Session 4 - “How to We De-Risk System Integration at Scale”

11 June 2026

Dong Chen

The National HVDC Centre *part of* Scottish & Southern Electricity Networks *together with* nationalgrid SP ENERGY NETWORKS NESO National Energy System Operator

The National HVDC Centre

Afternoon Session

Session 4 **"De-risking Integration": How do we de-risk HVDC integration at scale?**

13:15 **Introduction**
Dong Chen, The National HVDC Centre

13:25 **EMT Model Requirements for Plant Connections in EirGrid and SONI Systems**
Sebastien Dennetiere, RTE international & Treisa Sahaya, EirGrid

13:45 **Network Reduction Techniques for Interaction Analysis**
Diptargha Chakravorty, Siemens Energy

14:05 **TO experiences of de-risking HVDC integration**
Afshin Pashei, NGET

14:25 **Coffee Break**

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14:40 **System Operator Perspectives on the Future use and Operation of HVDC Technology**
Ankur Majumdar, NESO

15:00 **HVDC Supervisory Control Technology from the System Operator's Perspective**
Gumin Kwon, KEPCO

15:20 **Wrap-up**
Ben Marshall, The National HVDC Centre

15:30 **Close**

Scottish & Southern Electricity Networks

Empowering
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EMT Model Requirements for Plant Connections in EirGrid and SONI Systems

HVDC Operators' Forum 2026

11th June 2026

Sébastien Dennetière, RTE international & Treisa Sahaya, EirGrid

Agenda

1 EMT model requirements for system-wide stability assessment

2 Verification Tests and Acceptance Procedures

EMT model requirements

Main objectives

- Objective
  - Detailed specifications for EMT models
  - Designed to enable wide-area EMT network studies
  - Specified to be EMT-tool independent
  - Including validation/verification requirements and internal verification test procedures
- Applied to:
  - Battery Energy Systems
  - Wind Farms
  - Solar PV farms
  - HVDC
  - Synchronous Condensers
  - Conventional Synchronous Generation plant
  - Data Centre
  - Electrolyser load
  - Collocated plants

EMT model requirements

Overview

- Intended use
- Components
- Structure
- Accuracy
- Usability
- Documentation
- Delivery and Maintenance

EMT model requirements

Intended use

Operational Tool Usage

EMT models are practical operational tools **throughout the plant's lifecycle**, integrated in local to large-scale system simulations.

Dynamic Performance and Fault Analysis

Models assess dynamic performance under normal operations, small disturbances, and severe faults, aiding post-event root cause analysis.

Control Interactions and Sub-Synchronous Phenomena

Focus on studying control interactions and sub-synchronous events relevant to inverter-based resources, enhancing system reliability.

Additional Investigations and Limitations

Includes harmonic stability, transformer energisation, protection assessment, and advanced modes; **not for harmonic emissions compliance.**

EMT model requirements

Components

Model must be site-specific (no generic manufacturer data)

Electrical components that can impact the dynamic behavior of the plan are required
Converters (DC/DC, DC/AC), transformers, filters,
Network elements: cables, lines, breakers, filters, grounding systems

Control systems:
PPC, converter control, voltage/frequency/reactive control, All PLL
Include all dynamics <100 s (control, protection, tap changers)
All setpoints (active and reactive power, voltage, frequency, etc ...) available to the TSO from the real plant

Protection systems:
Any protection which can influence dynamic behaviour or FRT performance in the simulation period should be included such as OV/UV, OF/UF, RoCoF, islanding, harmonic protection

EMT model requirements

Structure

Mandatory 3-layer architecture:

- Layer 1: Interface with grid (PoC, voltage/current exchange)
- Layer 2: Plant-level control, HMI, setpoints, monitoring
- Layer 3: Detailed unit representation (converters, storage units)

