

# Towards Grid of the Future

Through the lens of Grid Integration Solutions

Dr Richard Zhang

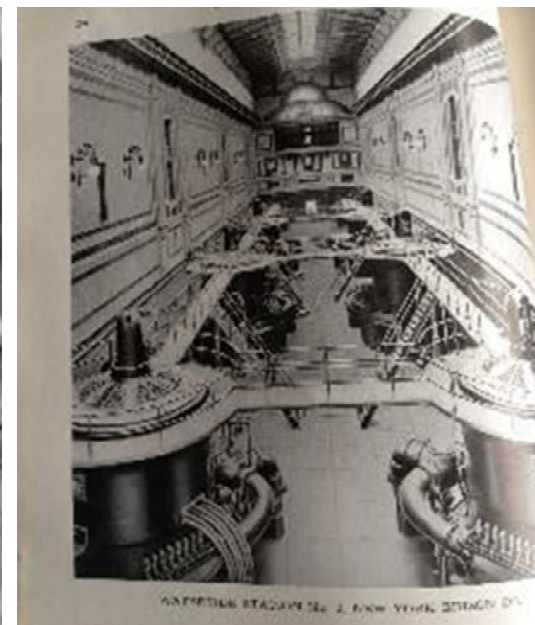
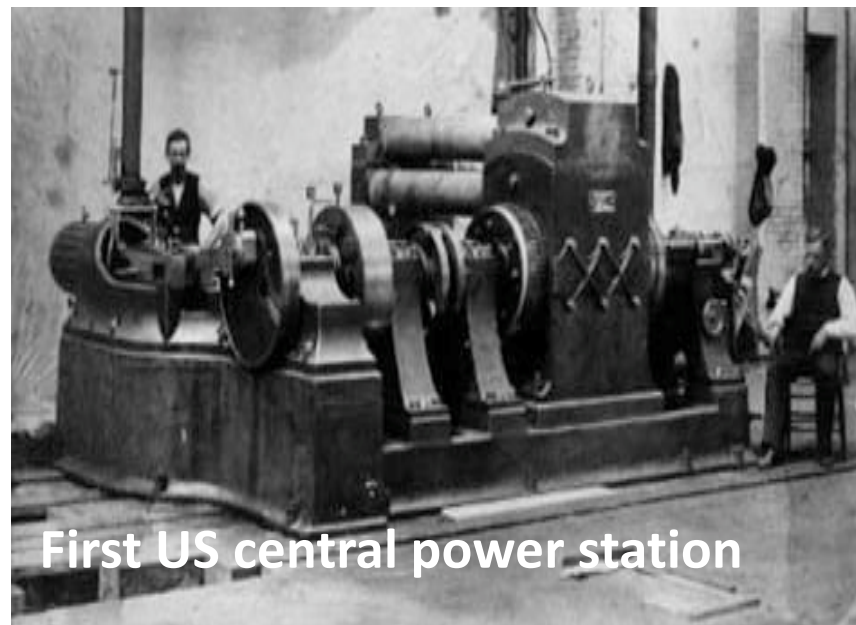
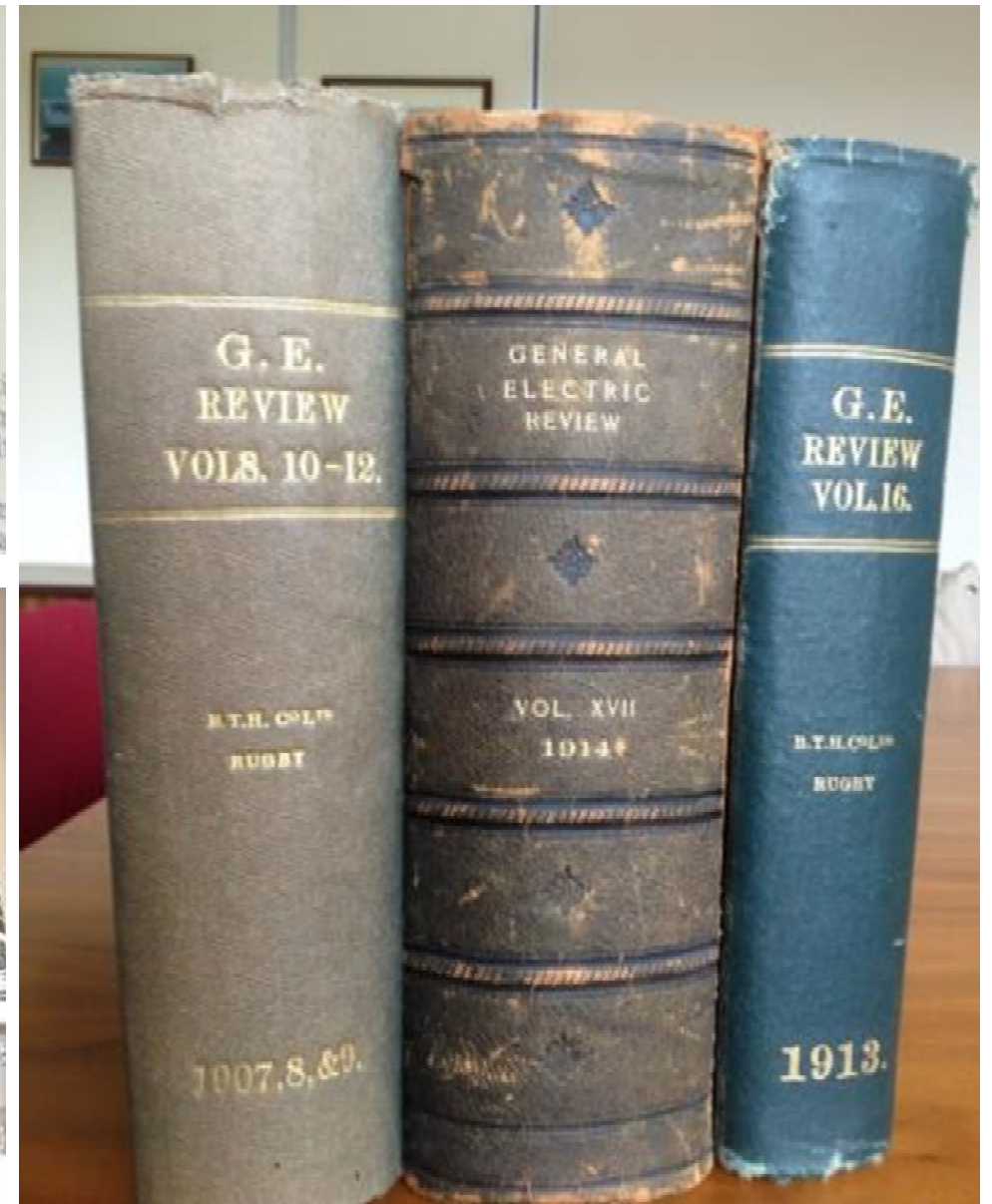
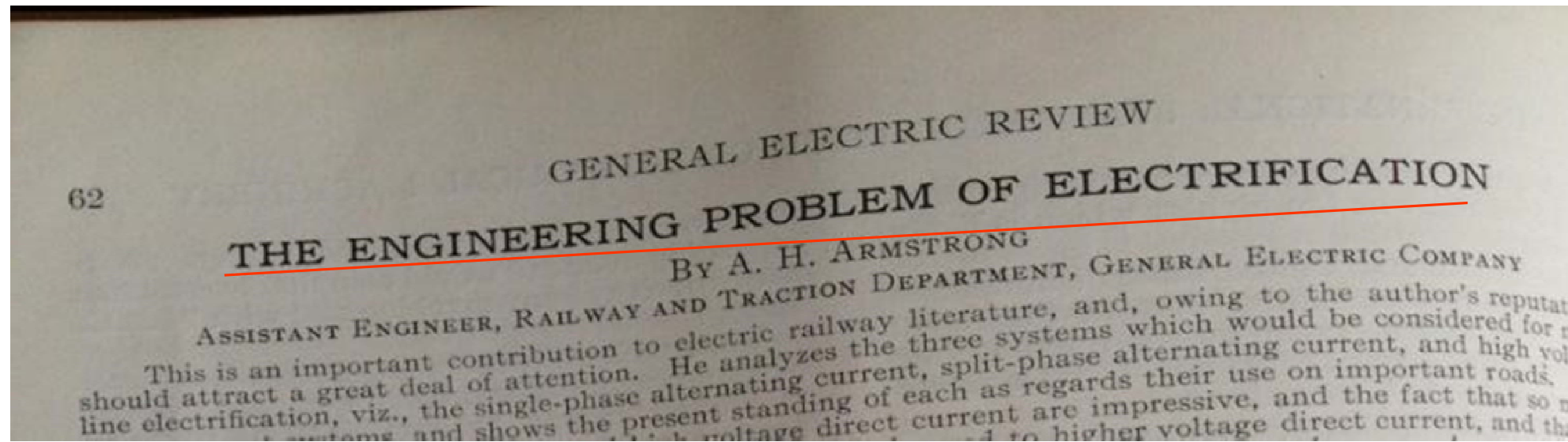
CTO, Grid Integration Solutions  
GE Renewable

