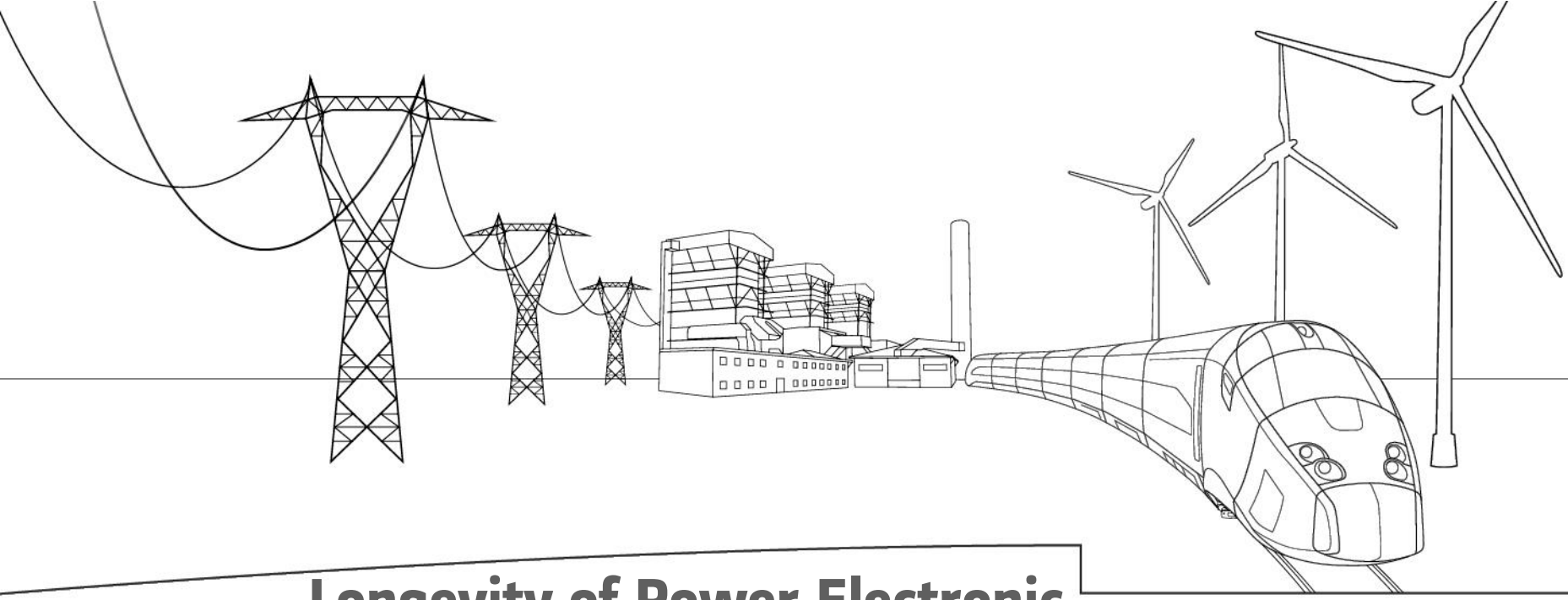

Longevity of Power Electronic Solutions in the Macro Grid

historical perspective of AC (FACTS) and DC (HVDC) installations

Reginald Mendis and Neil Kirby

ALSTOM Grid, Philadelphia, PA

Univeristy of Pittsburgh - Electric Power Industry Conference - November 11, 2013

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Shaping the future

AGENDA

- **Historical Perspective of Power Electronics Longevity**
- **AC Solutions (FACTS)**
  - Macro Grid Needs
  - Life Extensions
- **DC Soultions (HVDC)**
  - Macro Grid Needs
  - Life Extensions

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Summary

- Power Electronics Solutions used since the 1970s
- Refurbishments of 20-40 year systems
- Original need still relevant to today's expanding grid
- Existing equipment life is extended
- Power quality of the grid is enhanced
- Newer solutions have more "smarts"
- System Operators have become dependent on these solutions
- Life extension via refurbishment /upgrade is a growing business
- Validates original concepts/solutions as integral part of macro grid

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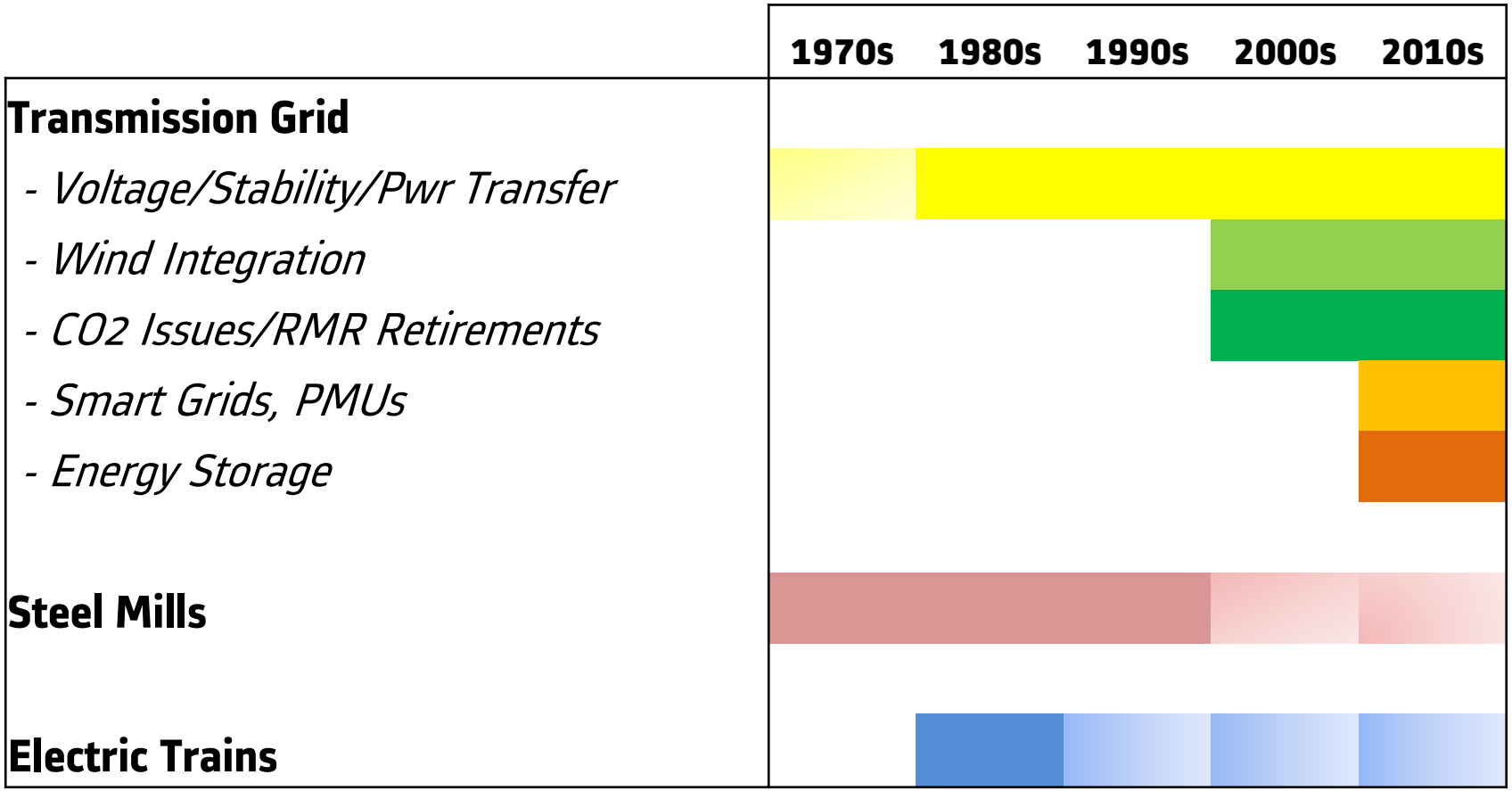
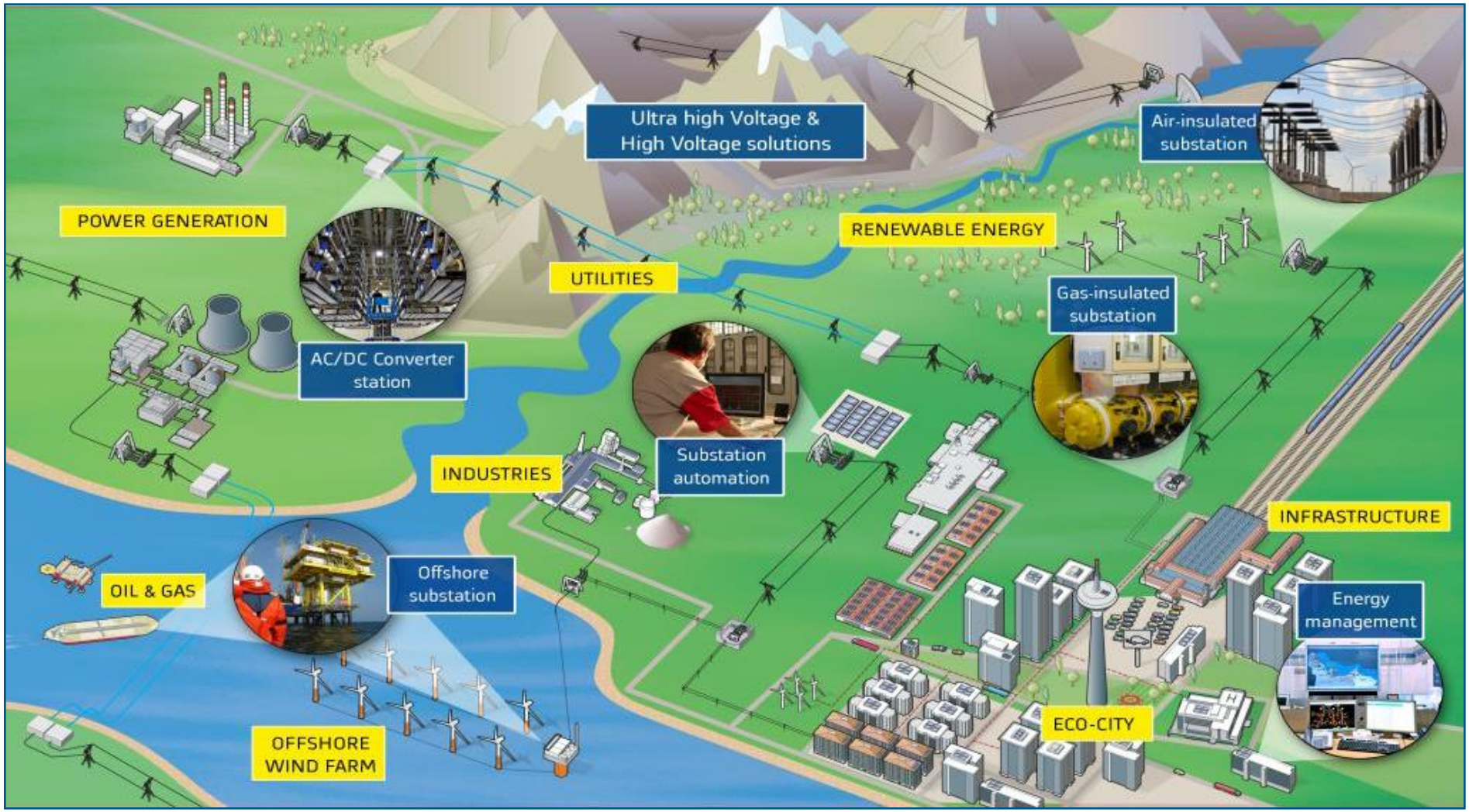
Historical Drivers for FACTS Solutions



