CIGRE US National Committee

2014 Grid of the Future Symposium

AVC of Danish Transmission System – Concept design

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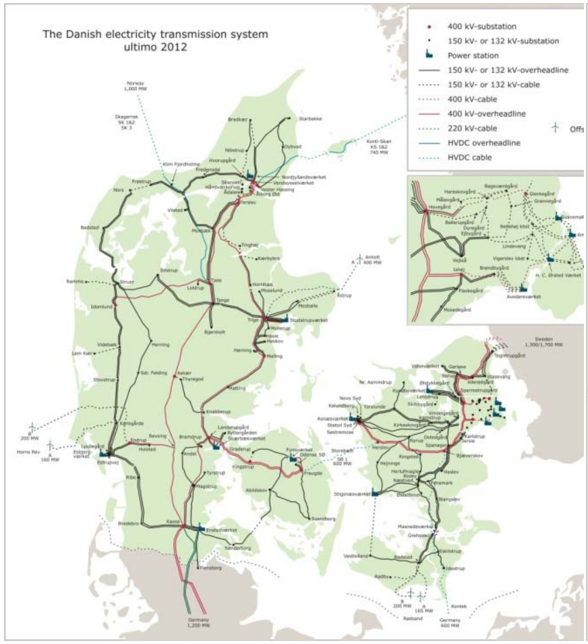
Agenda

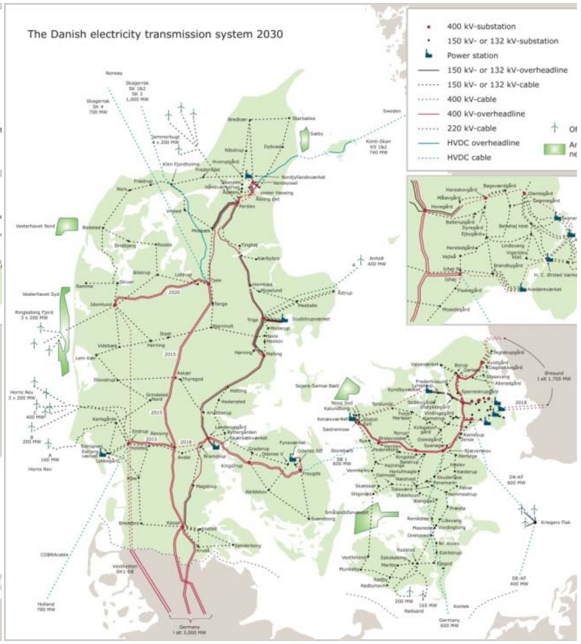
- Motivation
- AVC survey
- Concept of Danish AVC
- Cooperation opportunity

