Advanced Simulation tools in support of the design of the Power System architecture of the European Spallation Source (ESS)

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The E.ON Energy Research Center

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- June 2006: the largest research co-operation in Europe between a private company and a university was signed
- Five new professorships in the field of energy technology were defined across 4 faculties
- Research areas: energy savings, efficiency and sustainable power sources

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Outlines

- Background
- Simulation Project Goal
- Simulation Approach and Modeling
- Test Scenarios and Results
- Conclusions and Future works

Background

- ESS: European Spallation Source
  - A joint European project, which has partners from 17 European countries
  - Trend for reduction of energy consumption and greenhouse gas (GHG) emission
  - Design proposal: establish an energy concept for demanding energy targets to be
    - *RESPONSIBLE* – 20 per cent reduction in energy consumption
    - *RENEWABLE* – 100 per cent utilisation of renewable energy
    - *RECYCLABLE* – 60 per cent recycling of utilized energy
- Grid simulation project
  - Sustains for 2 years
  - Partners include:

EUROPEAN SPALLATION SOURCE
SUSTAINABILITY PARTNER
e·on LUNDS ENERGI

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Background

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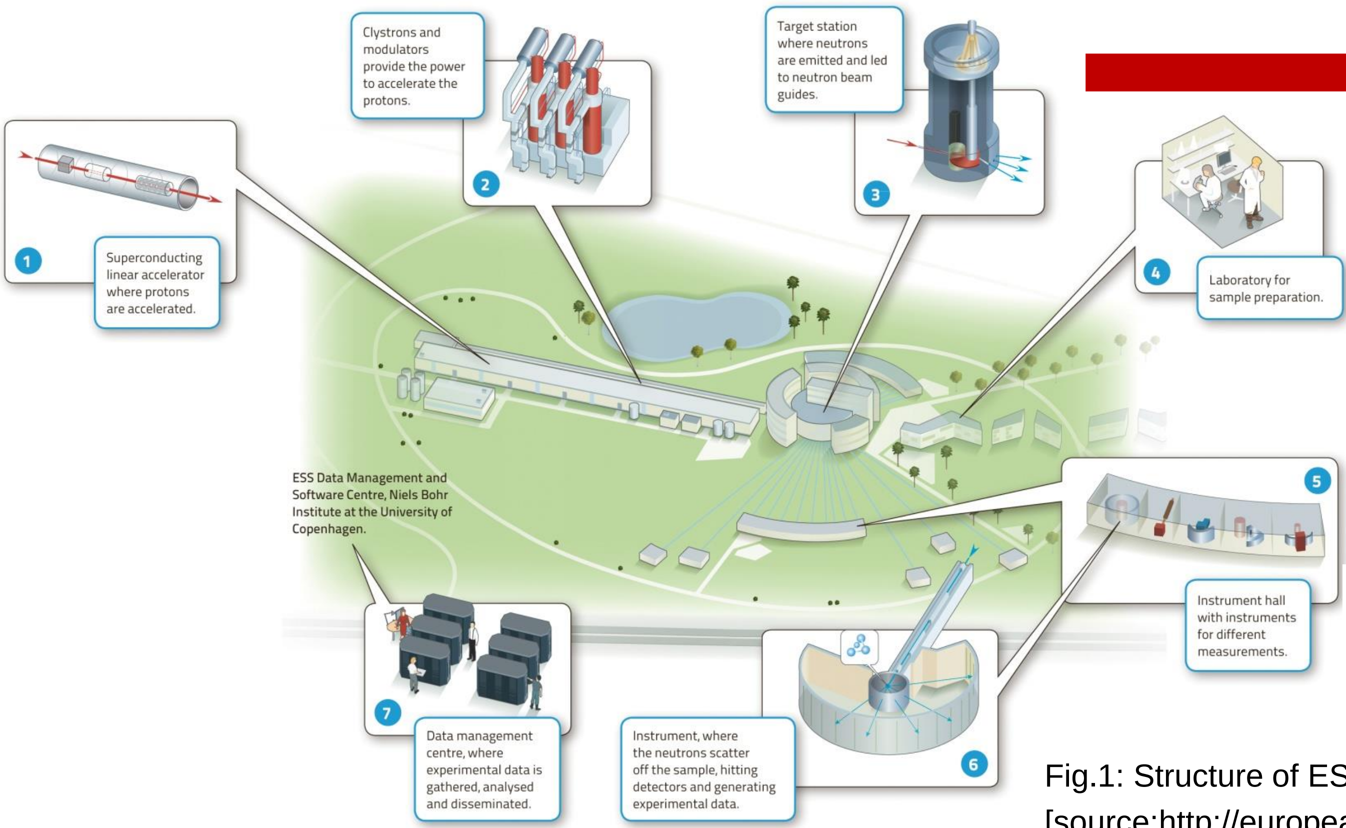

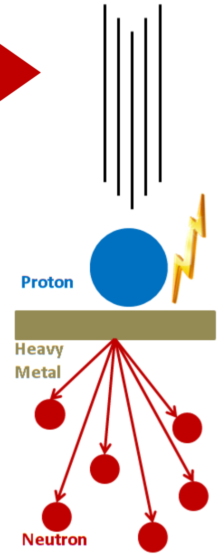

Fig.2: Process of generating neutron

Fig.1: Structure of ESS and operation [source:http://europeanspallationsource.se/photos-images]

- Internal ESS distribution grid, connected with several sections
- Linear accelerator (LINAC), the key component in ESS facility

Simulation Project Goal

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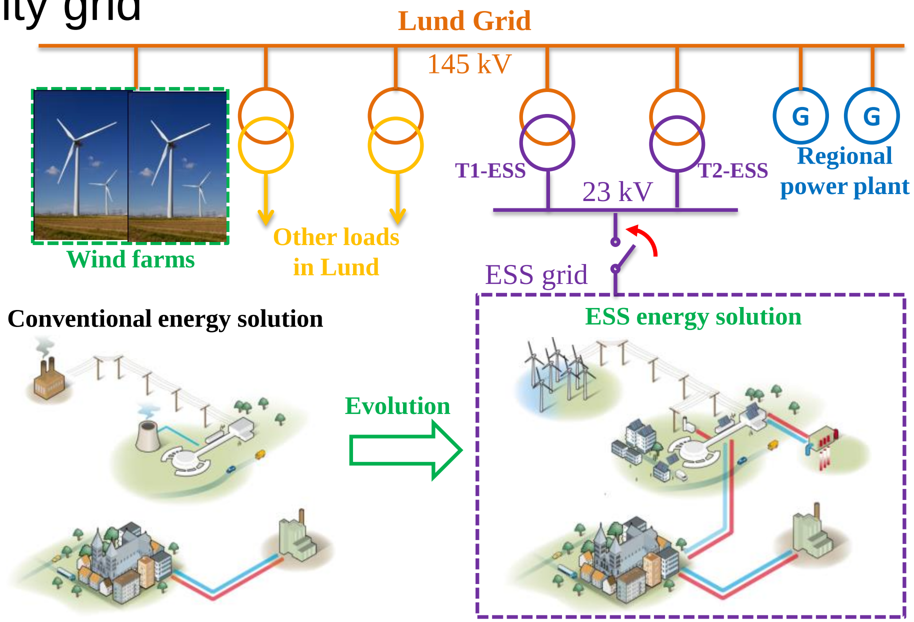
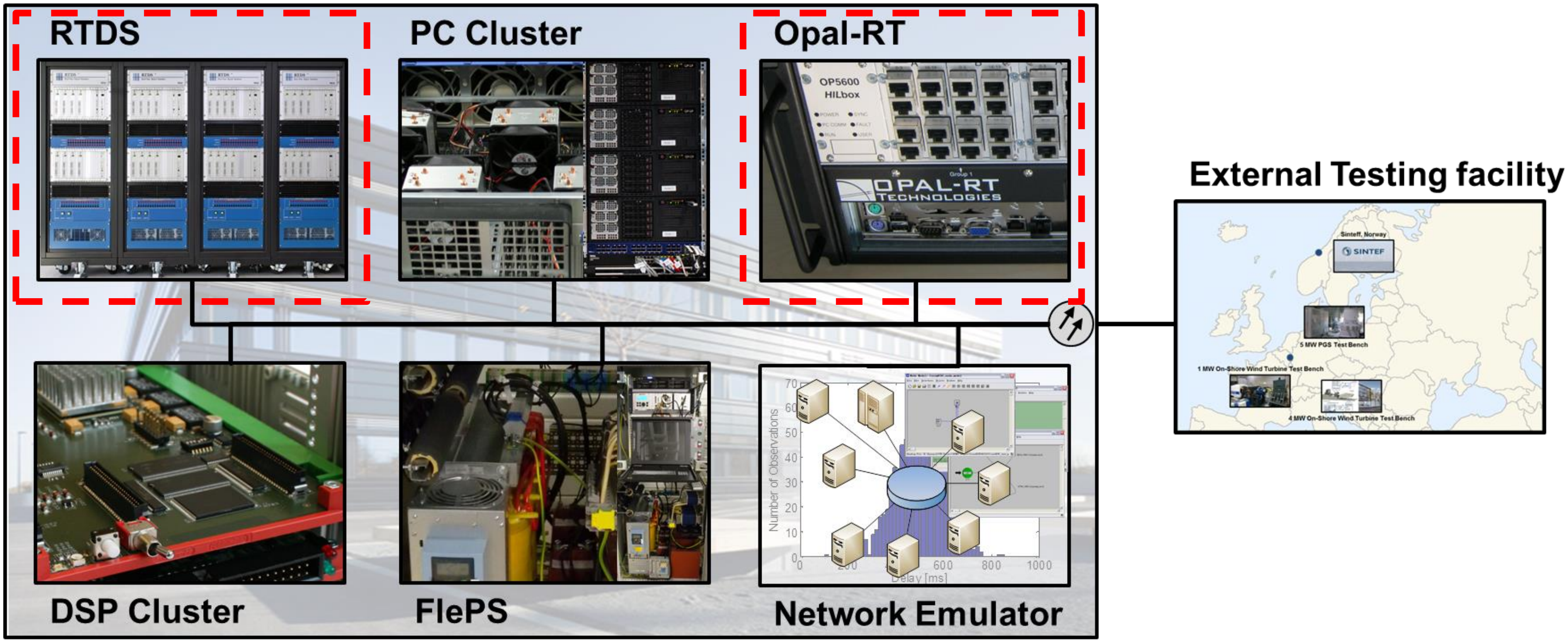
- Develop a simulation model for the regional electricity grid, including ESS grid
- Evaluate the mutual impact between newly integrated ESS and the regional grid:
  - predict disturbances that ESS can cause to the regional grid
  - predict disturbances in the operation of the ESS that can be caused by the regional electricity grid