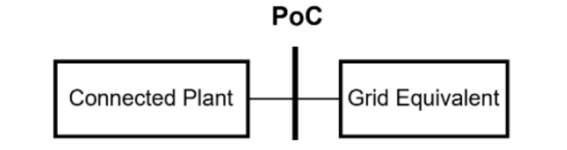


Figure 1: Layer 1 of the EMT model structure

Layer 2 centralises control modes, parameters and user interface

Diagnostic signals and outputs available at this level

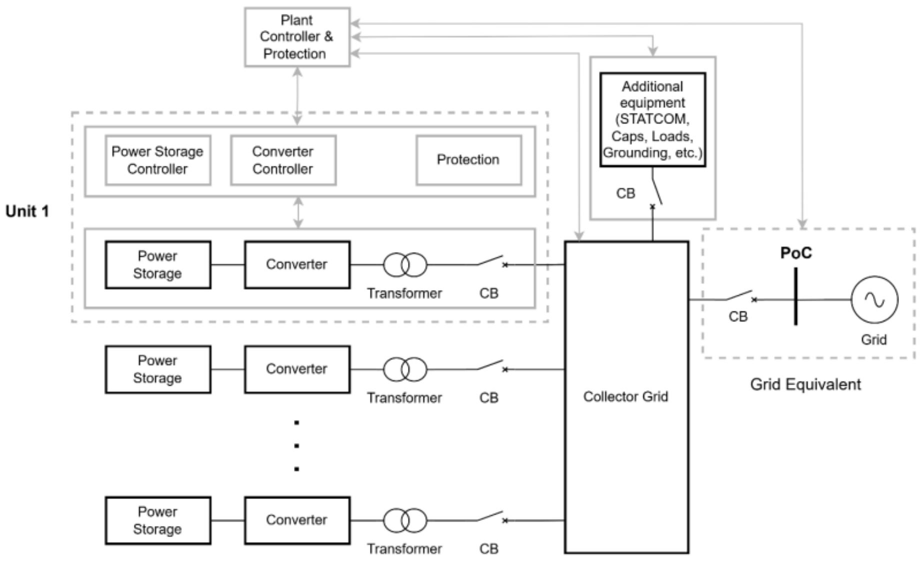


Figure 3: Layer 3 of the EMT model structure

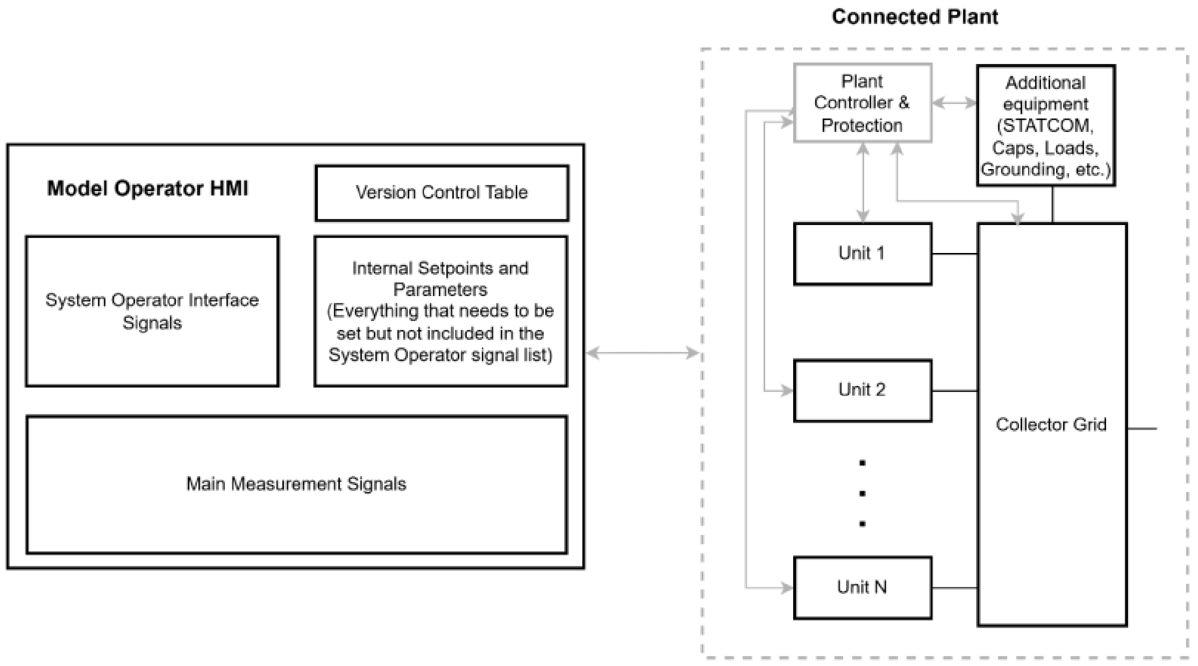


Figure 2: Layer 2 of the EMT model structure

EMT model requirements

Accuracy

Valid for frequency range 0.2 Hz to 2.5 kHz

Must be numerically stable for all grid conditions (SCR, X/R variations) and long simulation

