CIGRE CROATIA
Next Generation Network (NGN)

Electricity Supply Systems of the Future

Recent developments and future technological challenges

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CIGRE Next Generation Network (NGN)

- Next Generation Network (NGN) je platforma za **mlade inženjere** koja nastoji omogućiti uspješan **prijelaz u industriju za studente i mlade inženjere** u ranoj karijeri pružajući tehničke resurse i mogućnosti umrežavanja za osobni i tehnički razvoj. Cilj je osigurati da interesi novih članova budu zastupljeni u CIGRE-u, kako za njihovu vlastitu dobrobit, tako i za buduću održivost CIGRE.

- Ciljevi NGN-a su:
  - Poticati aktivno članstvo u CIGRE NGN-u, kako za dobrobit članova NGN-a tako i za NGN grupu.
  - Organizirati i promovirati aktivnosti (tehnički posjeti, predavanja i sastanci za CIGRE NGN).
  - Organizirati odgovarajuće CIGRE NGN događaje.
  - Sudjelovati u radnim grupama CIGRE (WG).
  - Redovito izvještavati Upravnom odboru CIGRE.
  - Pripremiti i održavati CIGRE NGN web stranice.
  - Poboljšati komunikaciju između članova CIGRE i NGN-a.

- Krajem 2019. godine Upravni odbor CIGRE zatražio je od NGN grupa da formaliziraju svoju strukturu odabirom međunarodnog NGN predsjednika koji će biti veza i imati mjesto u Upravnom odboru CIGRE

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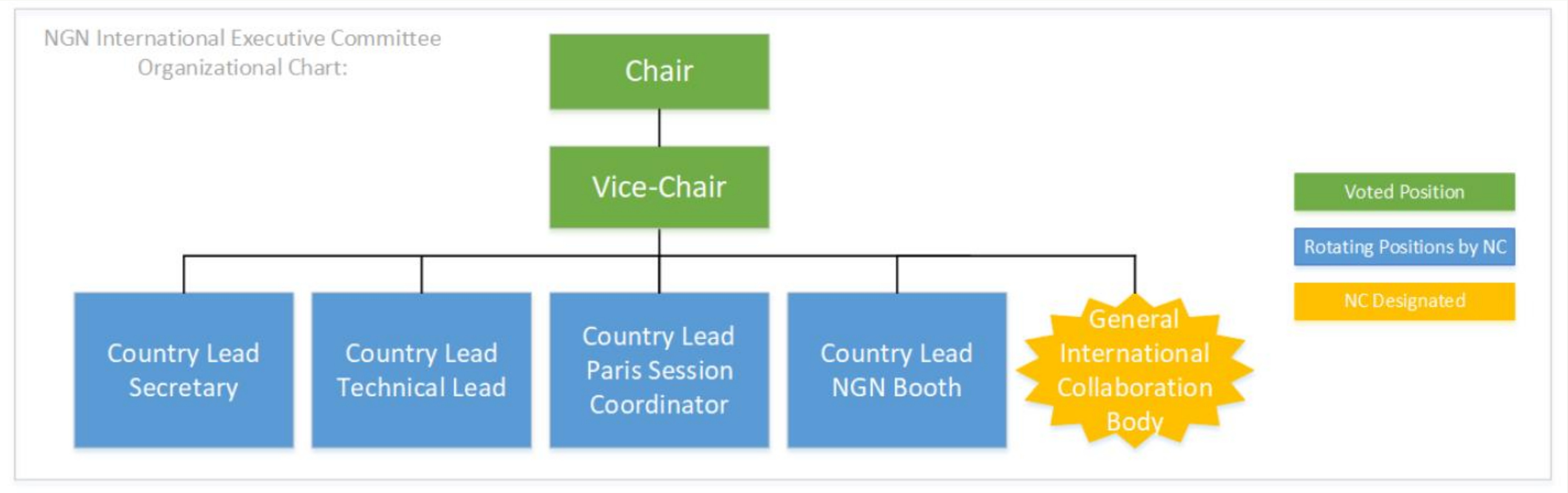
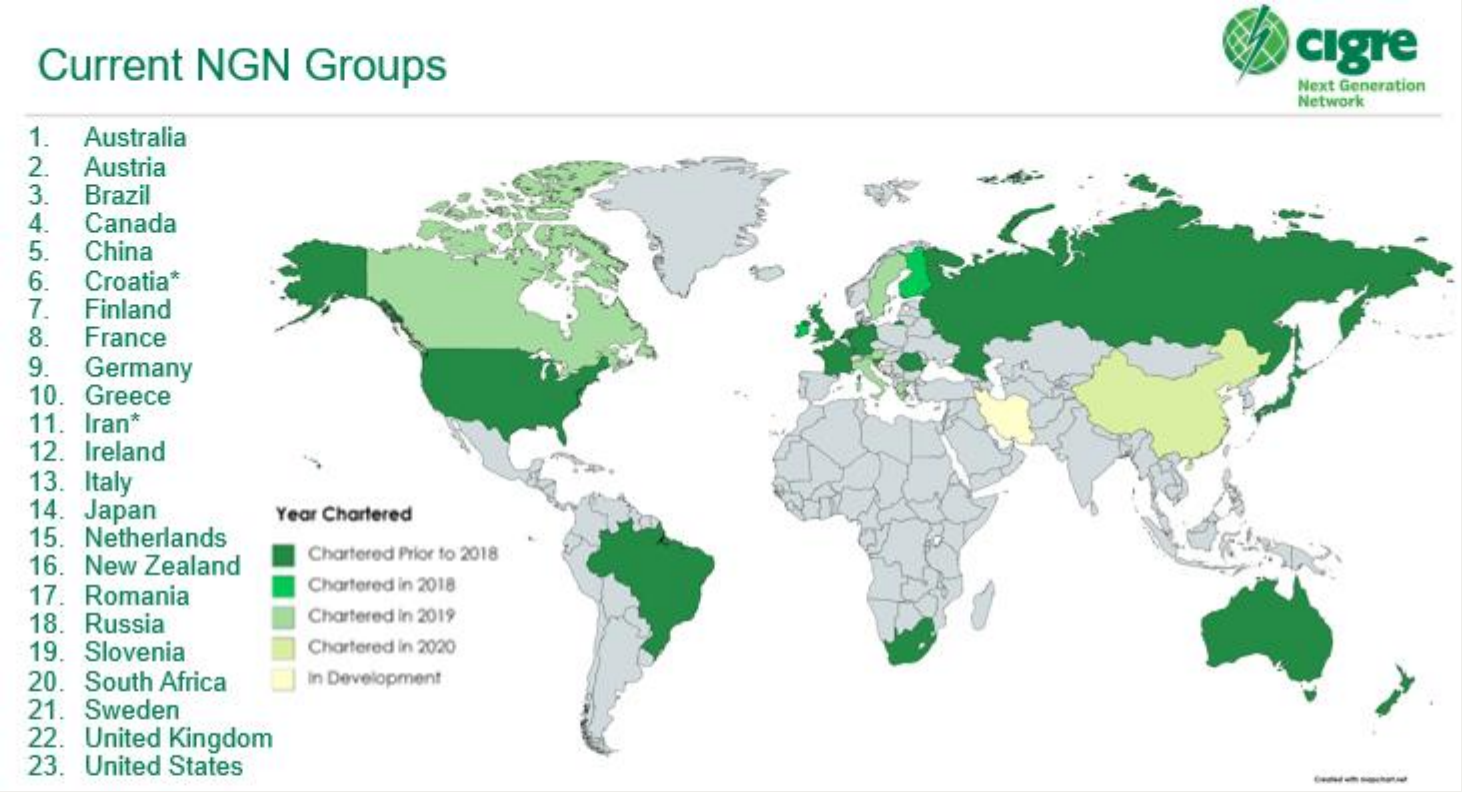
- Prijedlog za formiranje NGN međunarodnog izvršnog odbora, koji je poslan Upravnom odboru CIGRE na odobrenje.



- Međunarodni izvršni odbor NGN-a koordinira sve međunarodne NGN aktivnosti i organizaciju NGN događaja za Pariške sjednice.

CIGRE Next Generation Network (NGN)

- Chair: Stefanie Cray
- Vice-Chair: Stanislav Eroshenko



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- JAPAN
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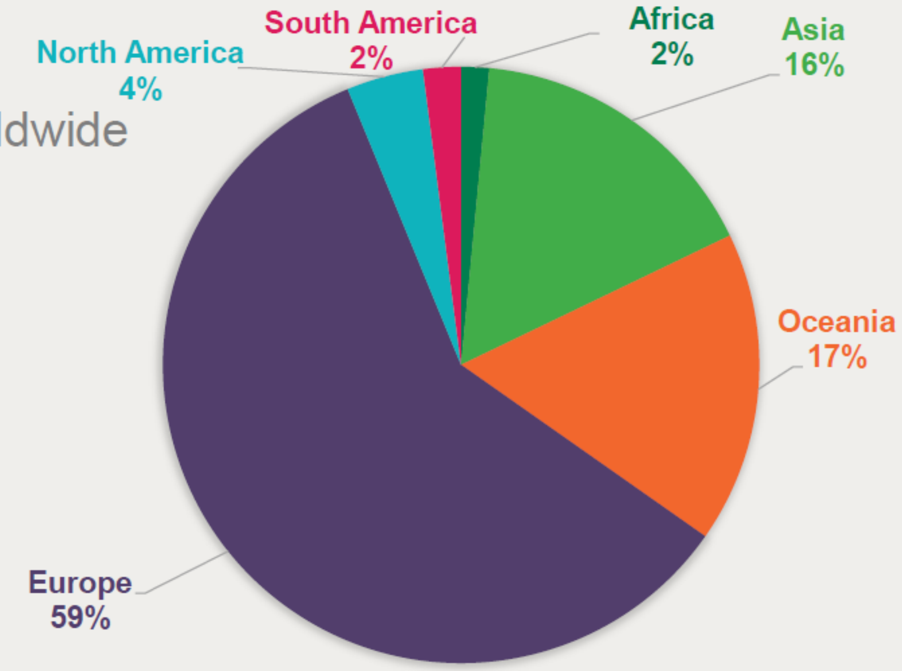
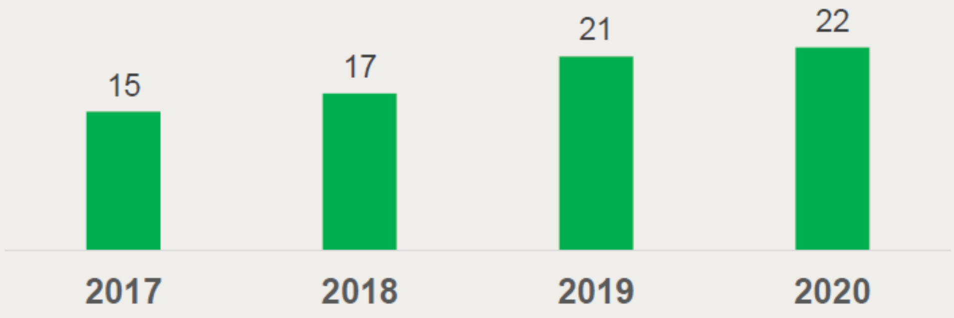
NGN Statistics

- Current NGN Membership*
  - ➢ Approximately 1.350 NGN members worldwide



- Growth of NGN Groups



*Based on 2019 NC Activity Reports and NGN group self-reports

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Prednosti članstva u NGNu:

- Informacije:
  - Pristup e-CIGRE web stranici i ELECTRA časopisu.
  - Mjesečni bilten o događajima koji dolaze i izvještaj s nedavnih događaja pod pokroviteljstvom CIGRE.
- Angažman:
  - Pristup radnim skupinama te mogućnost sudjelovanja u tehničkom radu CIGRE.
  - Pristup Pariškom zasjedanju koje je vrhumac tehničkih aktivnosti CIGRE.
  - Pristup namjenskim događajima (tehnički posjeti, predavanja,…).
- Mreža:
  - Interakcija i dijeljenje iskustva s kolegama diljem svijeta.
- Razvijanje:
  - Mogućnost poboljšanja ključnih vještina za profesionalni razvoj (komunikacija, organizacija, planiranje, tehničko znanje).