Today's Macro Grid – The Energy Landscape



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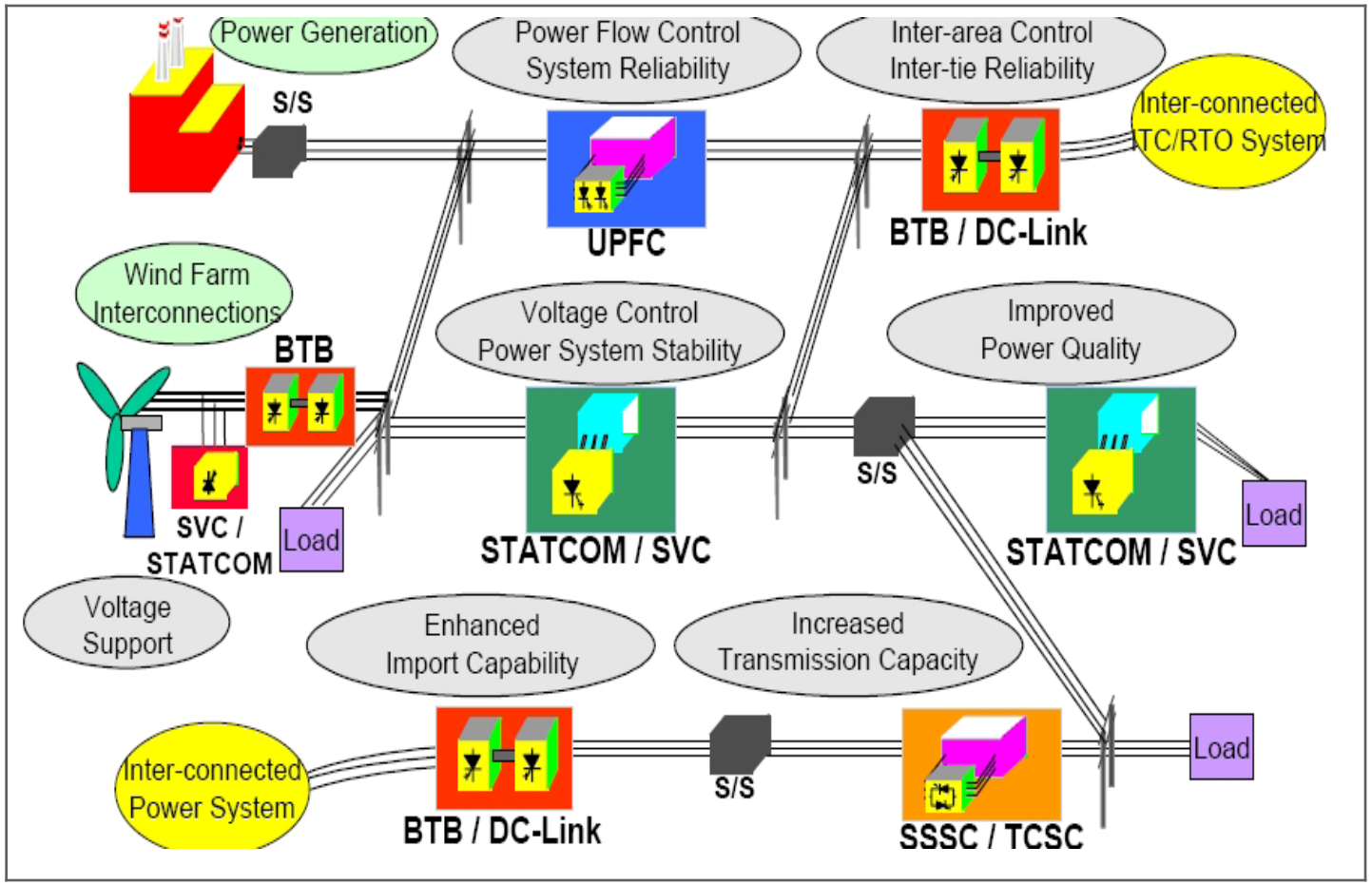
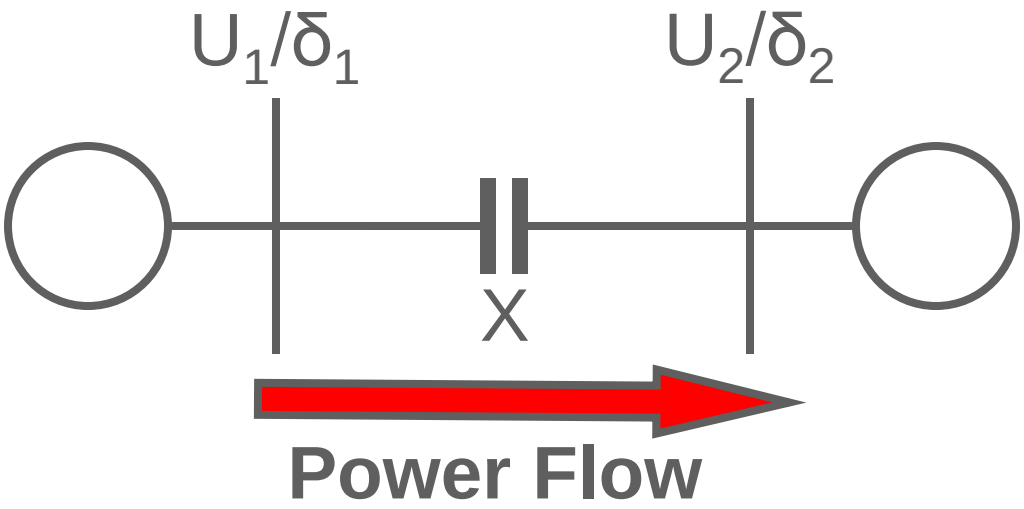
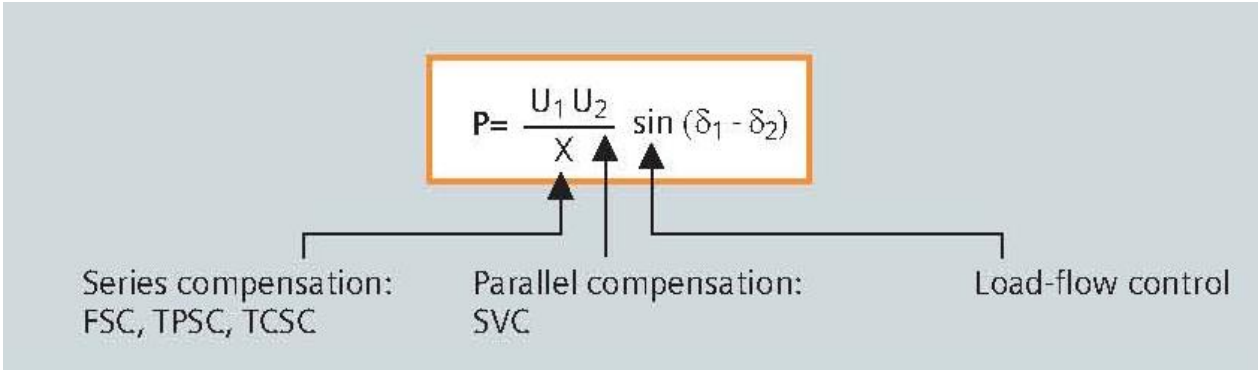
Macro Grid – Application of FACTS & HVDC Solutions



