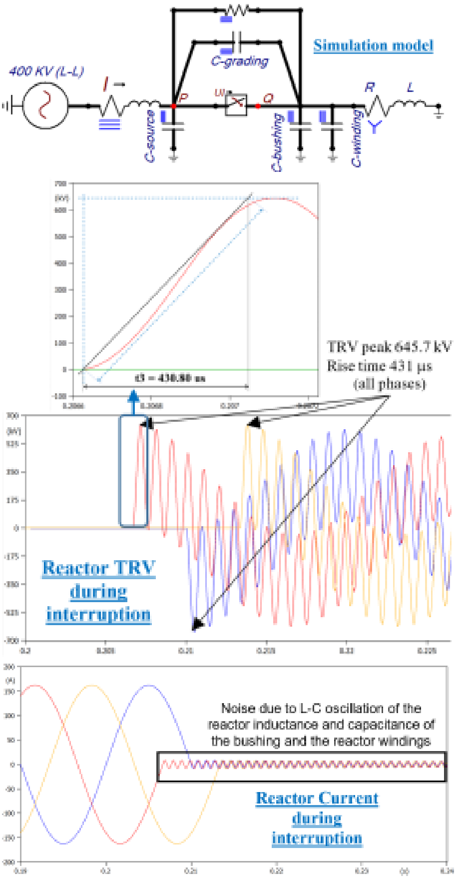
Field application of controlled switching & advanced digital monitoring techniques to mitigate switching transients for various power equipment connected with CBs with different drive technologies

Continued

Field Experience

a) *Controlled switching of 400kV, 80 MVAR grounded reactor on GIS with hydro-mechanical spring drive*

- TRV simulations to find suitable arcing time



Simulation model and TRV waveform for 400kV, 80MVAR reactor

Accuracy of controlled de-energization of shunt reactor with current feedback

Op. No	Actual arcing time (ms)			Electrical target error (ms) ref. to target arcing time (7.35ms)		
	L1	L2	L3	L1	L2	L3
11	7.32	7.27	7.10	-0.03	-0.08	-0.25
13	7.29	7.25	7.12	-0.06	-0.10	-0.23
15	7.30	7.34	7.15	-0.05	-0.01	-0.20

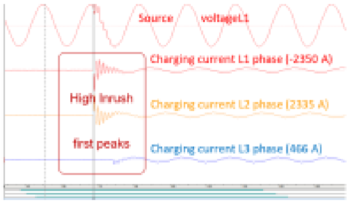
b) *Controlled energization of ungrounded 150kV, 26 MVAR capacitor bank by MTS CB with motor drive*

<u>Desired energization targets:</u>

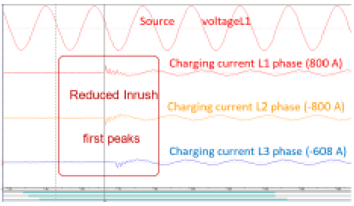
Switching sequence L1L2-L3
L1 & L2 Poles at L-L of 1.732 PU at gap voltage zero
L3 pole on 1.5 PU (neutral shift) at gap voltage zero

<u>Feedback for monitoring: Current</u>

Current starts only when both L1 & L2 poles are closed.
Hence, monitoring is not relevant for pole L1
Monitoring is performed only for L2 & L3 poles.



Operation with large target errors and high inrush



Operation with accurate targets & low inrush

c) *Controlled switching of coupled transformer by LTB with spring drive*

- Controlled opening to have repeatable flux pattern
- Controlled energization to minimize inrush for flux pattern achieved with previous controlled opening

<u>Desired energization Targets:</u>

L1-L3-L2 switching sequence
L1 pole at gap voltage peak at 1 PU
L3 pole quarter cycle post L1 pole at gap voltage 0.86 PU
L2 pole 1.5 ms post L3 pole (without any prestrike)

- *<u>Monitoring option 1:</u>* <u>Load voltages</u>
  (For a 150/23kV, YNd11 coupled transformer)
  - 3 ph. Fluxes are inter-linked due to delta winding.
  - All 3 ph. load voltages starts together when only L1 phase gets energized. So, are not suitable for monitoring of individual phases.
  - Special load voltage differential arrangement used to detect switching instant of individual phases
  - Upon energization of L1 & L3 poles, voltage will induce on L2 pole without any prestrike.
  - Hence, monitoring is only done for poles L1 & L3.