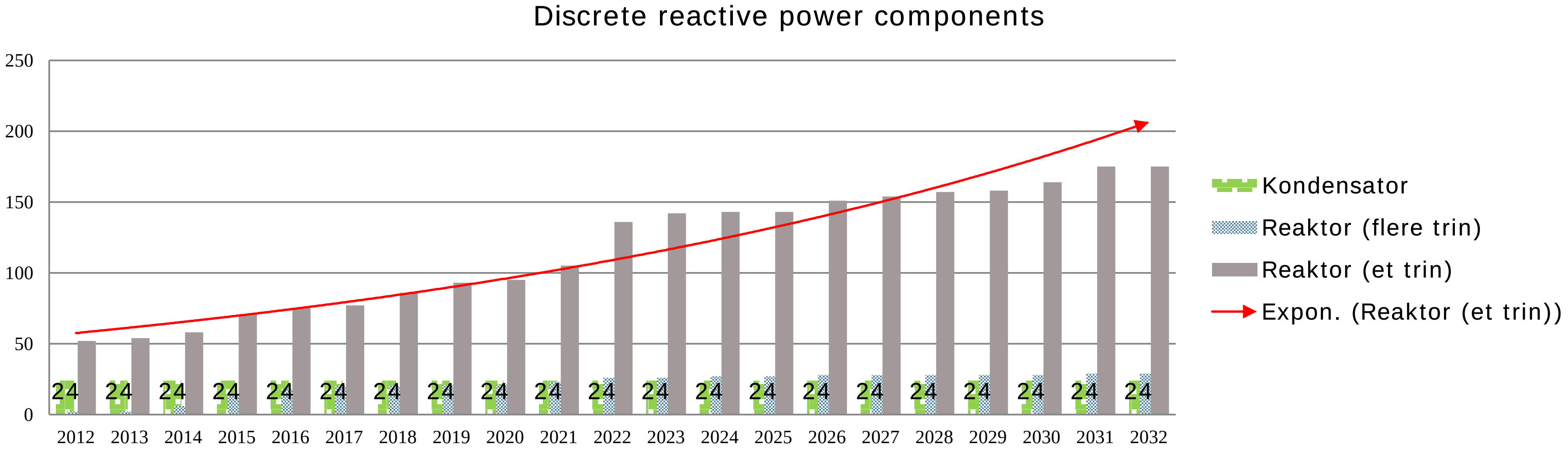
Challenges of voltage control

- ‘Cable action plan’ replaces the overhead lines to underground cables.
  - Full compensations at two ends of the cable i.e. a fixed shunt and a tap-able shunt
- ‘Energy policy’
  - 50% electricity comes from wind energy (load covering)
  - Central power plants are phased out
- Enhancement of interconnections
  - Need inter flow control i.e. HVDC ramps faster

Cable action plan → Compensation of cables
→ Voltage control in time?