Basic Theory of Power Transfer

$$P = \frac{(U_1 U_2)}{X} \sin(\delta_1 - \delta_2)$$

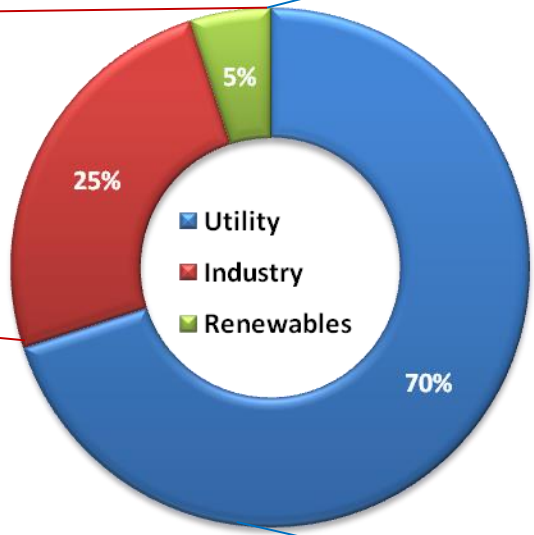




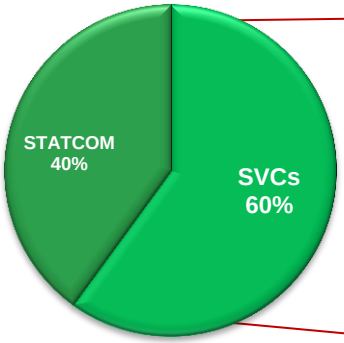
Global FACTS Market Segments

1,000 M€

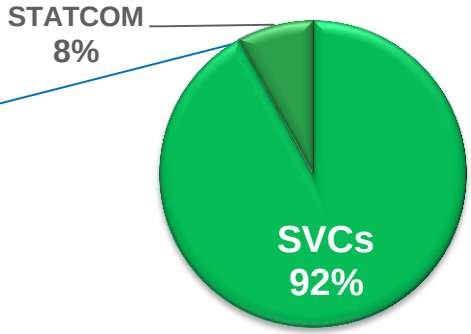
FACTS Market



Renewables

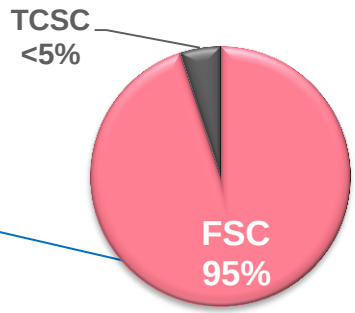


Shunt compensation = 80%



Utilities

Series Compensation = 20%



Electro intensive industries

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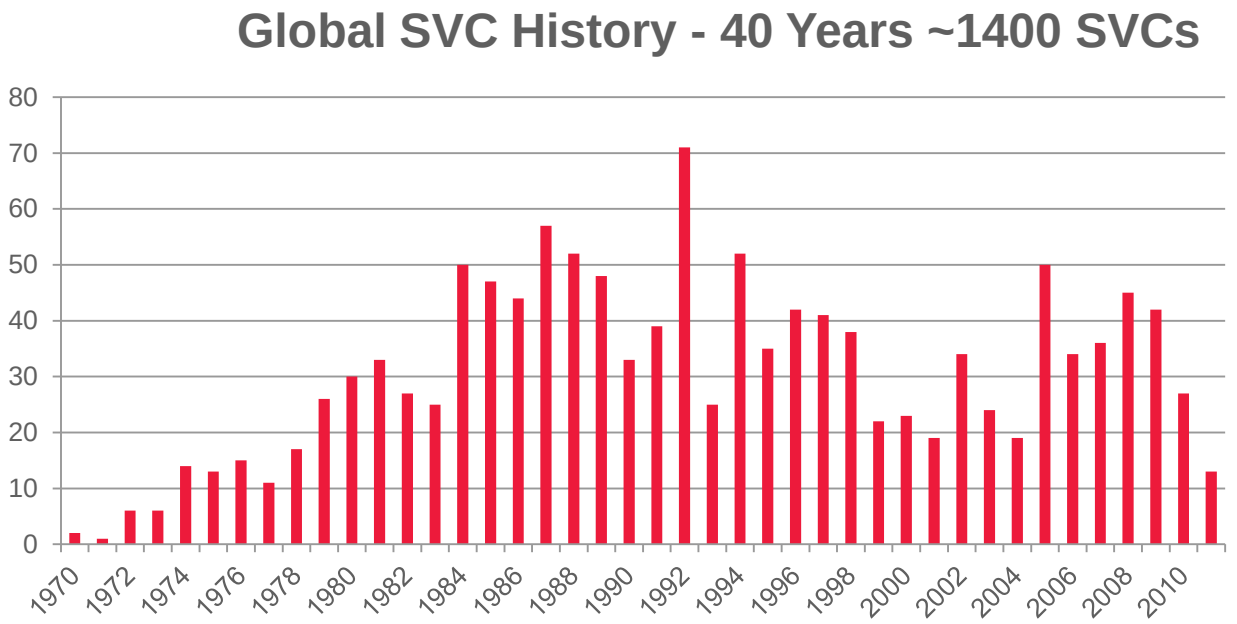
FACTS Global - SVCs installed - 40 yr history of use

Appr 1400 SVCs installed world-wide during a 40 yr period (1973-2012)



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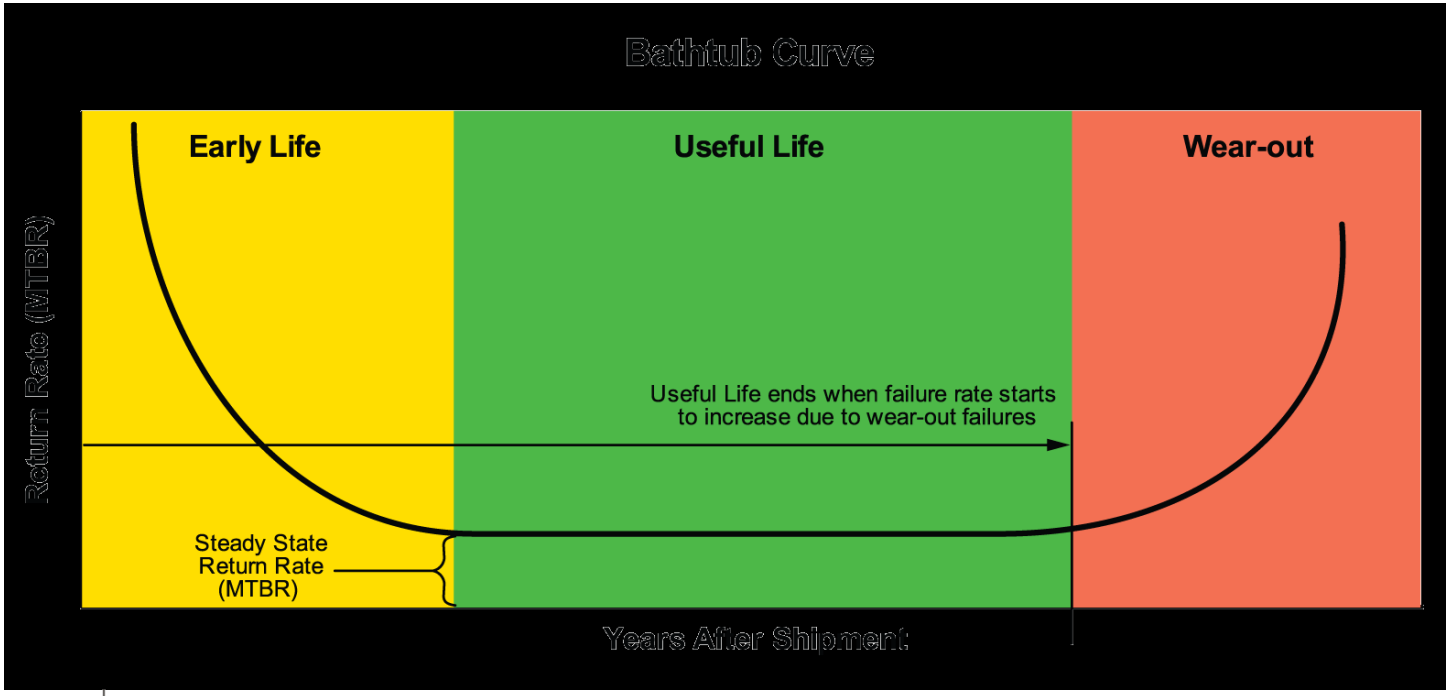
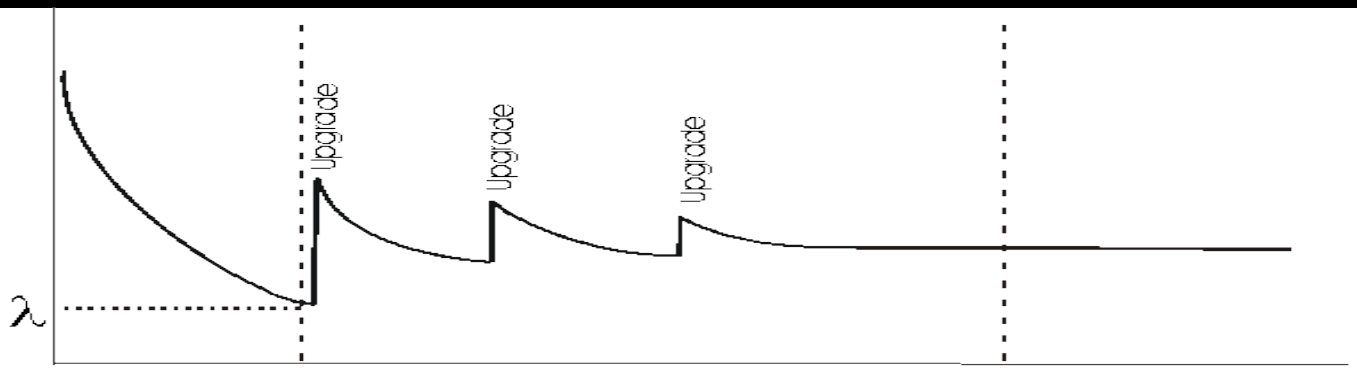
FACTS Life History Curve