Dec. 5, 2019



# GE – An Electrification Company...

pioneered electrification of energy source & load

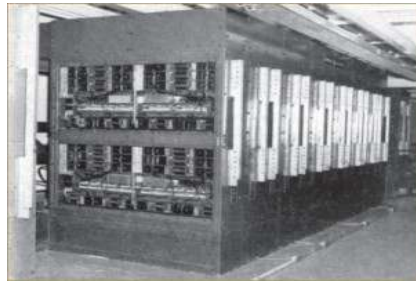


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Tenacious quest for over 135 years



# GE in Electrified Transmission ... ~90-Yr Journey



1972 world first  
Thyristor LCC  
HVDC



~1986s Thyristor  
H200 Valve (AC)



~1988 Thyristor  
H300 Valve (WC)

GE's 800 kV/3000MW LCC



~2004 Thyristor  
H400 Valve



World 1<sup>st</sup> DC Transmission 1932  
(Mechanicville-Schenectady)  
20 kV/5MW



1930-1970  
Mercury Valve

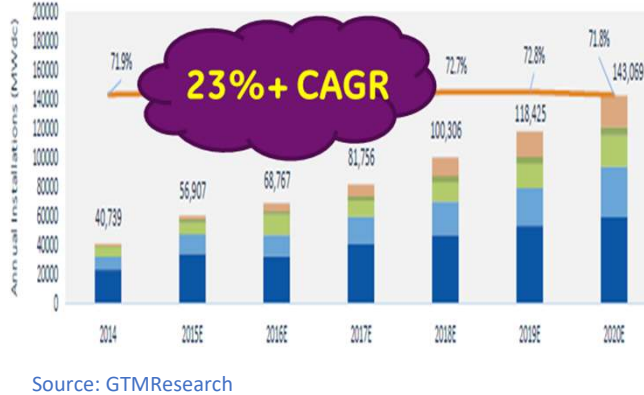
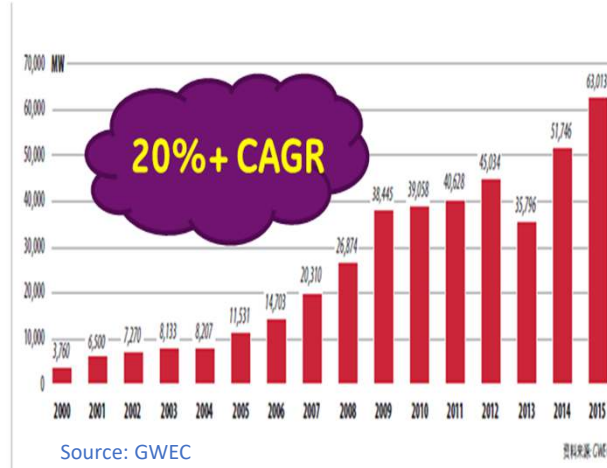


GE's VSC  
 $\pm 300$  kV/2x720 MW



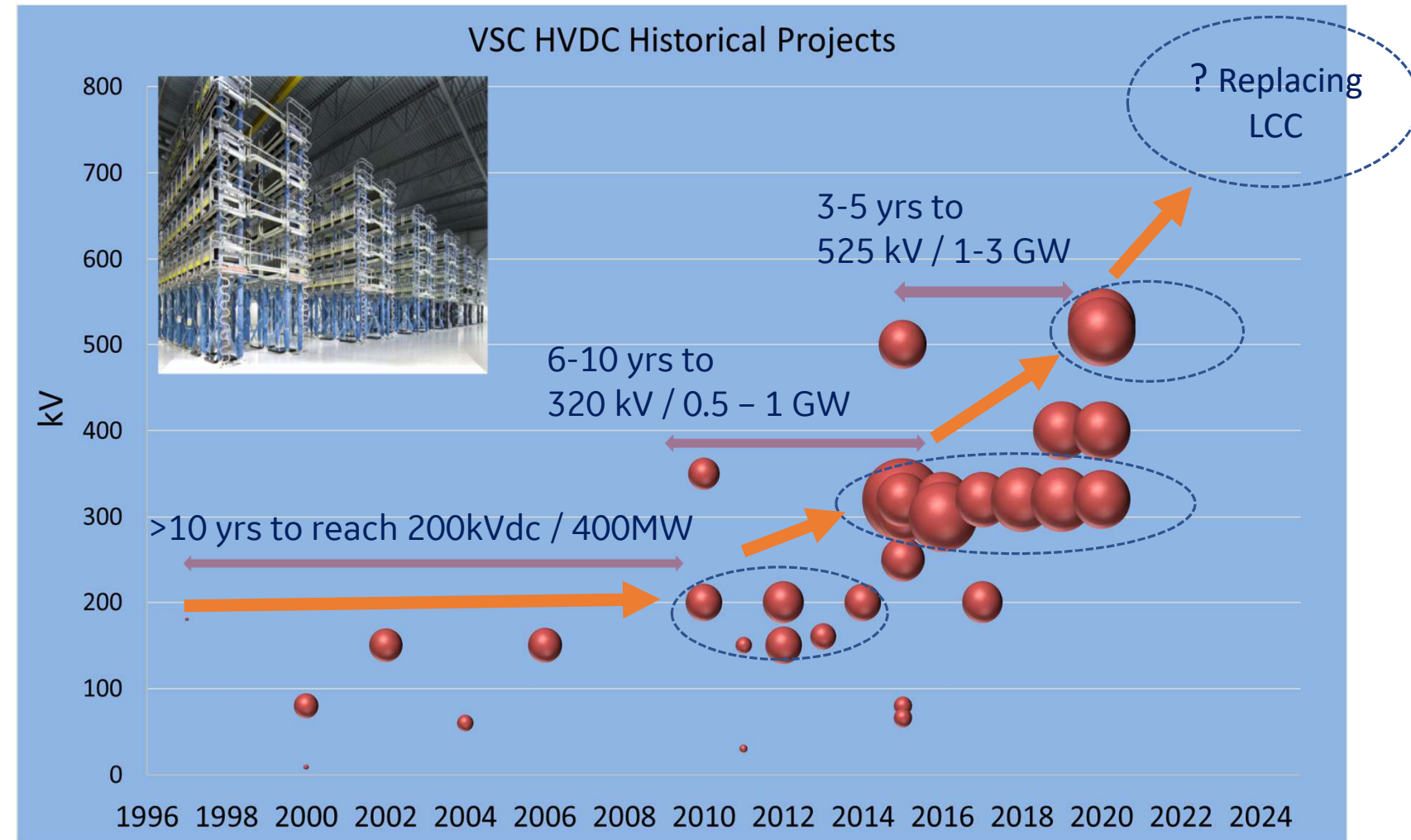
# Accelerated Change of Grid

## Changing Landscape for Power Generation



Accelerated Global Wind & Solar Installation ...  
driven by sharp reduction of LCOE of renewables