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CIGRE Croatia Next Generation Network – past activities

- Na 48. međunarodnoj Cigre konferenciji, koja je održana online, Next Generation Network (NGN) sekcija je imala forum, odnosno održana je prezentacija u trajanju od sat vremena. Moderator sesije je bio Anthony Giacomini, jedan od predsjednika američke NGN grupe. Sadržaj prezentacije se ugrubo može podijeliti na 4 dijela:
    1. Internacionalne NGN grupe
    2. Pregled rada NGN-a u 2020
    3. Dodjela nagrada NGN članovima sa značajnim doprinosom radu grupe
    4. Internacionalni izvršni odbor NGN-a

- Osnovane 22 NGN grupe u svijetu te se na prezentaciji navodi da je 2019. bilo preko 1350 članova NGN-a u svijetu. Najveći postotak, čak 60 % članova je iz Europe.

- NGN je platforma za mlade inženjere pomoću koje mogu prezentirati svoj rad i dostignuća široj, internacionalnoj CIGRE zajednici. Za sudjelovanje na pariškoj konferenciji, svaki nacionalni odbor predlaže do 4 kandidata. Na konferenciji 2020. čak 33 NGN člana su prezentirala svoje radove unutar pripadajućih studijskih odbora. Svaki studijski odbor je imao barem jedan NGN rad.

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CIGRE Croatia Next Generation Network - past activities

- 05.06.2020. održan je online sastanak CIGRE NGN sekcija na međunarodnoj razini.
- Na sastanku kojim je predsjedala Kerstin Weindl (NGN Austria) održano je ukupno 9 prezentacija NGN sekcija koje pripadaju nacionalima odborima CIGRE-a iz: Austrije, Finske, Njemačke, Grčke, Italije, Slovenije, Južnoafričke Republike, Ujedinjenog Kraljevstva i Sjedinjenih Američkih Država.
- Sastanku su prisustvovali i članovi NGN-a HRO CIGRE Ivana Damjanović, Nina Stipetić i Božidar Filipović-Grčić sa Fakulteta elektrotehnike i računarstva Sveučilišta u Zagrebu.
- Svaka pojedina NGN sekcija je prezentirala aktivnosti koje se provode u okviru djelovanja nacionalnih CIGRE odbora.

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CIGRE Croatia Next Generation Network – aktivnosti i planovi

- uključivanje studenata i mladih inženjera u članstvo CIGRE i NGN sekcije;
- aktivno uključivanje članova NGN-a u **radne grupe CIGRE** i sudjelovanje u izradi i pripremi tehničkih brošura;
- organizacija različitih događaja kao što su webinari, različite vrste predavanja, radionice;
- prezentiranje e-cigre.org stranice koja članovima omogućava **pristup velikom broju članaka, tehničkih brošura i knjiga;**
- aktivno uključivanje članova NGN-a u organiziranje događaja unutar nacionalnih CIGRE odbora (organiziranje konferencija lokalnog i međunarodnog karaktera, organizacija simpozija i kolokvija…);
- dodjele nagrada za najbolje radove članovima NGN-a koji su objavili rad u časopisima CIGRE ili na konferencijama;
- motiviranje NGN članova za pisanje radova na CIGRE konferencijama;
- uključivanje akademske zajednice i industrije u NGN aktivnosti;
- organizacija tehničkih posjeta postrojenjima i tvornicama;
- uspostavljanje kontakta između mlađih članova NGN-a i industrije (poslodavaca);
- omogućavanje određenog broja besplatnih kotizacija članovima NGN-a (na konferencijama CIGRE);

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Electricity Supply Systems of the Future – sadržaj

- Power System Operation and Control
- Overhead lines
- Power Transformers and Reactors
- Circuit breakers
- Power System technical performance: EMC, power quality, lightning, power system dynamics

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Power System Operation and Control – introduction

- System operation is an essential and complex task that has the goal to meet the energy demand continuously and adequately.
- Control room operator decisions and prompt actions require a trade-off analysis between system security and economic efficiency.

System operators face significant evolving conditions in power systems:

- increasing penetration of RES
- the growing competitiveness of the electricity market,
- the integration of new technologies
- the need to increase flexibility and control capabilities into the operational framework
- conventional synchronous generation in operation

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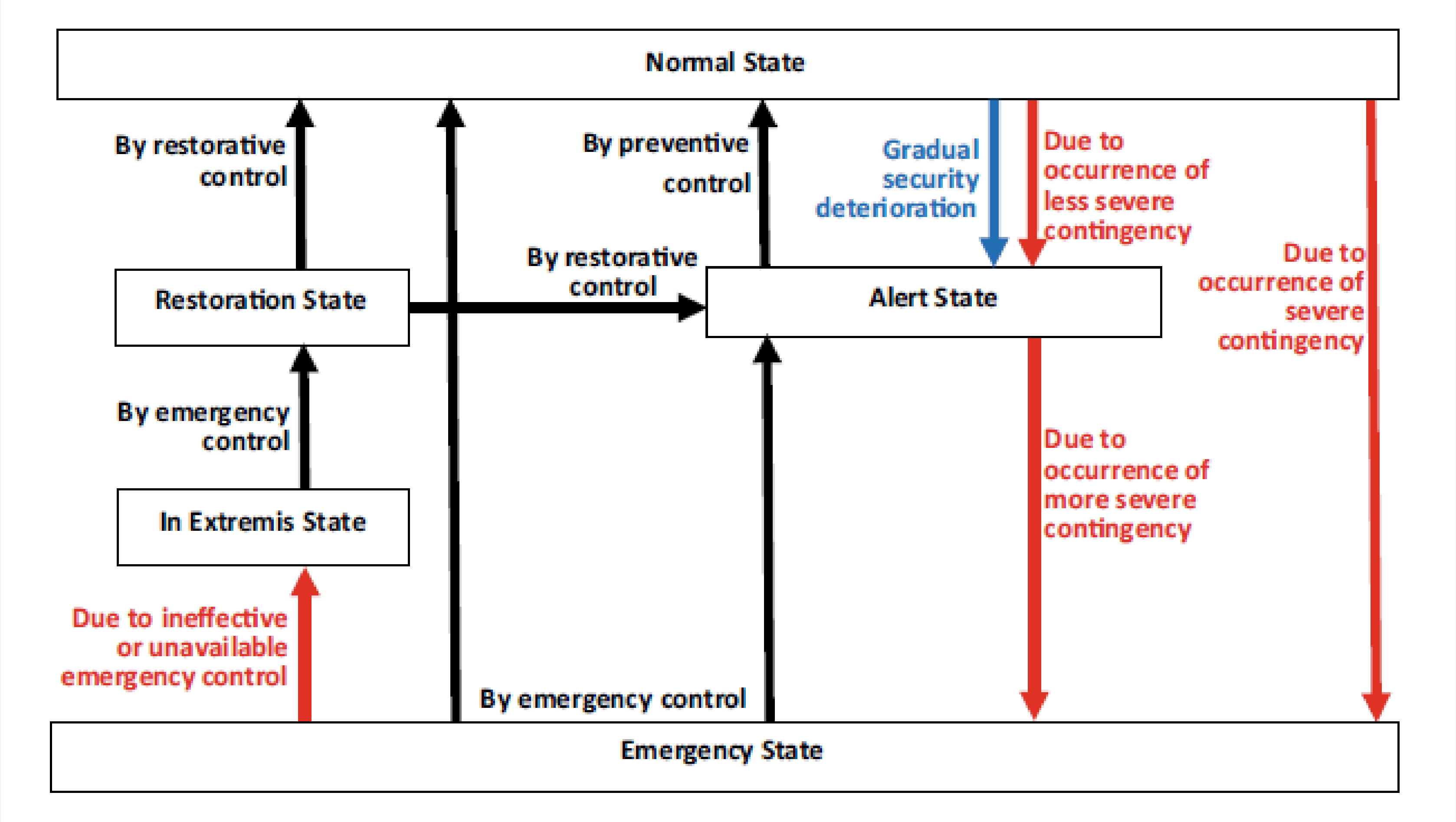
Power System Operation and Control – Power System States



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Power System Operation and Control – Operational Security Analysis

- The aim of the security analysis:
  - to identify possible security restrictions
  - associated remedial actions

- (N-1) security principle: voltages, currents and system stability criteria should remain within the defined limits.
- If any violations are detected, remedial actions are identified:
  - Topology changes
  - Adjusting settings of power flow control devices such as phase-shifting transformers (PST)
  - Changing reactive power compensation
  - Reduction of interconnection capacities
  - Generation redispatch

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Power System Operation and Control – Future of System Operations

- Control centers are an essential structure of power systems since they provide the coordination between all the major participants of the electricity chain.
- For many years, the information to the operators has been given through the supervisory control and data acquisition (SCADA), which is updated every two to six seconds.
- The ongoing energy transition incites the evolution of control centers.

- Increased System Observability
- SCADA/EMS and phasor measurement units (PMUs) within wide-area monitoring systems (WAMS) to enhance awareness and analytical capability to improve the restoration process.
- New generation of EMS/SCADA systems need more capabilities of handling complex analysis (e.g. dynamic security assessments and short-circuit power level calculations) and provide decision support to control room operators (e.g. remedial actions optimization).

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Overhead lines

Existing overhead lines of the transmission grid have been designed to build up a network or to strengthen it - as it was seen at the time of their erection. Due to the liberalization of the electricity market in the last years, the demand for production and consumption of electricity has changed. Also, more and more renewable energy sources (wind, solar, water) need to be integrated into the exiting transmission grid. Overloads of the lines must be prevented.

Some potential solutions:

- build new lines
- change of components on existing lines (e.g. other conductors with higher current capacity)
- increase the line voltage on existing lines (e.g. from 220 to 380 kV) or change from AC to DC
- application of thermal rating and dynamic line rating on existing lines.

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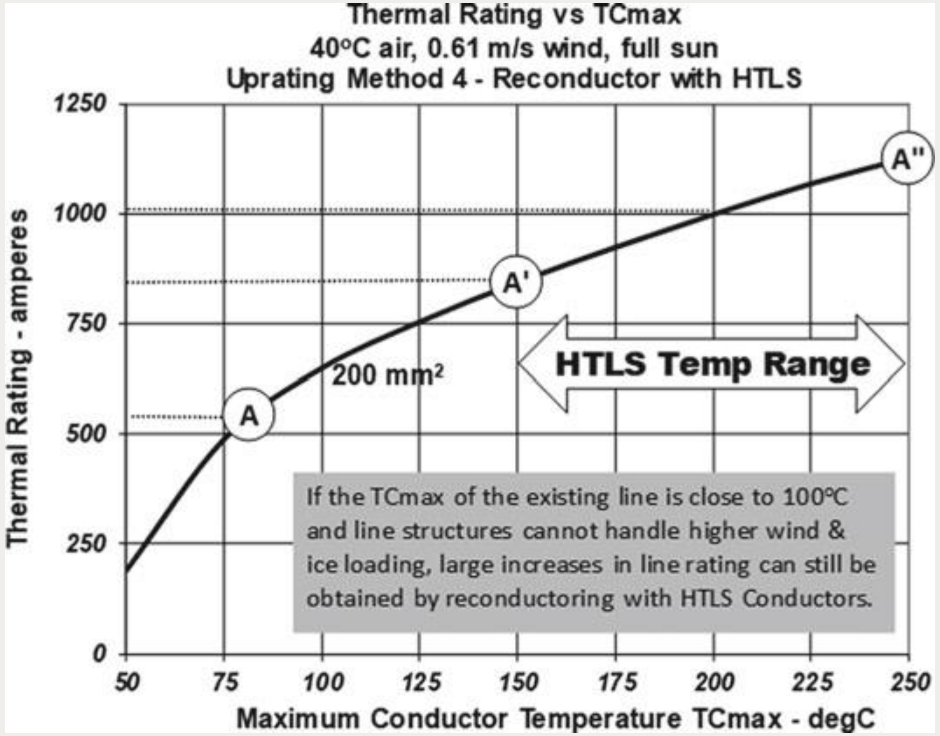
Overhead lines - High Temperature Low-Sag Conductors

Such conductors can increase the thermal capacity of an OHL remarkably.