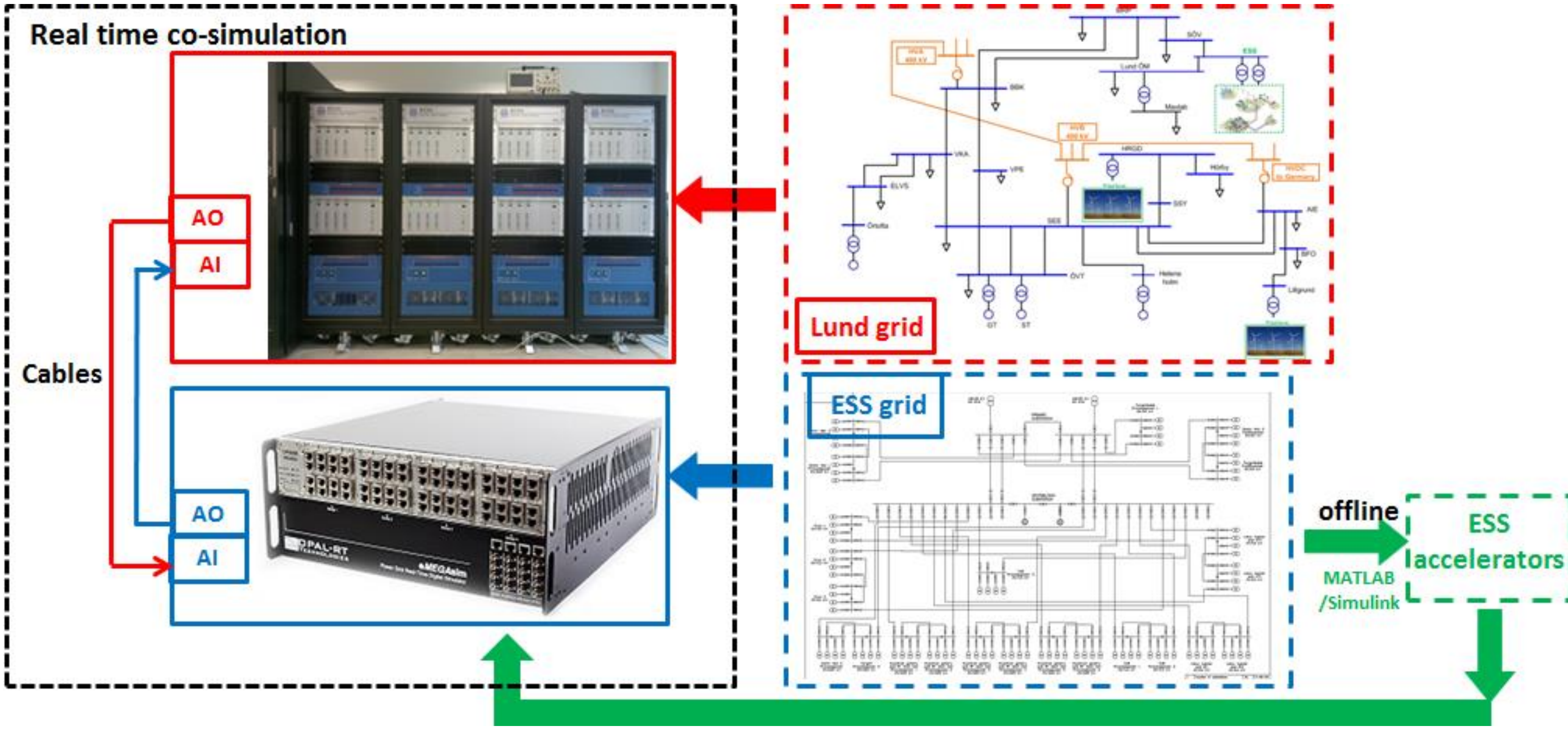
The RT Simulation Lab



Co-simulation Approach—Introduction

- Real time simulation and Hardware In the Loop methods are essential tools for the development of future complex power systems
- Given the complexity of such a scenario the use of a single tool is unfeasible
- Co-simulation approaches have to be developed, so that:
  - Dedicated tools and library can be shared
  - Different expertees can be capitalized
  - Facilities at different geographical locations can be interconnected
  - Multi-rate execution can be perfomed

Co-simulation Approach



- RTDS has a good ability to simulate electromagnetic transient, while Opal RT is compatible with the models built in MATLAB/Simulink
- The idea is to remain Lund grid models in RTDS, while to model ESS grid in Opal RT including the power electronics of LINAC
- Connection between two simulators for co-simulation by analog interface

