Advanced Real-time Power System Simulator for Korea Electric Power Systems: *Challenges and Opportunities*

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Yonsei University*, KEPCO Research Institute**

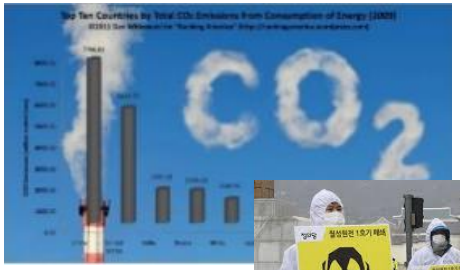
Aug. 8, 2018

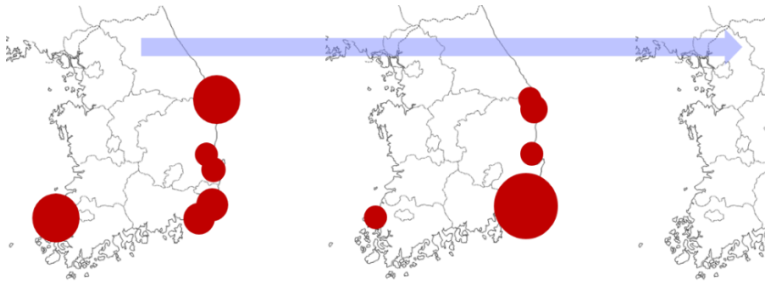
Agenda

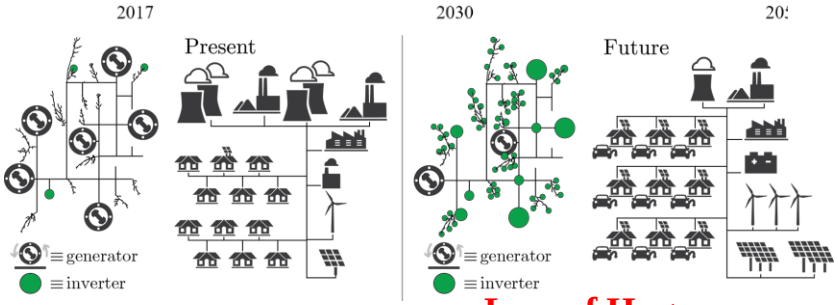
- Background
- **A**dvanced **K**orea **E**lectric **P**ower System **S**imulator (***AKEPS***)
  - **Real-time Digital Simulator** for Large Power System Modeling, Analysis and HILs
  - TSA (TSAT) - EMT (RTDS) Interface and Hybrid Simulation: ***TRI***
- Discussion

Background

- Transition to **Renewable** yet **Variable Energy Resources**: (Korea ***RE 3020 vision)***
  - Distributed PE-based G displacing traditional power plants; Change in dynamics (V, F weaker gird); Stability concerns
  - DER-rich Grid Planning and Operations: DER Impact, Hosting Capacity; Modeling, Analysis, Controls
  - T&D Integration
- **PE-based Controllable T&D** as Enabling Technologies
  - Grid (functional, service) requirements, Converter design
  - Harmonious integration into the existing grid: when, where, how, who
  - Dynamics Modeling, Analysis, Control



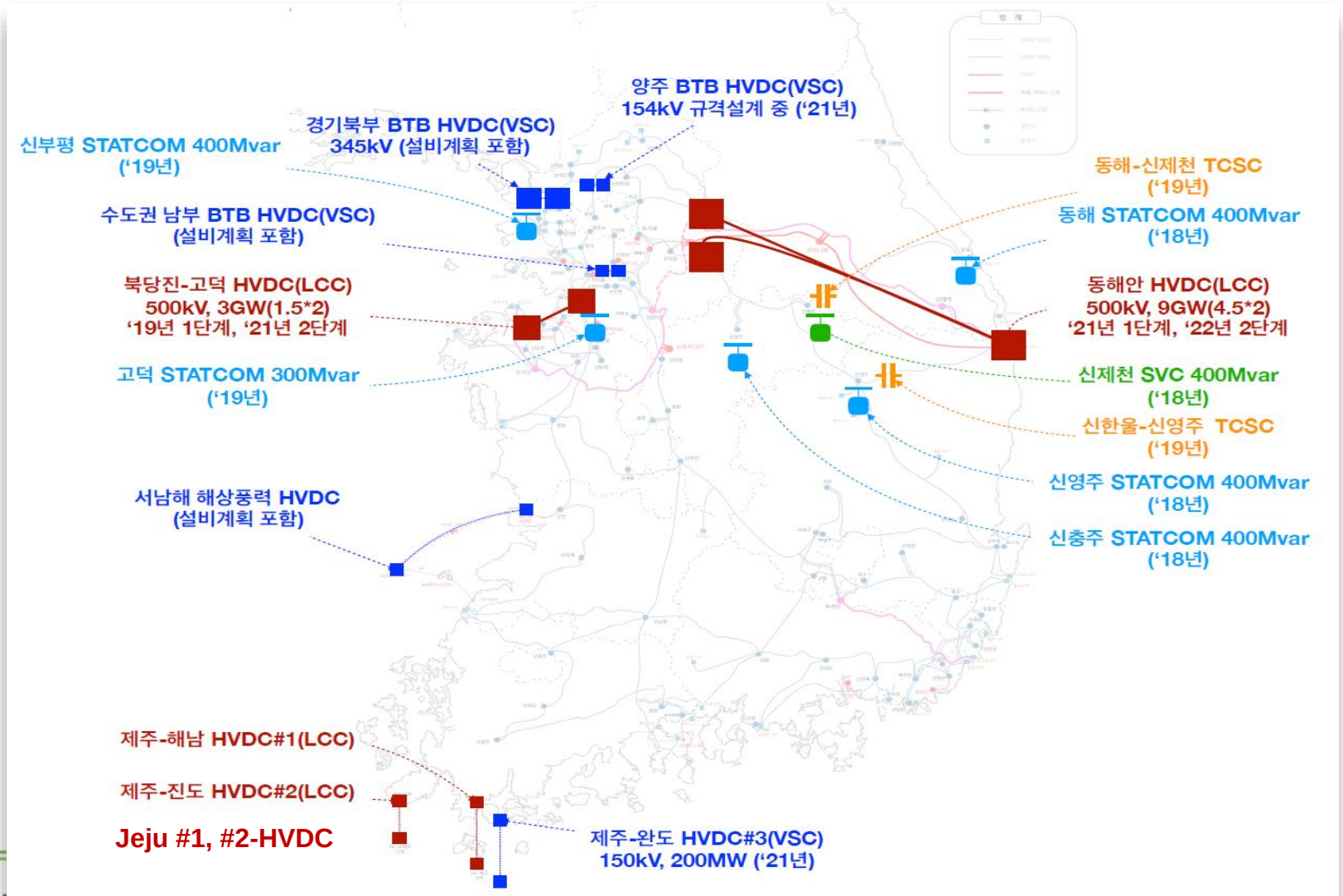




Img Src: NREL

Loss of Huge Electromechanical LPF

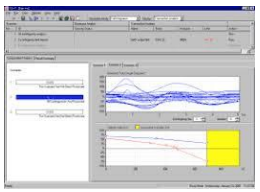
HVDC/FACTS in Korea Electric Power Grid

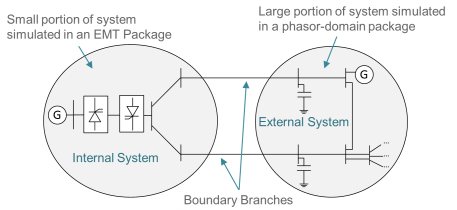


AKEPS Project Background

- Modeling & Analysis (Limitations)
  - Existing practice and tools: TSA (ex: PSS/e), EMT (ex: PSCAD, RTDS) -> local (equipment) vs. systemwide (grid) impact study
  - Limitations: Accuracy vs. Complexity vs. Time
- Operations, Control & Protection (SPS)
  - Learning **lessons** from real operations: Value of **post-mortem analysis**, **Sophisticated** operations and protection **strategies**
- Advanced tools and practices: Infrastructure, modeling, analysis
  - **Advanced (KE) Power System Simulator, TRI**
  - **Systemwide** impact of expanded adoption of PE-based controllers: **Critical decision-making support**

KEPCO Simulator





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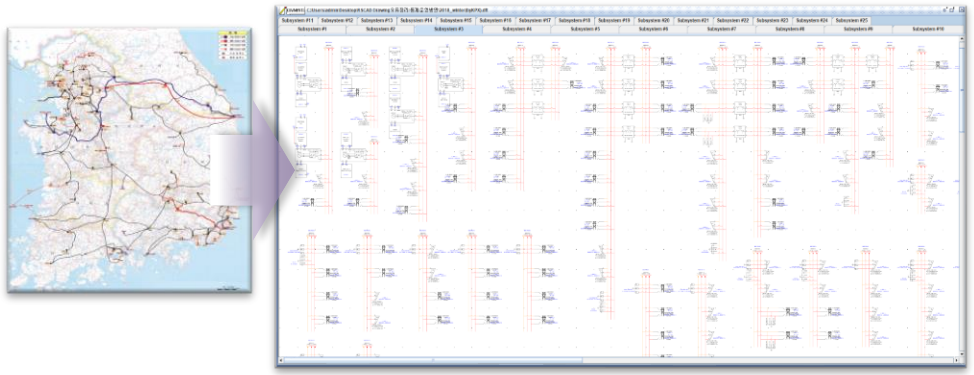
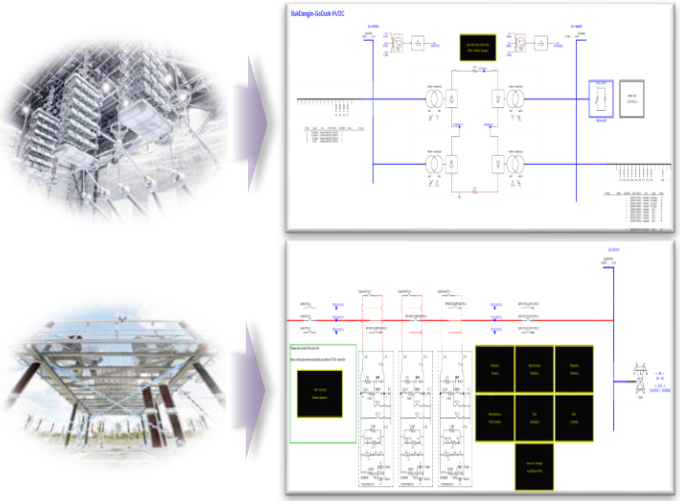
Modeling and Analysis

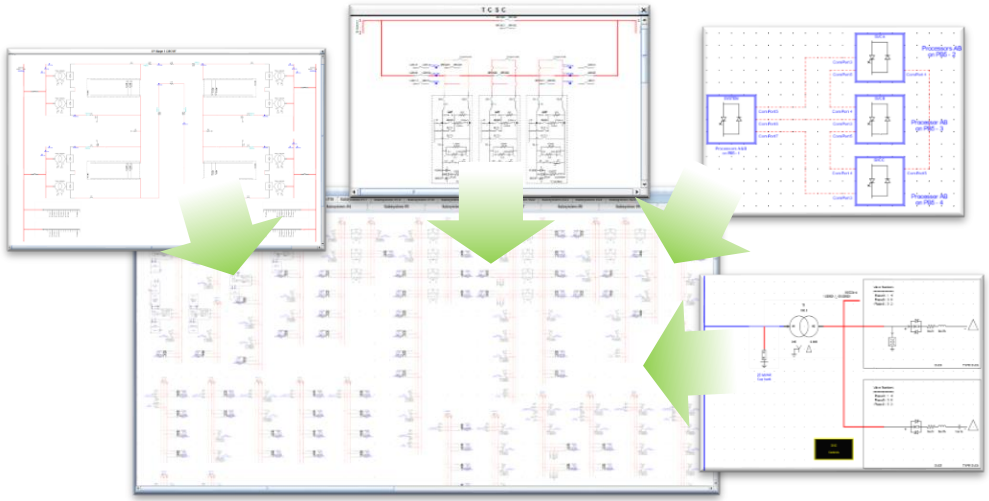
① RTDS, Replica controllers



② Large Power System Modeling and Simulation

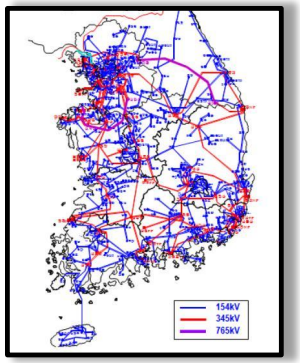


③ HVDC,FACTS Modeling



④Advanced Large Power System Analysis

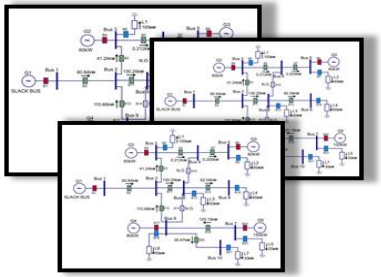
Large Power System Modeling with RTDS



KEPCO basecase (PSS/E)