Challenges of voltage control

- 'Cable action plan' replaces the overhead lines to underground cables.
  - Full compensations at two ends of the cable i.e. a fixed shunt and a variable shunt
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  - 50% electricity comes from wind energy (load covering)
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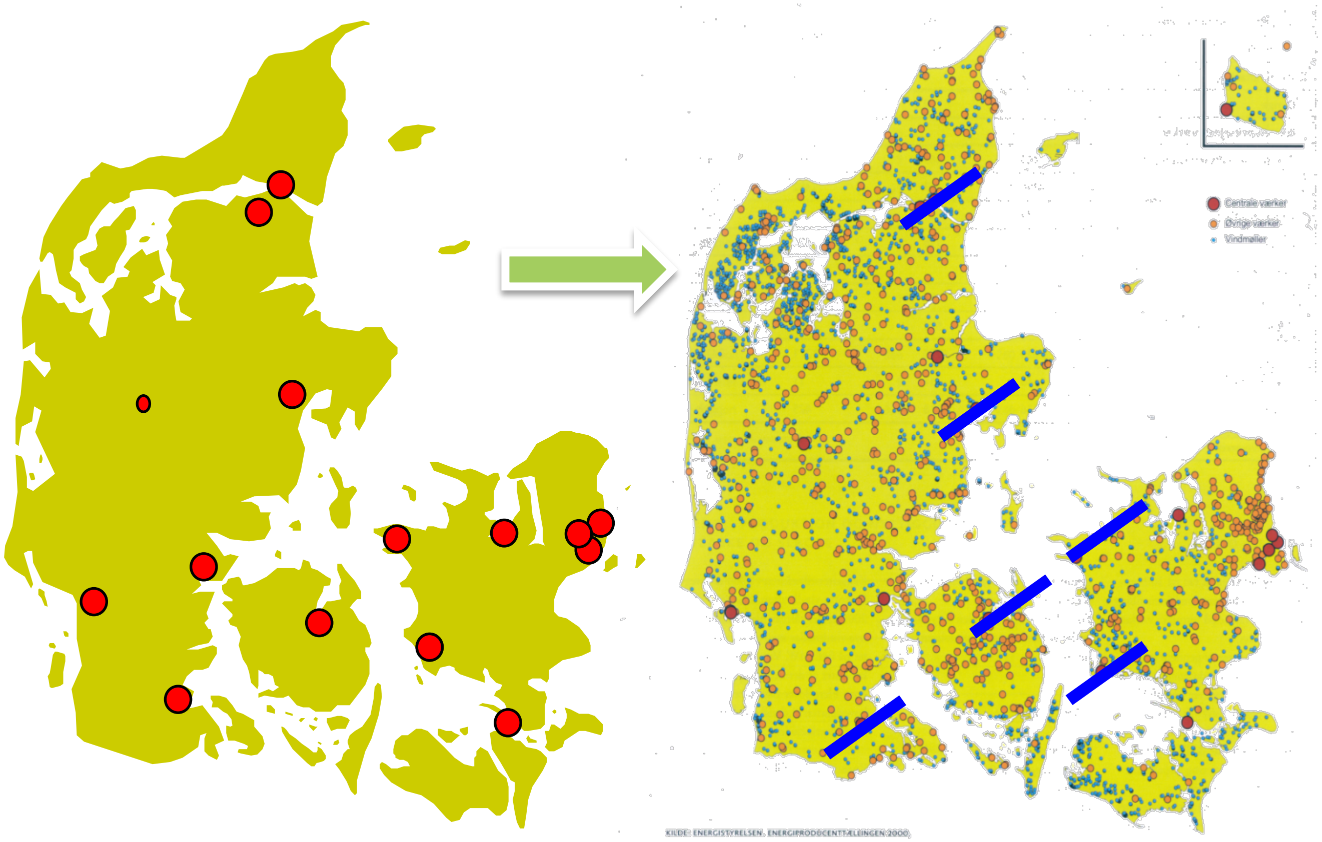
50 % wind power by 2020 → Conventional Power Plants are phasing out → Voltage source is missing