Modeling Lund Grid in RTDS

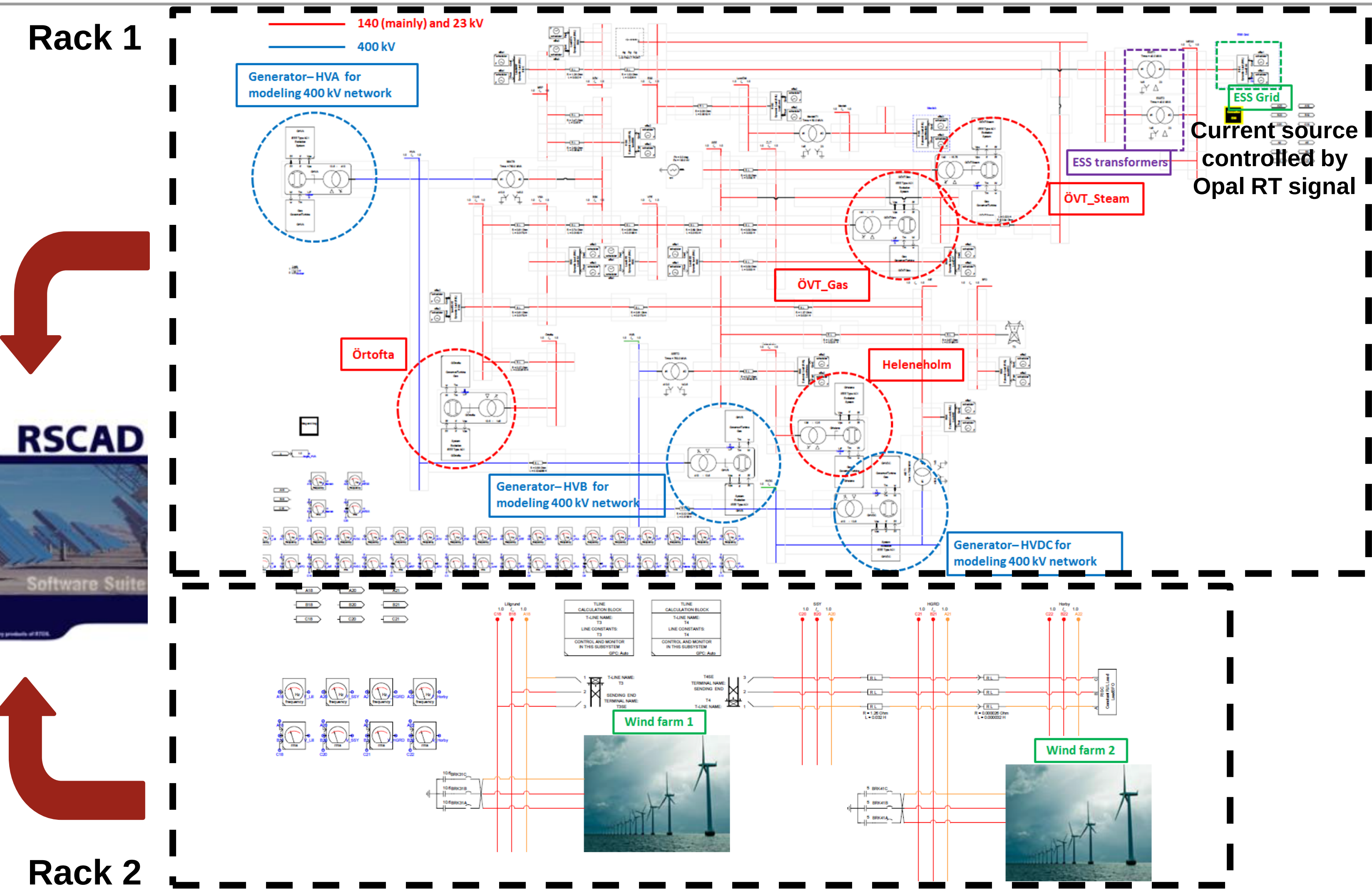
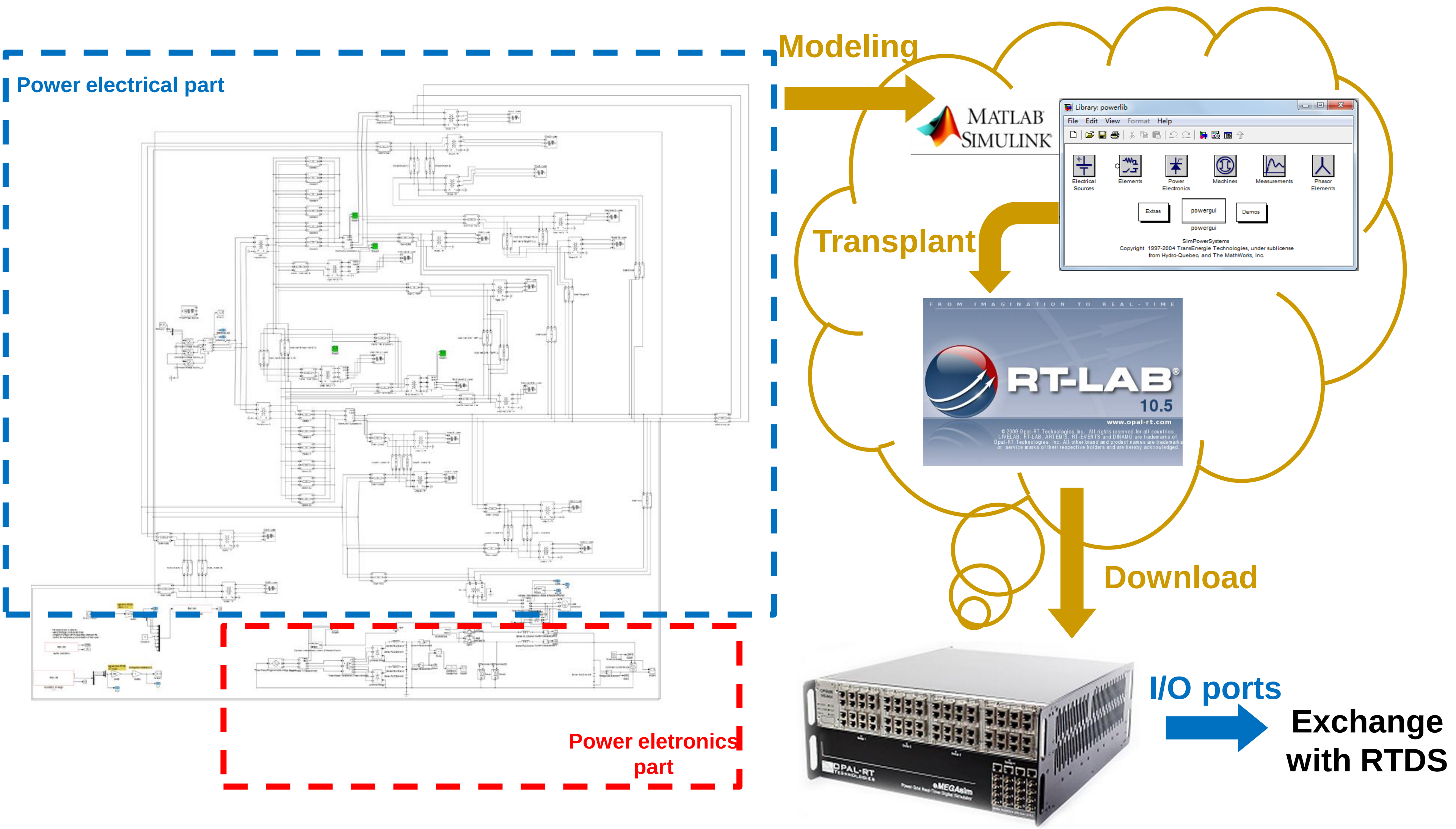


Fig.: Lund grid modeling in RTDS

Modeling ESS internal grid in MATLAB/Simulink



Modeling ESS internal grid in RT-LAB

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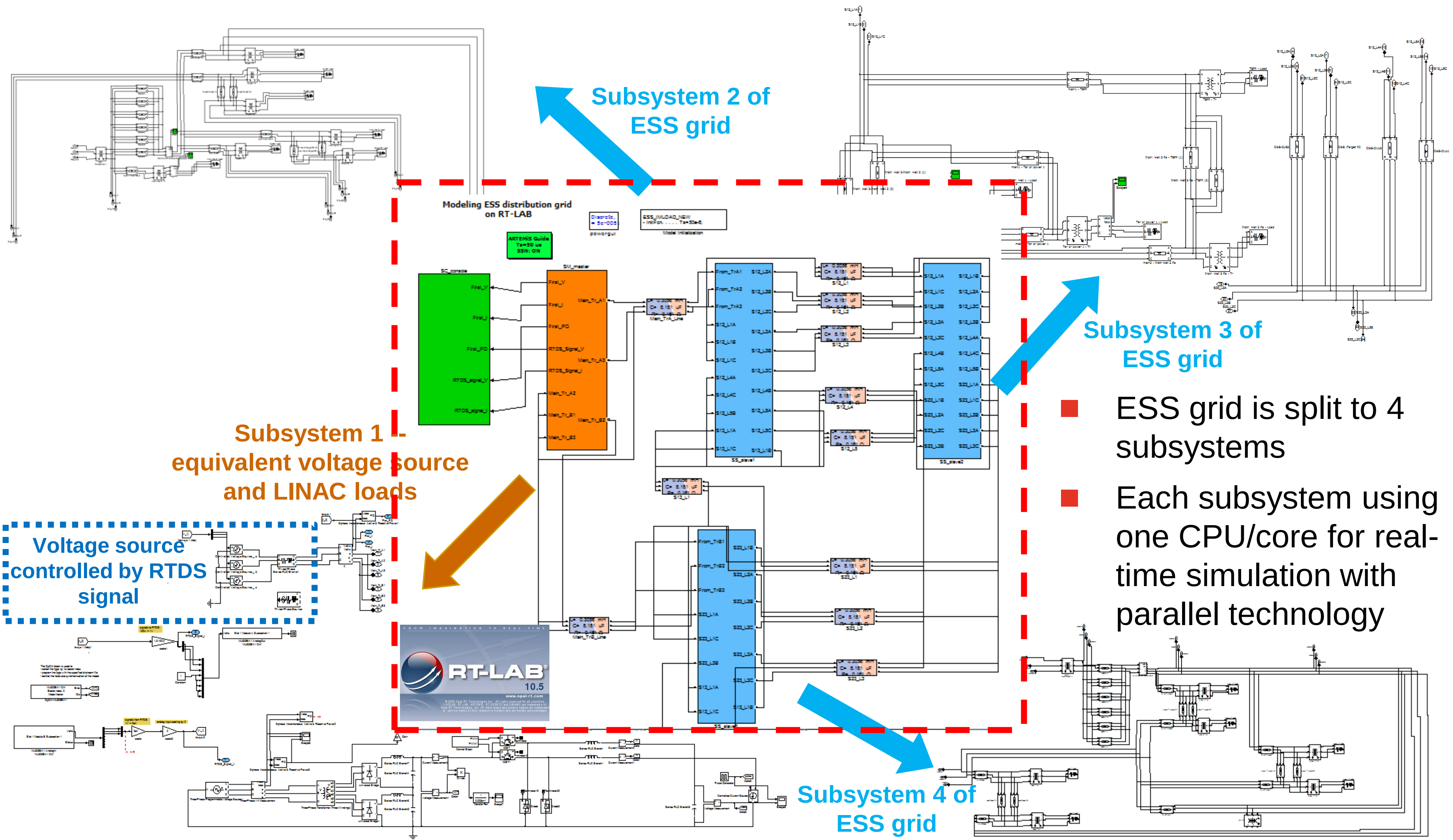