## Changing Landscape for Transmission



Data Source: WIKIPEIDA List of HVDC Projects  
[https://en.wikipedia.org/wiki/List\\_of\\_HVDC\\_projects](https://en.wikipedia.org/wiki/List_of_HVDC_projects)



# GE DoIWin 3 VSC HVDC Offshore Wind Farm Tie-back



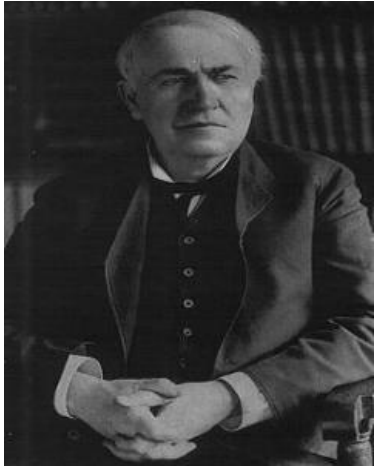
$\pm 320$  kV, 900 MW





# Power Electronics & Power Systems Trend

DC **or** AC



DC **in** AC



DC **and** AC



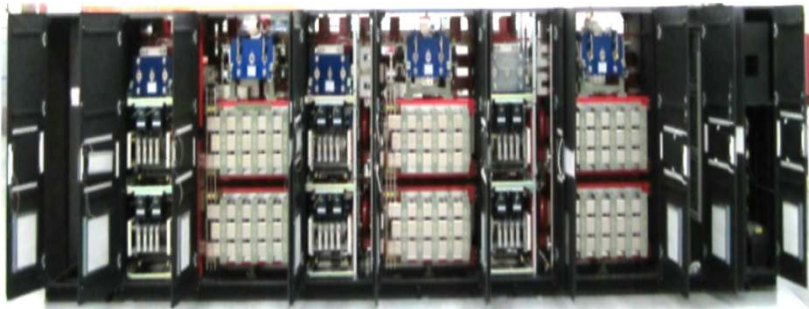


# Power Electronics & Power Systems Trend

## Power Electronics & Power Systems Parallel Universe



Passives dictate behaviour & protection



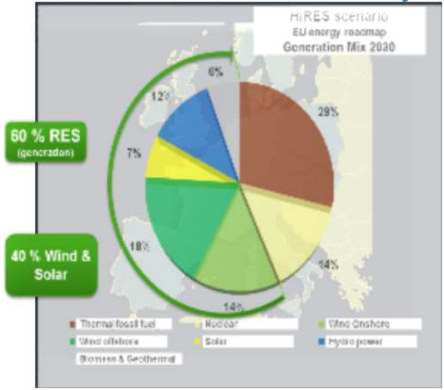
Minimize number of power switches

## Power Electronics **in** Power Systems



LCOE driven ... Efficiency, cost,  
reliability ... unit & farm level stability

## Power Electronics **is** Power Systems



High RES 2030	GW	Load factor (h/yr)
Solar (PV)	220	1100
Onshore wind	280	1900
Offshore wind	205	3200
Hydro	120	3800

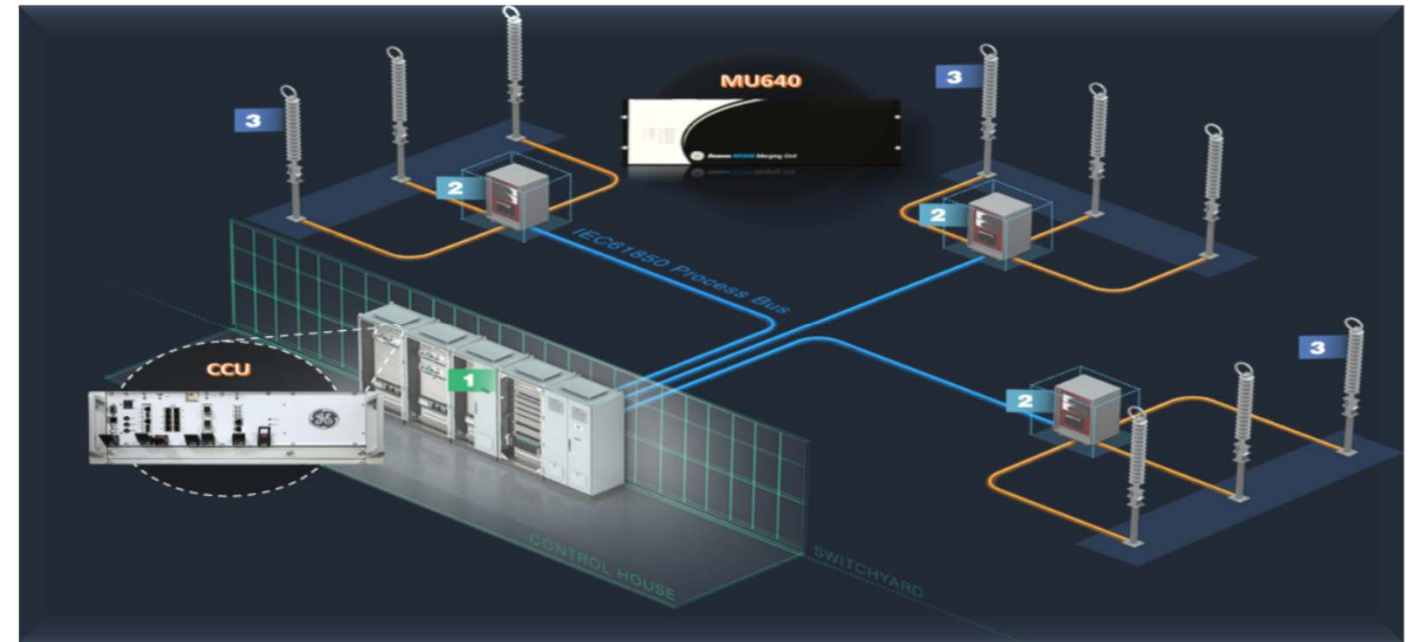
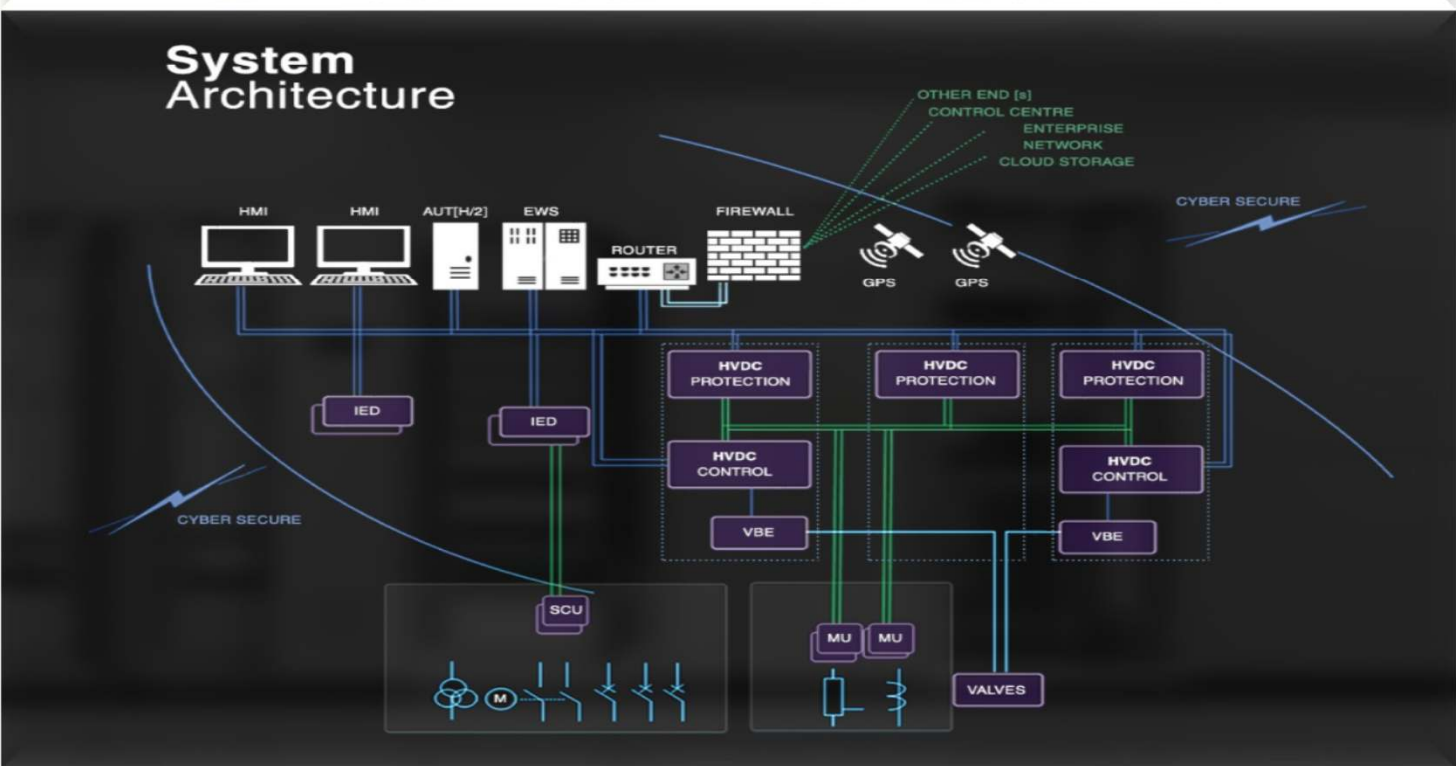
Information from “Technical and Economic Analysis of The European Electricity System with 60% RES” A. Burtin, V. Silva, EDF R&D, <http://www.energypost.eu/wp-content/uploads/2015/06/EDF-study-for-download-on-EP.pdf>