Different types of high temperature low-sag conductors



Increase of capacity (amperes) depending on the conductor temperature for a certain project

Overhead lines – Voltage uprating

- Voltage uprating means to increase the operating voltage of an existing OHL to increase its capacity.

- The increase of capacity for voltage uprating with unchanged conductors is in the range of 70% when changing from 220 to 380 kV.

Influence of parameters for voltage uprating

Parameter		Electric fields	Magnetic fields	Radio interference	Audible noise
Phase to phase distance	↑	↑	↑	↘	↓
Conductor height above ground	↑	↓	↓	↘	↘
Number of sub-conductors (for a given total cross-section)	↑	↑	=	↓	↓
Sub-conductor spacing	↑	↗	=	↗	↗
Total conductor cross-section	↑	↗	=	↘	↘

↑ Strong increase
↗ Slight increase
↓ Strong decrease
↘ Slight decrease
= No significant effect

Overhead lines – Conversion AC to DC

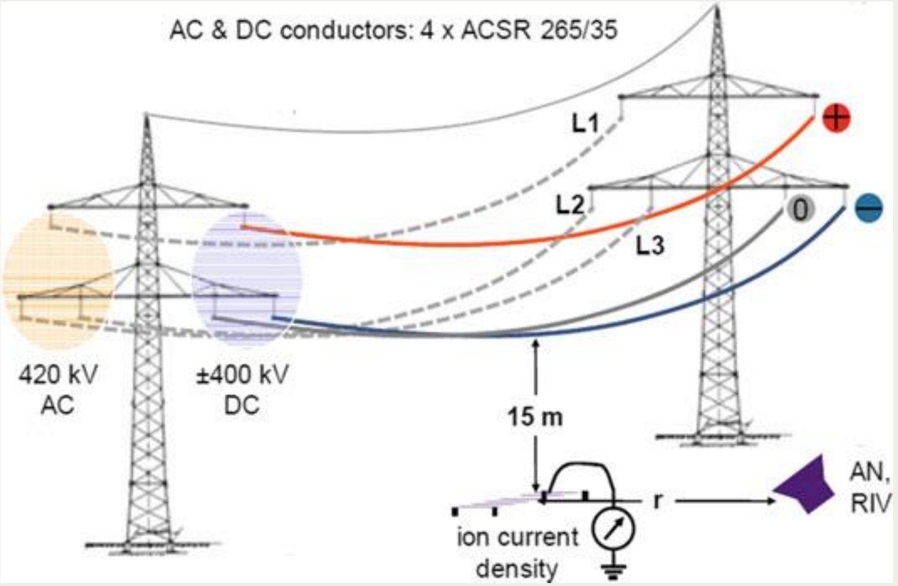
- The conversion of an existing AC overhead line to DC can increase its ampacity.

- The big advantage in general is the better control of the grid with a DC line.

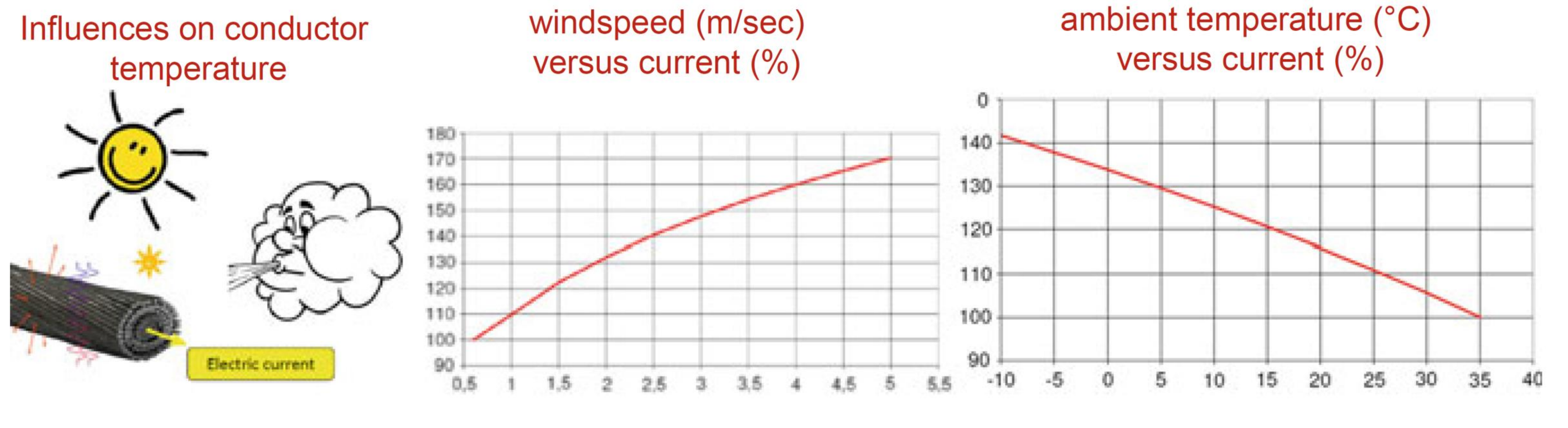
- The efforts for adaptions on the line, **the new built AC/DC- and DC/AC-converter stations at the ends of the line must be counterbalanced with the gained advantages**.

- In general, DC lines are used to transport large quantities of energy over long distances (typically
- exceeding 600 km) as point-to-point connections**. For shorter lengths AC lines are usually more economic.**

- A pilot project with the so-called hybrid line (one circuit at an existing OHL shall be changed to DC, the other one remains AC) is being constructed in Germany to check technical possibilities and electrical influences.

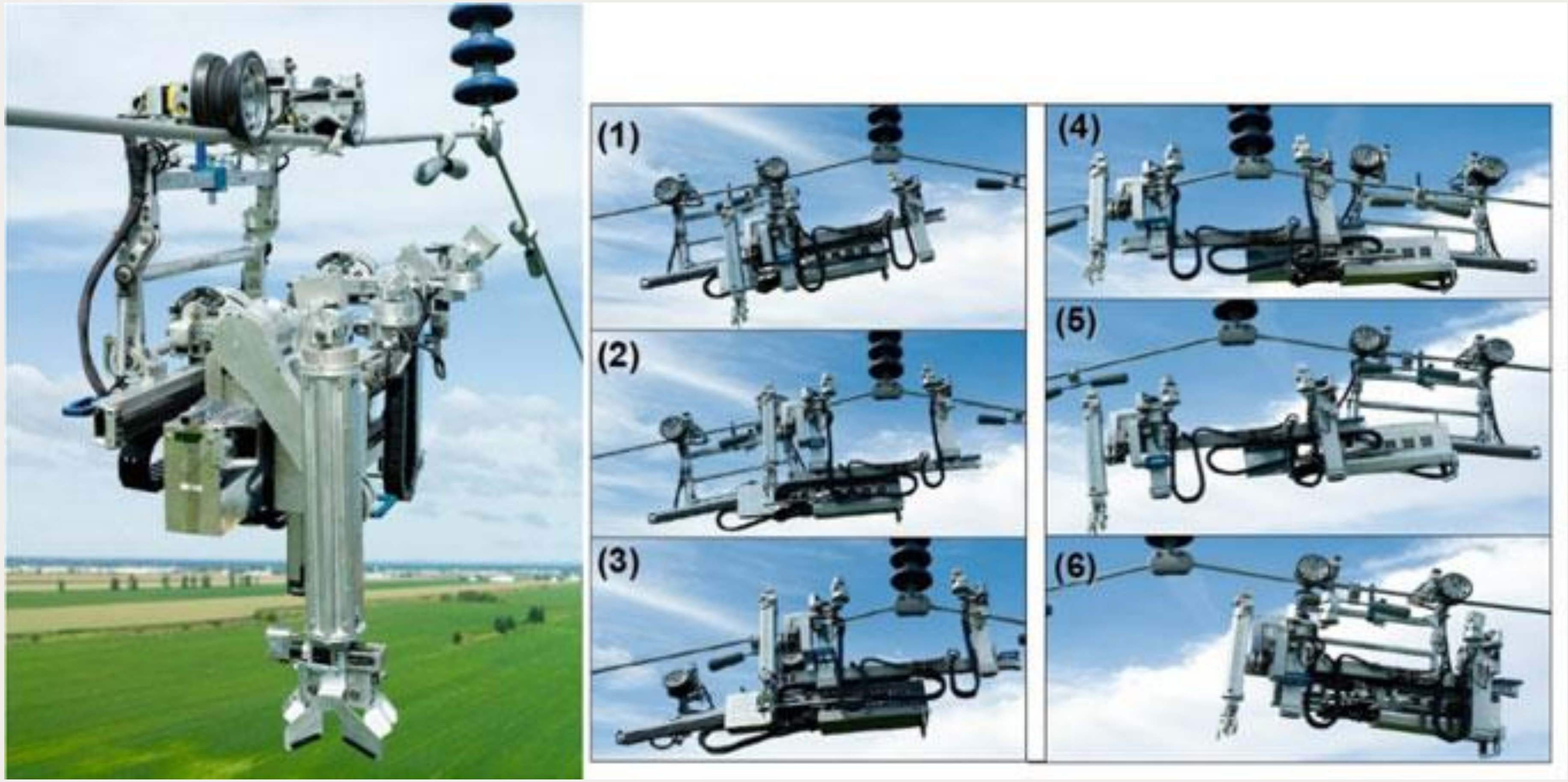


Overhead lines - Thermal Rating and Dynamic Line Rating



Principles of thermal rating, high wind and low temperature allow higher permissible current in the conductors

Overhead lines – maintenance with robots



LineScout Robot from Hydro-Québec; the robot is designed for live-line work up to 765 kV and can manage obstacles as suspension clamps (left: picture courtesy of Hydro-Québec; right: Pouliot et al. (2009),