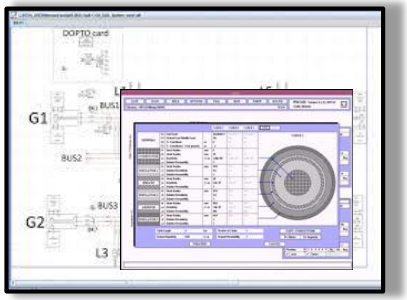
① Optimize the basecase

- *Data Sanity Check*
- *Network/Topology Processing*



Optimized PSS/E case

② Data Conversion

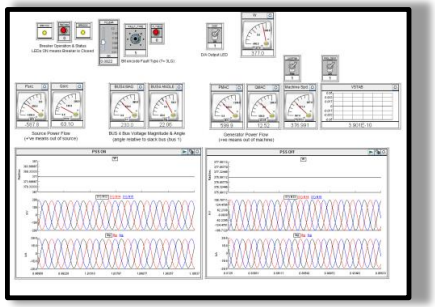


RTDS basecase

③ Basecase Study

RTDS with 35 Racks

④ System Analysis



Incorporate EMT models and conduct studies for various Operating Scenarios

Expedite the process through automated conversion app.

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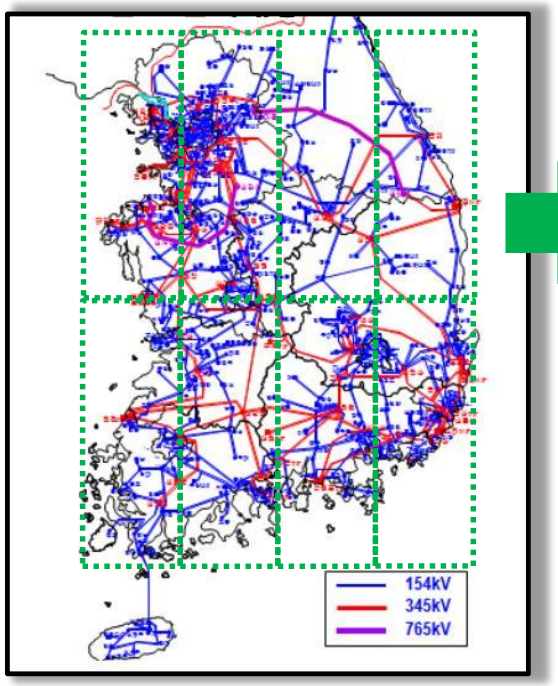
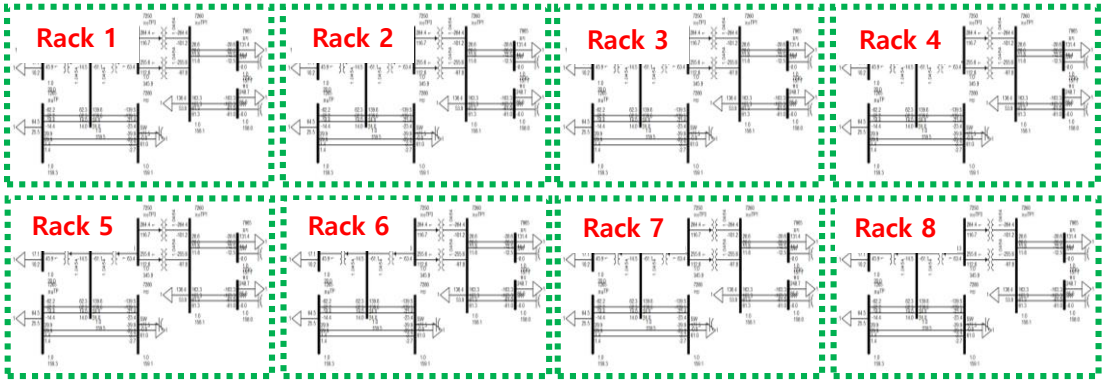
Large Power System Modeling with RTDS

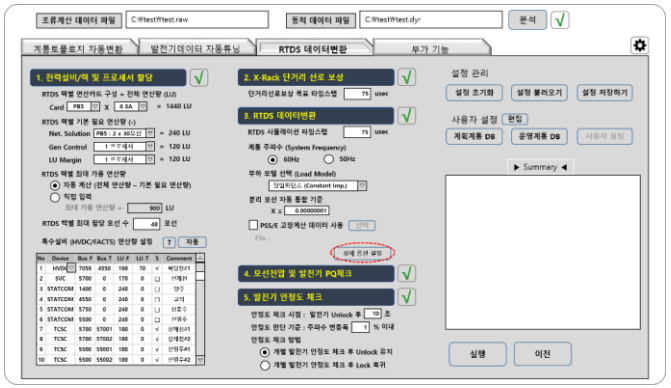
* Multi-rack Simulation : computation, topology

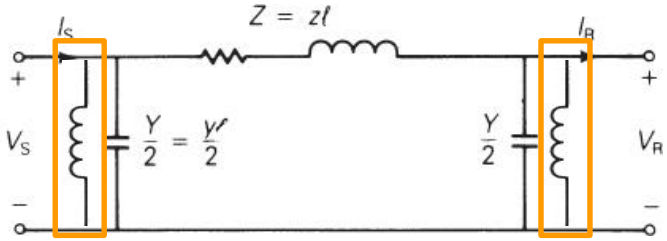




- Each rack can handle maximum 60 buses
- Each Rack can handle up to 1440LU (LU : RTDS Load Unit)

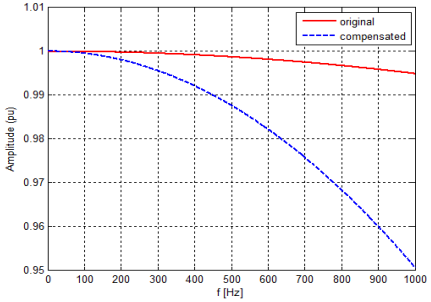
Large Power System Modeling with RTDS: Preprocessing

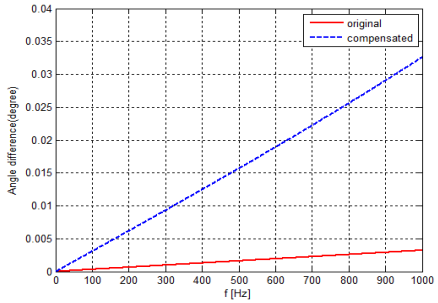




when travelling time is less than the RTDS sampling time

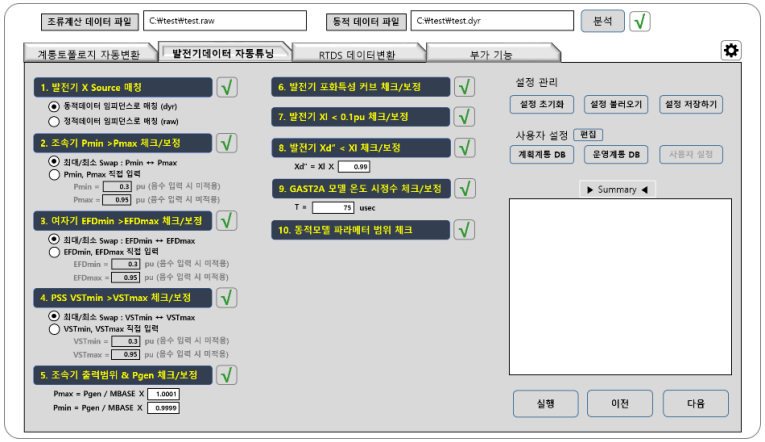
τ =5usec -> τ = 50usec





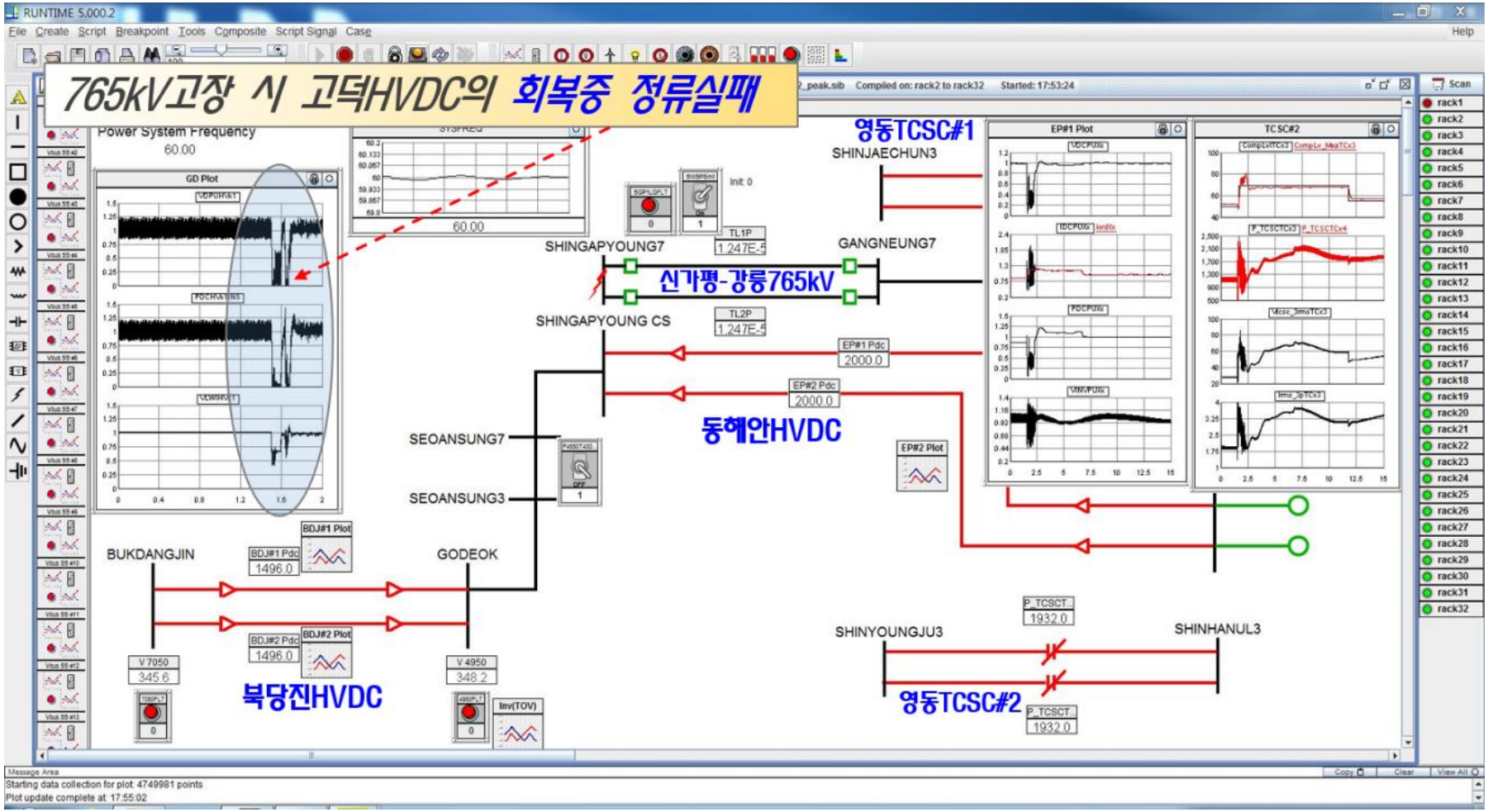
Static Data Preprocessing APP: Network (Data sanity check, topology processing, Models to be replaced by EMT