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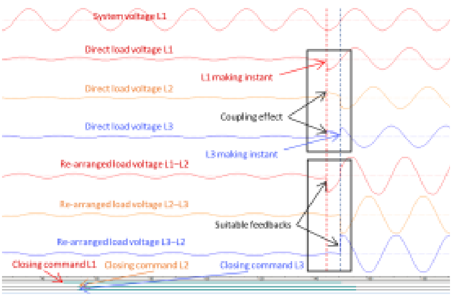
Field application of controlled switching & advanced digital monitoring techniques to mitigate switching transients for various power equipment connected with CBs with different drive technologies

Continued

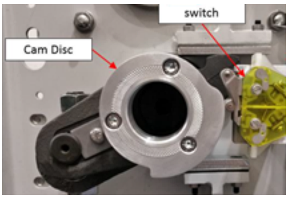


Special Trans. side PT arrangement for switching instant detection

Repeated operations with load PT monitoring feedback

DR No	Inrush current peak (A)			Electrical target error (ms)		
	L1	L2	L3	L1	L2	L3
8	-9.1	2.7	10.4	0.2	N/A	0.9
10	-8.9	-12.0	-8.6	-0.7	N/A	0.2
12	-10.0	-7.2	3.0	-0.6	N/A	0.3

- <u>Monitoring option 2: Mechanical feedback</u>
  (For a 400/220/11kV YNa0d11 auto-transformer)
  - Special shaft mounted cam follower sensor detects operating time variations “Mechanical Feedback”
  - The feedback shall provide accurate correlation of main contact with position sensor



Special position sensor as feedback for switching instant detection

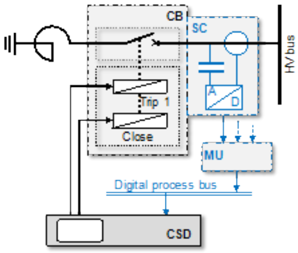
Repeated operations with mechanical feedback

DR No	Inrush current peak (A)			Electrical target error (ms)		
	L1	L2	L3	L1	L2	L3
14	-9.1	2.7	10.4	0.2	N/A	0.9
16	-8.9	-12.0	-8.6	-0.7	N/A	0.2
18	-10.0	-7.2	3.0	-0.6	N/A	0.3

Controlled Switching in Digital Substation

- Optimum switching performance together with digital monitoring & asset management
- Integration with IEC 61850 and SCADA
- IEC 61850 defines controlled switching as a logical node (LN) named CPOW

Outdoor MTS with redundant EIT & IEC 61850-9-2 (LE) process bus



* IEC 61850-9-2(LE) process bus sampled values in BLUE

Block diagram of Digital substation with CSD

- The entire substation has only electronic instrument transformers (EITs), which transmit digital sampled voltage and current values to the receivers including CSDs.
- Without losing functionality, this approach reduces the physical complexity of the installation with increased reliability and saving costs.

Conclusion

Controlled switching has been/can be successfully used…

- With different CB technologies : LTB, DTB, GIS & MTS
- For CBs with different type of operating mechanisms: Spring drive, hydro-mechanical drive and motor drive.
- For different applications: Reactors, Capacitor banks, Transformers etc. with diversified configurations

Suitable monitoring feedback to CSD ensures proper evaluation of target variation in successive operations.

For some applications (example: shunt reactor de-energization), CSD setting evaluation may need to be supported with simulation studies.

Modern CSDs are well suitable for integration in digital substation and offers advantages of…

- Reduced installation complexity
- Increased reliability
- Saving in costs