Control dictates behaviour & protection



Enhance number of power switches  
... power quality, system availability, control degree of freedom

# GE's eLumina™ HVDC Control Enables Total Integrated Grid Solutions

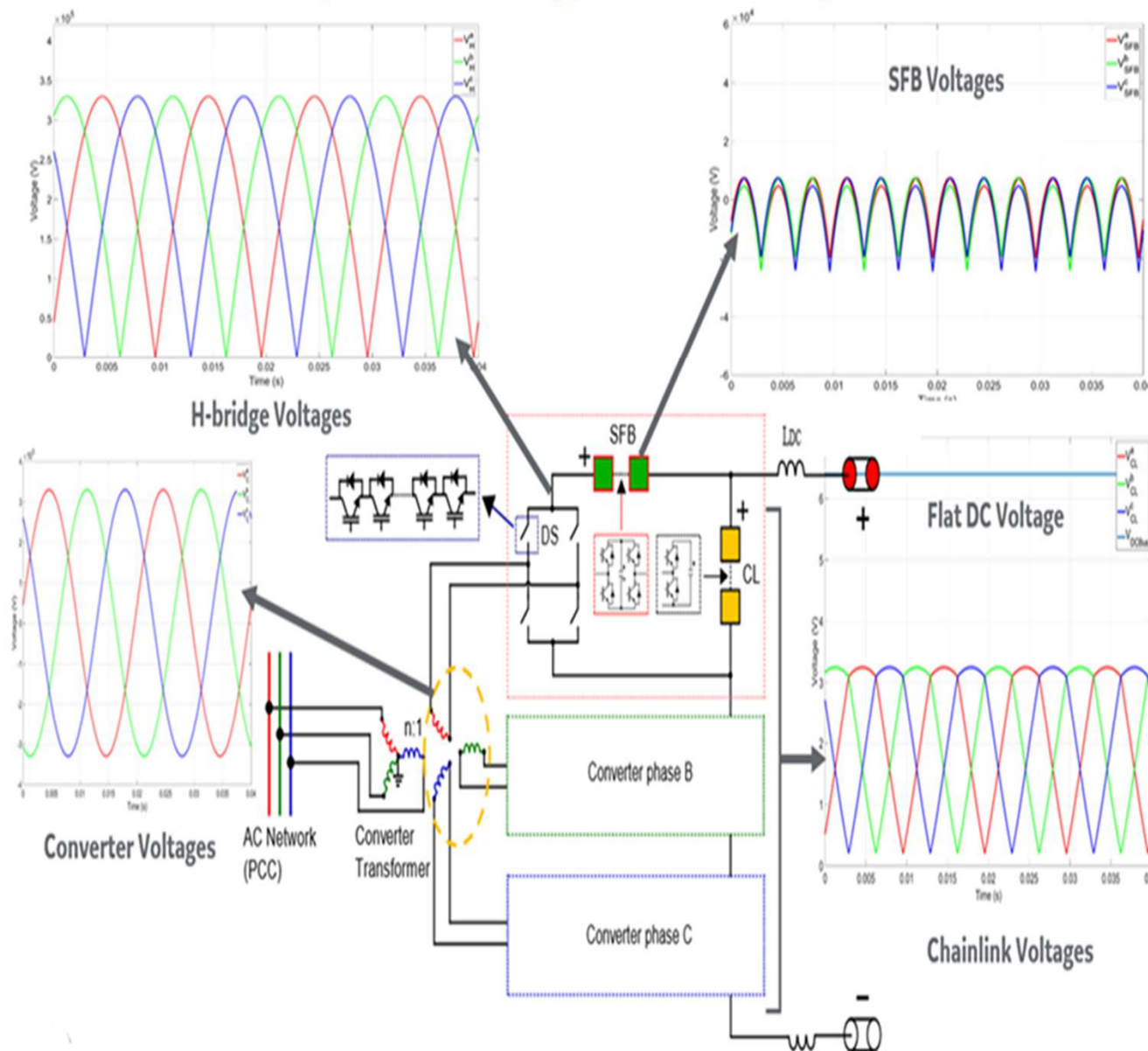


- Platform with 10x computing power
- Communication dictates control performance ... ultrafast, low latency
- Fully digitized remote measurements
- Interoperability for digital substation - DC & AC ... full IEC61850 communication protocol
- Built with Digital Analytics and Cyber Security