- ESS grid is split to 4 subsystems
- Each subsystem using one CPU/core for real-time simulation with parallel technology

Modeling power electronics for LINAC in RT-LAB

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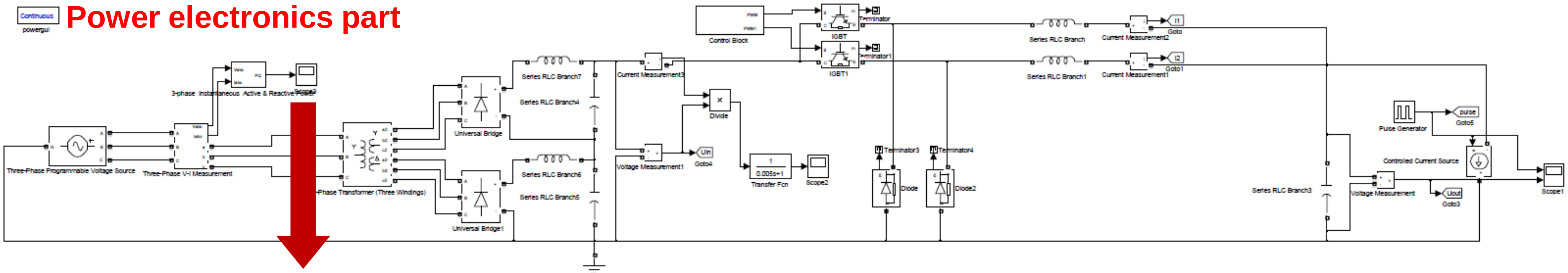
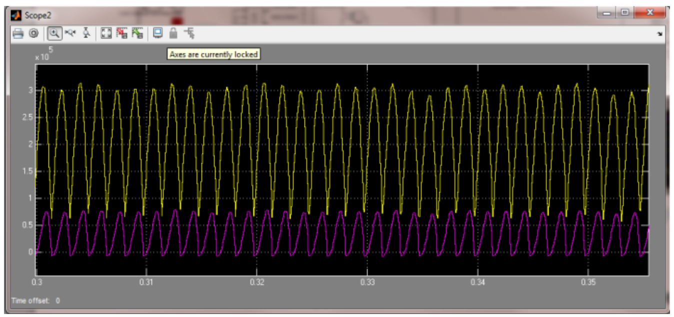
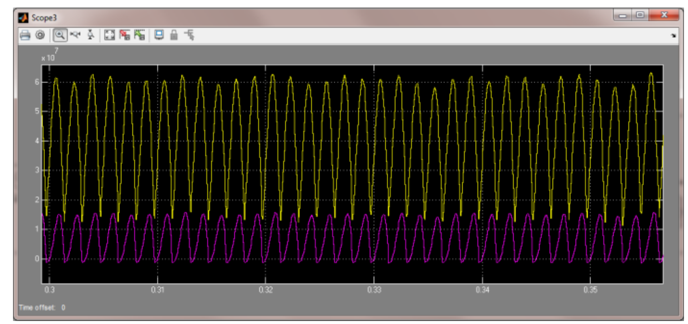
Power electronics part





amplify to 200 times



P: variation in range of [75, 310] kW

P: variation in range of [15, 62] MW

- Depends on control of power electronics, the power consumption is not very close to constant
- Simulate 200 LINACs with power electronics in real-time is infeasible
- Equivalent modeling with a controllable load and a amplified signal, is used to simulate power amplification

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Testing Scenarios—Short circuit

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Test scenarios	Location	Type	Conditions, purpose
Short circuit	ESS_in	three phase L-G	with different fault clearing times: 0.05 s, 0.1 s and 0.3 s
	ESS_in	three phase L-G	with different impedances of T1-ESS and T2-ESS: 11.5%, 15% and 20%
	ESS_in	three phase L-G	with different short circuit impedance: 0.01 Ω, 0.1 Ω and 1Ω
	ESS_in	Phase A and B L-L	compare with three phase L-G
	ESS_in	Phase A L-G	compare with three phase L-G
	ESS_out	three phase L-G	with different impedances of T1-ESS and T2-ESS: 11.5%, 15% and 20%
	ESS_out	three phase L-G	with different fault clearing times: 0.05 s, 0.1 s and 0.3 s
	ESS_out	Phase A and B L-L	compare with three phase L-G
	ESS_out	Phase A L-G	compare with three phase L-G
	SEE	three phase L-G	compare faults at different buses
	SEE	Phase A and B L-L	compare with three phase L-G at SEE
	SEE	Phase A L-G	compare with three phase L-G at SEE
	VKA	three phase L-G	compare faults at different buses

- To check the impacts when various types of short circuits happen at different locations, as well as impedances of transformers and grounding

Testing Scenarios—Loss of components

Test scenarios	Location	Type	Purpose
Tripping of power source	HVA	tripping	compare such kind of faults at different buses
	HVB	tripping	
	HVDC	tripping	
	Wind farm	tripping	
	Örtofta and Helene simultaneously	tripping	
	ÖVT Steam and Gas simultaneously	tripping	
Loss of branch and transformer	(SEE-ESS) and (ESS-Lund) simultaneously	loss	compare such kind of faults at different buses
	(SEE-ESS) and (HVA-BBK) simultaneously	loss	
	(SEE-ESS) and (SEE-VKA) simultaneously	loss	
	T2-ESS	loss	

- As common fault types - loss of components
- With cascading faults occurring more frequently than in the past, different combinations of component loss are relevant
- Loss of transformers connecting ESS and Lund grid - possible disruptive impact on the operation of ESS

Testing Scenarios—Normal operations

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Test scenarios	Location	Purpose
Connection	ESS_in	check the impact of such operations on the grid
Disconnection	ESS_in	
Charging schemes	ESS_in	compare with the impact caused by charging scheme I and III on grid
Harmonics	ESS_in	analysis for realistic data based harmonics
	ESS_in	analysis for the threshold of THD 8% (as defined in the grid code of E.ON Sverige AB) based harmonics
	SEE	
	Maxlab	
Wind farm	Lillgrund	check the impact of wind farm with different generation ratio: 0%, 50%, 100%, in aspect of power flow

- Normal operation of ESS may also impact the whole grid
- Charging schemes of LINAC mainly determine the load characteristics of ESS
- Variability of wind power generation impacts power flow and state variation in Lund grid