Trans.	West	East	
Conv.	3,148	2,921	MW
CHP	0	0	MW
Wind	369	373	MW
Σ	**3,517**	3,294	MW

Dis.	West	East	
Conv.	0	217	MW
CHP	1,995	610	MW
Wind	2,603	577	MW
Σ	**4,598**	1,404	MW

Significant amount electricity from the distribution level

Challenges of voltage control

- ‘Cable action plan’ replaces the overhead lines to underground cables.
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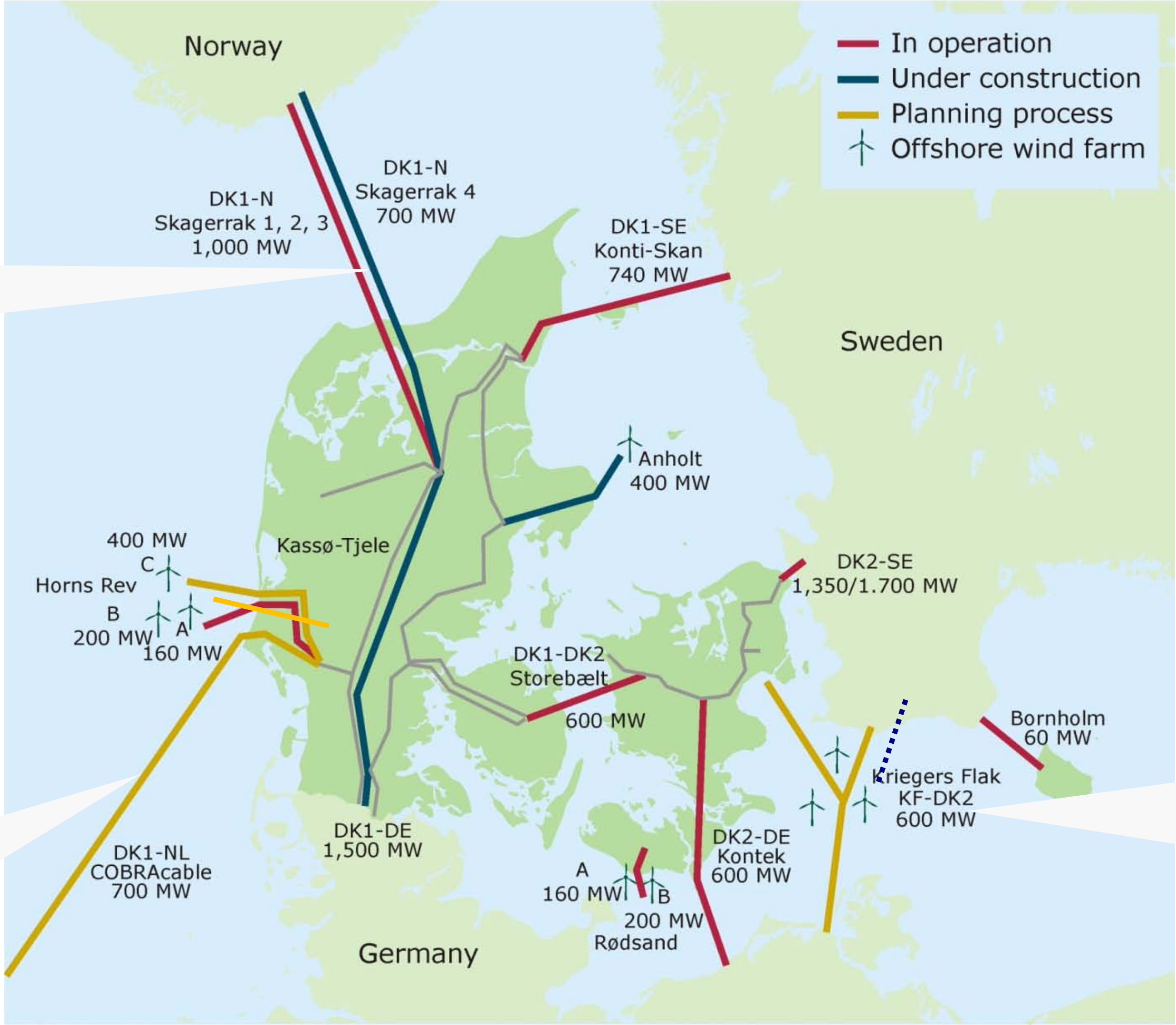
2. Upgrade the interconnections → Flexibility → Challenging the voltage control