# New Topology Beyond MMC

## SBC (Series Bridge Converter)



SBC leads to much higher density

**MMC**

Very large  
footprint

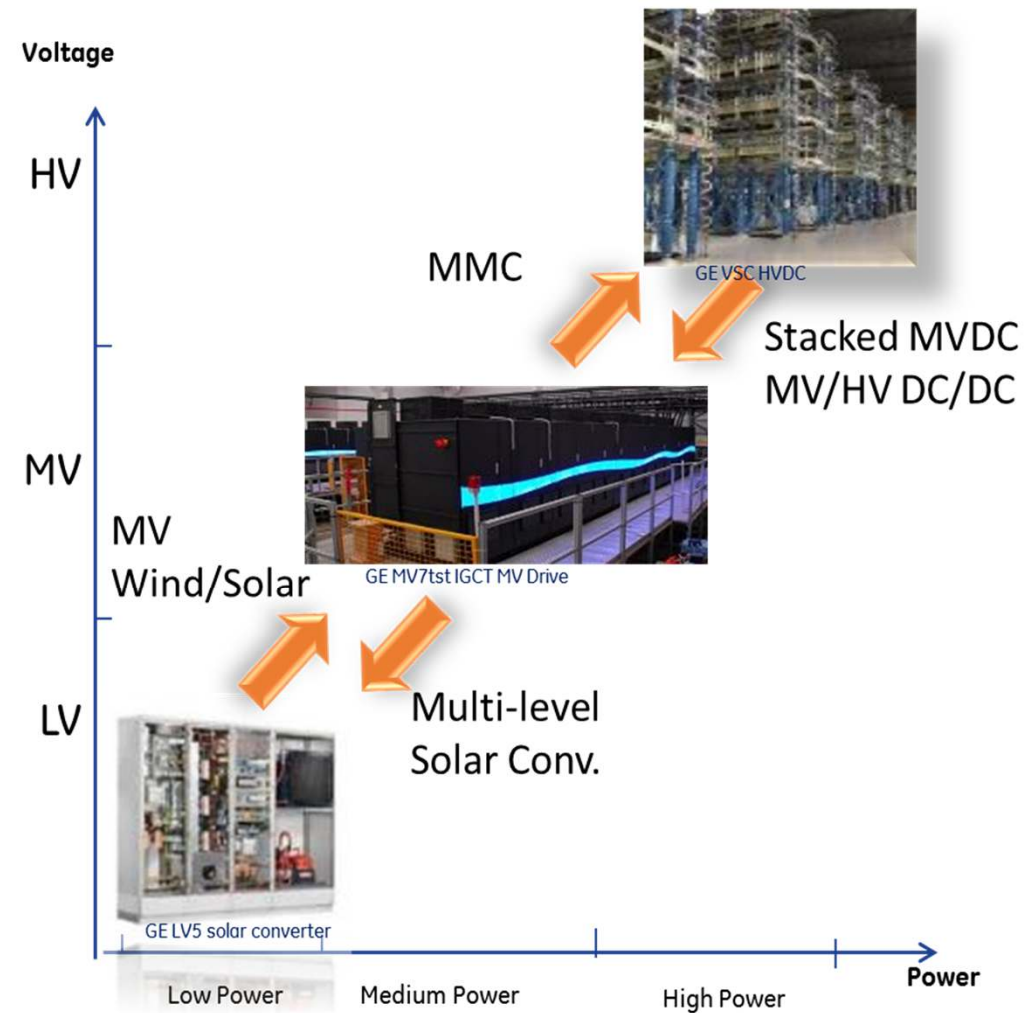
**SBC**

Up to  
50%  
less area

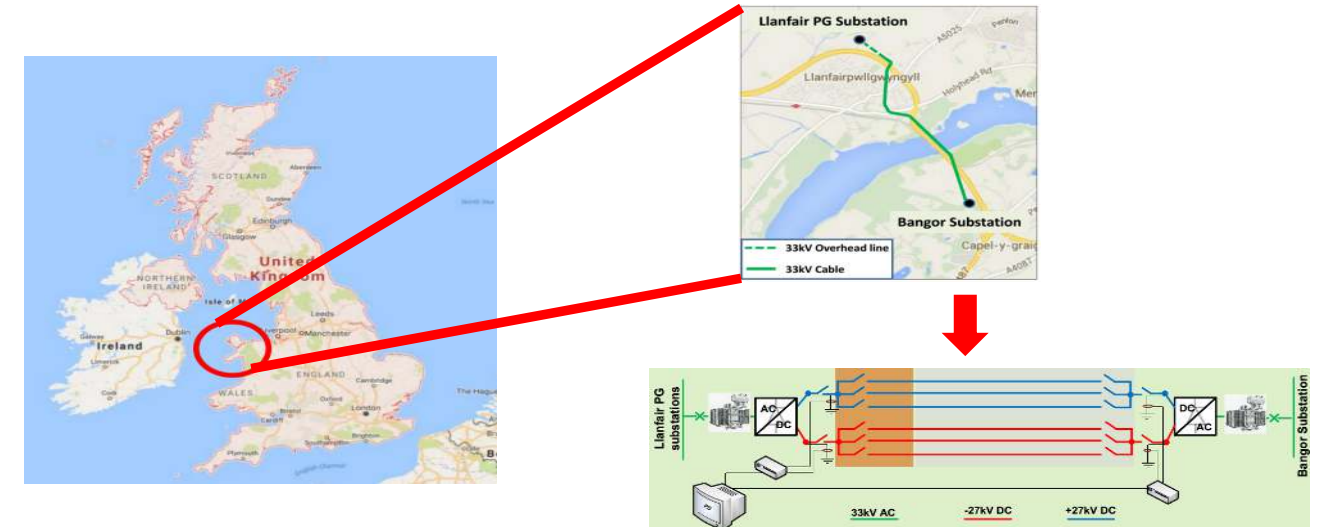
**Advantageous for:**

- Compact back to back stations
- Offshore wind
- City infeed
- MVDC

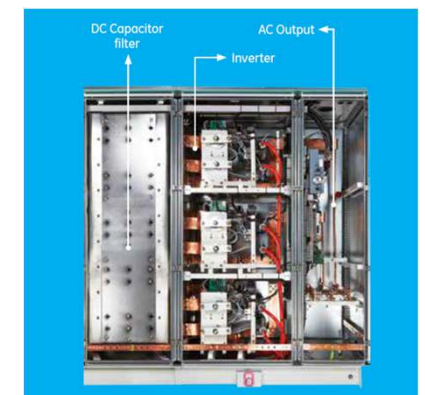
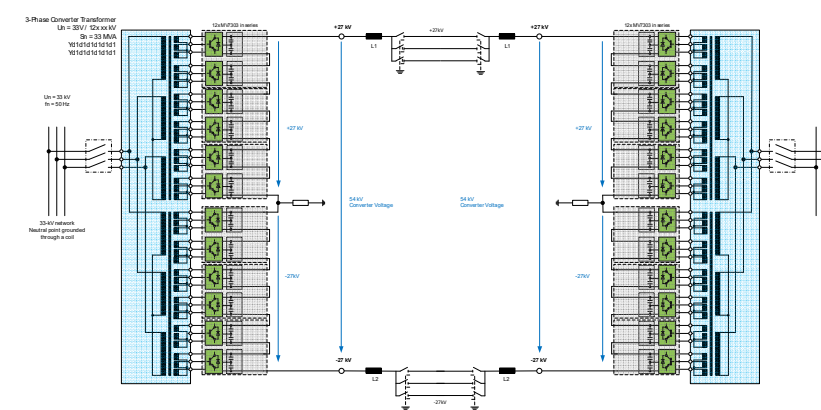
# MVDC ... Technology Fusion HV-MV-LV



## Angle MVDC with GE's MV Drive Technology



Yu J, Smith K, Urizarbarrena M, MacLeod N, Byrns R, Moon A, "Initial designs for the ANGLE DC project; converting AC cable and overhead line into DC operation", IET, ACDC 2017, February, Manchester, UK