Dynamic Data Preprocessing APP



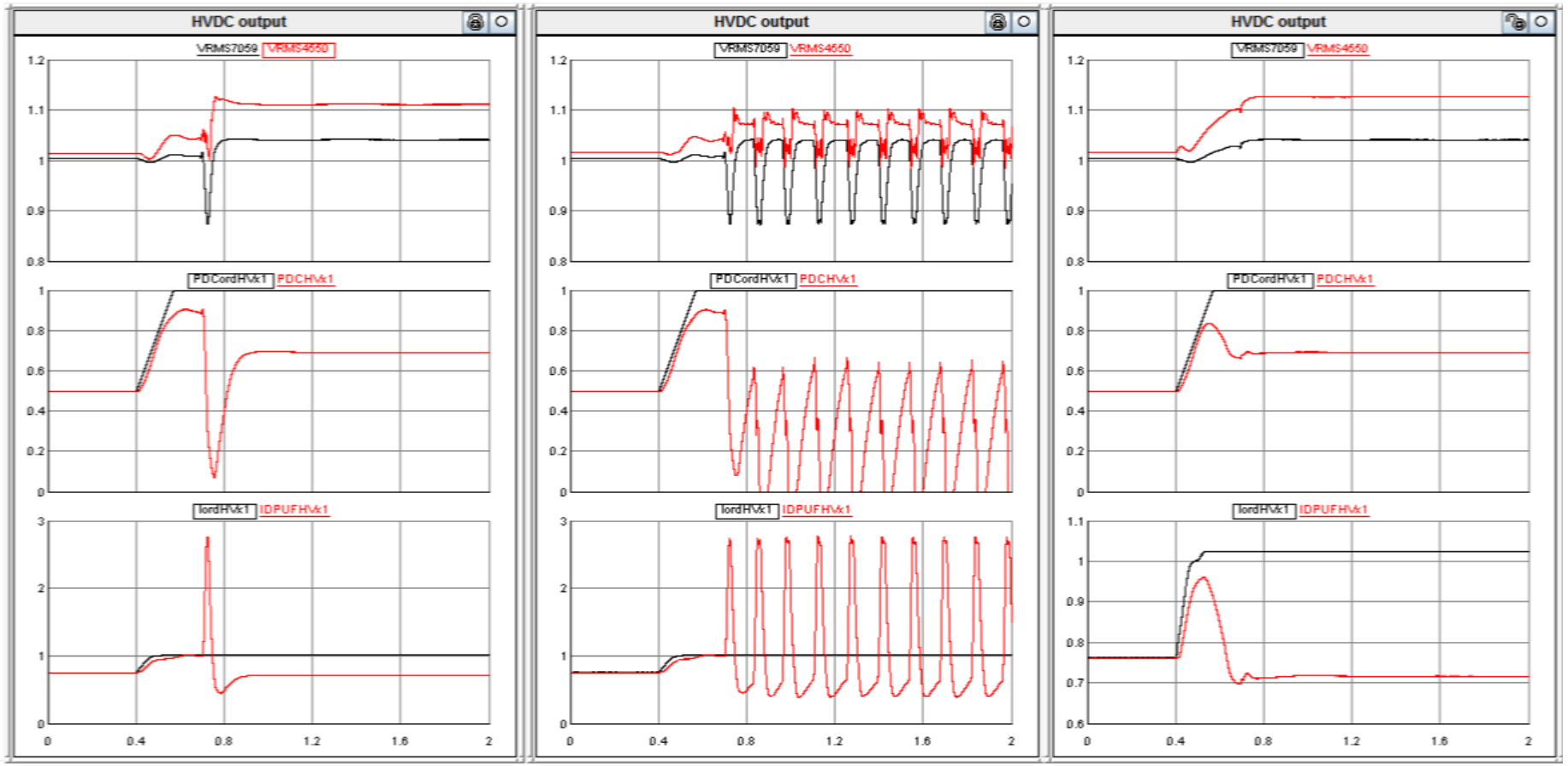
Modeling and Analysis

Commutation failure during the recovery



Impact of 765 kV Line Trip (East) on HVDC Operations (West)

Modeling and Analysis

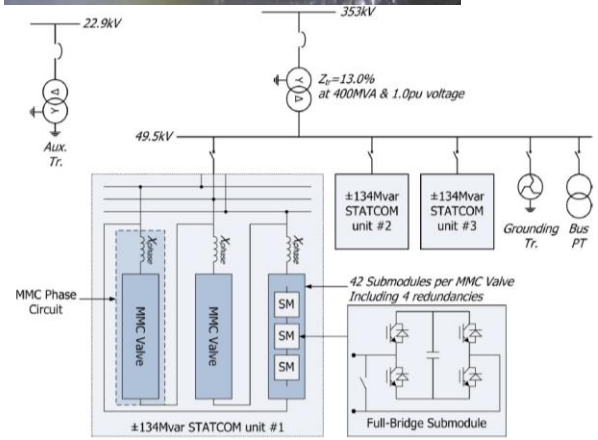


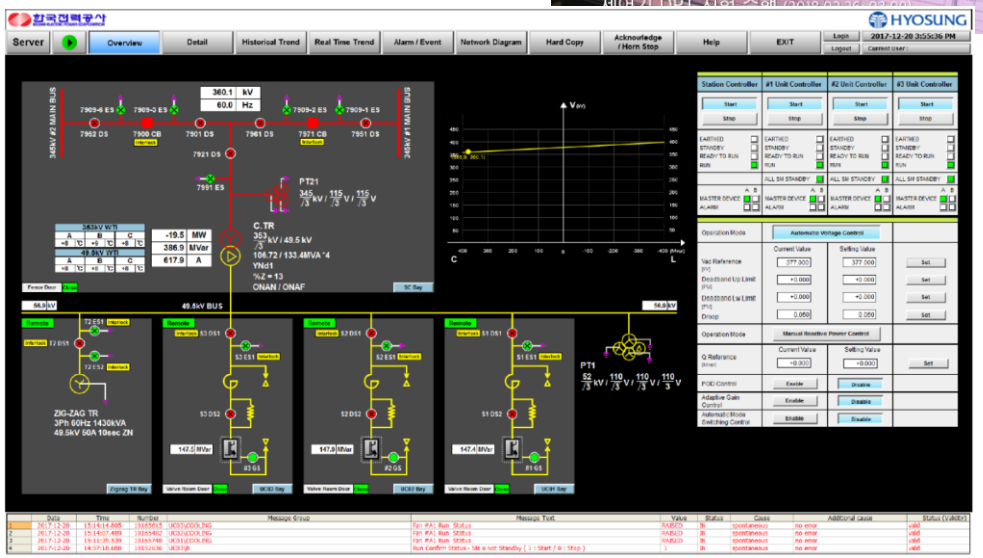
No STATCOM **STATCOM with CV** **Coordinated Control**

Adverse Control interactions

Coordinated Voltage Control of HVDC (ramp-up) and STATCOM –Q Control

Dynamic Performance Test of the Replica Controller





[STATCOM-HILS]

Dynamic Performance Test of the MMC-STATCOM Controller

RTDS

Digital Signals (CB status etc)

Digital Signal (Valve control etc)

Control & Protection

V, I measurements
(Signal level)

Power Amplifier

V, I measurements
(CT, PT level)

DPT of the MMC-STATCOM Controller

Scenarios:

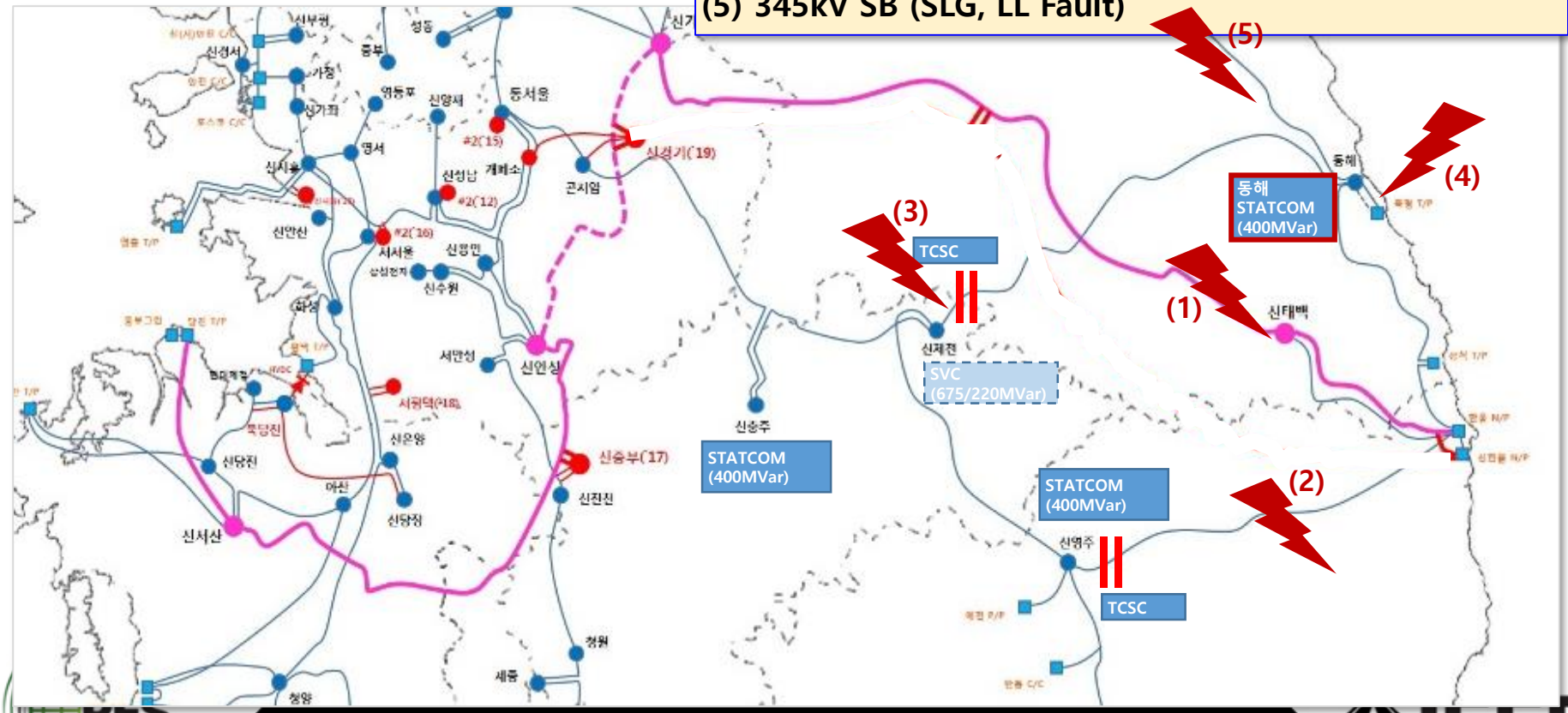
(1) 765kV double CKT line trip: SPS/ TCSC Emergency Control