Skagerrak 4

700 MW - HVDC

NO-DK1

HVDC - VSC



Kriegers Flak

600 MW Wind farm offshore

600 MW – HVDC

HVDC - VSC

DE-DK2

EC co-funding

COBRA

700 MW - VSC

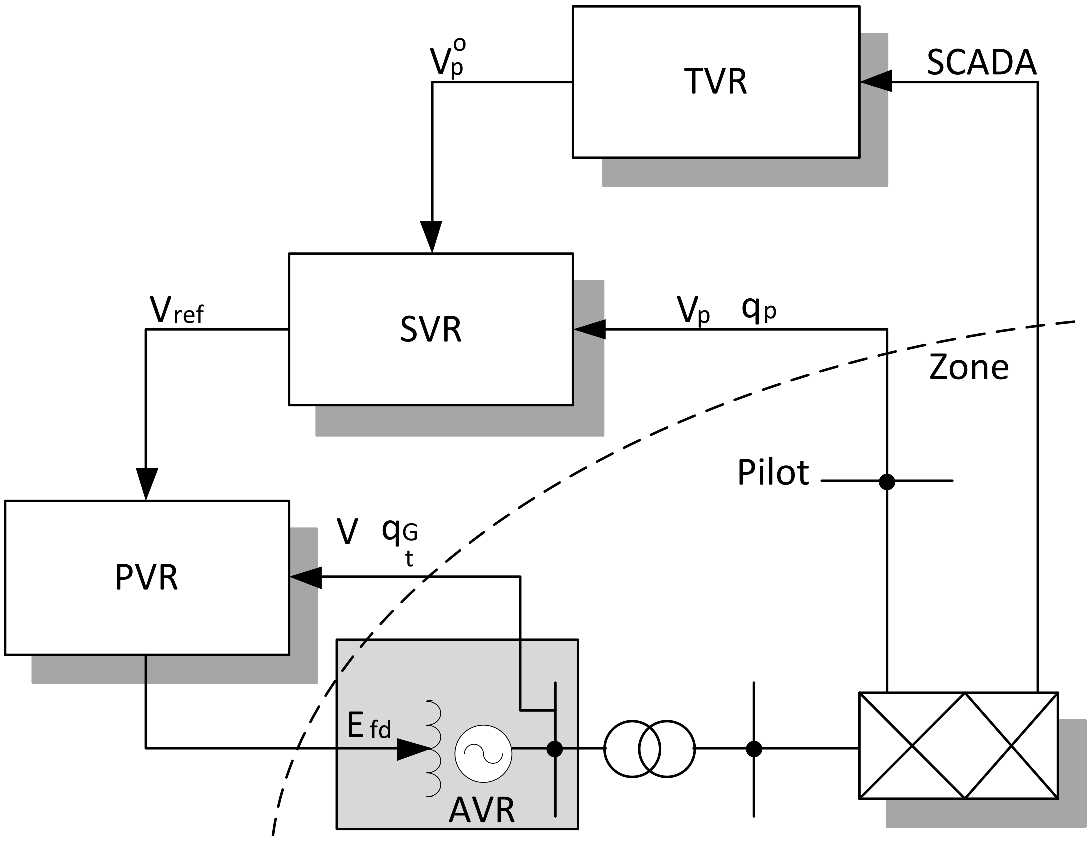
NL-DK1

EC co-funding

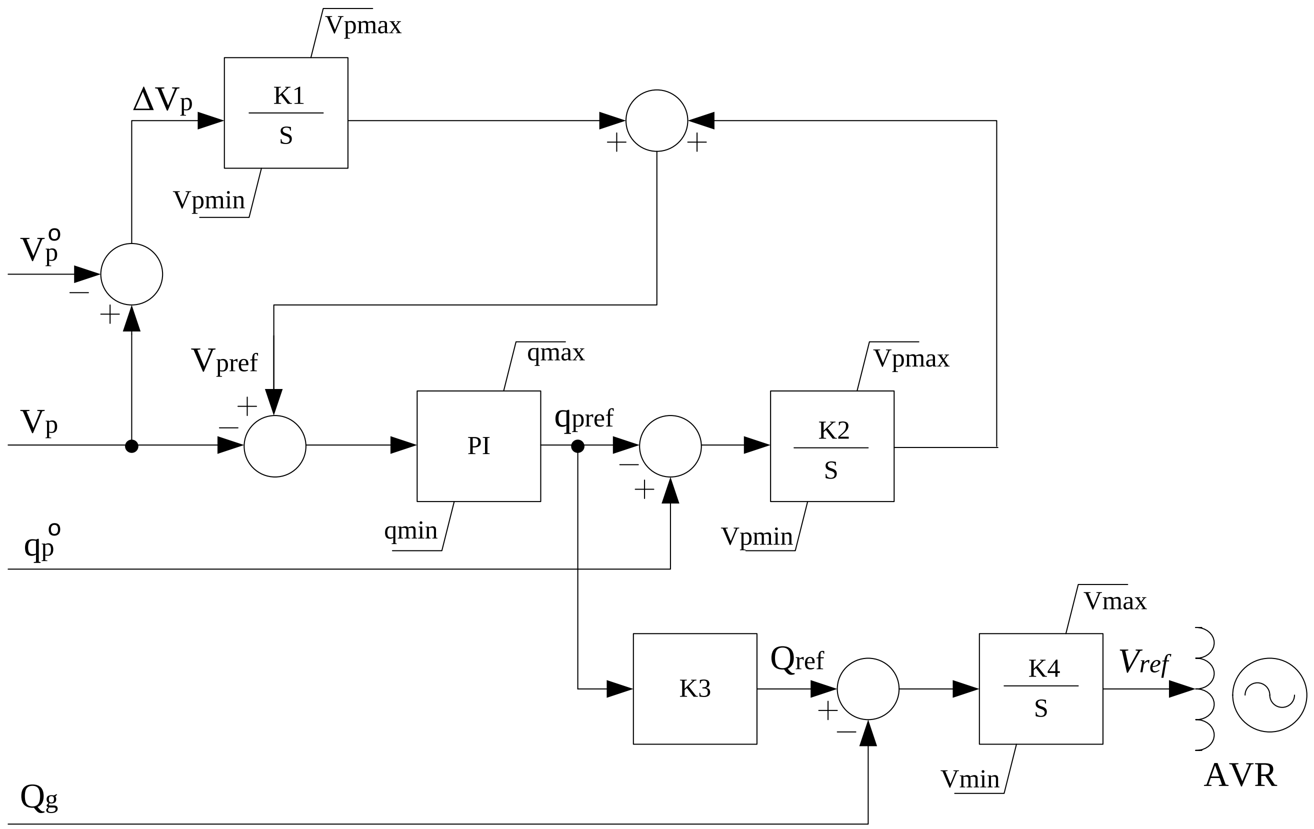
AVC survey

Country	Architecture	Close loop	Fore cast	Objective	Controllers	Inequality constraints
France [11, 13, 28]	H	x		✓ Correction of voltage violation pilot bus ✓ Correction of terminal voltage for generators ✓ Correction of reactive power violation for generators	✓ Synchronous generators ✓ High voltage Capacitors	✓ Voltage variation at the terminal of generators ✓ Voltage magnitude at the sensitive bus ✓ Voltage magnitude at the high-voltage side of the generators ✓ Reactive power generation of generators
Italy [30]	H	x	x	✓ Correction of voltage violation of pilot bus including the effect of forecast set points for losses minimization ✓ Correction of reactive power violation of zones including the effect of forecast set points for losses minimization	✓ Synchronous generators ✓ Shunt Capacitors/Reactors ✓ Taps ✓ FACTs	✓ Voltage limits ✓ Components limits