Test Result 1

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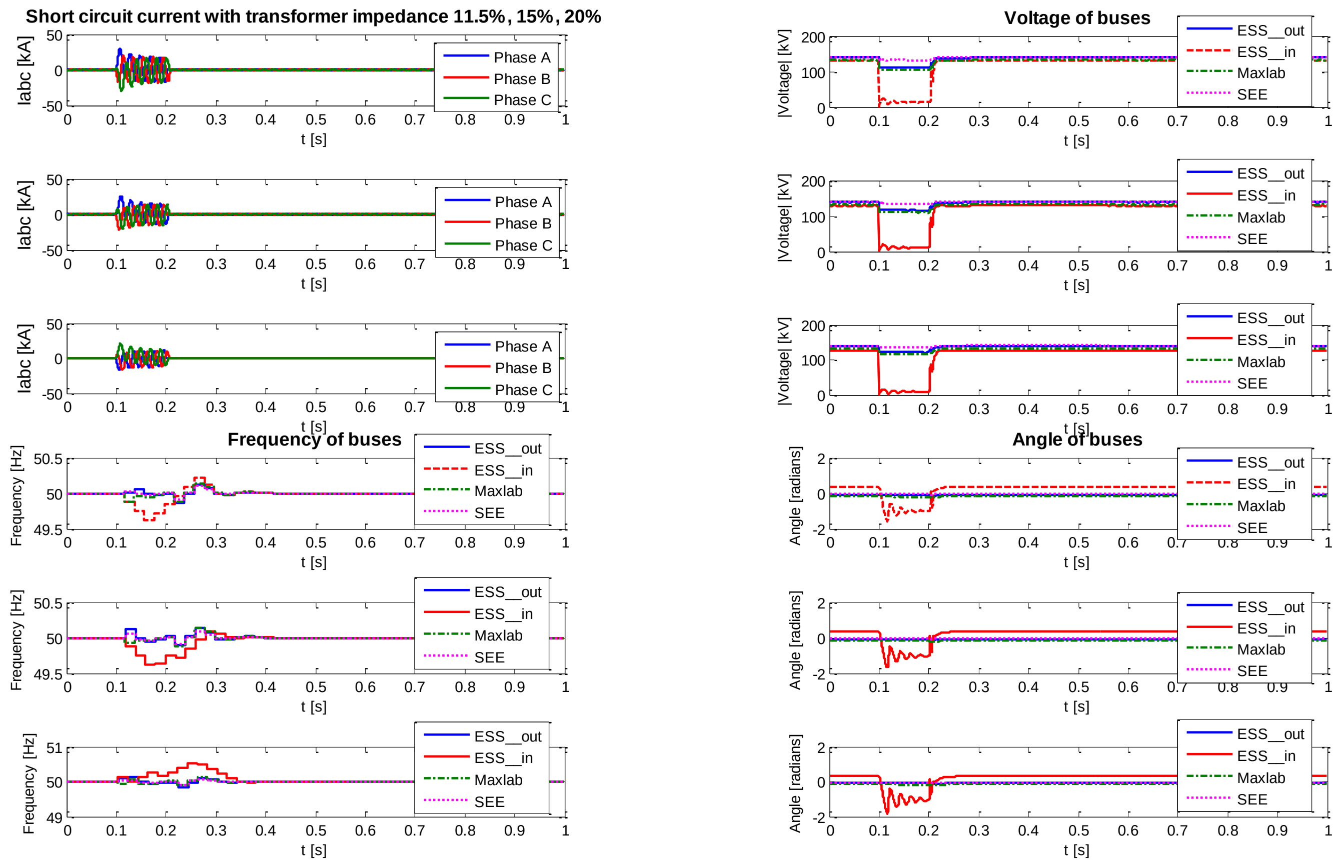
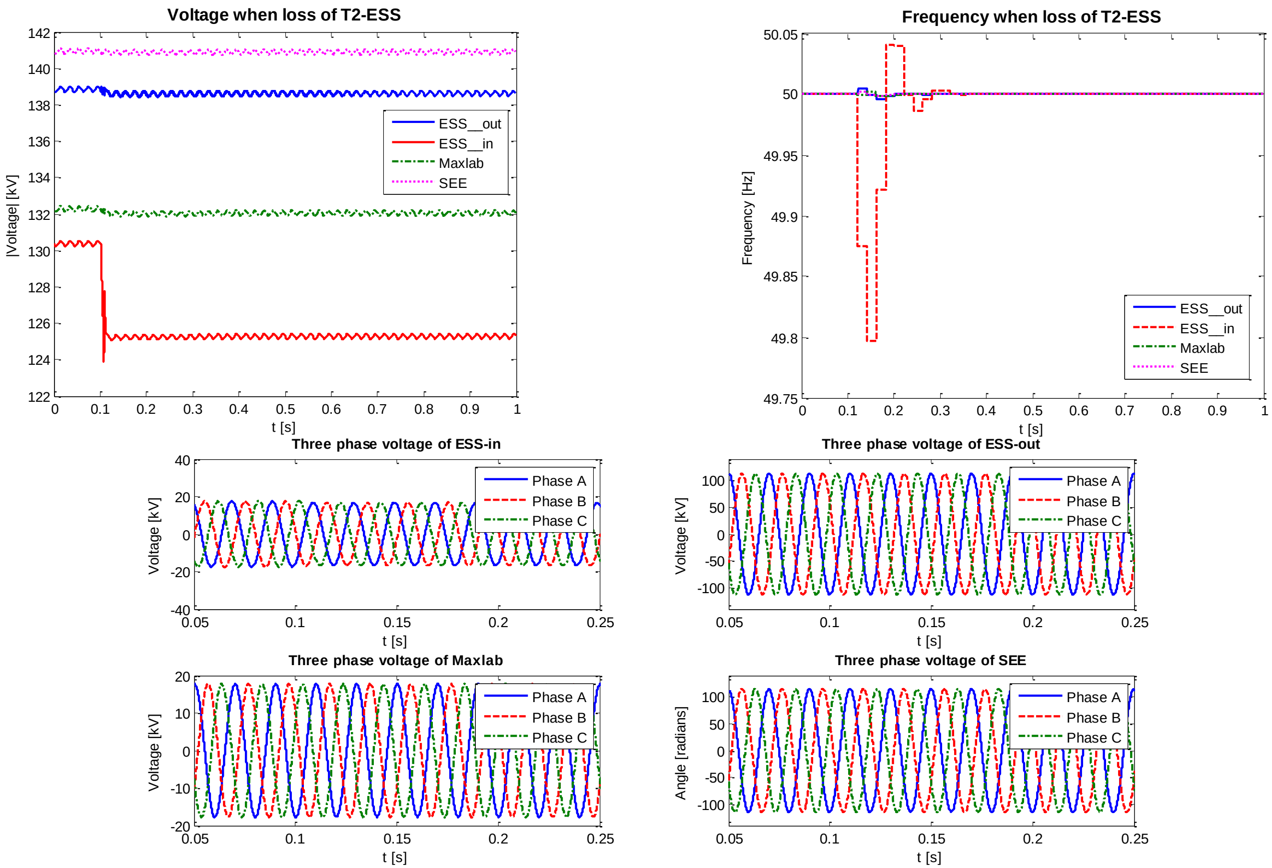
3-phase L-G short circuit at ESS_in with different transformers impedances



- With different impedances of transformers 11.5%, 15% and 20%
- Maximum of AC short circuit current are 30.16, 26.54 and 21.59 kA individually
- Higher impedance of the transformers can restraint the short circuit if such kind fault happens at ESS internal

Test Result 2

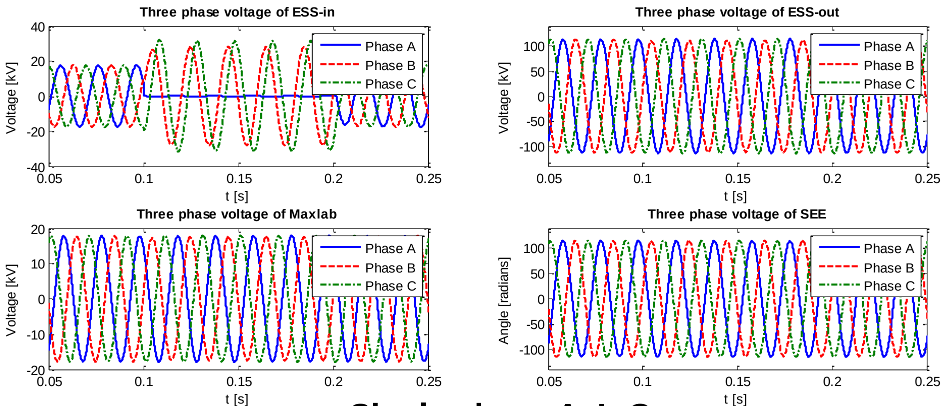
Loss of transformer T2-ESS



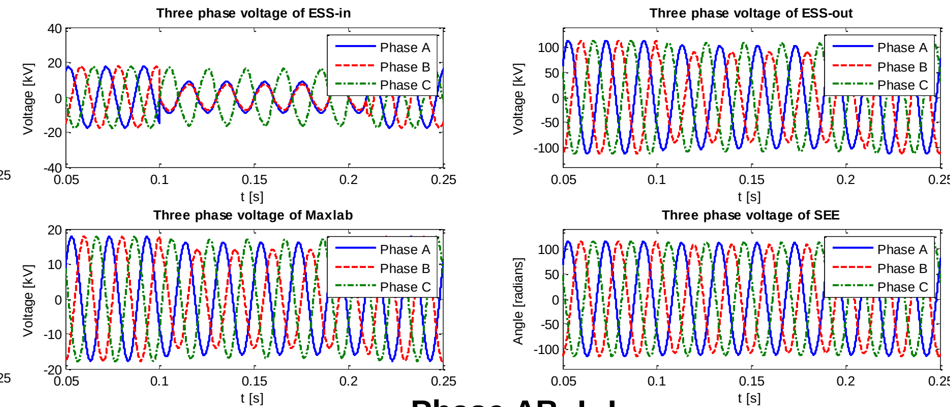
- Maximum power consumption of ESS 47 MW, while capacity of transformer 40 MVA
- Once any one of the transformers is out of work, there is a potential risk of overload for the other one
- For the voltage of ESS_in, the decrease is over 10%