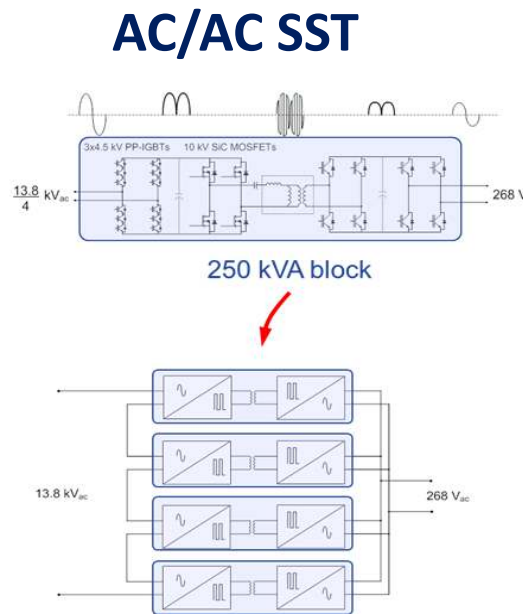


# MV Solid State Transformer – AC/AC, AC/DC

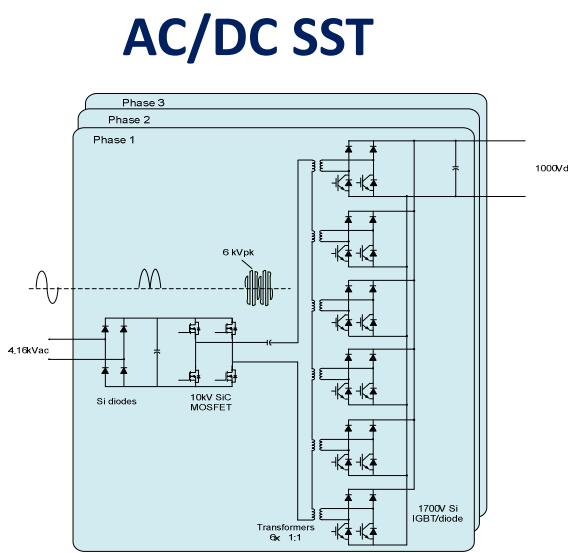
1 MVA, 13.8 kV AC/ 265 VAC  
solid-state power station  
operating at 20 kHz



Source: GE led HPE – SSPS  
a DARPA/ONR/NAVSEA program

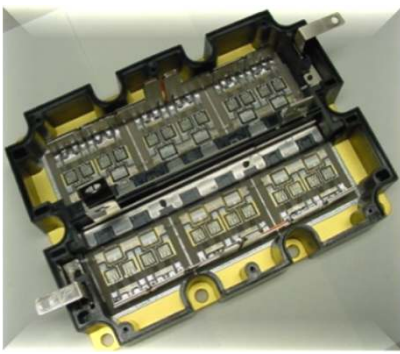


13.8 kVAC/265 VAC, 1MW



4160 VAC/1000 VDC, 1MW

10 kV SiC MOSFET

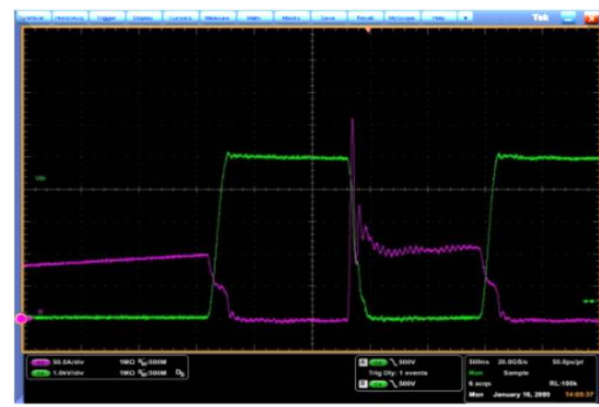


Source: Cree/ Powerex

40 kHz transformers



6x 100 kVA in one case

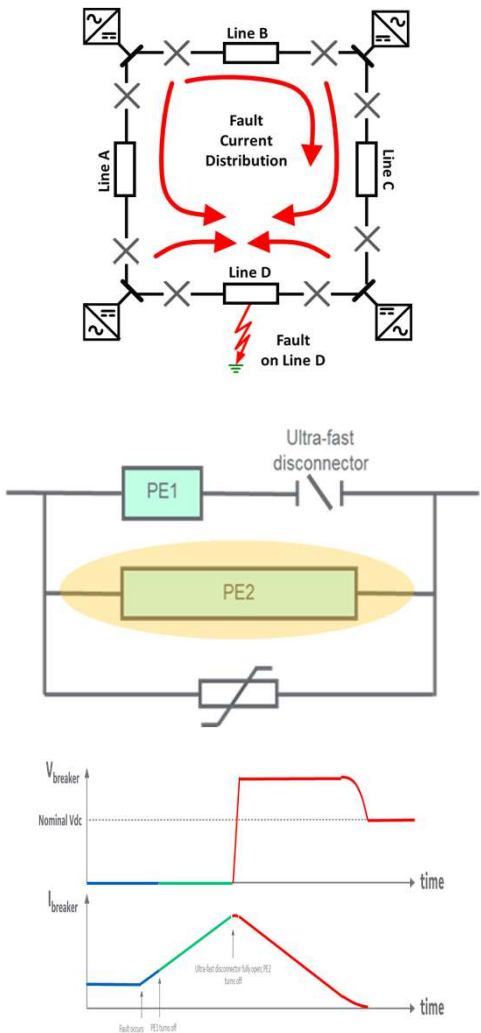


turn-on/ turn-off in 100 ns @ 5kV, 100A

- 20 kHz-40 kHz operation, 98% efficiency demonstrated
- 1/3 to 1/10 size & weight conventional transformer & filter
- SiC switch & high-freq high-power magnetics key enabler
- Cost challenge & efficiency – density trade-off