Belgium [43]	H			✓ Maximization of the reactive power margin on each group of synchronous generators ✓ Minimize the switching of capacitor banks ✓ Restricted inter reactive power flow to neighbor systems ✓ Voltage correction	✓ Synchronous generators ✓ Shunt capacitors ✓ Taps	✓ Voltage limits ✓ Components limits
Spain [44]	H		x	✓ Solve congestions ✓ Correction of voltage violation primary for solve low-voltage problem	✓ Synchronous generators ✓ Shunt reactors ✓ Taps	✓ Voltage limits ✓ Components limits ✓ Auxiliary services limits
Switzerland [41]	C		x	✓ Cost minimization of losses plus reactive power payments	✓ Generators ✓ Taps	✓ Voltage limits for all nodes ✓ Voltage differences between nodes ✓ Reactive power flow on ties ✓ Components limits
China [25]	H	x		✓ Adaptive Pilot selection ✓ Losses minimization ✓ Correction of voltage violation	✓ Synchronous generators ✓ Taps ✓ Shunts	✓ Voltage limits ✓ Components limits
British Columbia [42]	C			✓ Losses minimization ✓ Correction of voltage violation	✓ Shunt Capacitors/Reactors ✓ Synchronous condensers ✓ SVCs	✓ Voltage limits for the selected nodes ✓ Components limits