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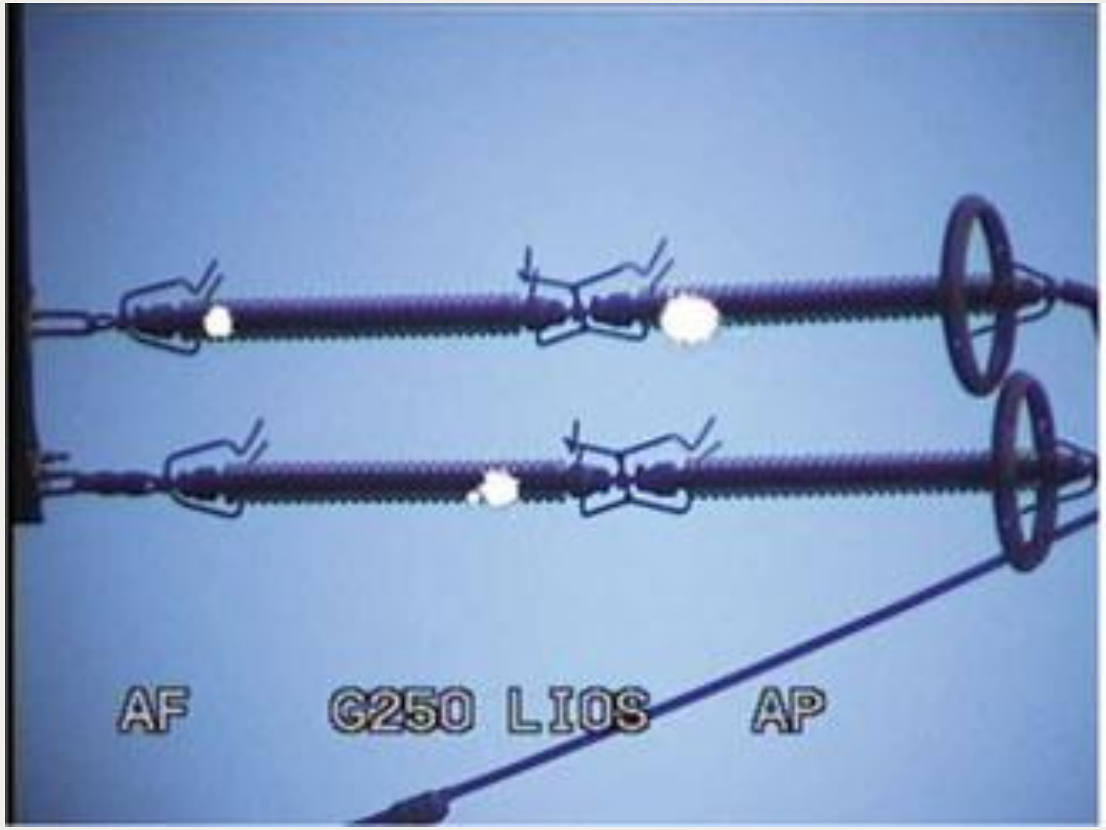
Overhead lines – Unmanned Aerial Vehicles (UAV)



Left: corona discharges due to heavy pollution on insulators, detected from an UAV (overlaid UV and visible recording), right: check of earth wire connections

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Overhead lines – Future Vision for the Use of Robots

Left: Metallic surface climbing robot from helical robotics; right: live-line insulator cleaning robot (Korea Electric Power Research Institute)

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Overhead lines – Conclusions

- There is an increasing demand of new lines in many countries. This concerns the replacement of existing lines, the erection of newlines and the increase of the capacity of existing lines. The big majority of those lines will be overhead lines (HV, EHV and UHV).
- It is increasing difficult to build and maintain highly reliable overhead lines while keeping cost for the lines low. It is also difficult to provide highly reliable supply of power while optimizing available resources (financial and manpower).
- The development of new, advanced technologies and materials in designing and maintaining overhead lines can help to keep the chosen risk level in design and maintenance while keeping reliability level high.
- Long-term reliability, long service life, cost efficiency and consideration of environmental aspects are required. Modern approaches, materials, methods and design help to fulfil these requirements.

Power Transformers and Reactors – future challenges

Challenges of special relevance for power transformers and reactors include the following:

- **Bidirectional** power and data **flows** at the distribution level
- Increased use of **DC and power electronics** at all voltage levels
- New and more **advanced tools for modelling**
- Increased **environmental constraints**
- Increased use of **right-of-way capacity**
- **Offshore and subsea** infrastructure

Power Transformers and Reactors - bidirectional power flows

- **Bidirectional power flows** from increased integration of distributed renewable energy resources have led to large variations in distribution voltage in some areas with abundant resources.

- These variations in voltage have in some cases exceeded consumer and operator expectations, and even limits imposed by regulators or legislation.

- In response, so-called **voltage regulating distribution transformers** have been developed. These are effectively distribution transformers with **on-load tap-changers**, allowing better control of the distribution network voltage.

Power Transformers and Reactors - transformer monitoring systems

- In recent years, there has been rapid progress in **transformer monitoring systems**

- Possibly the biggest challenge to the successful application of transformer monitoring systems is the **aggregation of results**.

Power Transformers and Reactors - HVDC

- Two recent developments have extended the possible use of DC transmission — VSC converters have reduced the technical challenges in constructing DC converter stations and the development of DC circuit breakers has allowed the possibility of multi-terminal DC networks.

- Other recent developments include the use of DC transmission for connection of offshore wind generation and also the development of smaller-scale DC transmission. IEC have recently published an improved standard for HVDC transformers.

- The **large size** of many modern HVDC transformers combined with **the remoteness of many installation sites** may make transport to site very challenging. An emerging technology which has been developed to meet these challenges is **site assembly**. It is likely to be an important enabling technology for use of higher AC and DC voltages.

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Power Transformers and Reactors - integration of RES

- **Phase-shifting transformers** are used to counteract loop flows in transmission networks and to enable better use of the **network capacity**.

- Even in case of centrally planned networks loop flows can arise, but **integration of distributed renewable resources** has made the problem worse in many areas.

- IEC have recently published an improved standard for phase-shifting transformers.

Power Transformers and Reactors - environmental impacts

- Possible **environmental impacts** of uncontrolled **loss of oil, fire or explosion** in the event of a power transformer or reactor failure cannot be tolerated in environmentally sensitive areas and sometimes also elsewhere.

- A large number of **alternatives to conventional oil-immersed transformers** have been developed, of which the most promising seems to be transformers immersed in **natural and synthetic esters**. Both have now successfully been applied to transformers up to 420 kV class. Study Committee D1 have established working group D1.70 to examine the functional properties of insulating liquids.

- Another major environmental impact of power transformer and especially reactors is **audible sound**.

- CIGRE working group A2.54 was established to consolidate this work, and in 2019 published an interim report concerning typical and minimum no-load sound levels in 2019.

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Power Transformers and Reactors - losses

- A further major impact of power transformers and also reactors is **losses**. For many years, there has been pressure on users to reduce losses and on manufacturers to produce designs with lower losses in response.

- Many countries have adopted statutory **regulation of power transformer losses**

- CIGRE working group A2.56 was established to provide users with some guidance on how best to specify and transformer losses. It is also expected that the working group will provide some useful guidance to countries planning to adopt new statutory regulations on different methods of doing so.

Power Transformers and Reactors - challenges

System challenge	Transformer challenge	Responses
Bidirectional power flows	Variable distribution voltage	VRDT [59, 60] New JWG led by A3
	Variable system frequency	Better specifications WG A2.57 New JWG led by A3
Bidirectional data flows	Better monitoring systems	WG A2.27 [24] WG A2.44 [25]
	Better analytical techniques	[26]
Modelling tools		
Environmental constraints	Oil	Ester liquids WG A2.33 [15] WG A2.35 [47] WG D1.70
	Audible sound	Better specifications Better design and construction WG A2.54 [21]
	Losses	Better specifications Better design and construction WG A2.56
Increased use of right-of-way capacity	Higher DC voltages	Latest IEC standard [39] Site assembly WG A2.59 New JWG led by A2
	Higher AC voltages	Site assembly WG A2.59
	Phase-shifting transformers	Latest IEC standard [43]
Offshore infrastructure	Offshore transformers	WG B3.26 [33]
	Subsea transformers	
Stakeholder engagement		New Green Book(s) Support for Africa initiative

Synthetic ester immersed transformer for 420 kV class

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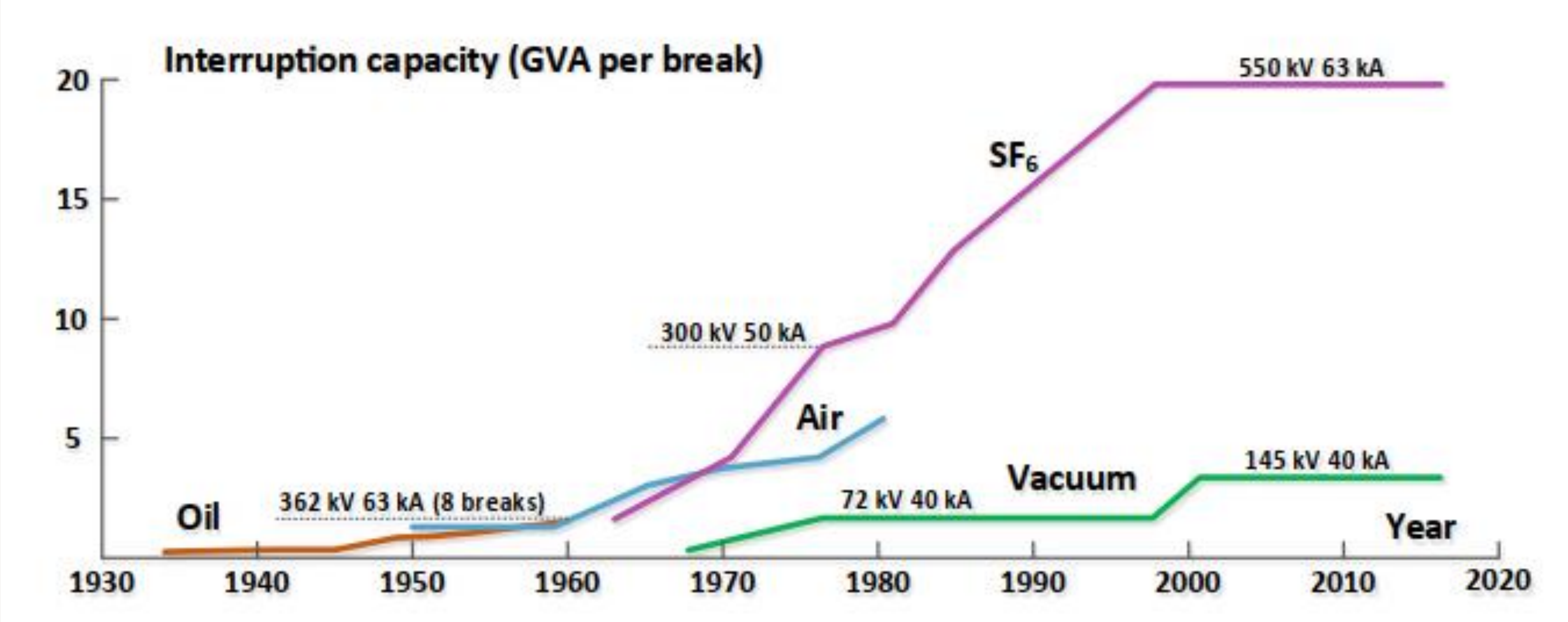
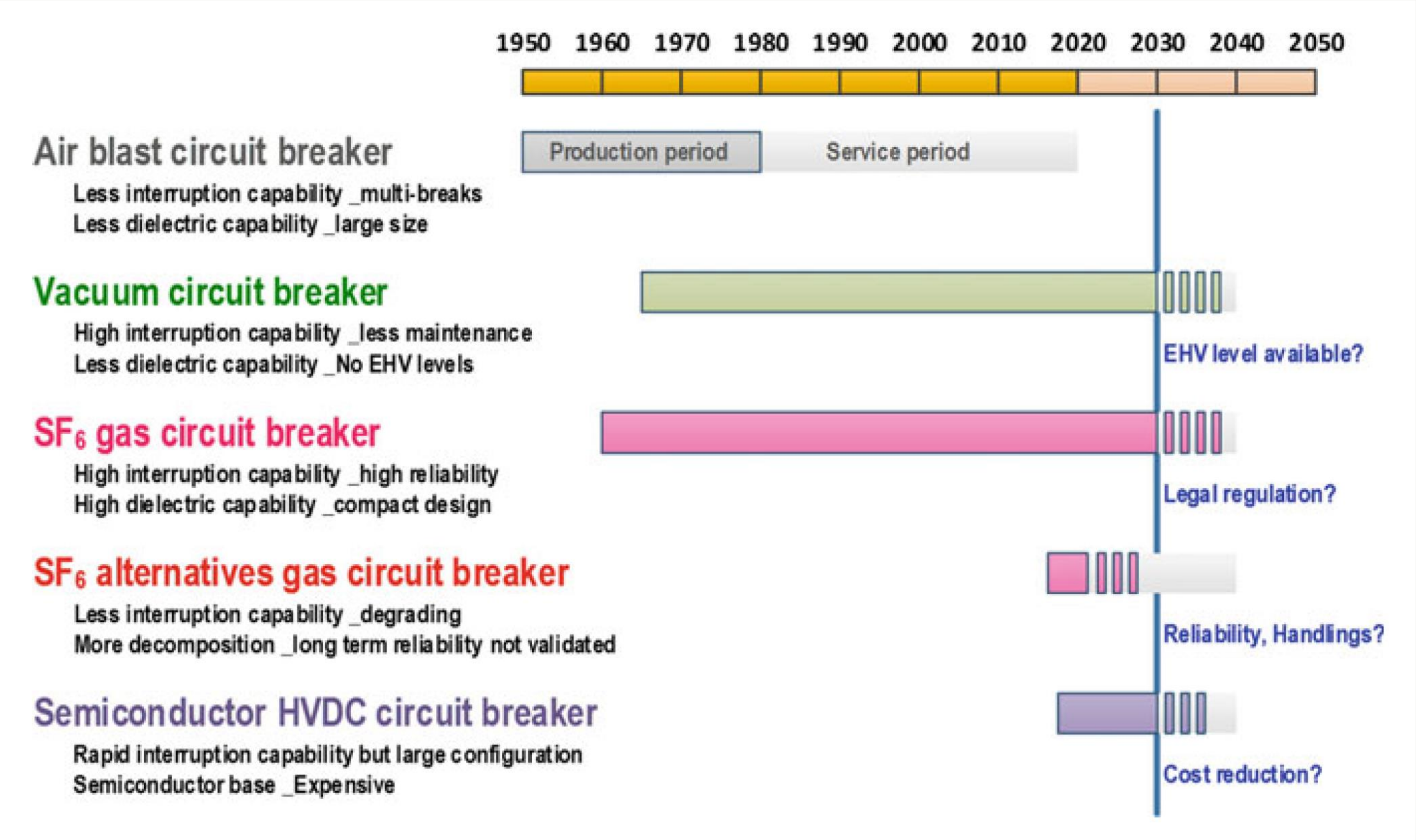
Transmission and Distribution Equipment – Developments in HV Switchgear