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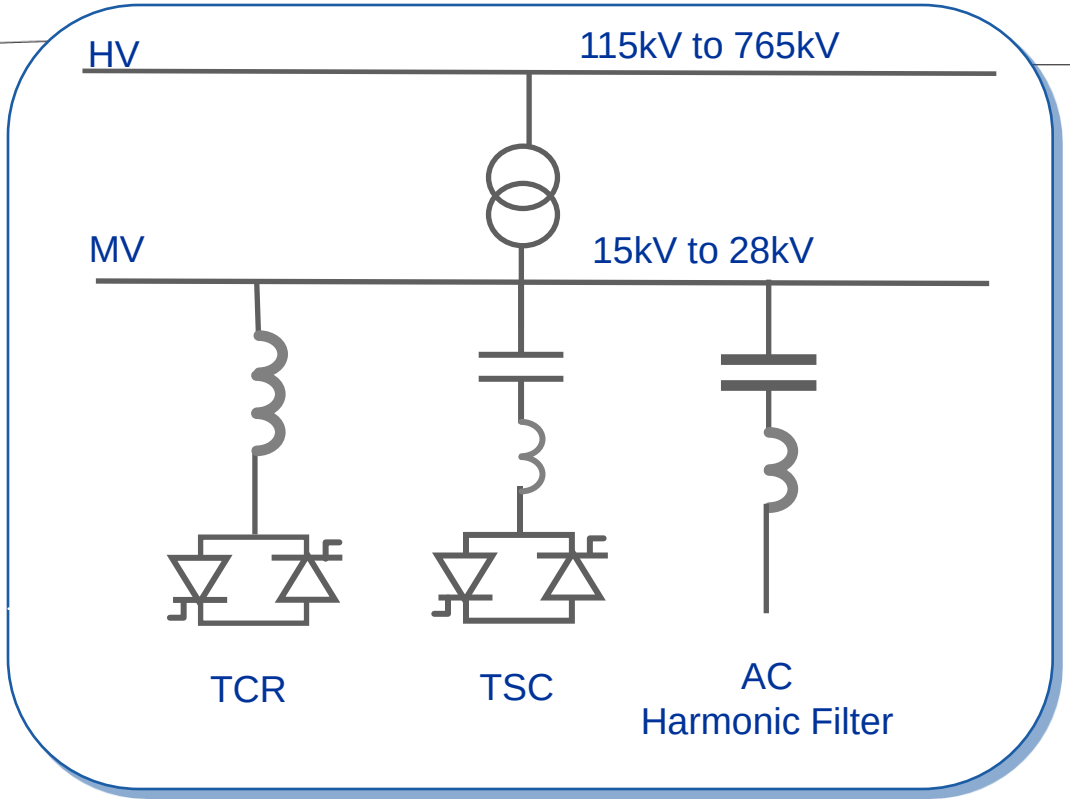
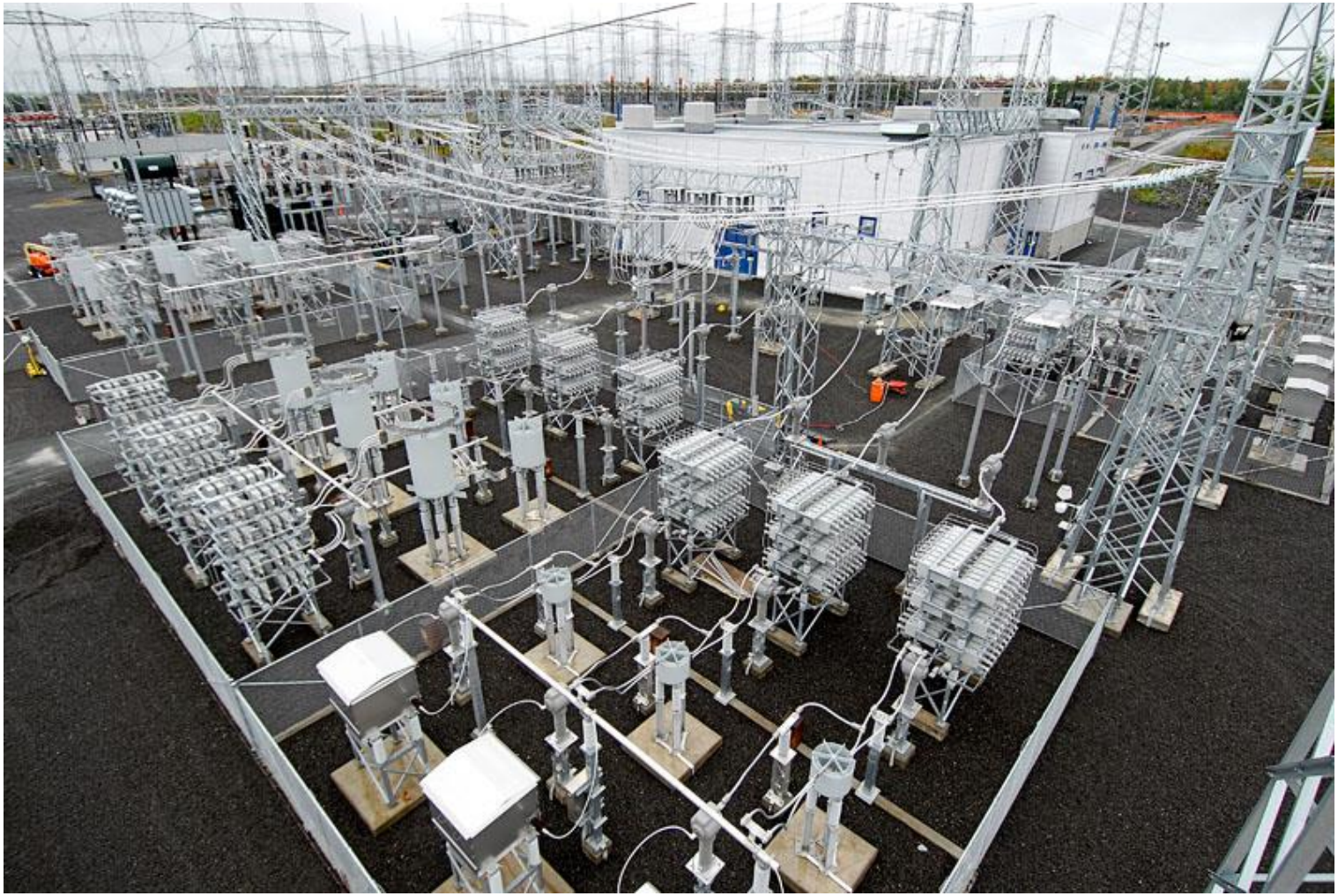
Utility SVC Single Line - Example



Main components

Thyristor Valves | Capacitors | Reactors | Power Transformer | Control

A **FACTS** System is an Electrical Substation with a Building that contains advanced power electronics & controls equipment



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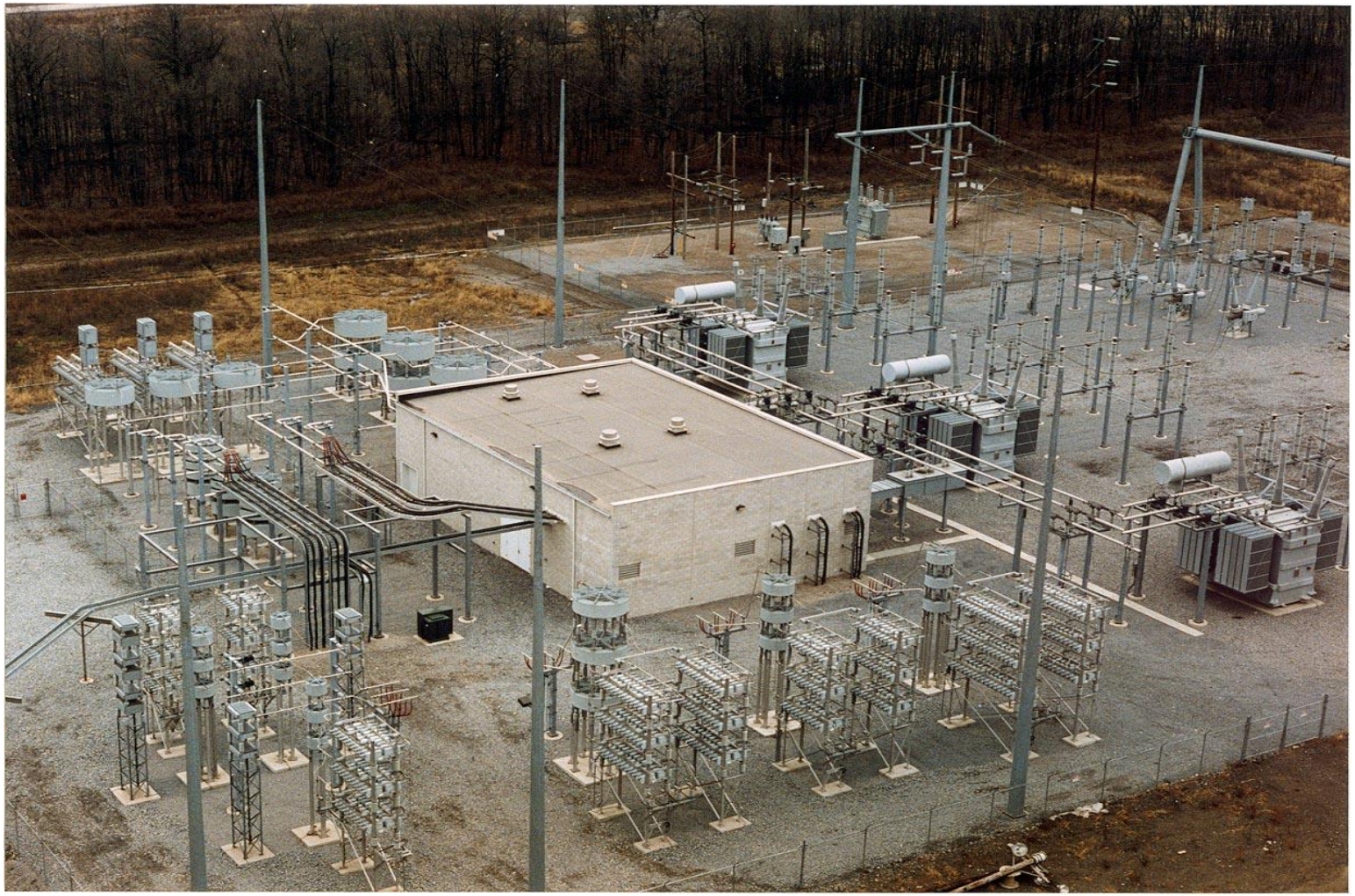
A **FACTS** System is an Electrical Substation with a Building that contains advanced power electronics & controls equipment