Test Result 3

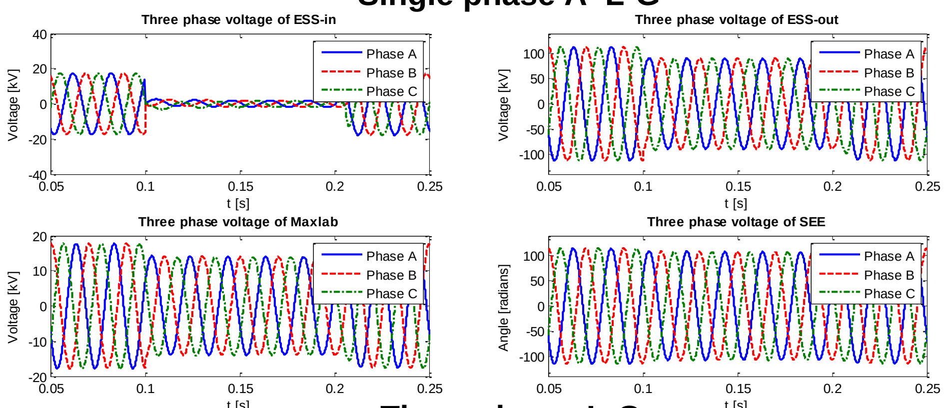
Short circuit at ESS_in with different fault types



Single phase A L-G



Phase AB L-L



Three phase L-G

Fault type	Va (kV)	Vb (kV)	Vc (kV)
Single phase A L-G	0.3778	28.04	31.48
Phase AB L-L	8.94	7.48	16.37
Three phase L-G	2.14	2.06	2.39

- Recordings about the instantaneous voltage at ESS_in, ESS_out, Maxlab and SEE
- Single phase L-G short circuit introduces overvoltage to the other two phases of ESS_in
- Two-phase L-L short circuit lead voltage decrease in the two phases of ESS_in
- Three-phase L-G cause serious undervoltage for each phase of ESS_in

Test Result 4

3-phase L-G short circuit at different locations in the Lund grid

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Bus_Name	Number
AIE	1
BBK	2
BFO	3
ELVS	4
ESS	5
HVA	6
HVB	7
HVDC	8
Helene	9
Lund ÖM	10
MRP	11
Maxlab	12
ÖVT	13
Örtofta	14
SEE	15
SÖV	16
VKA	17
VPE	18
HRGD	19
Hörby	20
Lillgrund	21
SSY	22

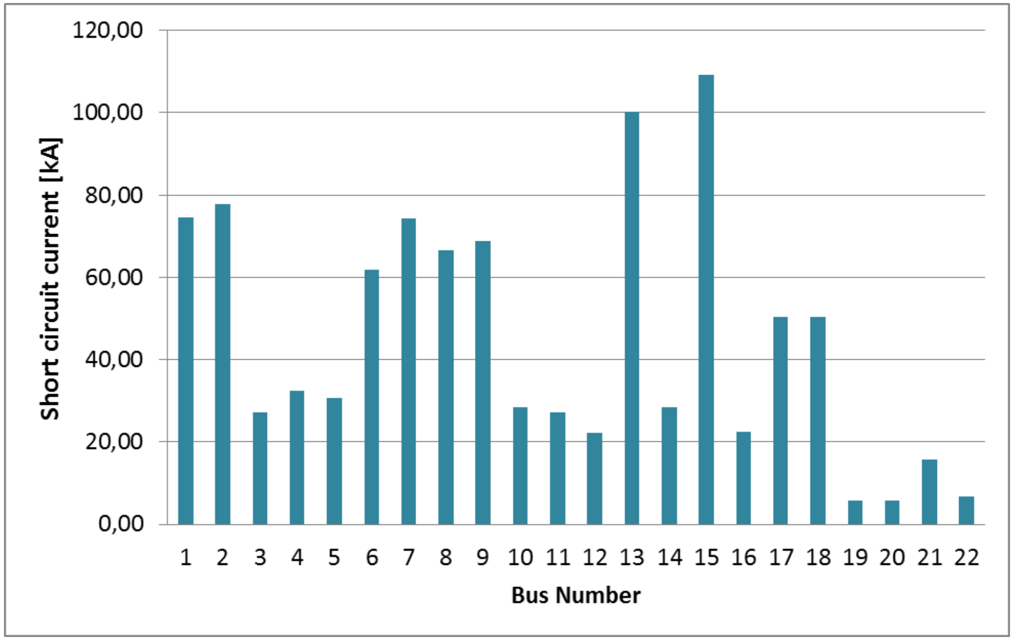

Fig.: Maximum instantaneous amplitudes of three-phase L-G short circuit current of each bus when ESS is connected to Lund grid

- Three-phase L-G short circuit is the most detrimental to the system
- Effects of short circuit faults highly depend on their locations in the grid
- The fact that the ESS is connected or disconnected from the Lund grid has a minor impact on the short circuit current

Test Result 5

Impact from different charging schemes of LINAC of ESS grid

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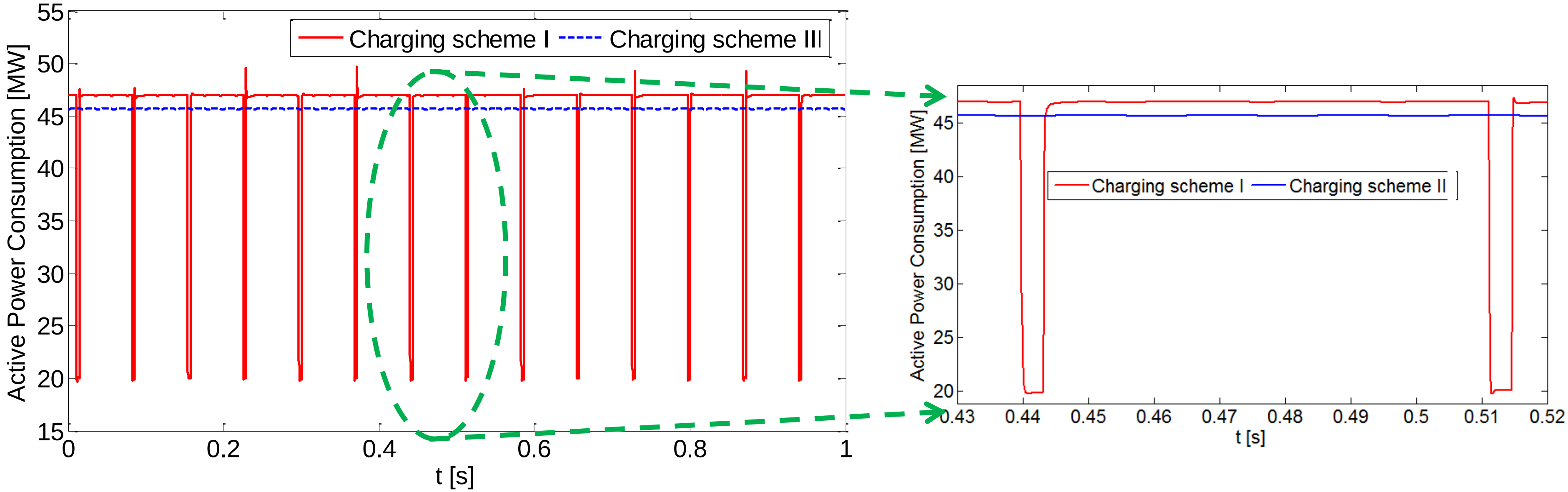
Base load (estimation)	Active Power P (MW)	Reactive Power Q (MVar)
Transformer Rating	26 MVA (Q is assumed 15% of P)	
Maximum load level	20	3
Minimum load level	6	0.9

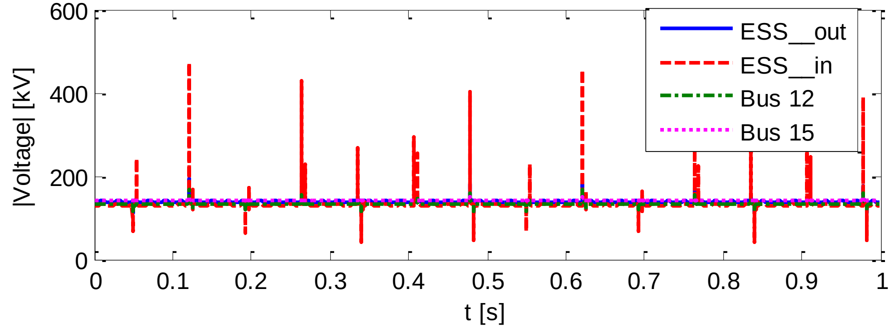
Charging Scheme according to report by Carlos Martins	Active Power P	Reactive Power Q
I	27 MW for 67.9 ms 0 MW for 3.5 ms	Option 1: diode component, 12 MVar Option 2: IGBT component, 2 MVar
II	25.7 MW constant	