Moving forward, circuit breakers will continue to evolve in order to be able to meet the future requirements of the power grid

Transmission and Distribution Equipment – Developments in HV Switchgear



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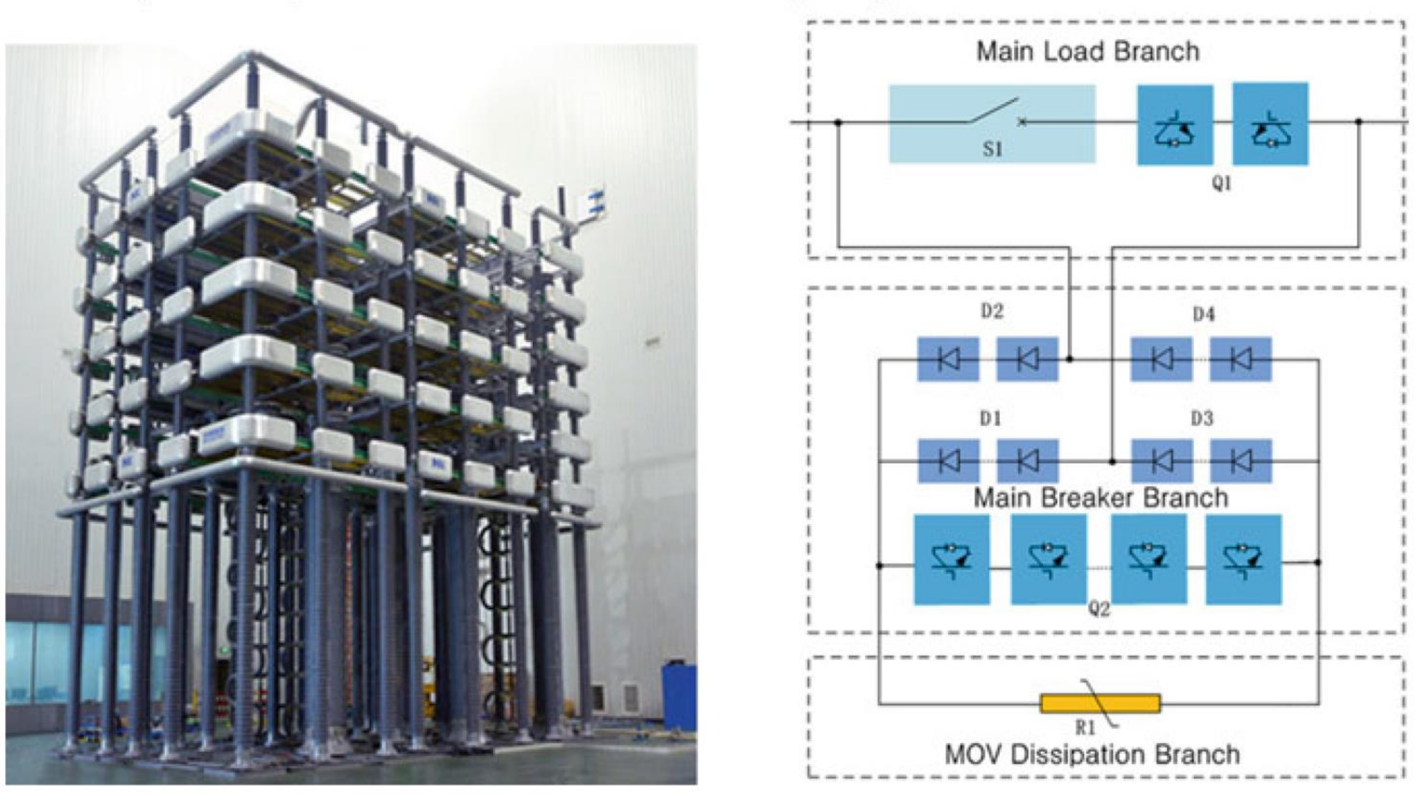
Developments in HV Switchgear – HVDC circuit breakers

- With the need of connecting huge amounts of medium sized generators (commonly offshore windfarms) spread across a large surface, meshed HVDC grids or multi-terminal HVDC systems are being realized in small scale and conceived in a large scale, aimed to harvest hundreds of gigawatts in a few decades from now.
- A key requirement of such meshed HVDC grids is the possibility to de-energize faulted branches of the grid, without endangering the integrity of the system as a whole.



500 kV DC circuit breaker (Hybrid mechanical and power electronic switch)—Courtesy of NR Electric, State Grid Corporation of China

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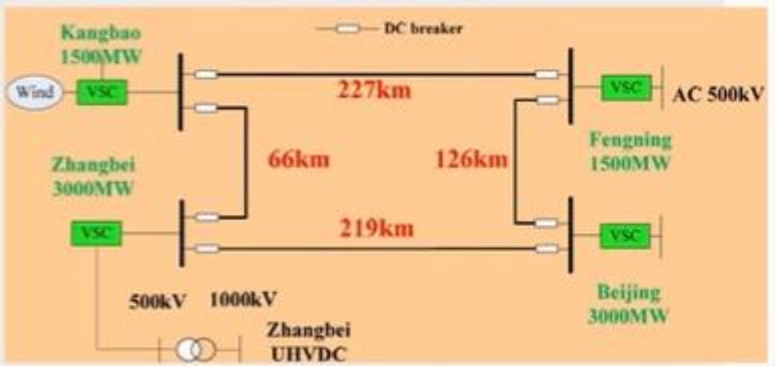
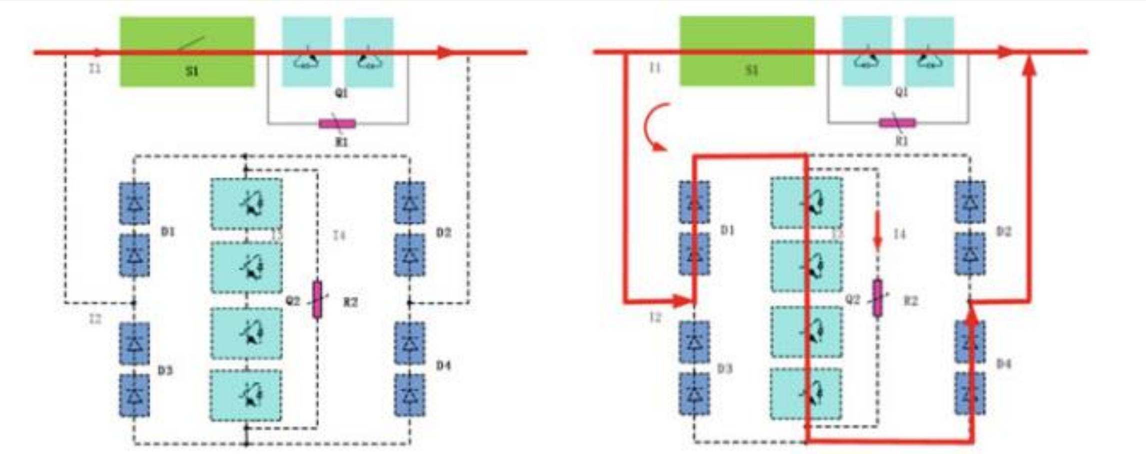
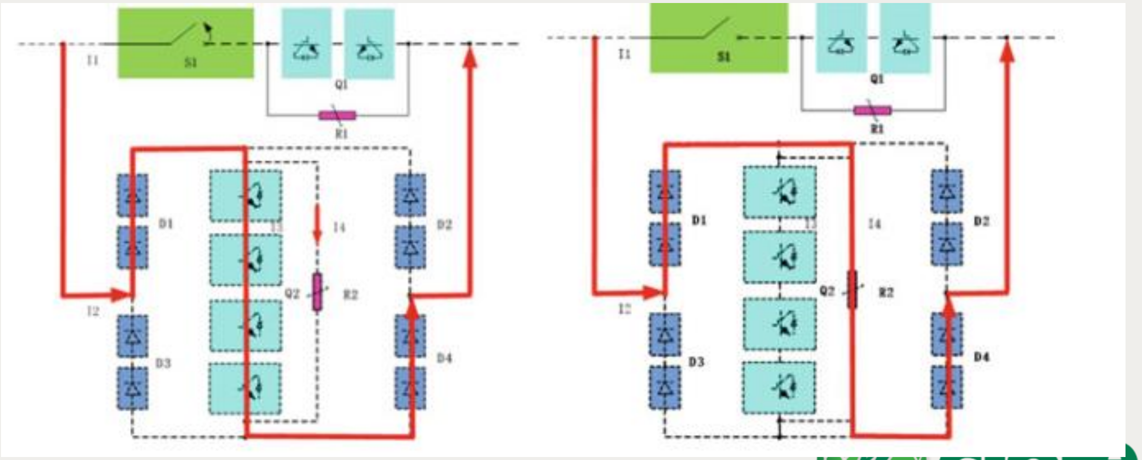
Developments in HV Switchgear – HVDC circuit breakers