(2) 345kV double CKT line trip

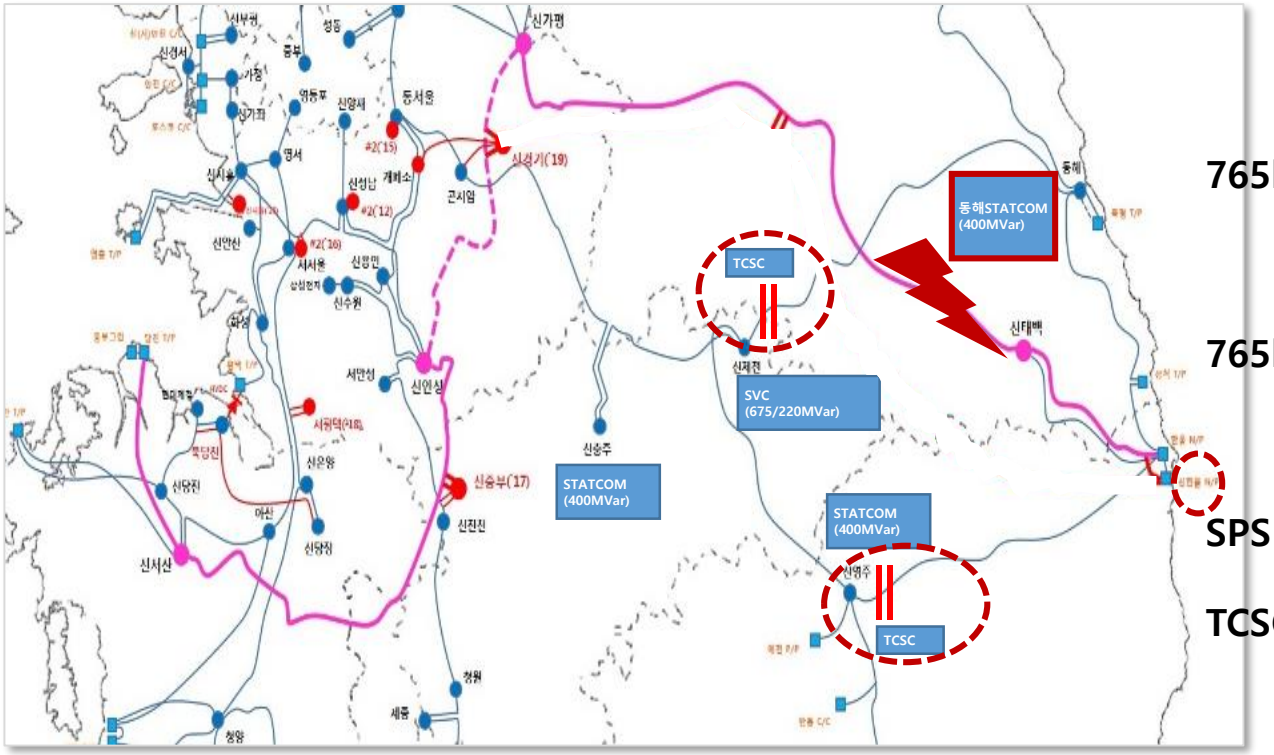
(3) TCSC failure

(4) Generator trip (TP, 600MW)

(5) 345kV SB (SLG, LL Fault)



DPT of the MMC-STATCOM Controller



765kV double CKT line trip; Bus Fault

83 msec (5 Cycle)

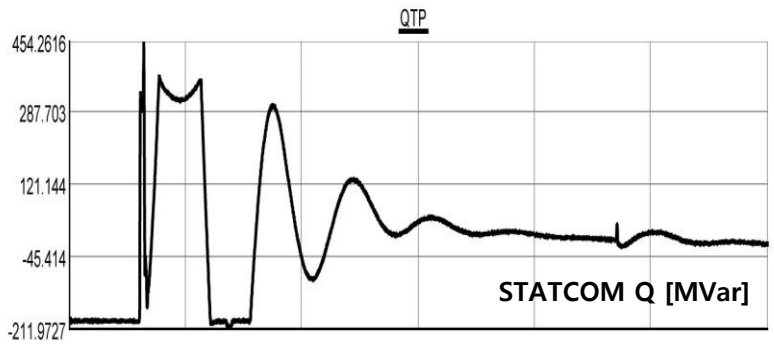
765kV line open

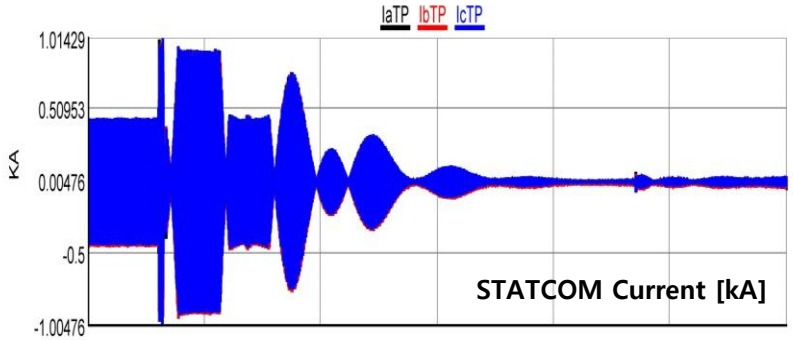
50 msec (3 Cycle)

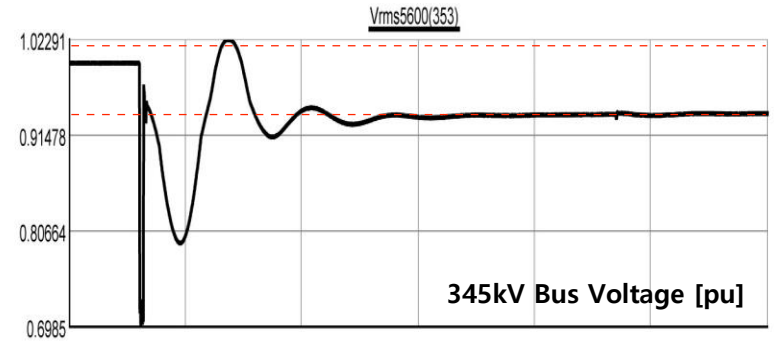
SPS (Generator tripping)

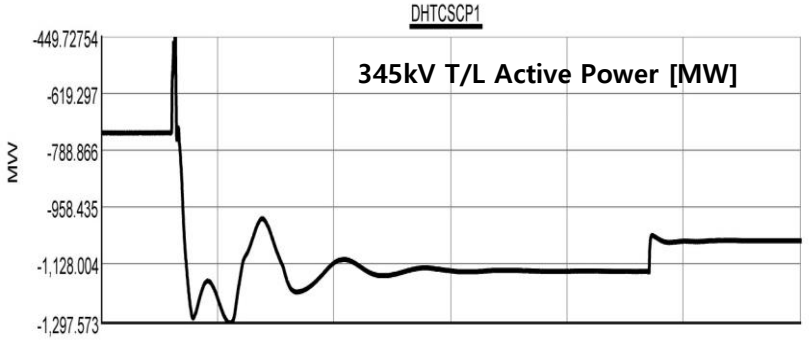
TCSC Boost-Up (50%→70%, for 10 sec)

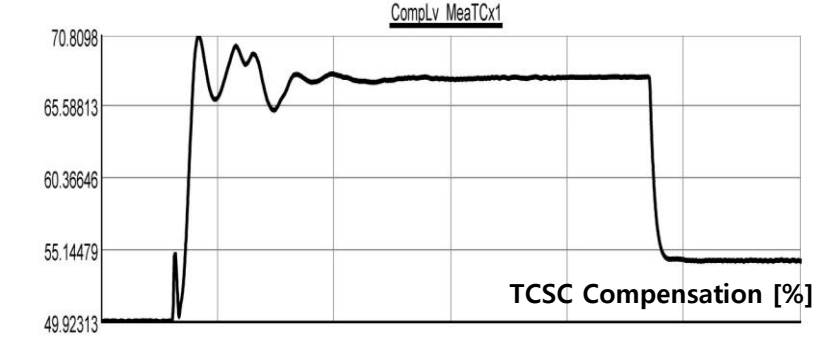
DPT of the MMC-STATCOM Controller

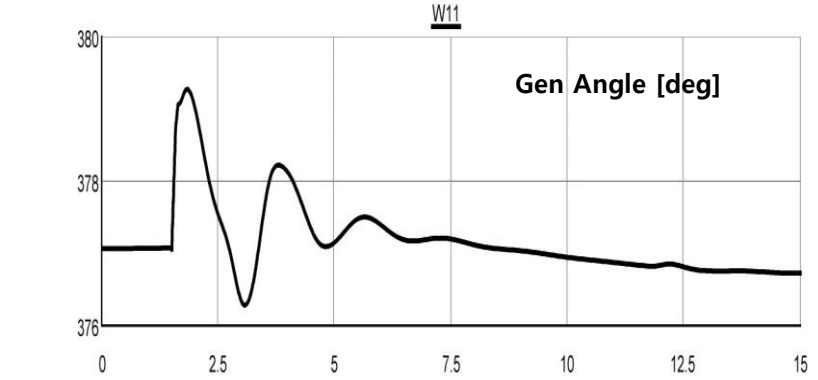












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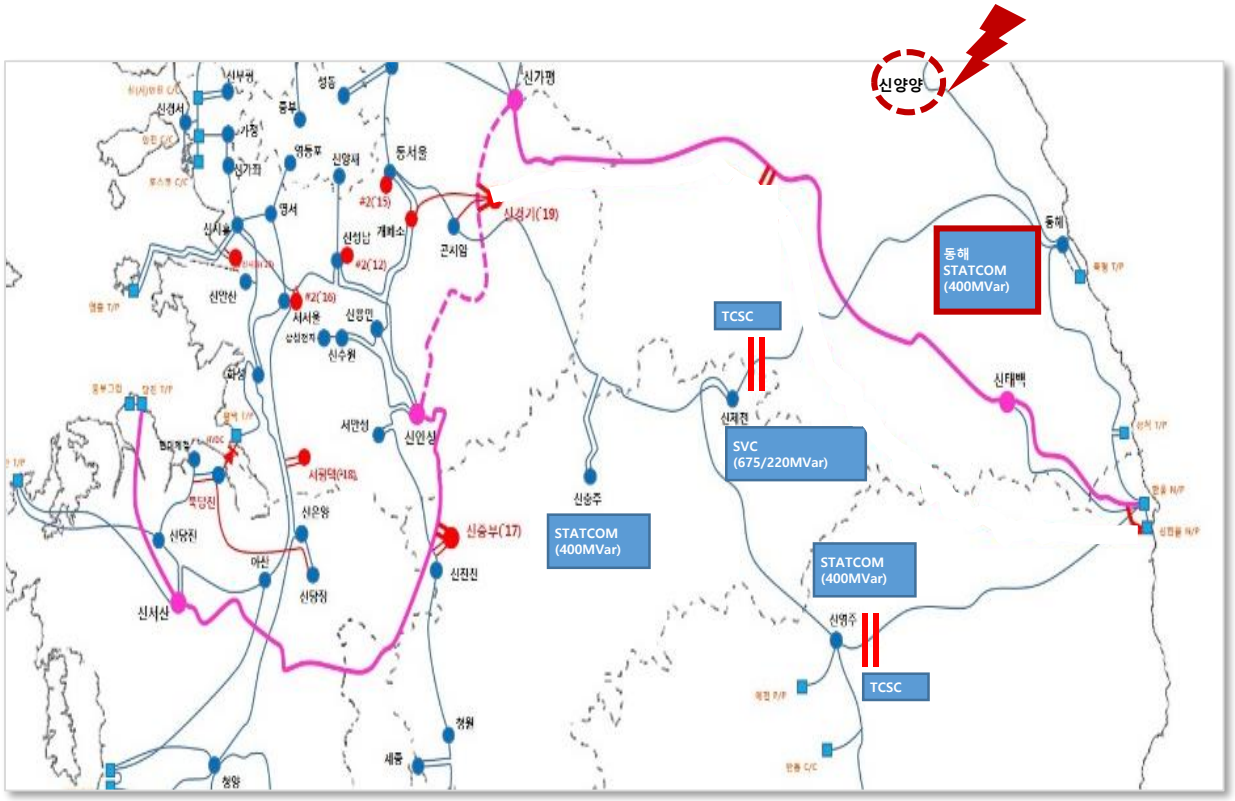
DPT of the MMC-STATCOM Controller