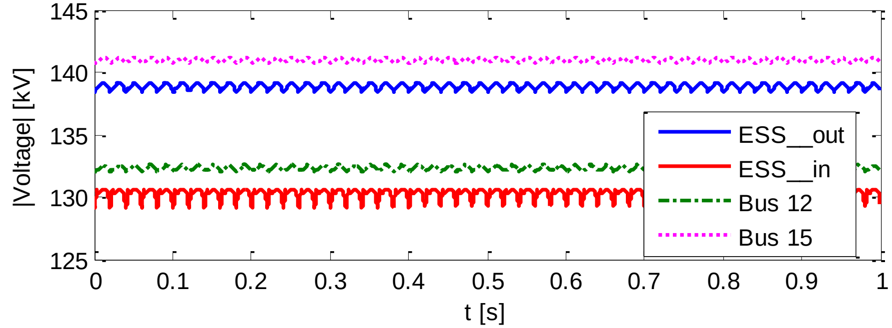
Test Result 5

Impact from different charging schemes of LINAC of ESS grid

Scheme I:



Scheme II:



- Voltage: the Charging Scheme I yields high flicker to the other loads, especially for Bus 12 (another research facility around)
- Frequency of the voltage pulses is identical to charging frequency of **Scheme I** (constant current)
- With respect to the voltage, Charging Scheme I is worse than Charging **Scheme II** (constant power)

Test Result 6

Wind farm with different generation ratios

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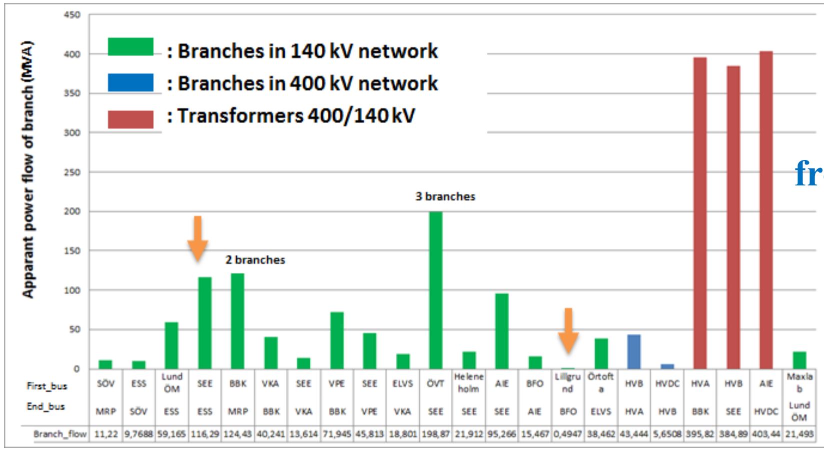
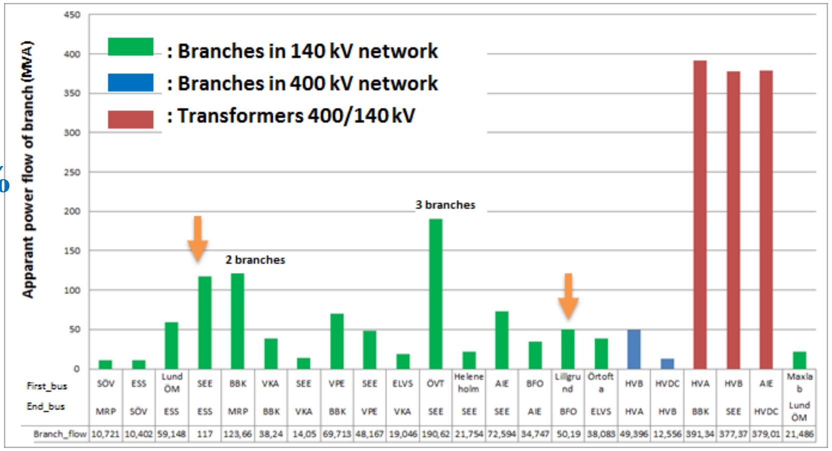
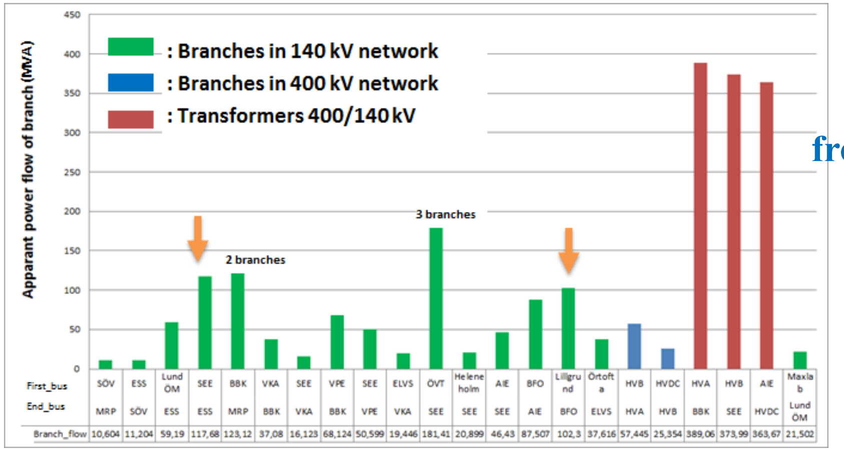


from 0% to 50%



from 50% to 100%



- Due to the power being mostly provided by transmission network, the impact aroused by the wind farms is limited, from the point view of power flow distribution

Test Result 7

Uncertainty analysis for the variation of loads and wind farm generation

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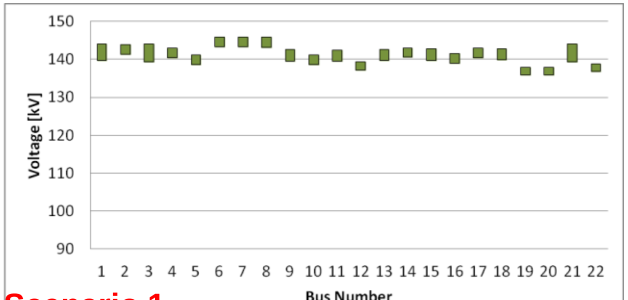
Load condition		
Substation	**Maximum (MW)**	**Minimum (MW)**
AIE	400	45
BBK	75	25
BFO	15	4
ELVS	55	10
Heleneholm	25	10
Lund ÖM	35	15
Maxlab	20	15
MRP	110	25
SEE	235	100
SÖV	15	2
VKA	15	4
VPE	110	50
ÖVT	10	2.5
ESS (Charging Scheme II)	45.7	31.7

Test scenario	Uncertainty source
1	Load variation of Bus AIE, MRP, SEE and VPE
2	Intermittence of the two wind farms
3	Load variation of ESS
4	Load variation of the four buses in test scenario 1 together with ESS, and intermittence of the two wind farms

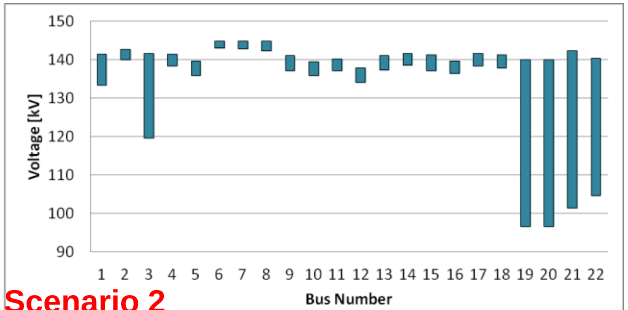
- Loads vary with uniform distributions, while the Weibull distribution for wind speed of wind farms
- Uncertainty sources include five selected load buses with large loads and two wind farms
- RTDS simulation co-operated with Monte Carlo (MC) method is adopted to investigate the uncertainty issue, (10000 MC simulations)

Test Result 7

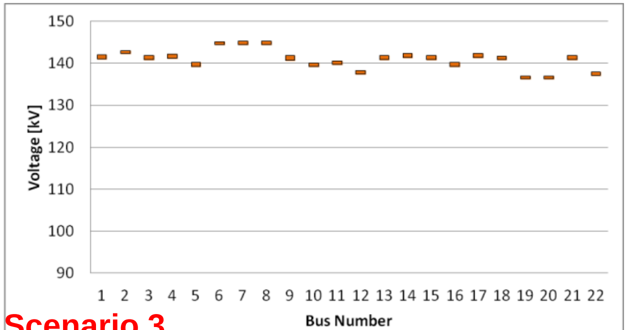
Uncertainty analysis for the variation of loads and wind farm generation