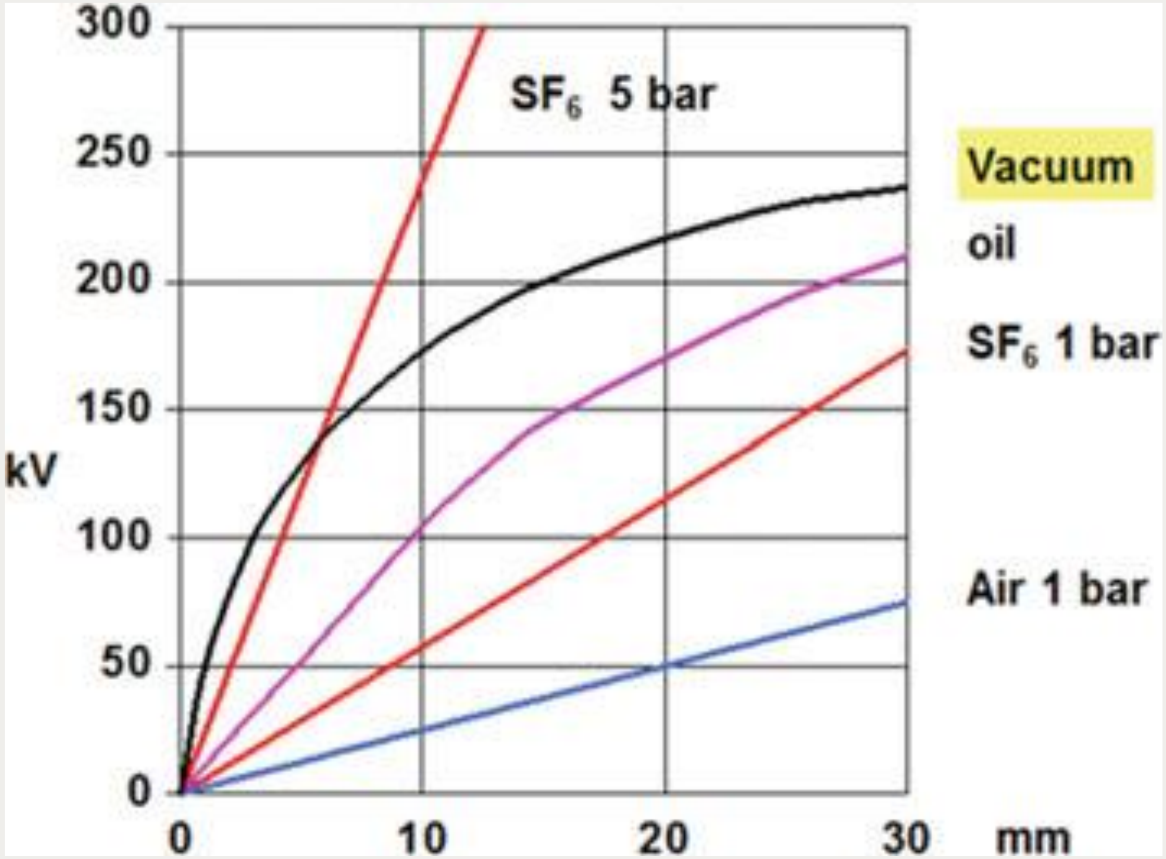
- CIGRE Technical Brochure 683 “Technical requirements and specifications of state-of-the-art HVDC Switching Equipment” was issued.
- HVDC circuit breakers are in service in several projects in China - ±160 kV four terminal Nan’ao project (2013) operated by China Southern Power Grid, ±200 kV Zhoushan five terminal island link (2014), from State Grid Company of China, ±500 kV Zhangbei meshed HVDC grid, also a project in China, will initially include 16 HVDC breakers of five different designs







Developments in HV Switchgear – Vacuum Circuit breakers



Dielectric performance in vacuum

Developments in HV Switchgear – Vacuum Circuit breakers

- Vacuum breakers will **dominate the distribution systems** and in the coming years will be more compact and may have a separate electromagnetic drive for each phase.
- A 145 kV vacuum breaker is already available and the next steps will be a 245 kV double break and a 550 kV with 4 vacuum interrupters immersed in oil.

Installation of Vacuum circuit breaker in 110 kV substation (courtesy of Siemens)

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Developments in HV Switchgear – Vacuum Circuit breakers at Transmission Level

- Excellent service experience of vacuum circuit breakers in MV power systems obviously resulted in exploration of possibilities to **develop vacuum switchgears for transmission voltage levels**. CIGRE investigated the service experience of HV vacuum circuit breakers and summarized the state-of-the art regarding the impact of the application of vacuum switchgear at voltages above 52 kV.

- **Companies in Europe are now bringing HV vacuum circuit breakers on the market** and have started pilot projects to gain experience in the field. In the modern generation of HV vacuum circuit breakers, SF6 is tended to be avoided as outside insulation media of the vacuum interrupter, and instead, nitrogen or dry air is preferred.

- **Experimental ('hybrid') designs with SF6 and vacuum interrupters in series** have been reported as well. The idea is to use the very fast recovery of a vacuum interrupter to withstand the initial TRV, whereas an SF6 interrupter with a reduced amount of SF6 should withstand the peak value of the transient recovery voltage.

- Moving forward, it is expected to develop single VCBs for even higher voltage level classes. A mock-up of a 245 kV/63 kA VI has been already shown at CIGRE 2018 exhibition.

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Developments in HV Switchgear – Interrupting Performance of SF6 Alternative Gases and Gas Mixtures

- With the C5-PFK mixtures for HV pilot installations have been in operation successfully since 2015 in Switzerland and Germany, pilot installations with the CO2/C4-PFN mixture are planned in several European countries, such as a 145 kV indoor GIS in Switzerland, 245 kV outdoor current transformers in Germany and outdoor 420 GIL in the UK. As the latest SF6 alternative, research and test results were published on a breaker filled with a CO2/O2 mixture.

	Operating pressure (MPa)	Dielectric strength/pu	SLF performance compared to SF6/pu[a]	Dielectric recovery speed/pu
SF_s	0.6	1	1	1
CO_2	0.8 … 1	0.5 … 0.7	0.5 … 0.83	>0.5
CO_2+C5-PFK/O^2	0.7 … 0.8	Close to SF_6	0.8 … 0.87	Close to SF_6
CO_2/C4-PFN	0.67 … 0.82	Close to SF_6	0.83…(1)[b]	Close to SF_6

[a] At same pressure build up
[b] Same performance as SF_6 is stated but it is not clear if this was under same conditions

Developments in HV Switchgear – Offshore Switchgear Applications

- As offshore wind turbines continue to grow in size and power output, wind farm developers and operators are preparing to switch over to 66 kilovolt (kV) technology rather than the current 33 kV technology. The wind turbines being developed will be 12 MW reaching heights of 250 m.

- HV switchgear installed in these turbines will need to be **compact and to have minimized maintenance costs.** Circuit breakers will have to be able to **switch higher capacitive currents in a very long AC cables**. Also, it is possible that current zero will be missing due to large reactive compensation onshore.

Compact 66 kV switchgear for offshore applications - courtasy of GE

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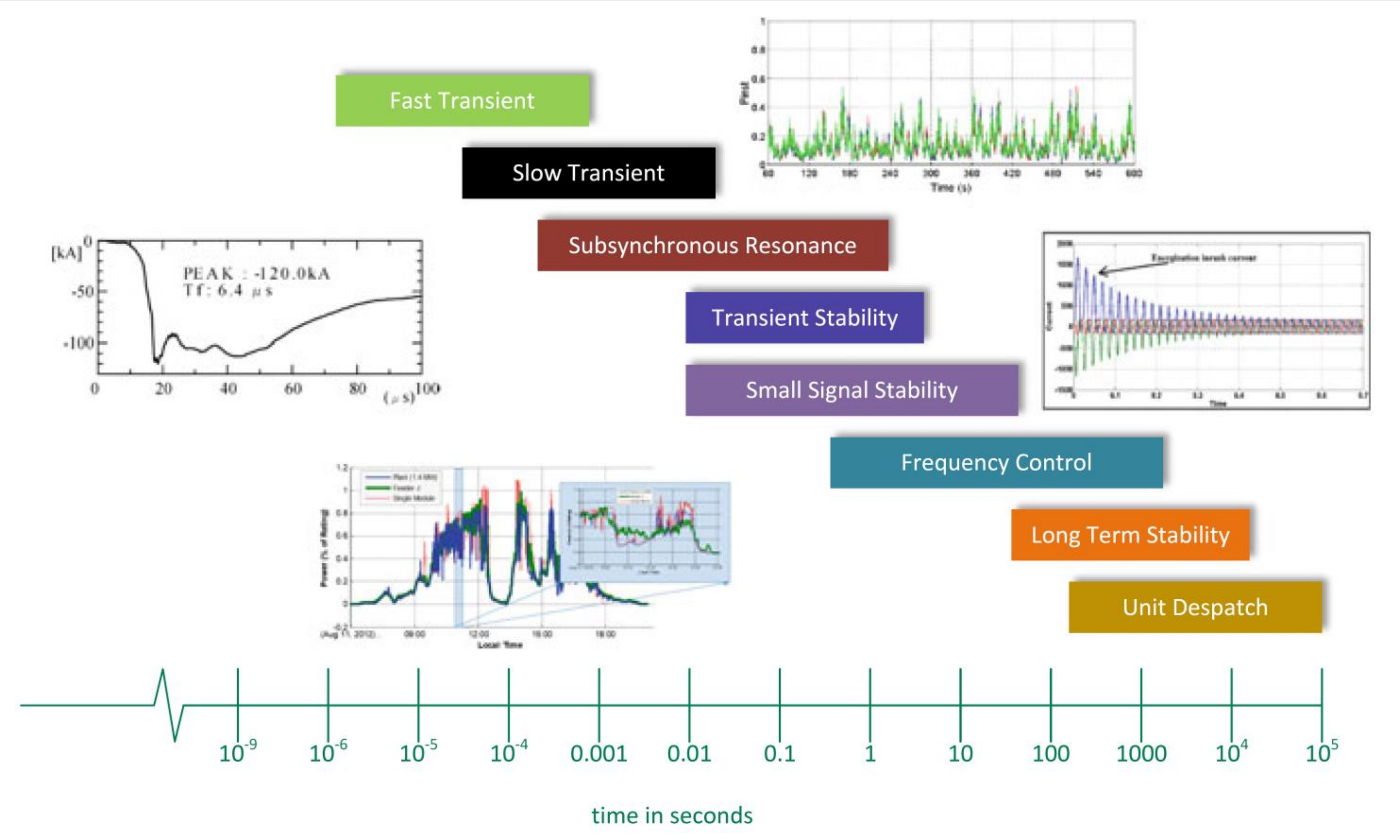
Power System Technical Performance



- Power system technical performance issues involve the **development and review of methods and tools for analysis** with specific reference to **dynamic and transient conditions** and to the interaction between the power system and its apparatus/subsystems, between the power system and external causes of stress and between the power system and other installations.