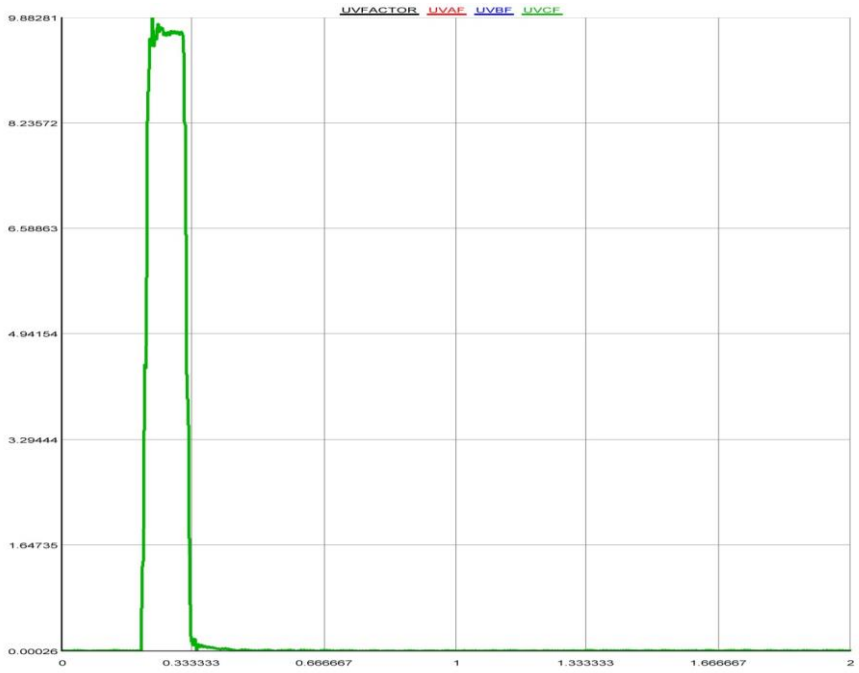


345kV SB (SLG Fault)

100 msec (6 Cycle)

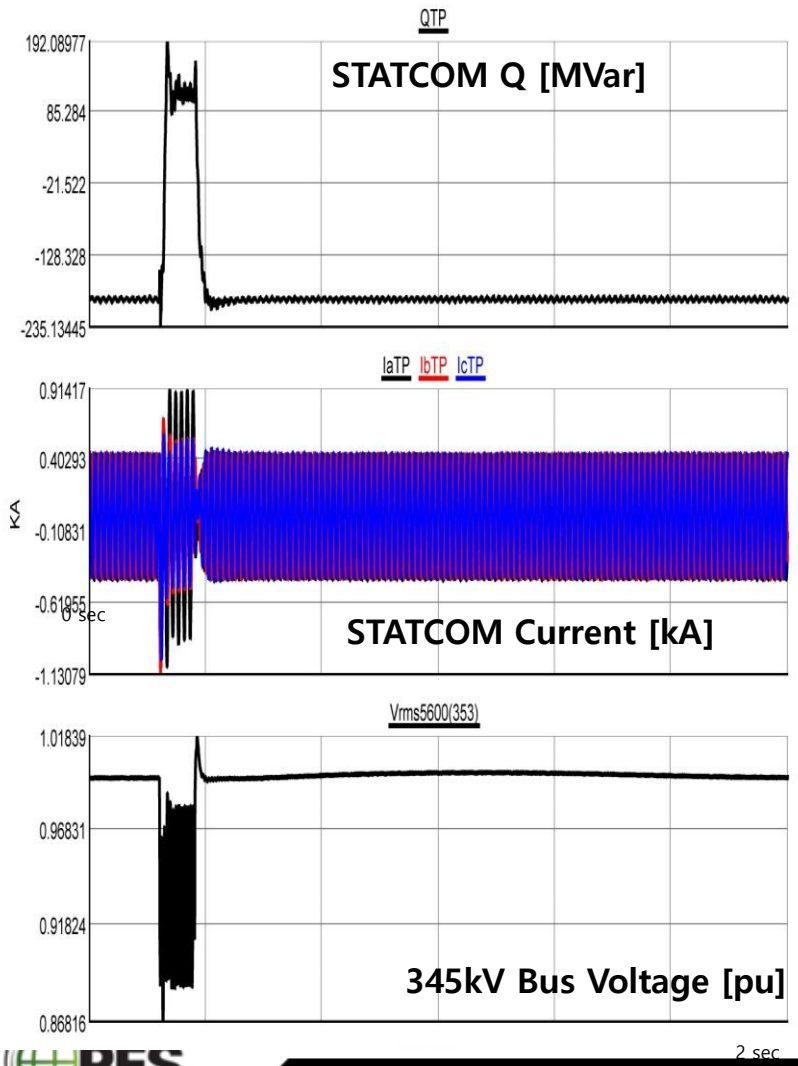
Bus fault clear

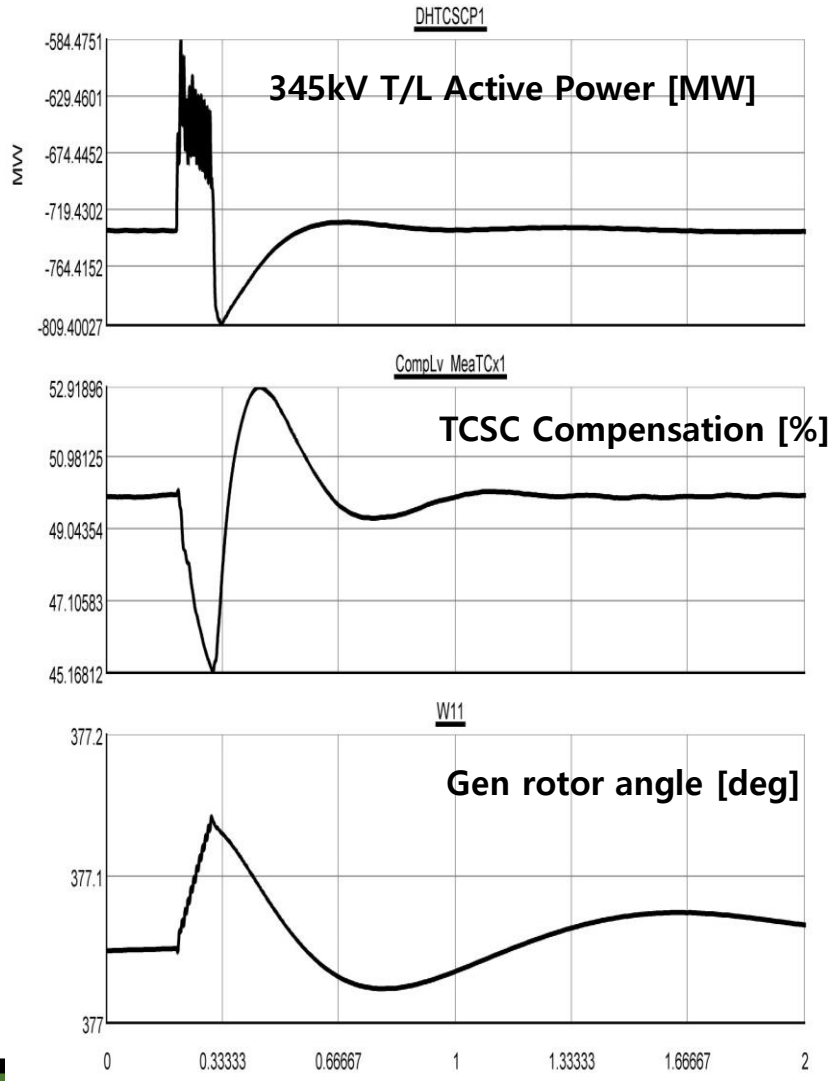
DPT of the MMC-STATCOM Controller



Voltage unbalance factor: 9.98%

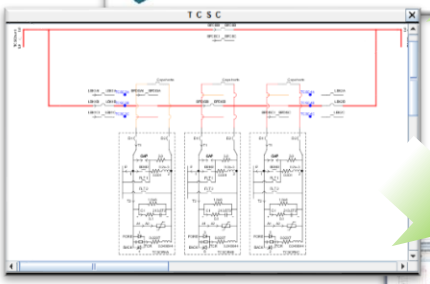
DPT of the MMC-STATCOM Controller

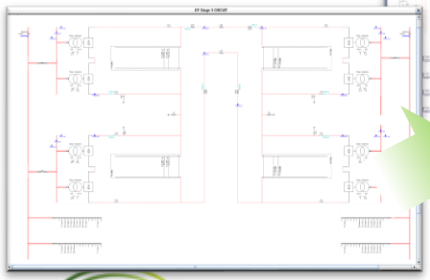


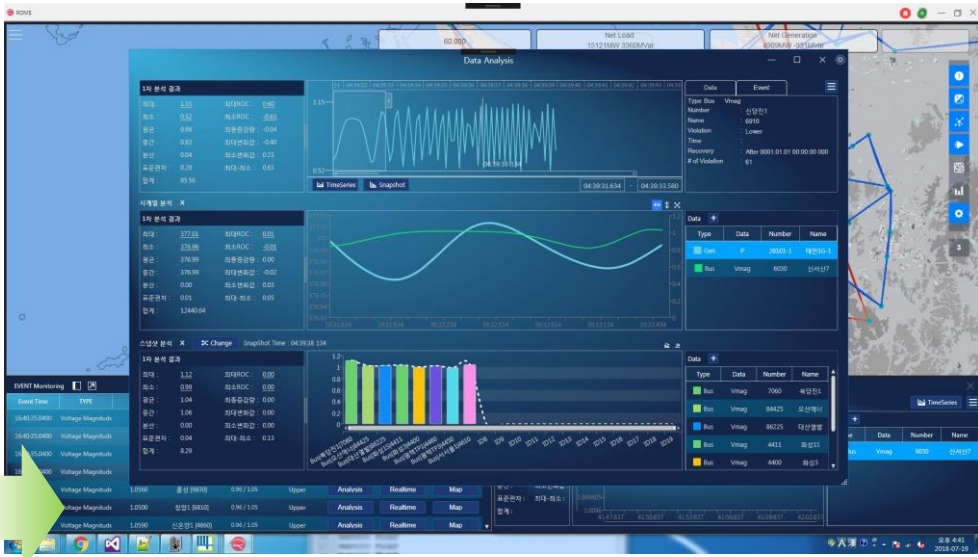


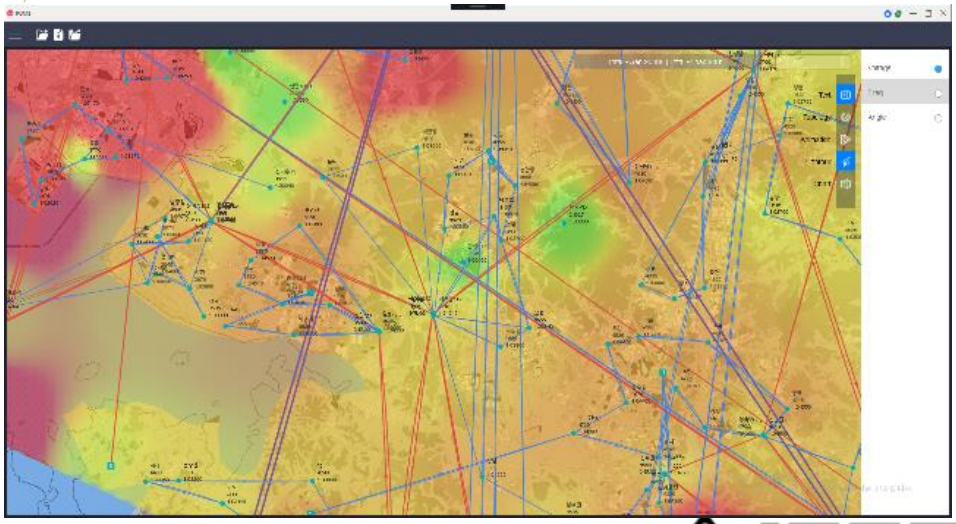
Modeling and Analysis

Large Power system-HILS









TSAT-RTDS Interface (TRI)

- Hybrid simulation approach addresses the challenges by using both EMT and phasor-domain simulation methods
- Advantages
  - Effective in analyzing impact of low-frequency oscillations on specific components and vice-versa
  - A cheaper solution for studying large systems compared to full-EMT simulation
  - **Takes advantage of rich modeling library available in EMT and phasor-domain simulation packages**
  - Perform Hardware-In-Loop simulation with a large system model with a replica controller

TRI TSAT-RTDS Interface

TRI is an advanced platform with the cutting-edge technological advancements in the area of power systems dynamic simulation to perform Co-Simulation studies using TSAT and RTDS™.