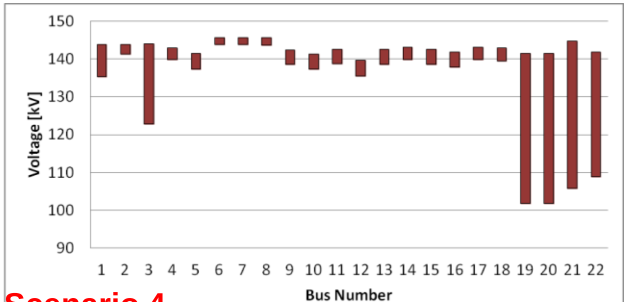
Scenario 1



Scenario 2



Scenario 3



Scenario 4

- Ranges of voltage variation in scenarios are different
- Some voltages even drop to an unacceptable range in test scenario 2 and 4 due to the integration of wind farms
- Voltage is more volatile at the buses located with wind farm or heavy loads

Test Result 7

Uncertainty analysis for the variation of loads and wind farm generation

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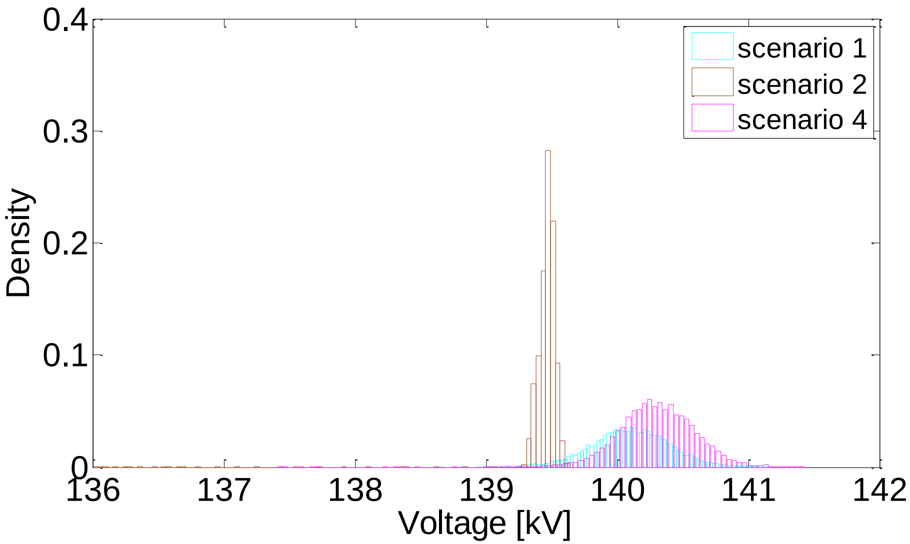

Fig.1: Frequency histogram of voltage at Bus 5 in test scenario 1, 2, 4 respectively.

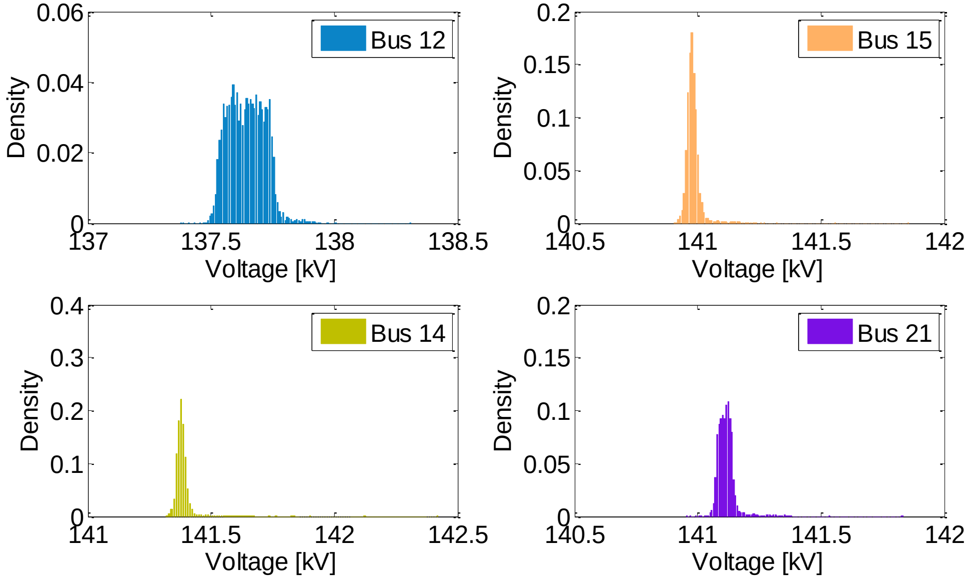

Fig.2: Frequency histogram of voltage at Bus 12, 14, 15 and 21 in test scenario 3

- Uncertainty merely from wind farm generations does not yield a large variation to the voltage Bus 5 (ESS), while variations from the four largest load buses lead to a broader range of possible voltage values
- Uncertainty of wind farms can mitigate the impact from stochastic load variations
- In terms of voltage variation, Bus 12 (Maxlab) is larger in comparison with Bus 14 (power plant), Bus 15 (big load consumer) and Bus 21 (wind farm)

Test Result 8

Uncertainty analysis for the variation of loads in future scenarios

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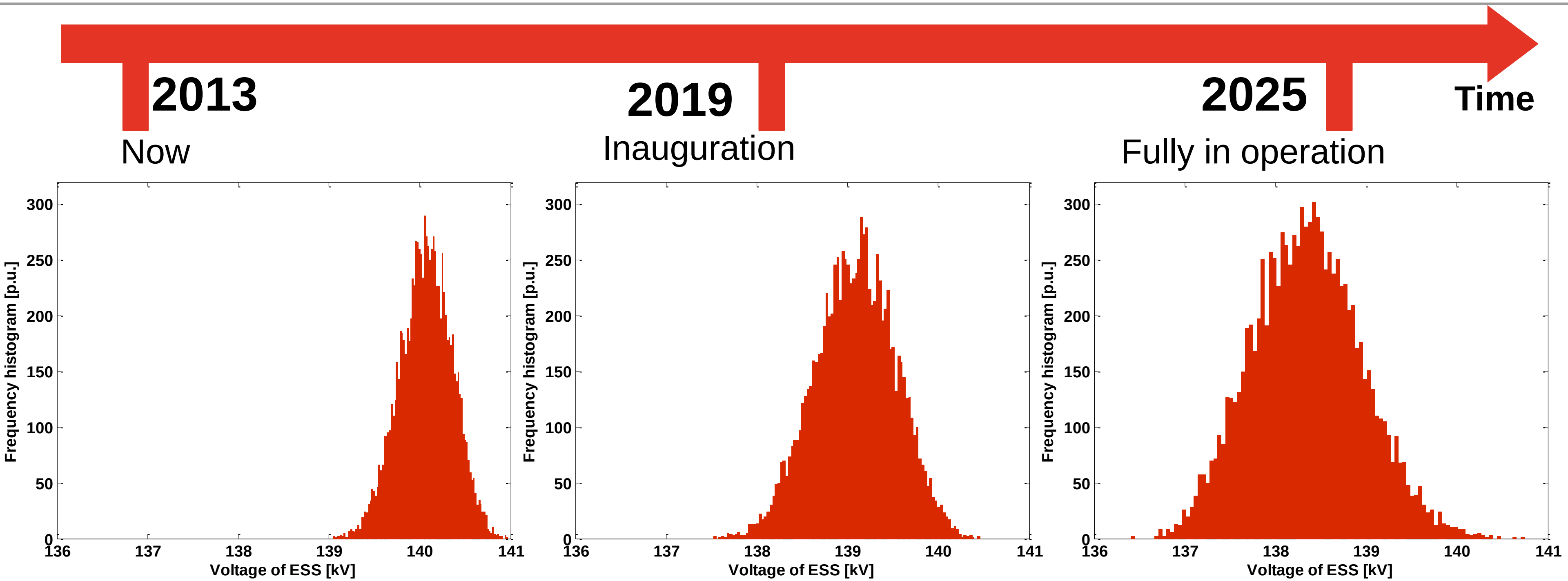

- Load demand is uniform distributed, and its growth rate is assumed 5% per year
- Errors in load prediction following a normal distribution (0, 0.01), the incrementals are 0, 30%*(1±0.03) and 60%*(1±0.03) individually
- Uncertainty increases along with time, the impact will be bigger and more chanllenging in future scenarios

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Conclusions

- Main transformers connecting ESS grid and Lund grid highly decide the status of ESS grid
- Load characteristics of ESS grid mainly depends on the charging schemes of LINAC, which is possible to disturb the power quality of Lund grid
- Integration of ESS brings a minor impact on short circuit current of the buses in Lund grid
- Involvement of wind farms has a slight influence on the operation of ESS grid and Lund grid
- A deeper awareness about how uncertainty from the renewable sources and loads affects the operation of ESS grid and Lund grid is obtained

Future works

- Heat energy can be also considered in ESS grid, as well as Lund district heating system, will be modeled in RT-LAB to evaluate the energy efficiency from a global view in co-simulation
- A platform is under construction for combining real-time simulation and uncertainty quantification, to provide a possibility to extend such analysis even to Hardware in the Loop and Power Hardware in the Loop tests

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Thanks for your attention!

Any question?