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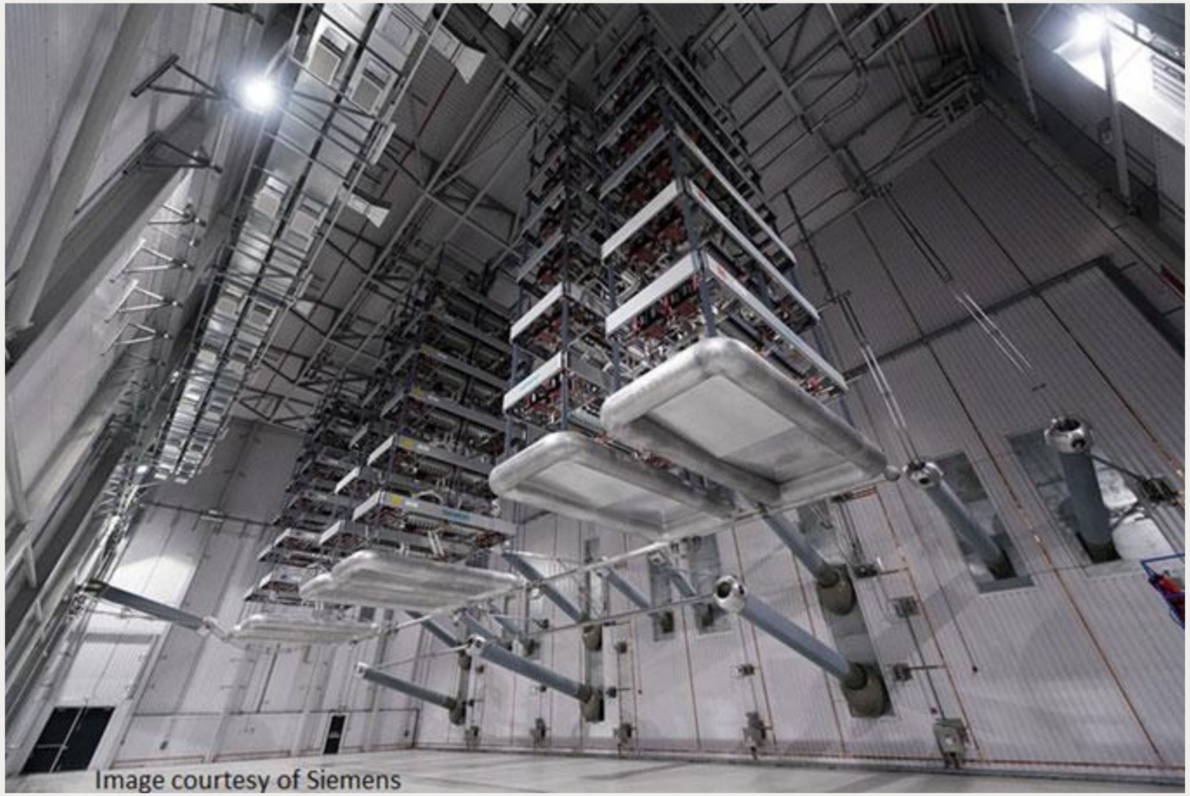
Power System Technical Performance - Potential Future Impacts

- A major source of **high-frequency disturbances** in the future grid will be converters consisting of circuits that use power semiconductor devices

- Additional developments include the trend to **switch converters at higher frequencies** to reduce the size of the filter components and to switch the power semiconductor devices faster (shorter turn-on and turn-off times) to reduce the power semiconductor device switching losses. Both **raise the frequencies of the conducted voltage disturbances and the radiated electromagnetic disturbances**.



Converter hall

Power System Technical Performance - EMC/EMI and Their Importance in Electricity Supply Systems of the Future

- Research is required into the immunity of equipment to high-frequency radiated electromagnetic fields **up to 86 GHz**, the immunity of equipment to medium-frequency conducted voltage disturbances (from 2 to 150 kHz), the **immunity testing using voltage waveforms actually found in practice rather than immunity testing at single frequencies**

- Next-generation converters would include **resonance-responsive converters** (converters that change their switching frequencies to avoid exciting grid resonances), **PLC-responsive converters** (converters that change their switching frequencies to avoid interference with PLC), **co-ordinated operation** of multiple converters to reduce emissions and converter switching strategies

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Power System Technical Performance - Power Quality

- PQ is of increasing interest and importance due to several factors:

- Growing use of **power electronics** and digital control systems in power systems and customer equipment and installations leading to **increased PQ immunity requirements**

- Increase in **voltage distortion** due to the use of power electronic systems associated with renewable energy, especially when connected at remote locations where the system strength is already low

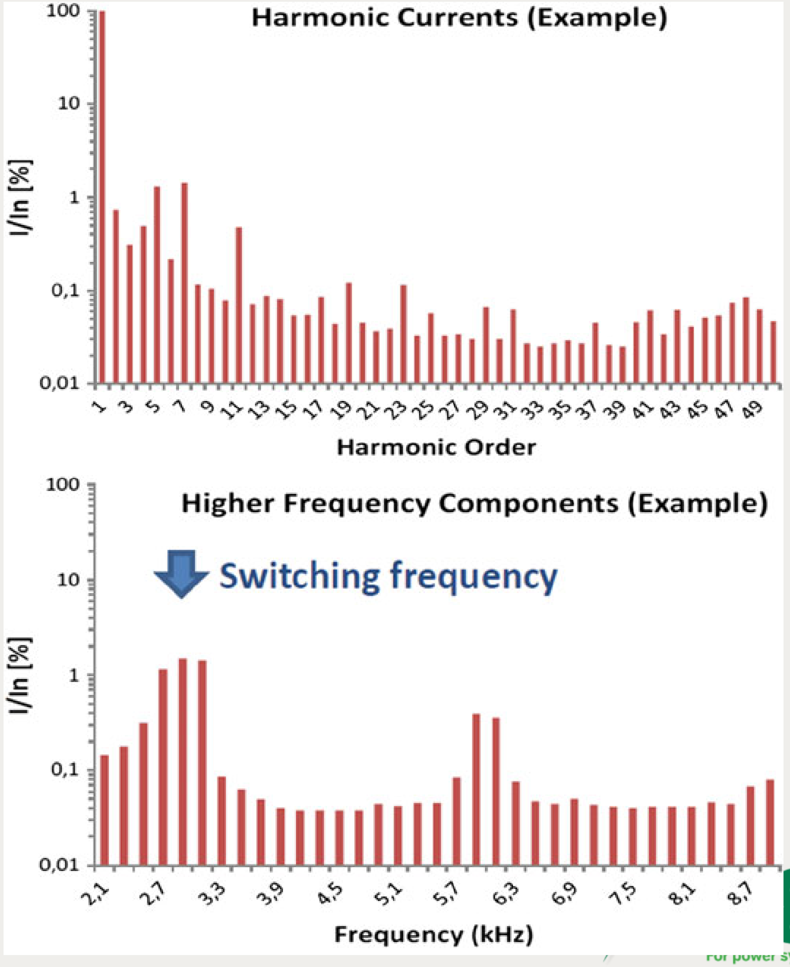
- Modification of existing harmonics due to **frequency shift of resonances** with the increased use of power factor correction **capacitors and underground cables**. Harmonic resonance issues within wind and solar farms can become problematic as the collector systems of such farms are based on underground cables

Power System Technical Performance - Power Quality – potential future impacts

- In electricity supply systems of the future with increased penetration levels of power electronic converters, it is vital to pay attention to ensure that the **connected equipment continues to operate without being disturbed and does not experience accelerated ageing**.

- Large-scale power electronic systems associated with wind and solar farms may be of the voltage source converter (VSC) type and their high-power semiconductor devices are switched at around 3 kHz

Example harmonic currents and switching frequency



Power System Technical Performance - Power Quality – potential future impacts

- Generators with power electronic grid interfaces that inject active and reactive power into the grid usually behave as positive-sequence sources. Considering the remote locations of such generators connected to long un-transposed transmission lines, negative-sequence voltages at remote ends can develop due to line asymmetry, thus requiring voltage unbalance mitigation at strategic locations such as using dedicated STATCOMs.

- Voltage fluctuations which arise as a result of the intermittency or variations of wind and solar generating systems can be expected and these can be managed using dynamic reactive power sources (e.g. STATCOMs).

- Threat to system strength due to the replacement of conventional synchronous generators. This reduction in system strength can impact on a range of power system operational issues including PQ.

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Power System Technical Performance – Power Quality - Future Analysis Requirements

- **Proactive PQ management** is based on three main activities:

a. Understanding the requirements of relevant standards and embedding appropriate practices into power system planning, operation and maintenance
b. Long-term PQ monitoring to understand system PQ performance at an appropriate range of sites at all voltage levels
c. Using results from (b) and from analysis of network incidents and individual customer complaints to improve PQ management practices.

- **PQ standards need development to allow them to deal with future grid evolution**

- PQ monitoring will need to be further developed, development of new sensors such as high-frequency voltage transducers to give useful measurements of supraharmonics

- **Electromagnetic transient (EMT) models need development which can represent the harmonic emission and network resonance behaviour of power electronic based generating systems. System assessment studies involving harmonic instability and resonance studies will need to be facilitated using such high-fidelity models where root mean square (RMS) models are insufficient.**

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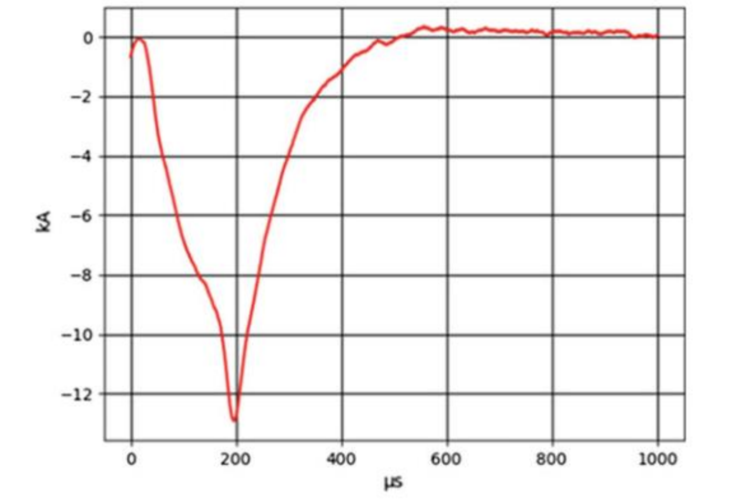
Power System Technical Performance – Lightning protection

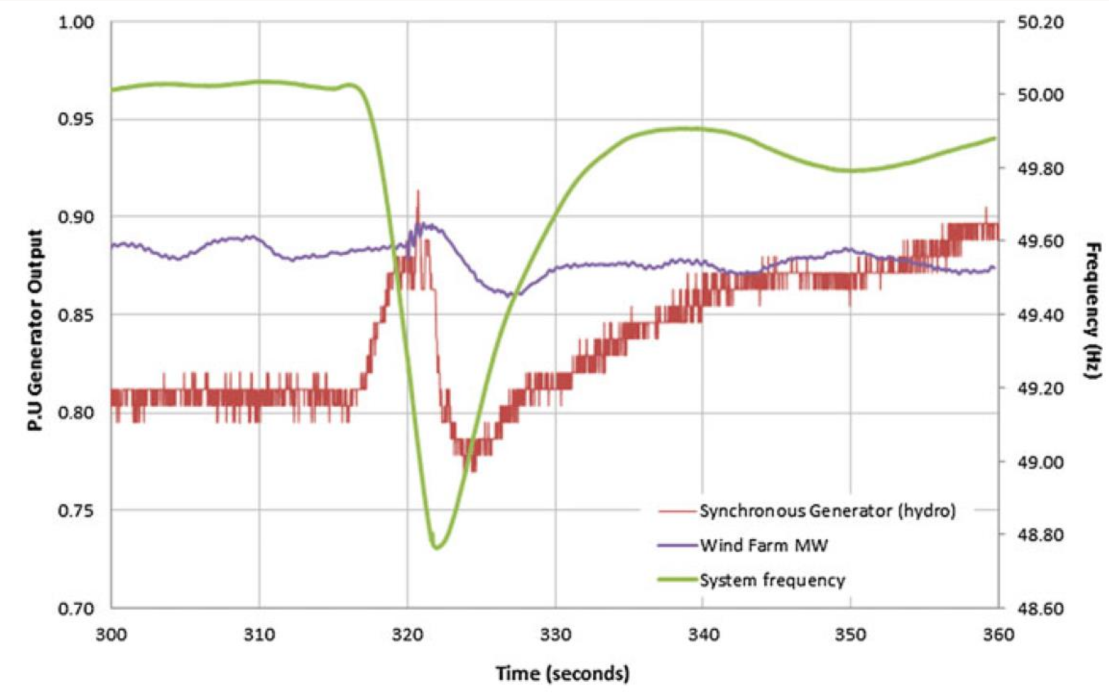
- Lightning is one of the **key factors threatening the safe and reliable operation** of power systems
- **Improvement of existing models for numerical simulations**, obtaining parameters and model validation. Analysis of future power systems will see an increased application of EMT simulation, and the development of **new EMT models will be required in order to accurately capture the abovementioned aspects**.
- The **effective application of line arresters** has been demonstrated in distribution and transmission systems.
- Improvement of LLS operating principles, exploitation of data provided by LLSs for improved lightning protection



Power System Technical Performance – Power system dynamics

- Power system dynamics investigations have traditionally revolved around preventing **‘angle instability’ or ‘voltage instability’** and in some cases also frequency instability. It can be reasonably expected that future power systems will exhibit **more frequent, faster and less damped dynamic phenomena** than has previously been experienced.