Co-Simulation studies aim at combining detailed modeling capability available in Electro-Magnetic Transient (EMT) packages with bulk power system simulation of Transient Stability Assessment (TSA) tools. This approach helps engineers to simulate a much larger system while reducing cost, effort, and time needed to set up and run the system. Additionally, the engineer can analyze aspects of system dynamic behavior that may not be captured in a pure EMT- or TSA-study.

The TSAT-RTDS Interface (TRI) module is an add-on module to TSAT that enables user to perform Co-Simulation studies using TSAT and RTDS™. The TRI performs a real-time simulation where both TSAT and RTDS™ simulate the system in real-time. Moreover, the Co-Simulation performed by TRI is synchronized, meaning that TSAT and RTDS™ exchange results at the end of every TSAT simulation time-step, which facilitates studying interactions between TSAT- and RTDS-side systems.

The TRI's Co-Simulation starts by dividing the power grid into an internal and external system. The internal system is typically small enough to be simulated on available RTDS™ racks at a typical EMT time-step ranging, e.g. 50µs, while external system is much larger and it is simulated in TSAT at a typical planning/operation study's time-step, i.e. 1/4 to 1/2 cycles. Using an interface board sitting on PCI/E slot of the PC, TSAT exchanges simulation results with RTDS™ and enables engineer to study the interactions between internal and external systems.

TRI module is a joint development with Korea Electric Power Corporation (KEPCO) and Yonsei University

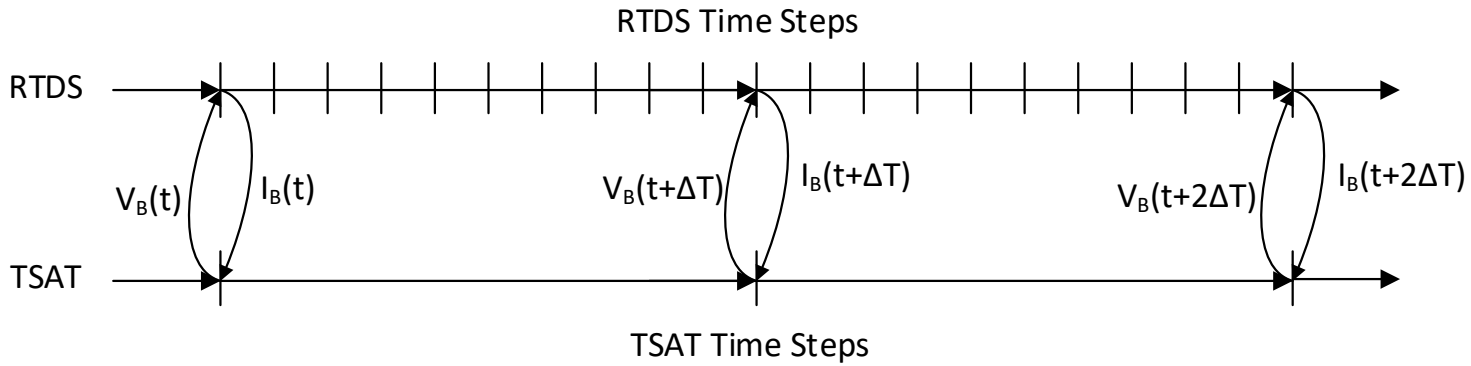
PRODUCT FEATURES:

- *Performing synchronized and real-time Co-Simulation studies using TSAT and RTDS™*
- *Supporting multiple RTDS™ racks*
- *Handling real-time simulations for systems with more than 5000 buses*
- *Taking advantage of rich model libraries available in TSAT and RTDS™*
- *Synchronized simulation of multiple sub-systems in real-time*
- *Supporting RTDS™ GPC, PB5, and NovaCor architectures*

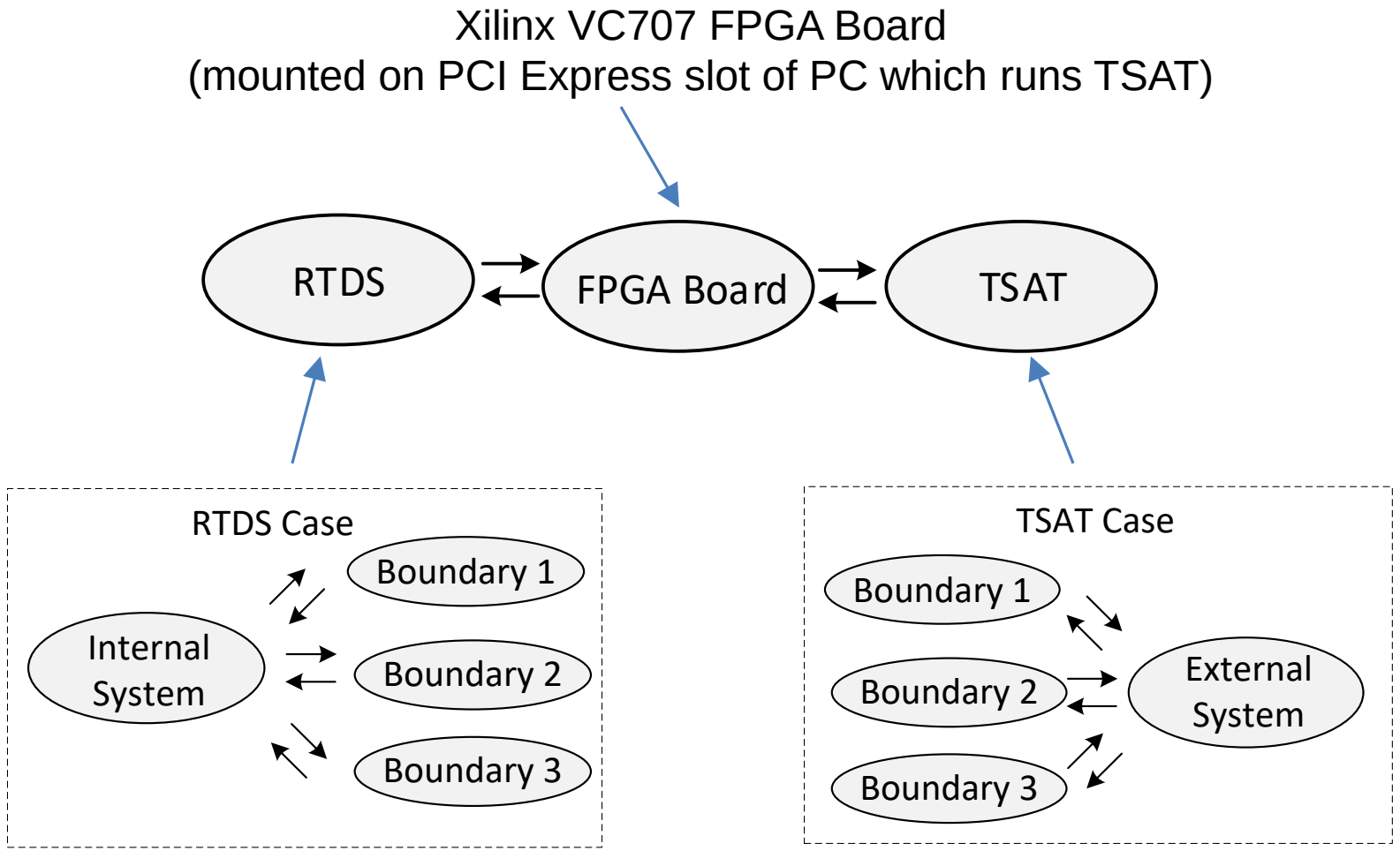
Powertech

TSAT-RTDS Interface (TRI)

- A tool for performing hybrid simulation studies
  - Using both TSAT from Powertech Labs and RTDS from RTDS Technologies
- TRI is developed with special focus on practical aspects
  - User-friendly, minimizing case setup efforts, simplifying results analysis steps etc.
- How does TRI work
  - TSAT simulates external system at normal time-step (e.g. 4ms)
  - RTDS simulates internal system at normal time-step (e.g. 50us)
  - Boundary injections are exchanged at the end of every TSAT time-step

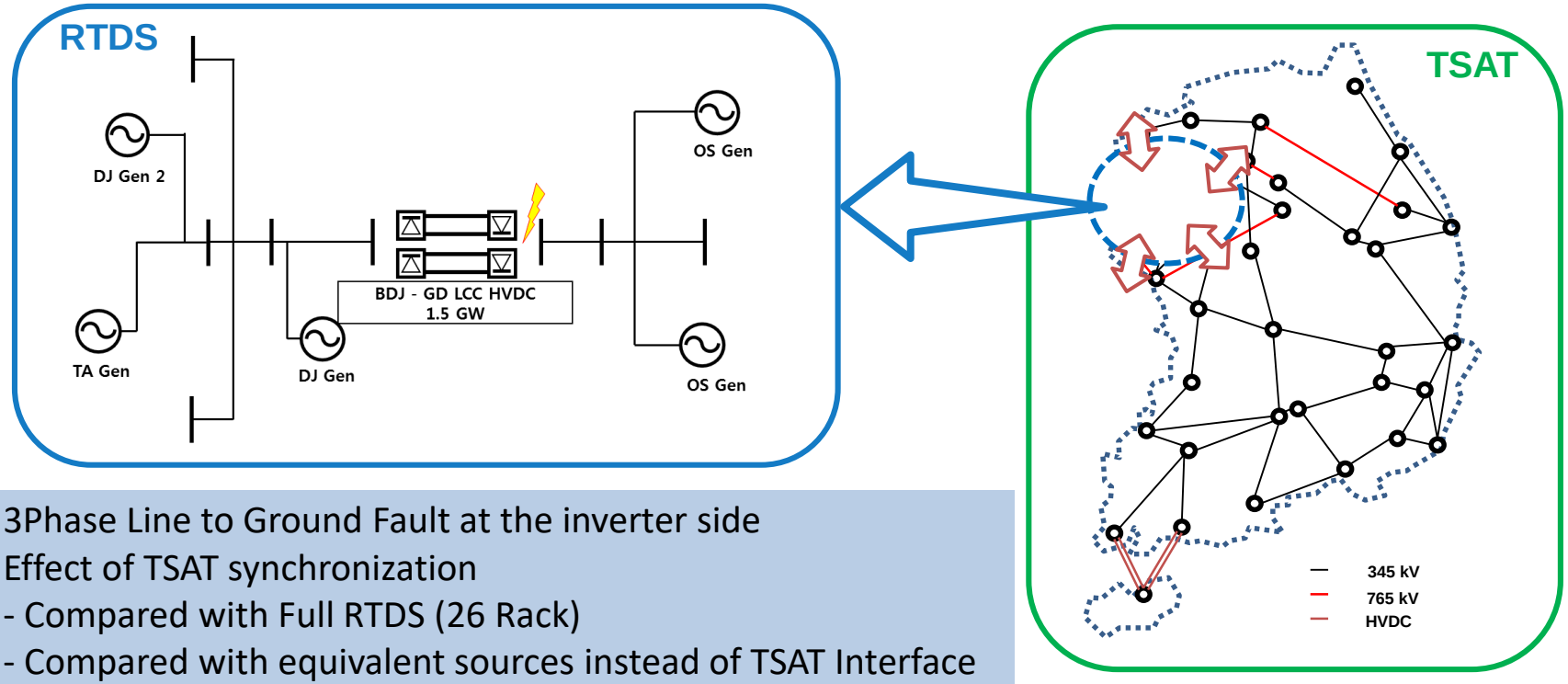


TRI Structure



TRI Application

☐ Hybrid Simulation Test for Korean Power System (Bukdangjin – Goduk HVDC Case)

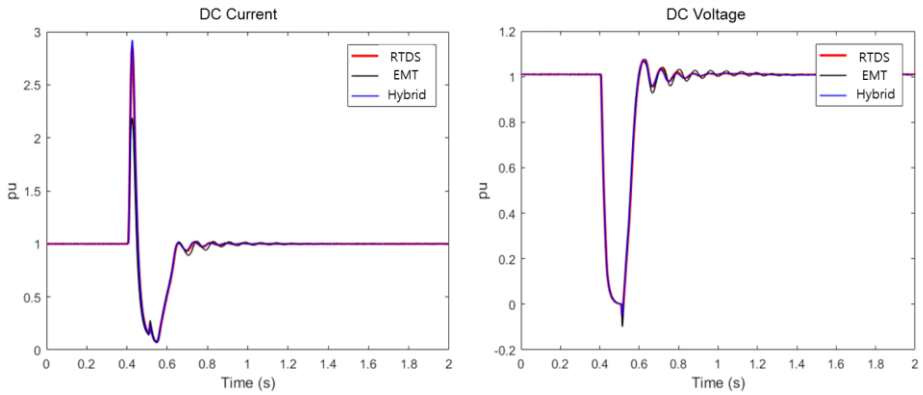


- 3Phase Line to Ground Fault at the inverter side
- Effect of TSAT synchronization
  - Compared with Full RTDS (26 Rack)
  - Compared with equivalent sources instead of TSAT Interface