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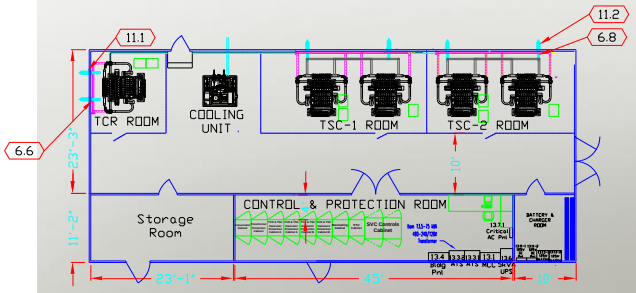
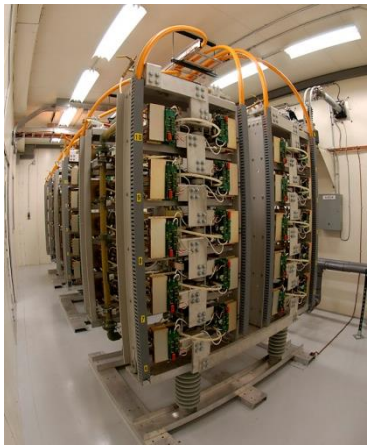
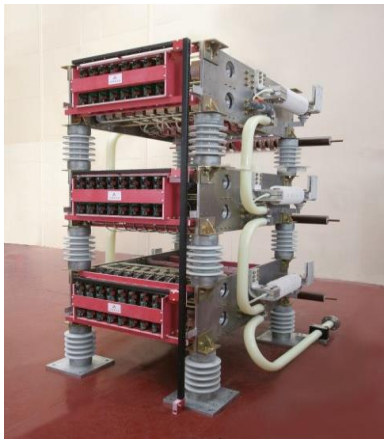
SVC Building (1TCR + 2 TSCs)



SVC Equipment





Thyristor Valves

Cooling Plants

Controls

Buildings

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Design Life of SVC Equipment

SVC Equipment	Yrs
Controls	15-20
Thyristor Valves	25-40
Cooling Systems	15-30
Aux Systems	20-25
Protection	25-30

Other	Yrs
SVC Buildings	50
Civil Works	50
Busbars	50

Substation Equipment	Yrs
Circuit Breakers	30-35
PTs / CTs	30-35
Capacitors	25-30
Reactors	25-30
Surge Arresters	35-40
Disconnect Swiches	35-40
Transformers	40-50

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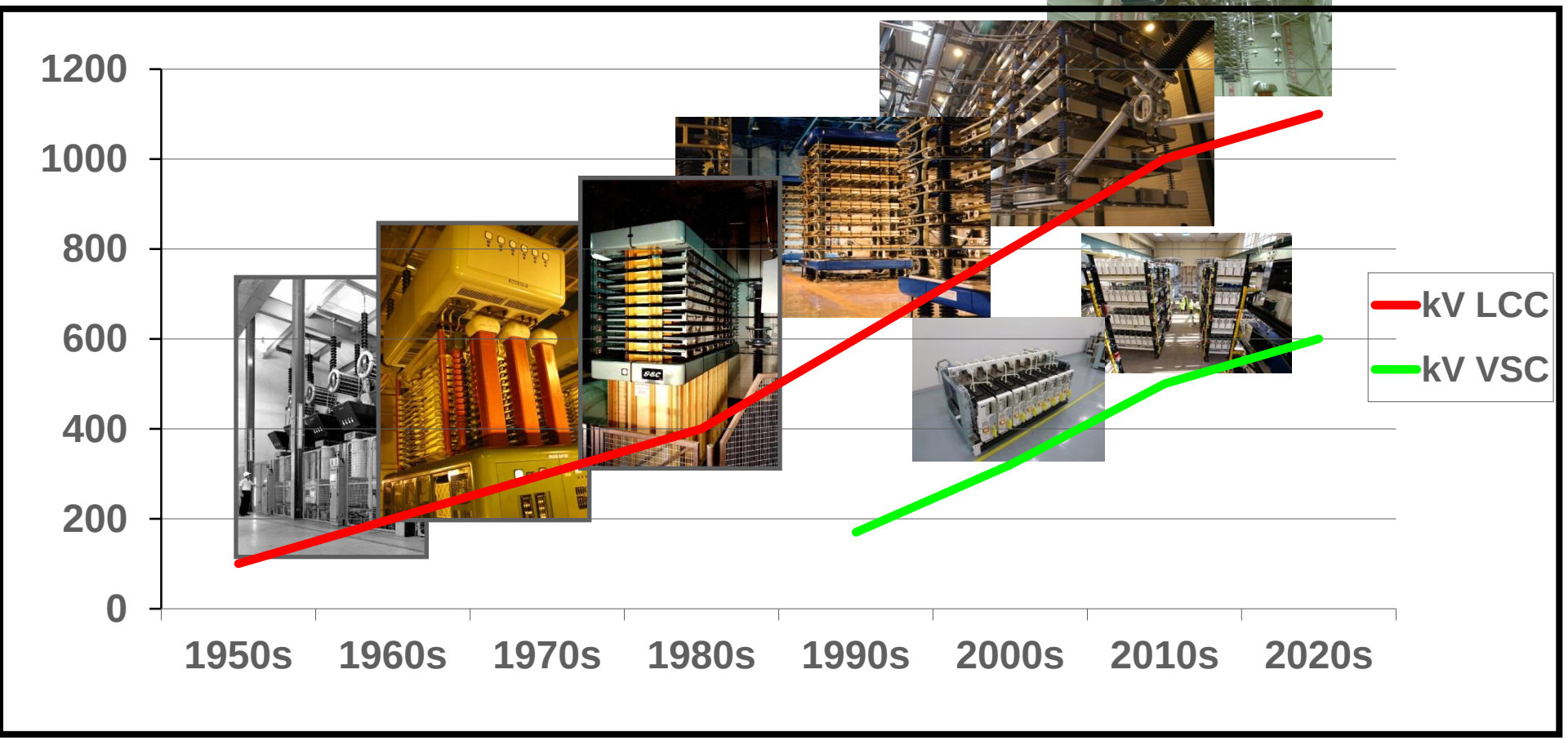
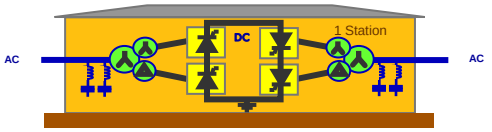
Evolution of HVDC



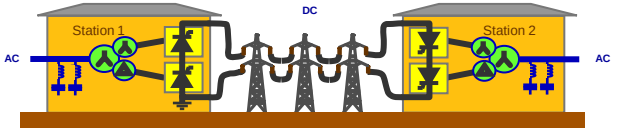
Refurbishment of HVDC Projects

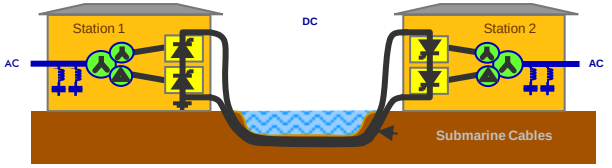
- HVDC transmission systems have been in operation for over 50 years
- Design life typically 30 years
- Many Installations Already Partially Refurbished or Replaced
- Others are in the planning stages for some method of life extension

HVDC Continues to Grow



- Asynchronous Interconnections
- High Utilitization
  - Reliability
  - Base Load
  - Market Variable
  - Merchant





- Have become an indispensable part of many power networks around the world
- Future development of DC Grids

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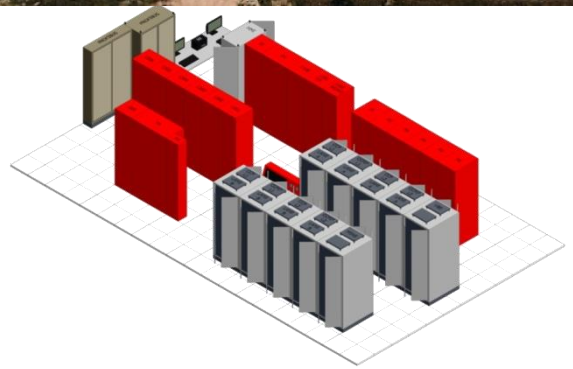
McNeill Back-to-Back