- As a practical example, consider Figure which shows the measured frequency disturbance following the fast runback and trip of a large generating unit. The active power response of a medium-sized hydro-generating unit and wind farm is overlaid for comparison. While the **wind farm output remains relatively constant during the frequency disturbance, the inertial and governor response of the hydro-unit can be clearly identified, helping support the control of network frequency**.



Measured response of hydro generation and wind to fast-moving frequency disturbance

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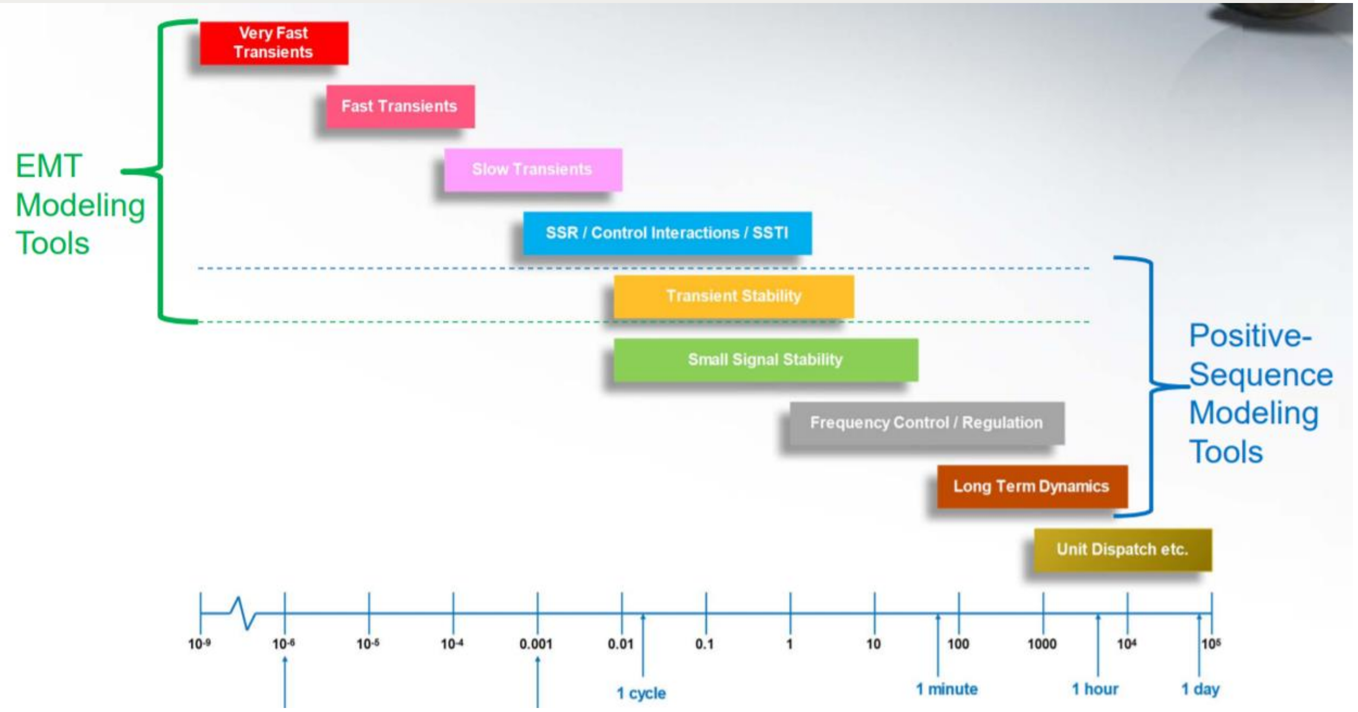
Power System Technical Performance – Power system dynamics - Future Analysis Requirements

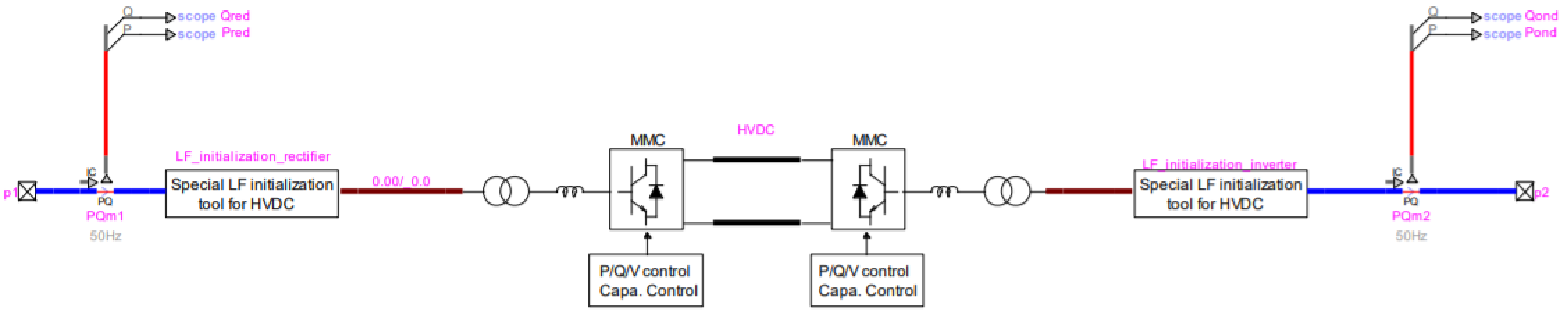
- In general, there is an increasing need for **three-phase EMT simulations** to accurately predict the dynamic behavior of fast-acting power electronic. Computing power has improved dramatically, but EMT simulations are still relatively slow compared with traditional positive-sequence-based transient stability tools **unless large areas of the network are reduced and replaced by an equivalent representation**.

- There is a potential **loss of accuracy** if network reduction is not undertaken appropriately.

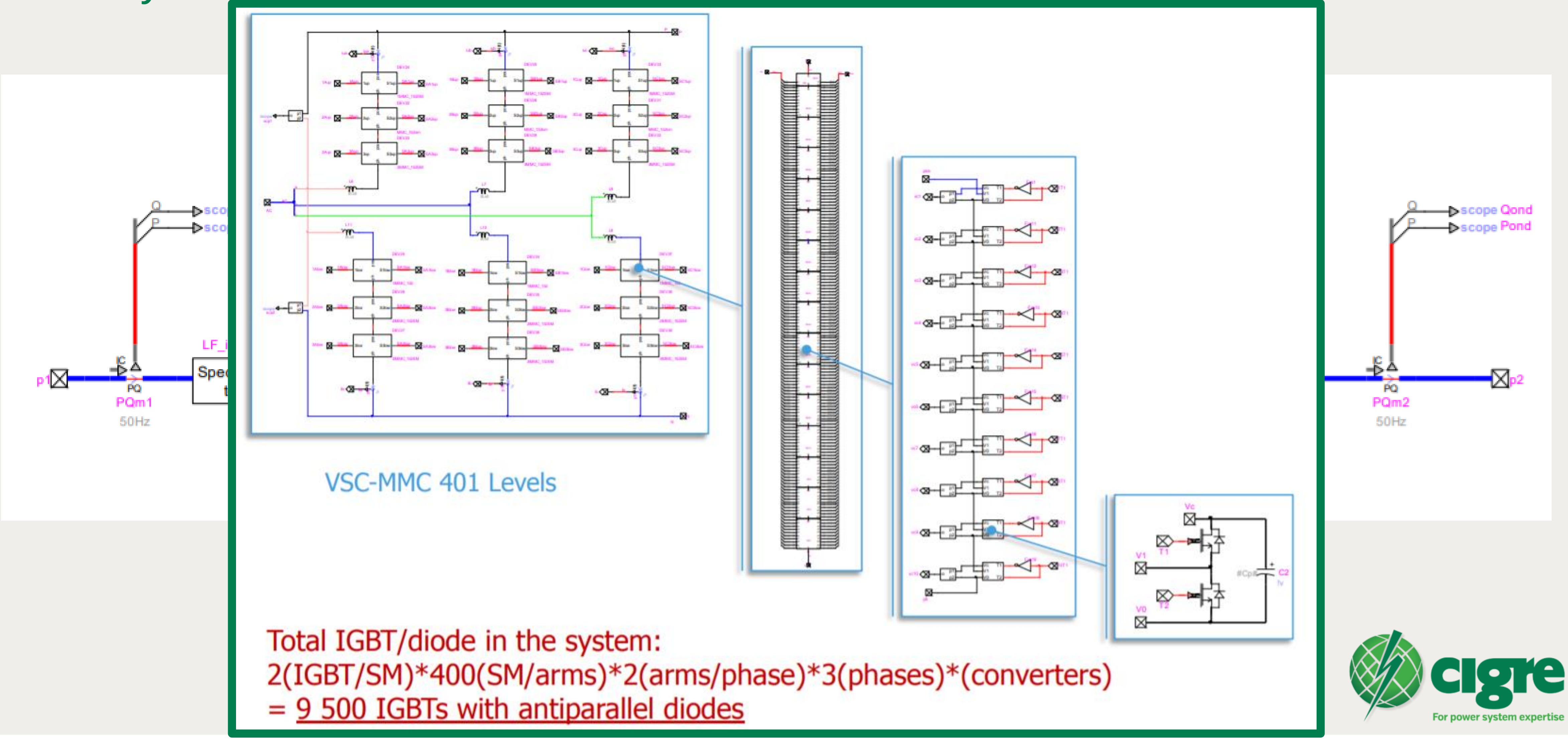
- The use of **hybrid simulations** which enable **EMT and positive-sequence models to be interfaced and run together in parallel** is another already available tool.



Power System Technical Performance – Power system dynamics - Analysis example – France – Spain DC link



Power System Technical Performance – Power system dynamics - Analysis example – France – Spain DC link



Power System Technical Performance – Power system dynamics - Future Analysis Requirements

- With more converter-interfaced generation in the system, together with a lack of experience about the system's actual dynamic behaviour, it may be impossible to know what simulation model parameters give the correct results.

- It follows that **specialised grid tests may be needed in future for model and parameter verification**.

- Where tests are not practical to implement, there is likely to be an increased reliance on model verification using high-speed measurement data coming from phasor measurement units (PMU) and other such transient recording equipment.

- To address these challenges, it is important to recognise the need to develop new skill sets in conjunction with the required analysis tools. The operation of power systems is becoming **increasingly complex** and will require the ongoing upskilling of current practitioners as well as the development of appropriate training courses for the **next generation of engineers**.

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