- **RTDS**
  - LCC HVDC, 3 Generator at Rect. side, 4 Generator at Inv. side.
- **TSAT**
  - All remaining parts of the KEPCO system

TRI Application

- Hybrid Simulation Test for Korean Power System (Bukdangjin – Goduk HVDC Case)



	DC Current (p.u.)	DC Voltage (p.u.)	DC Power (p.u.)
Equiv.	4.31e-4	3.67e-4	8.04e-4
Hybrid	**2.4e-4**	**1.89e-4**	**6.7e-4**

<Steady State Value Difference compared with Full RTD

	Mag	Damping(%)	Freq. (Hz)
Full RTDS	0.0153	-7.88	12
Hybrid Sim.	0.014	-8.56	12
Difference	**0.0013**	**0.68**	**0**

<Dominant Frequency Characteristics- Rectifier Voltage>

	DC Current (p.u.)	DC Voltage (p.u.)	DC Power (p.u.)
Equiv.	0.0077	0.0477	0.0595
Hybrid	**0.0068**	**0.002**	**0.0133**

<Minimum Value Difference compared with Full RTDS

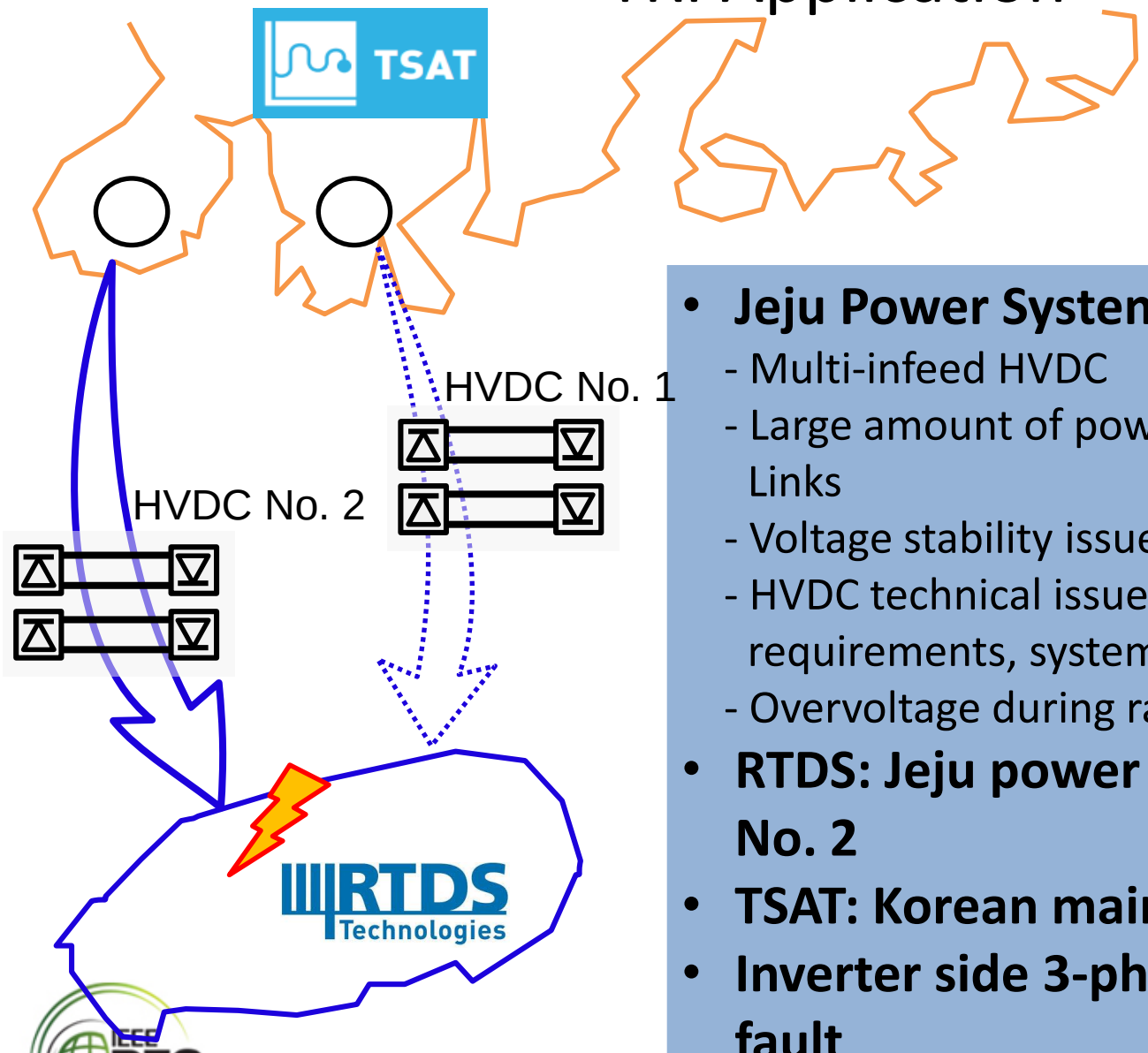
	Mag	Damping(%)	Freq. (Hz)
Full RTDS	0.0484	-9.93	12.2
Hybrid Sim.	0.0475	-8.19	12.1
Difference	**0.0009**	**-1.74**	**0.1**

<Dominant Frequency Characteristics- Inverter Voltage>

	DC Current (p.u.)	DC Voltage (p.u.)	DC Power (p.u.)
Equiv.	0.6782	0.0096	0.0288
Hybrid	**0.0568**	**0.0017**	**0.0002**

<Maximum Value Difference compared with Full RTDS

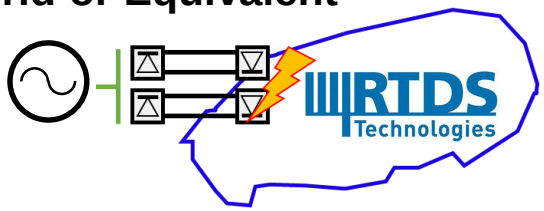
TRI Application



- **Jeju Power System:**
  - Multi-infeed HVDC
  - Large amount of power transfers between DC Links
  - Voltage stability issue on the main land
  - HVDC technical issues : reactive power requirements, system tolerances, loss, etc.
  - Overvoltage during ramp-down or recovery
- **RTDS: Jeju power system and HVDC No. 2**
- **TSAT: Korean mainland power system**
- **Inverter side 3-phase line to ground fault**

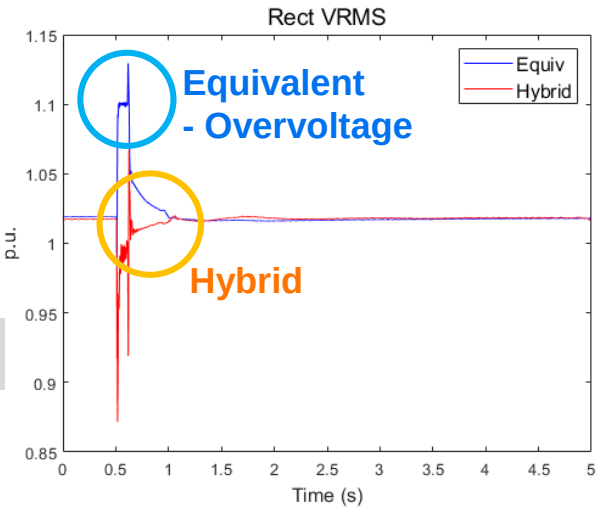
TRI Application

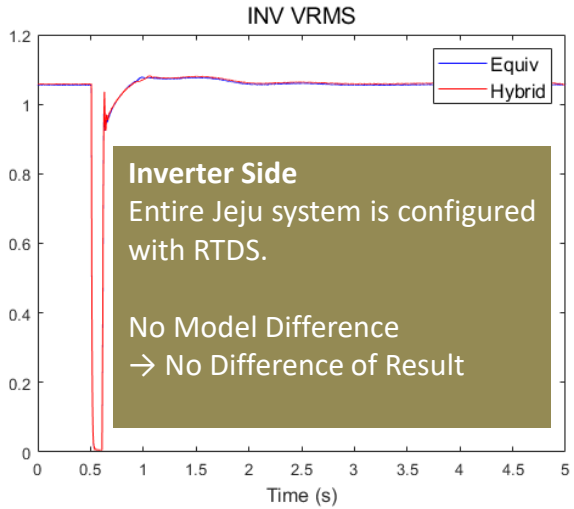
Hybrid or Equivalent



3 phase Line to Ground Inverter Fault

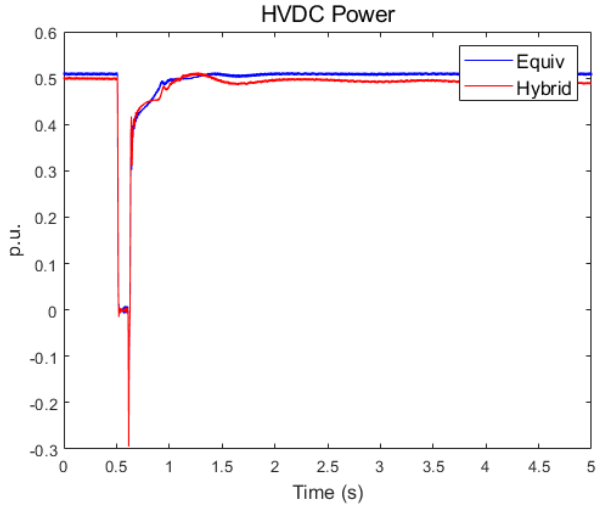
NB. Multi-infeed HVDC Jeju

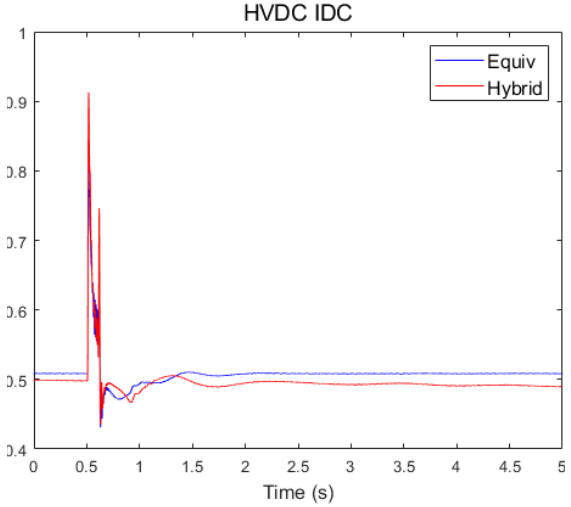


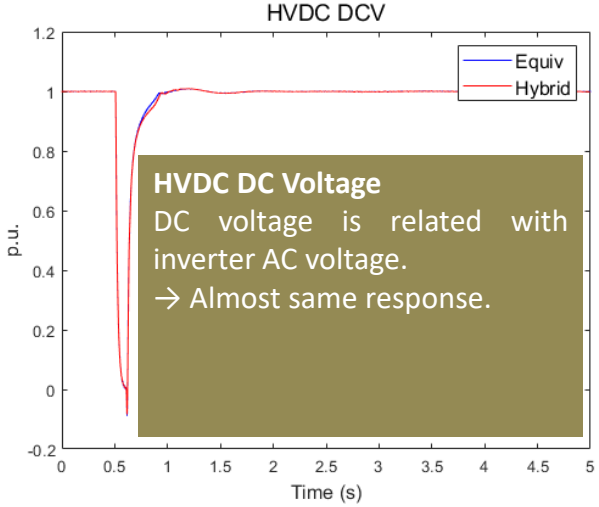


Inverter Side
Entire Jeju system is configured with RTDS.