Conventional hierarchical AVC



Example of SVR in hierarchical AVC

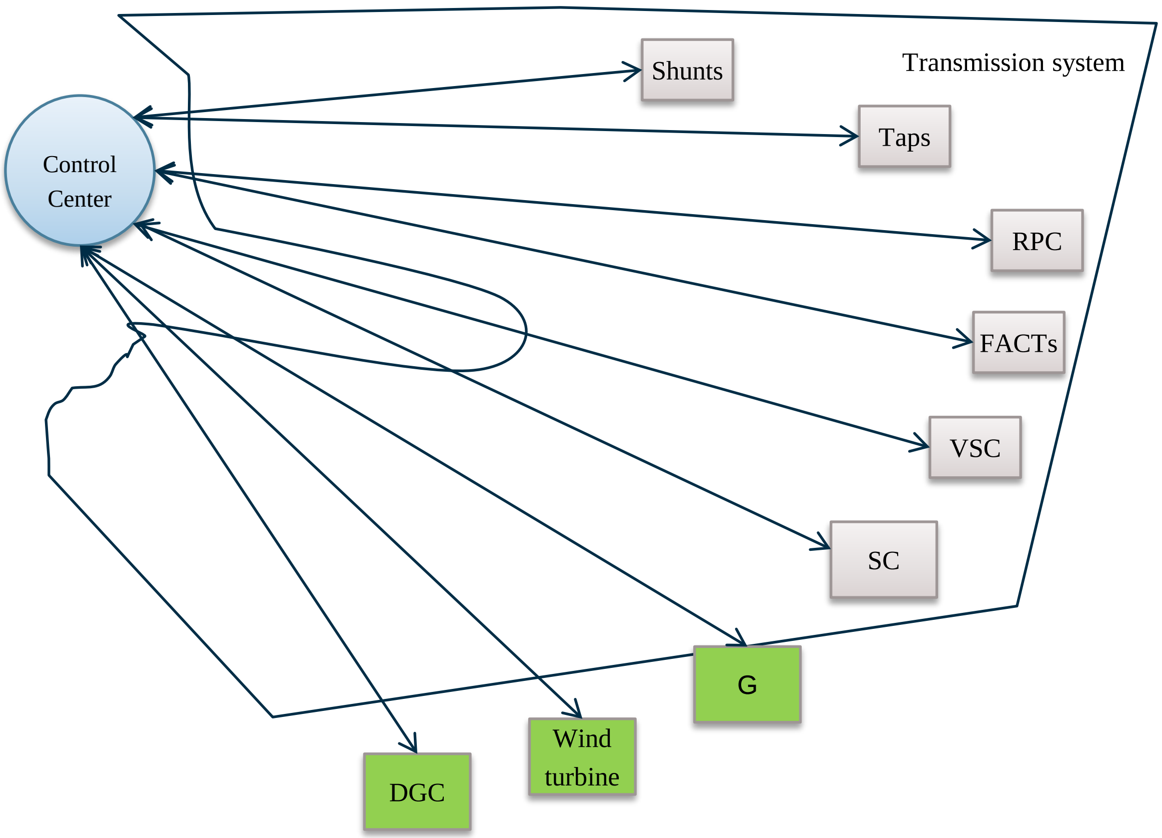


Danish AVC system in the first phase

- Need pilot bus?
- Prioritize the controllers?
- What is the objective? Losses minimization?
- Forecast?
- Fallback?
- How to cope with RPC?
- DSO for power factor correction?

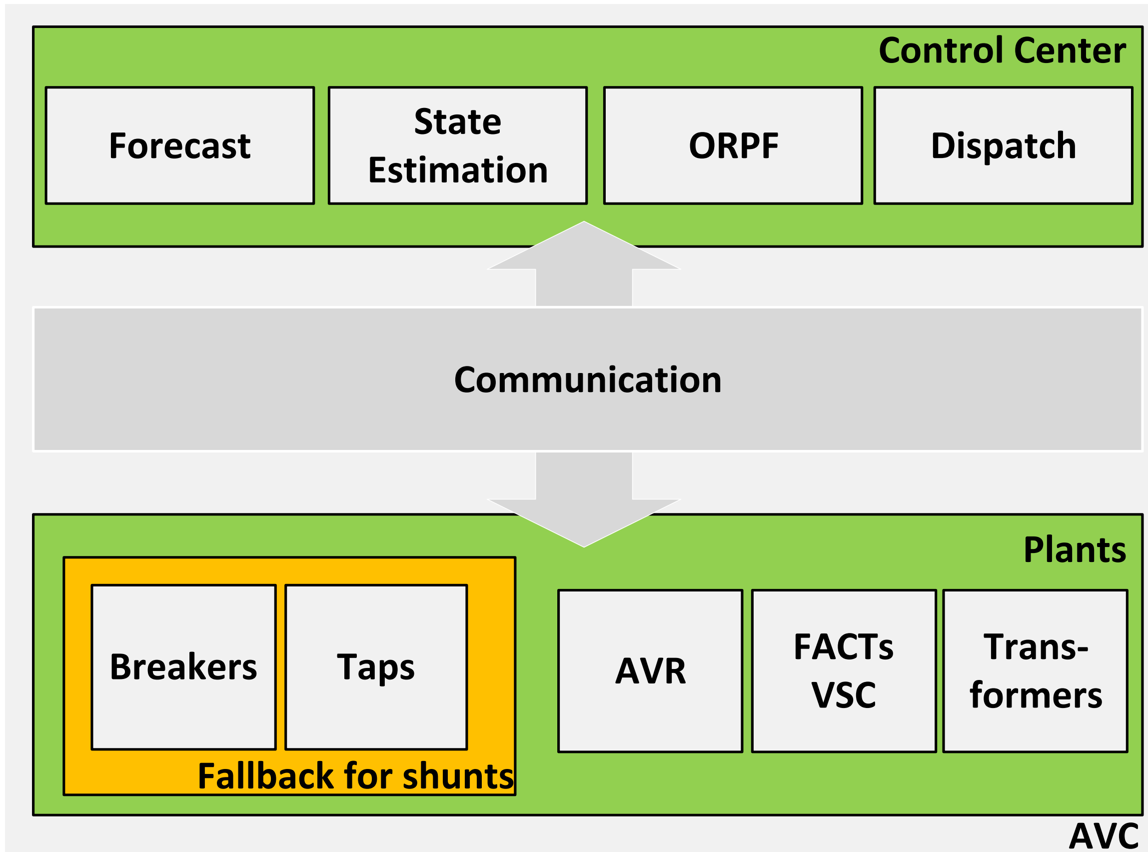
- All buses in transmission levels.
- Cheapest first.
- Maximize energy saving in €.
- Reactive power schedule.
- Local control without coordination.
- Integrate RPC as a whole.
- Limited effect.