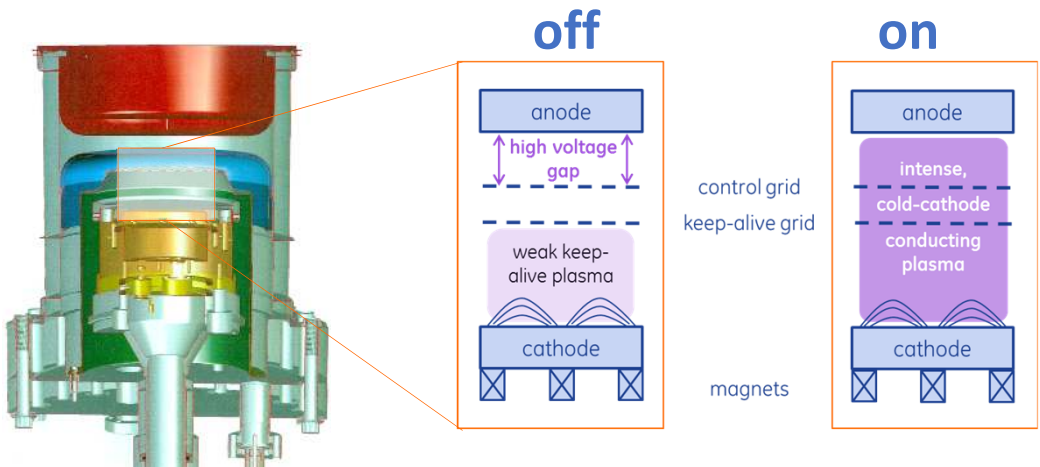
# Gas Tube Based HV DC Circuit Breaker

## Hybrid HV DCCB

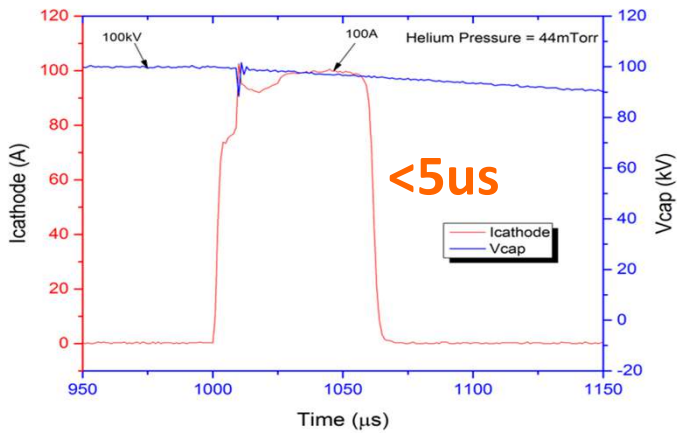


Challenge: High Cost, Bulky

## Gas Tube ... alternative high density HV power switch

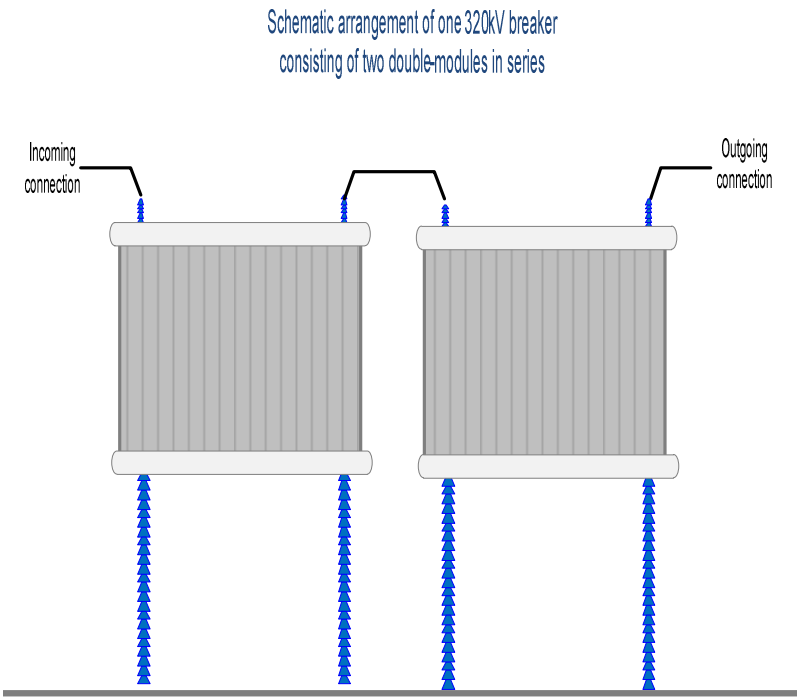


## 100 kV Switching



Leverage GE's X-Ray tube technology

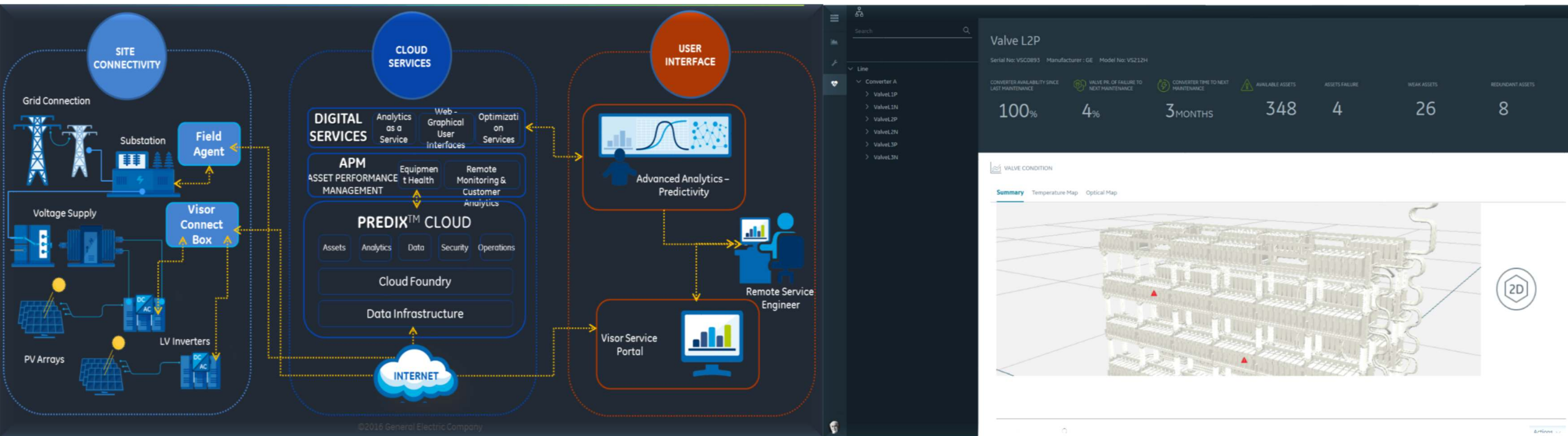
## Containerized 320 kV DCCB



Ultrafast, High Density, Lower Cost



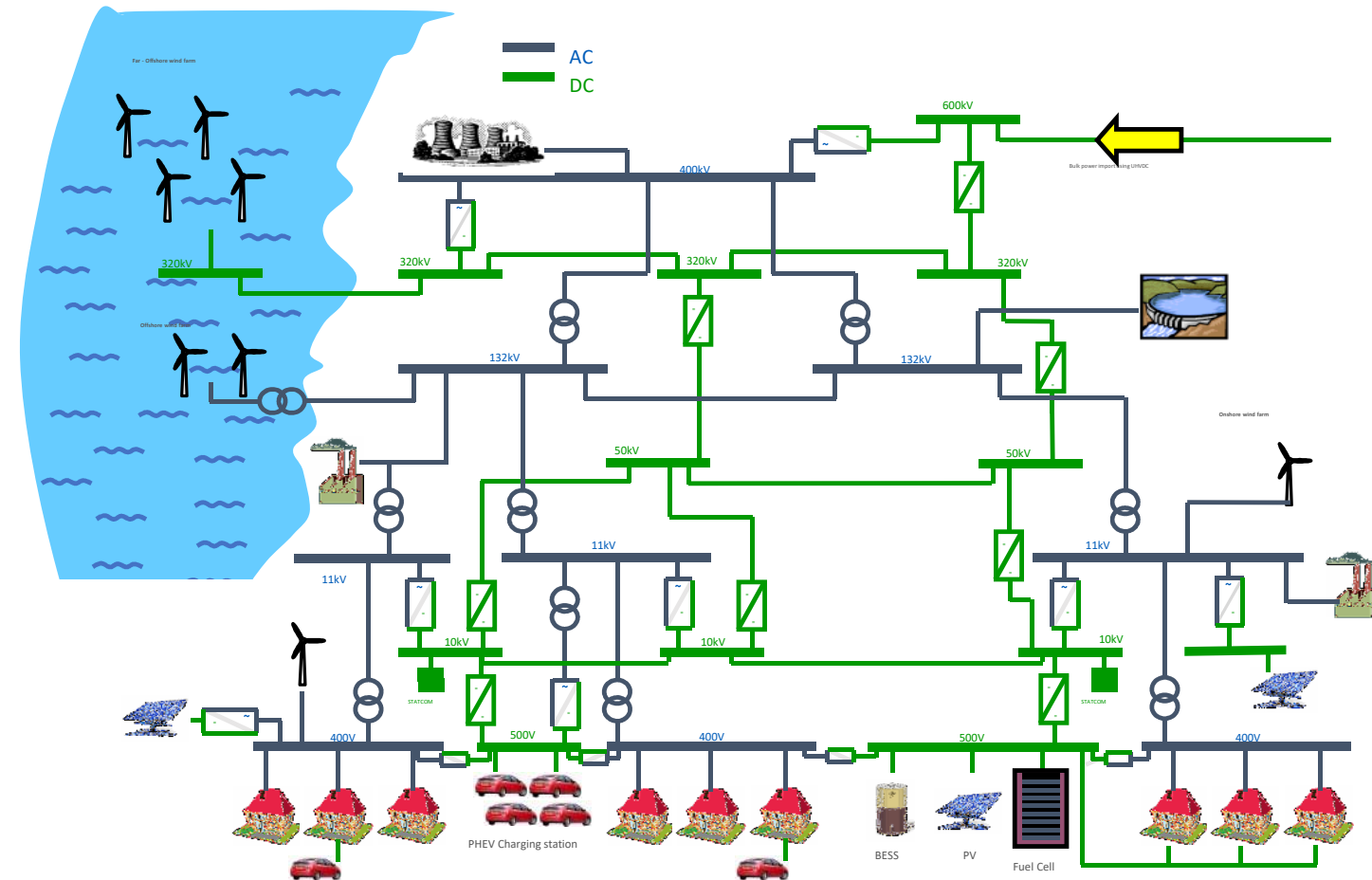
# Digital Solution for Grid of the Future