No Model Difference
→ No Difference of Result

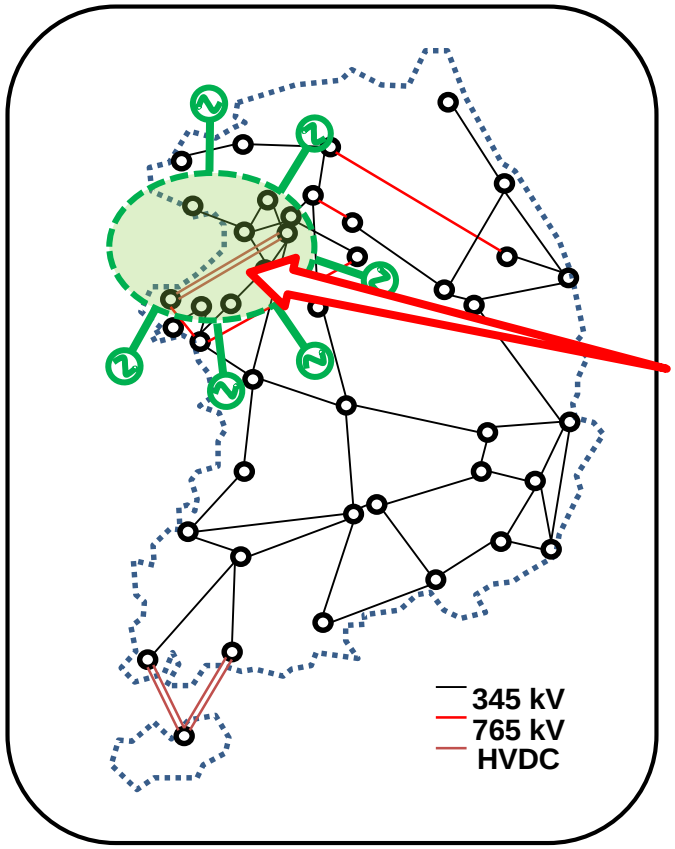


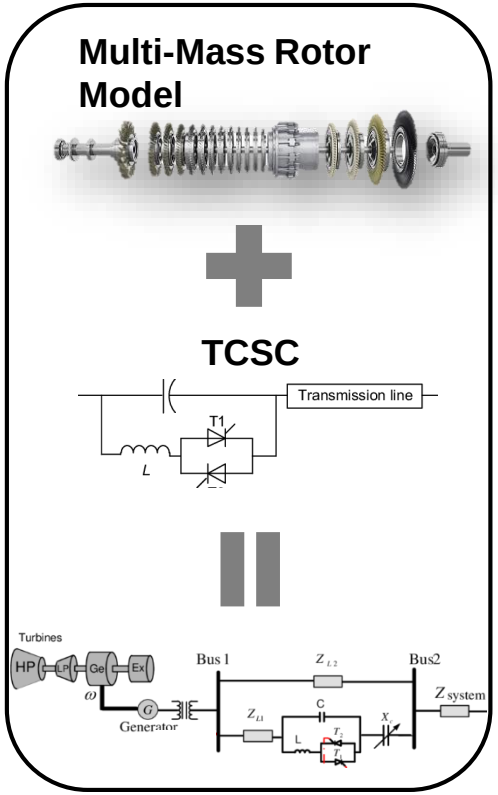


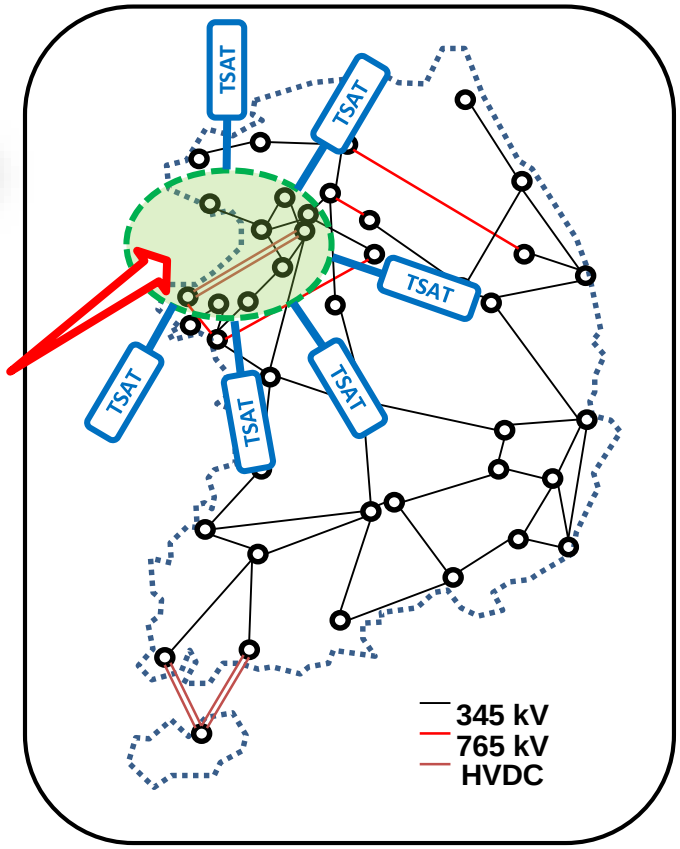


HVDC DC Voltage
DC voltage is related with inverter AC voltage.
→ Almost same response.

TRI Application

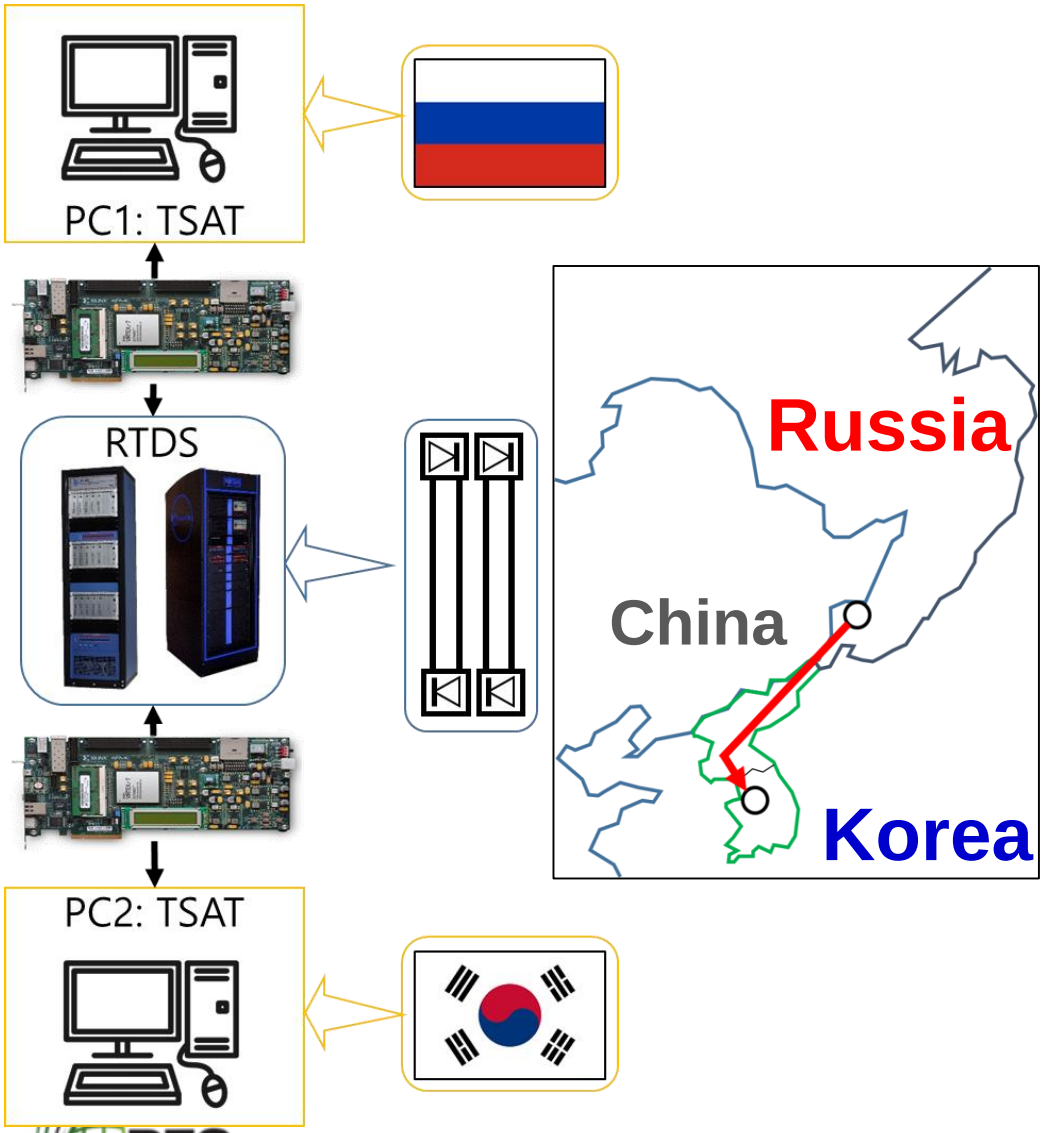






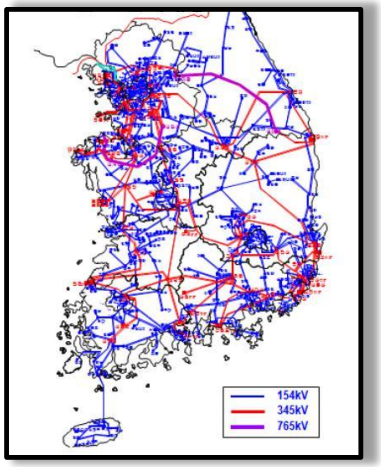
- **Control interactions between multiple HVDC and FACTS**
- **SSO concerns**

TRI Application

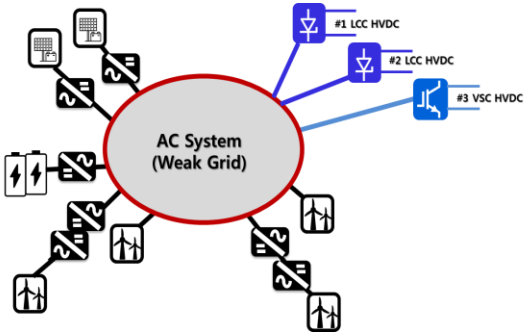


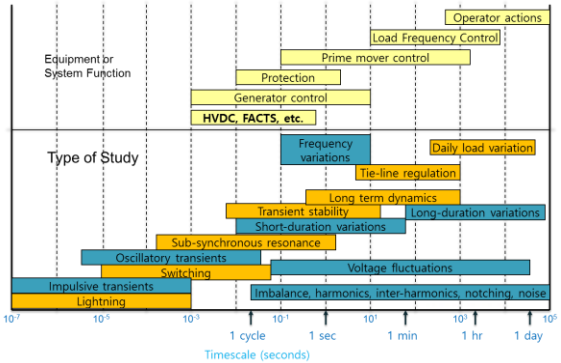
- **Multiple TSAT running**
- **Northeastern Asia Supergrid operating case**
- **TSAT1: Russian Power Grid** (Assume)
- **RTDS: 1.5 GW LCC HVDC** (A Sxx Substation)
- **TSAT2: Korean Power Grid**

Achievement & Lessons



- **Tools are ready and valuable cases are being built**
  - Multiple HVDC/FACTS, DERs, Sensing/Monitoring Devices
  - Post Mortem Analysis, EMS Applications/Online DSA, HIL (Replica controllers, Protections, Grid services, etc.)
- **EMT vs. TSA**
  - Interconnection of different dynamic models and tools; Synergy or Misuse (Abuse?), Accuracy vs. Complexity vs. Uncertainty (structure, parameters), Understanding (limitations of each)
  - Multiple interfaces, Decoupled subsystems, frequency dependency (FDNE), buffer zone (don't care zone?), load dynamics, DER aggregation, Spurious oscillations, etc.
- **Workforce training**; Expertise in PE and PS, Grid requirement, Converter design, Critical decision-making





Based on operating scenarios/assumptions