Canada, linking Saskatchewan and Alberta … most northerly link between the WECC and East

Control System Replacement only

- Originally installed in 1989
  - 150MW Back to Back HVDC system
  - Extremely Weak AC systems on both sides
  - Operates Unmanned
  - No redundancy in original control system
- Refurbishment Drivers
  - System Performance was good
  - Control System Obsolescence
  - some specific components no longer available
- Contract
  - Award in 2011
  - Completion 2013
- Scope
  - Control System + HMI



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McNeill HVDC

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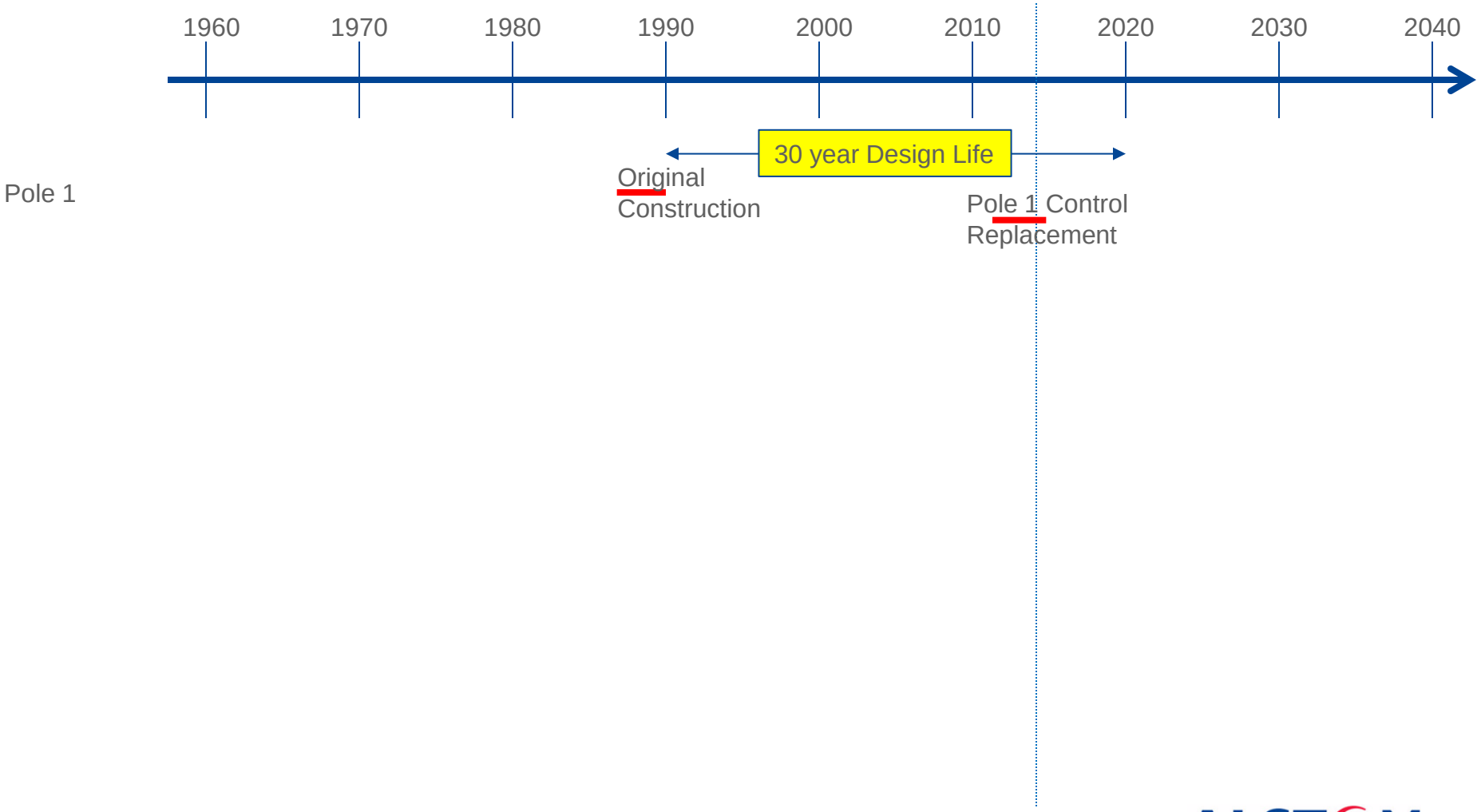

UK-France Cable (IFA2000)

Linking UK and France … Highest Rating Submarine Cable Link

- Originally installed in 1986
  - 2000 MW HVDC cable link between UK and France Air-cooled Thyristor valves
  - World's Highest rating submarine cable link
  - 2 independent 2 x 500 MW / 270 kVdc Bipoles
  - 8 HVDC cables and 4 converters at each terminal
  - Different Suppliers and different owners
    - UK - National Grid
    - France - RTE
- Refurbishment Drivers
  - Separate and inefficient O&M, Spares, Training, etc.
  - Performance at each station different
  - Increasing failure rates on the air cooled thyristor valves, primarily at Les Mandarins
  - Availability of spare components for obsolete analogue electronic control systems at both ends
- Link is critical to both power networks
  - essential power support
  - energy trading to both countries
- Scope :
  - Thyristor Valves, Cooling Plant, Control System
  - Re-use existing buildings and other power eqpt
  - One Bipole (4 converters at 2 terminals) replaced 2011
  - Second Bipole followed a year later (2012)

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UK-France Cable (IFA2000)

Linking UK and France … Highest Rating Submarine Cable Link

Sellindge CS, England
Supplied by GEC (UK)

Les Mandarins CS, France
Supplied by CGEE ALSTOM (France)

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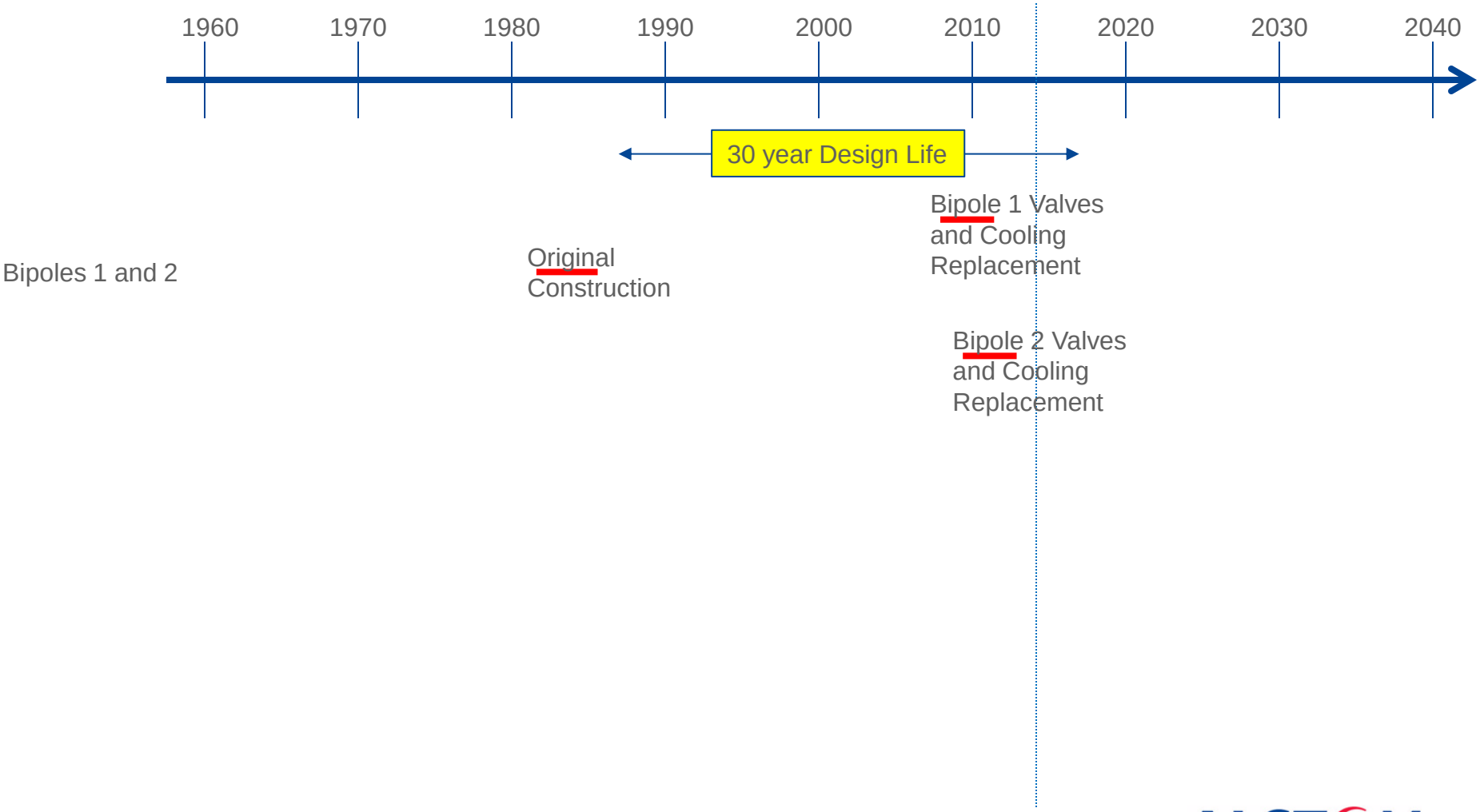
UK-France Cable (IFA2000)