- Value creation for Total Integrated Grid Solutions ... grid resilience and OPEX reduction
- Deeper insights into equipment operation & asset utilization
- From schedule based maintenance ... to condition based maintenance
- A-B-C-D-E of every digital solution ... **A**lgorithm, **B**usiness value, **C**omputing & **C**ommunication Platform, **D**ata, **E**xecution



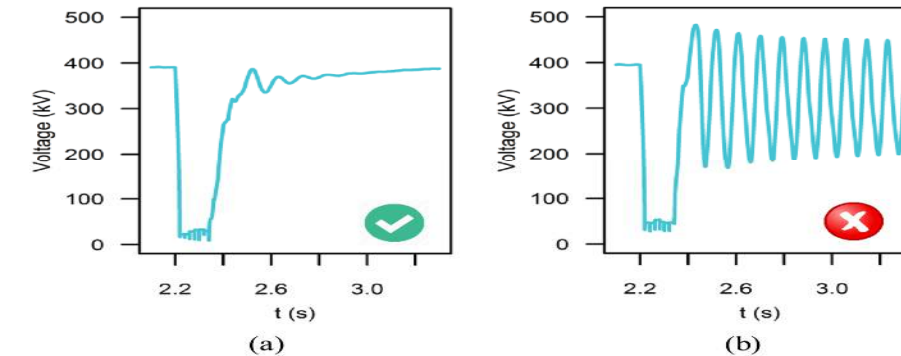
# Grid of the Future? No Shortage of Challenges...



- Mixed AC & DC
- Power electronics based control
- Fluctuating renewable energy
- ...

## “Performance of Phase-Locked Loop Based Converters” System Operability Framework by NationalGrid

**Figure 1:** System voltage with PLL (a) tracks (b) loses voltage phase reference

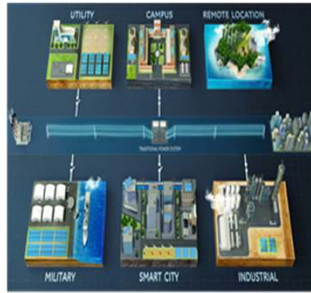


- System architecture ... mixed AC & DC, Multi-terminal DC
- Control & protection ... new philosophy or status quo?
- Power balance & ancillary service
- Synchronization mechanism w/o SG
- Reduction of inertia & fault current contribution
- Increased voltage sensitivity & RoCoF
- Dynamic stability risk
- ...



# Towards Grid of the Future ...

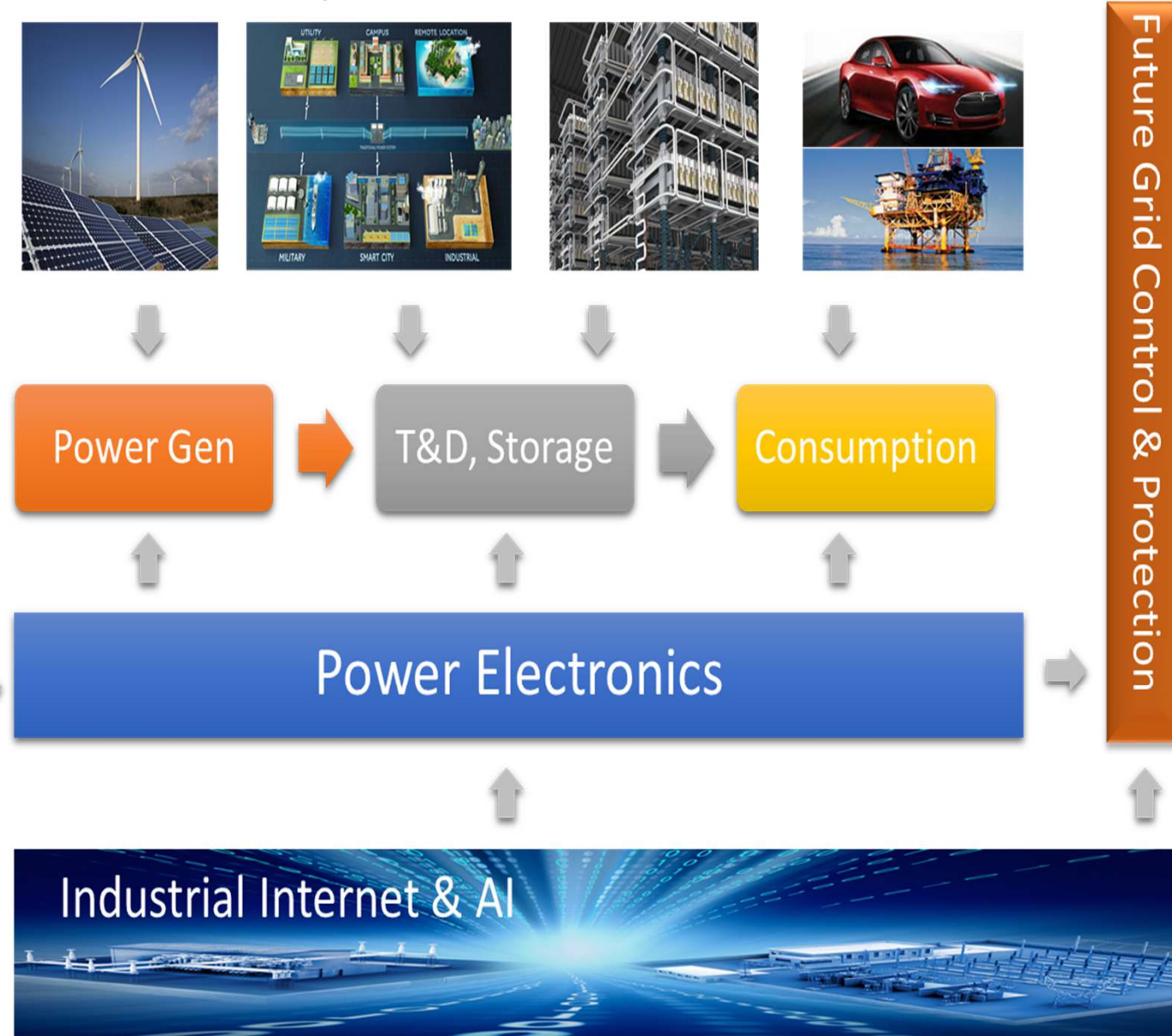
Renewable    Micro/Smart Grid    Mixed DC & AC    Electrified loads



WBG devices



Adv. Control  
& topo.



## Power Electronics ...

- Continued innovations in control, circuits, components, applications, and digital
- Becomes integral part of Grid of the Future
- Presents challenges for Grid of the Future
- Is also the solution for Grid of the Future

# Questions?



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# Acknowledgements of Leadership & Contributions

## GE's Grid Solutions

- Carl Barker
- Colin Davidson
- Dr. Omar Jasim
- Dr. Colin Oates (late)
- Tim Stott
- Dr. David Trainer
- Leandro Vacirca
- Dr. Konstantin Vershinin

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- Dr. Ravi Raju
- Dr. Tim Sommerer

## GE Power Conversion

- Dr. Ushe Mupambireyi
- Dr. Joerg Janning