Centralized AVC in Danish power system



- Efficiently assist operators to maintain the voltage
- Minimize the loss in the transmission grid considering the switching cost
- Locally control the switchable shunts to maintain the voltage if AVC malfunctioned

Overall structure of Danish AVC system



Country	Structure	Closed loop	Forecast	Objective	Controllers	Inequality constraints
France [6-8]	H	x		✓ Correction of voltage violation at pilot bus ✓ Correction of terminal voltage for generators ✓ Correction of reactive power violation for generators	✓ Generators ✓ High voltage Capacitors	✓ Voltage variation at the terminal of generators ✓ Voltage magnitude at the sensitive bus ✓ Voltage magnitude at the high-voltage side of generator ✓ Reactive power of generator
Italy [9]	H	x	x	✓ Correction of voltage violation of pilot bus including the effect of forecast set points for losses minimization ✓ Correction of reactive power violation of zones including the effect of forecast set points for losses minimization	✓ Generators ✓ Shunts ✓ Transformer ✓ FACTs	✓ Voltage limits ✓ Components limits
Belgium [23]	H			✓ Maximization of the reactive power margin on each group of synchronous generators ✓ Minimize the switching of capacitor banks ✓ Restricted inter reactive power flow to neighbor systems ✓ Voltage correction	✓ Generators ✓ Shunt capacitors ✓ Transformer	✓ Voltage limits ✓ Components limits
Spain [24]	H		x	✓ Solve congestions ✓ Correction of voltage violation primary for low-voltage problem	✓ Generators ✓ Shunt reactors ✓ Transformer	✓ Voltage limits ✓ Components limits ✓ Auxiliary services limits
Switzerland [14]	C		x	✓ Cost minimization of losses plus reactive power payments	✓ Generators ✓ Transformer	✓ Voltage limits for all nodes ✓ Voltage differences between nodes ✓ Reactive power flow on ties ✓ Components limits
China [11]	H	x		✓ Adaptive Pilot selection ✓ Losses minimization ✓ Correction of voltage violation	✓ Generators ✓ Transformer ✓ Shunts	✓ Voltage limits ✓ Components limits
British Columbia [25]	C			✓ Losses minimization ✓ Correction of voltage violation	✓ Shunts ✓ Condensers ✓ SVCs	✓ Voltage limits for the selected nodes ✓ Components limits
Denmark	***C***	***x***	***x***	✓ ***Correction of voltage violation*** ✓ ***Maximize energy saving***	✓ ***Shuns*** ✓ ***Condensers*** ✓ ***SVCs*** ✓ ***VSC-HVDC*** ✓ ***Transformer***	✓ ***Voltages limits for all bus*** ✓ ***Components limits (reactive power reserve)*** ✓ ***Cost on regulations***

Future work

- Suppress the voltage violations on the sensitive buses
  - Pilot bus selection method – Identifying the pairs of controllers and the target
  - PMU data application – Inputs for adaptive control
  - Control optimization
- Integrate forecast to AVC system for obtaining a reactive power schedule
- Assess the impact of D2T strategy
  - Evaluate the effect of supporting from distribution to transmission grid
- Algorithm for OPF calculations
  - Distributed OPF processing

Questions and comments?

Biography

- *Nan Qin* – received M.Sc in electrical engineering from Technical University of Denmark in 2009. From 2009 to 2013, he was working on system stability assessments in the Danish Transmission System Operator, Energinet.dk. He is now an industrial ph.d student in Aalborg University, Denmark. His main research interests include automatic voltage control system and system optimizations.