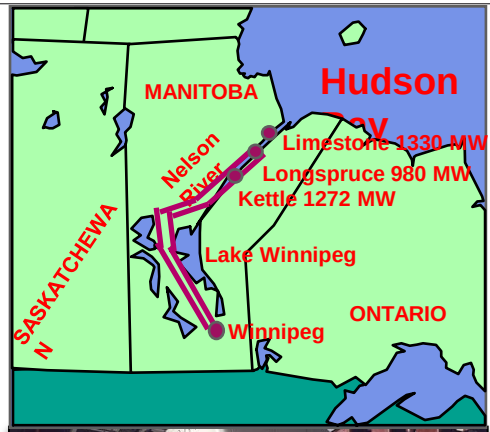
Linking UK and France … Highest Rating Submarine Cable Link



Nelson River Bipole 1

Interconnection between hydro generation in northern Manitoba and Winnipeg

- Originally supplied in 1972
  - Mercury Arc converters Rating 1,620 MW, 450 kV
  - 3 series 6-pulse bridges per pole
  - 890 km HVDC overhead lines
  - Achieved relatively high availability
- Issues with Mercury Arc Valves in Bipole 1
  - labor-intensive maintenance
  - HS&E concerns
  - use of mercury arc technology in decline
- Refurbishment Issues and Strategy:
  - Investment necessary to achieve high availability, and long life
  - major component of the infrastructure in utility network
  - major source of revenue in the economy of the province
  - High-level Pole Control retained
  - New Valve Control and Valve Base Electronics
- Replacement of mercury arc valves started in the early 1990s
  - Converter Equipment in 3 Valve Groups of Pole 1 Replaced
  - One VG at a time, both ends concurrently
  - Entire Valve Halls cleared and new construction from ground up
  - New Cooling Plant
  - Outage duration for each VG about 6 weeks



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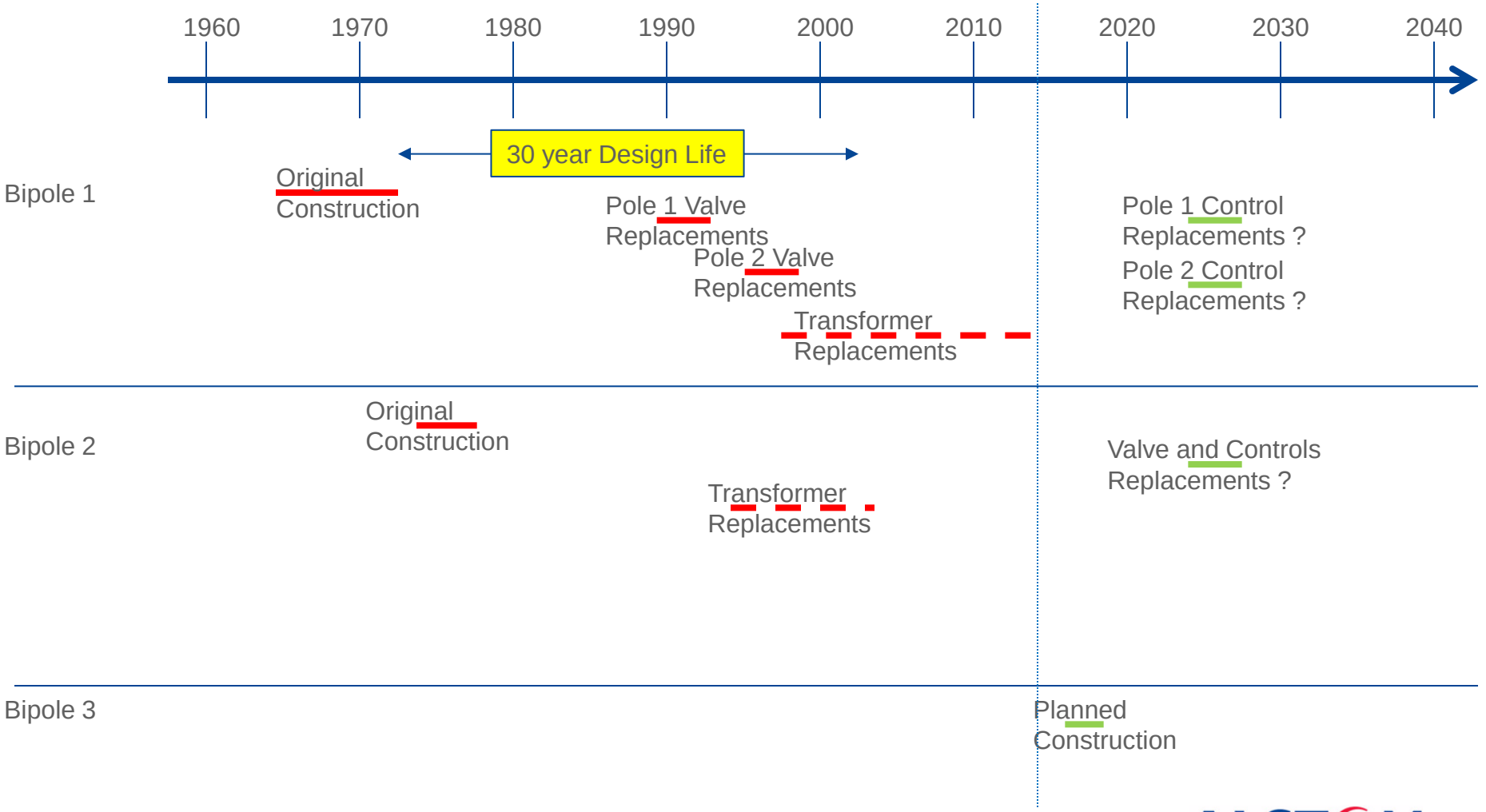
Nelson River HVDC Project

Interconnection between hydro generation in northern Manitoba and Winnipeg

Continuously Evolving and Expanding



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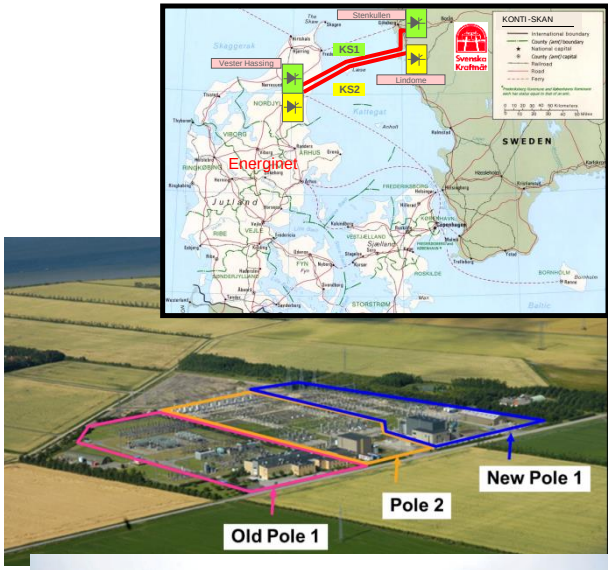
Konti-Skan Pole 1 Replacement

- Pole 1 Originally supplied in 1965 - Mercury Arc Valves
  - 250 MW, 250 kV, 1000 A
- Pole 2 added in 1988 - Thyristor Valves
  - 300 MW, 285 kV, 1050 A
- DC circuit
  - 115km in 3 sections of Line, + 2 sections of Submarine Cable
  - Sections of cable have been replaced/repaired/upgraded
  - Unused capacity in the overall DC conductor circuit
- Denmark Converter Station
  - 2 poles adjacent
- Sweden Converter Station
  - Pole 1 and Pole 2 converter stations located 30km apart



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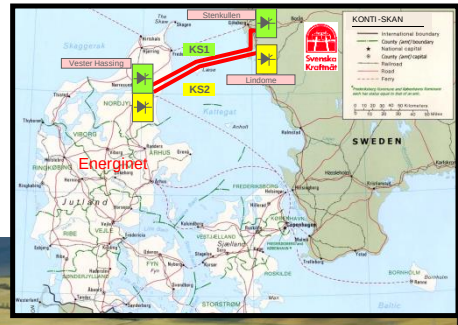
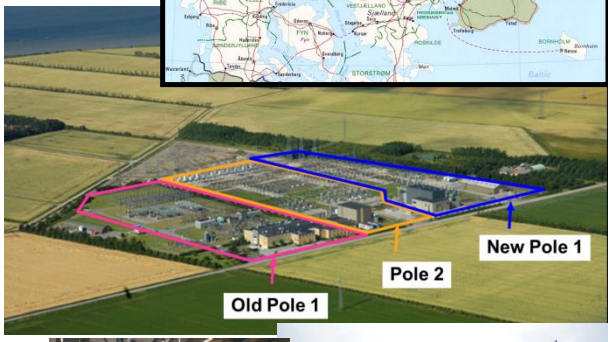
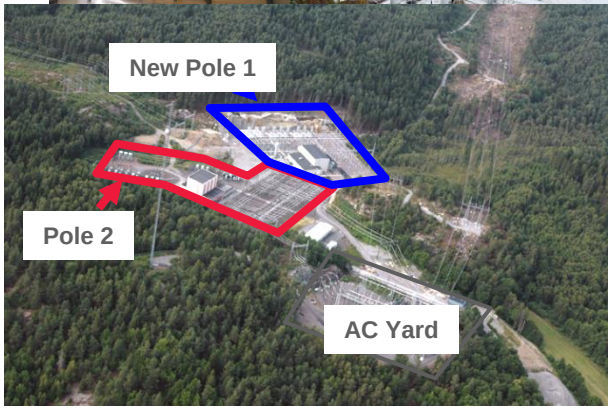
Konti-Skan Pole 1 Replacement

- Refurbishment
  - Drivers
    - Remove Mercury for EHS reasons
    - Reduce Maintenance
    - Increase Pole 1 Rating up to cable and line capacity
    - Replace Obsolete Control System
    - Replace Power Equipment At/Near End Of Life
  - Strategy
    - Completely replace Pole 1
    - Co-locate Poles 1 and 2 at Lindome
    - Allowed continued operation of both Pole 1 and Pole 2 during construction
  - Scope:
    - Denmark : Energinet carried out all construction
    - Alstom Grid manufactured, installed and commissioned the equipment
    - Sweden : Svenska-Kraftnat contract Full Turnkey
    - Alstom Grid scope including civil work, AC and DC switchyards, etc.







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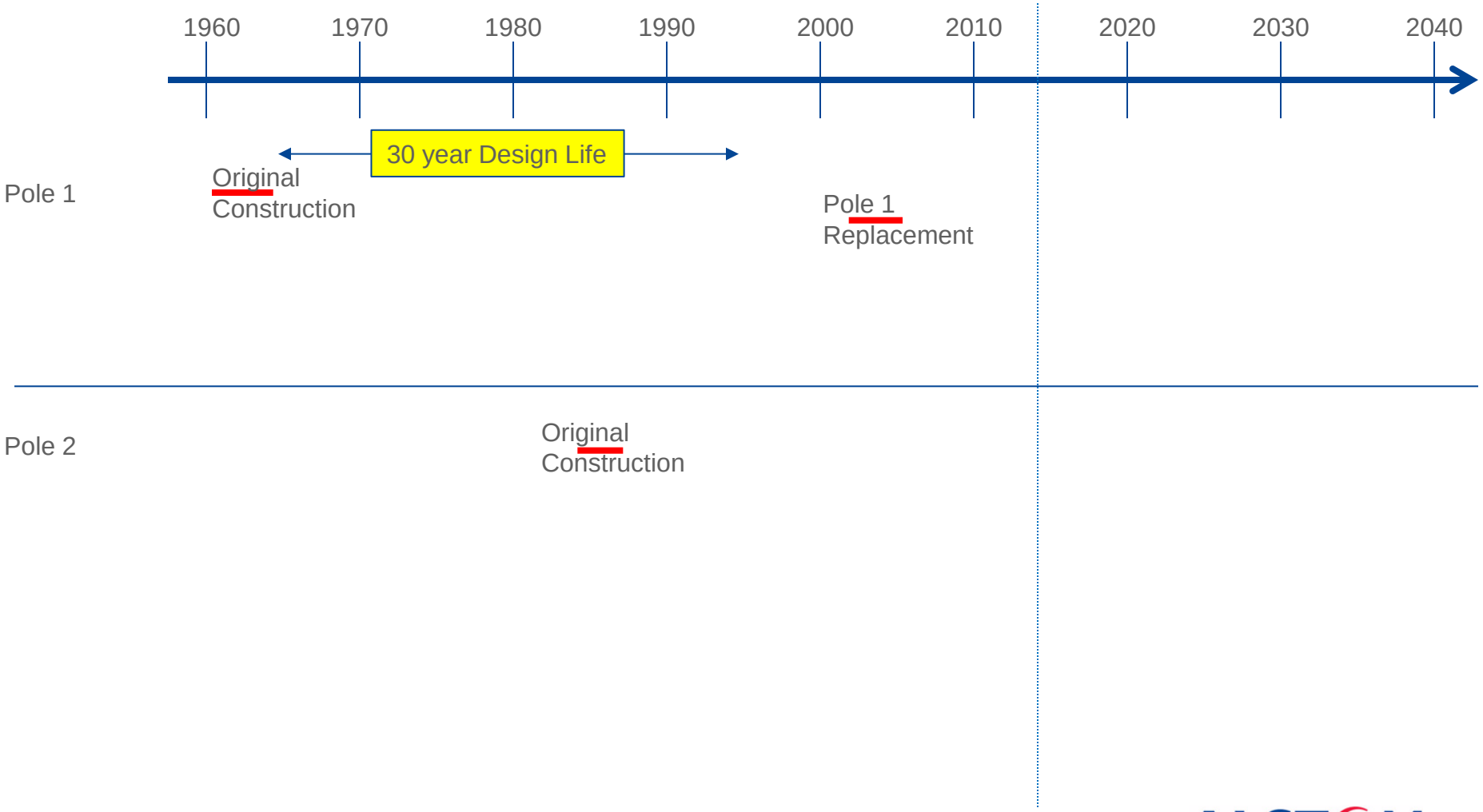
Konti-Skan Pole 1 Replacement

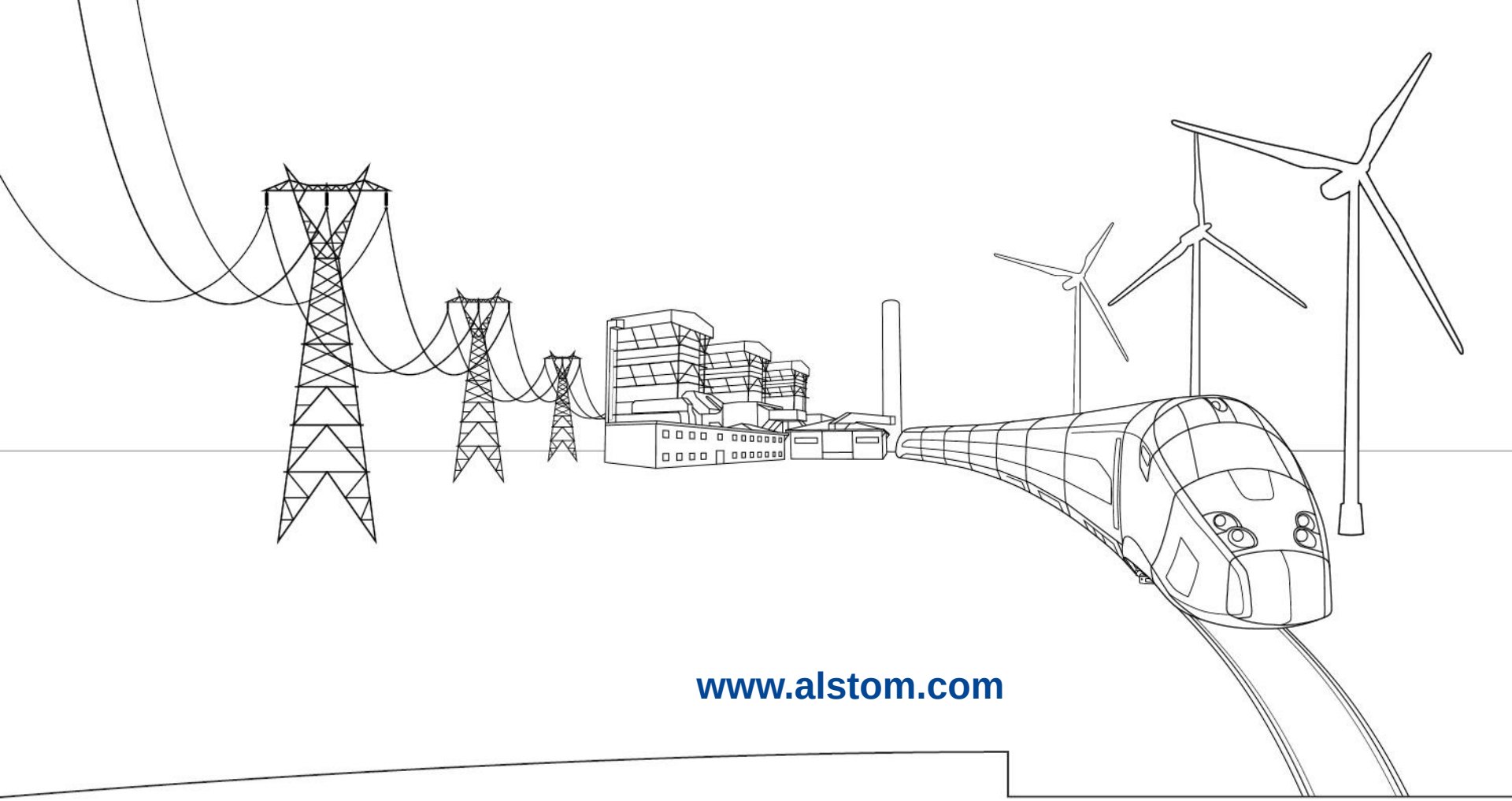


Other Recent Refurbishment Projects

- Jeju Island, S Korea
  - Haenam-Jeju 300 MW Cable Bipole
  - Addition of new Jeju-Jindo 400 MW Bipole
  - Replacement Control System for Bipole 1
- New Brunswick, Canada
  - Eel River 2 x 100MW Back-to-Back
  - Replacement of Valve, Controls and Cooling Plant
- Oklahoma, US
  - Oklaunion 220 MW Back-to-Back
  - Total Replacement with new 220 MW System
- …..

Summary & Conclusion

- No single solution fits all Power Electronics installations
  - Original installations were mostly unique
  - Similarly the refurbishment process must be addressed with that particular system and owner in mind
- Technology Advancements
  - Control Hardware/Software, Converter Power Electronics, and other areas of plant
  - Offer existing owners extended functionality and lifetime
- HVDC and FACTS systems in service since the 1960s
  - Ever-increasing number of systems being installed
  - Future increase in attention focussed on
    - How to design-in the future refurbishment of plant
    - Refurbish installations to make best use of the existing system
    - Modularity, Standards in converter equipment



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