Specific EMT electrical models:
Transformers (saturation), cables, lines,...
The converter model type choice (i.e. with detailed representation of semi-conductor devices or simplified/average model) is the responsibility of the model developer (validation is required)

Control/protection implemented using real code and tool independent approach
IEEE/CIGRE DLL interface specified in CIGRE TB 958

Aggregation required for performance, with equivalence to detailed model

EMT model requirements

Usability 1/3

The model shall run on the EMT simulation software specified by the TSO (PSCAD / EMTP)

Model must be self-initializing and reach steady-state within 3 seconds

Time step flexibility: 10 μs to 50 μs

Multiple instance capability

Export capability to any other schematic implemented within the same EMT software without any manual modification

All electrical components shall be open and accessible.

EMT model requirements

Usability 2/3

Submitted simulation model package

Package = {EMT model + all files required to run the simulation + Documentation}

Precompiled elements are forbidden (such as .lib, .obj, etc.), only DLL files are accepted for control and protection functions.

All submitted files shall be identified with a name that includes a unique version identifier.

When the model package is resubmitted for whatever reason (e.g. following an update), all corresponding files must be renamed with a new unique identifier.

EMT model requirements

Usability 3/3 – output signals

V(t), I(t): 3 phase instantaneous and RMS voltage and current
Vpos, Vneg, Vzero: Positive, negative and zero sequence voltages
Ipos, Ineg, Izero: Positive, negative and zero sequence currents
Iposd, Iposq: Positive sequence current on d and q axes
P, Q: Active and reactive power
Ppos, Qpos: Positive sequence active and reactive power
RoCoF: Calculated rate-of-change-of-frequency
PLL input and output signals: frequency and angle

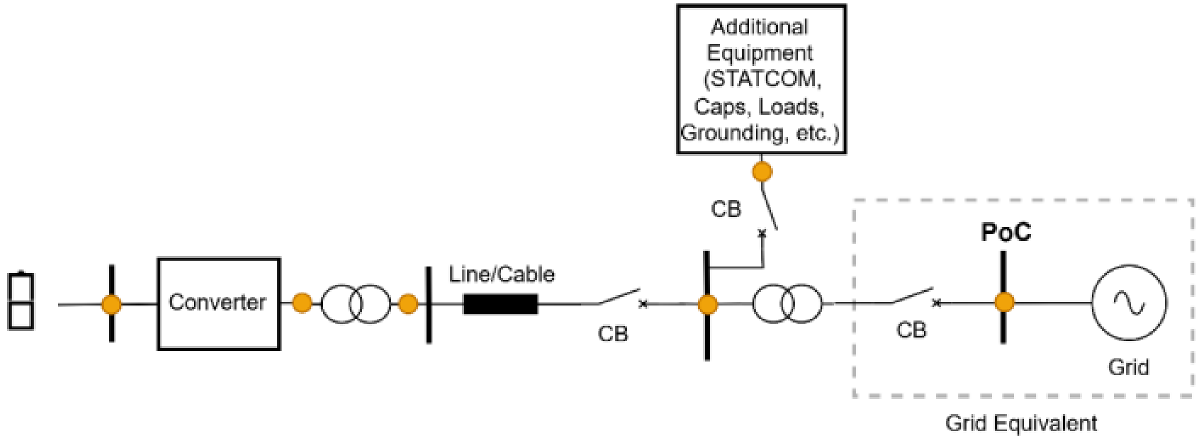


Figure 5: Measurement nodes in the EMT model

EMT model requirements

Documentation

2 reports:
Model User Guide and Model Design Documentation

Model User Guide includes:
Model description, parameters, assumptions, limitations
Provides versioning, file structure, and compatibility info
Includes full signal list (inputs, outputs, parameters)
Include test case with simulation results

Model Design Documentation includes:
Plant single-line diagram (SLD) showing main components up to the PoC
Control philosophy,
Equipment data

EMT model requirements

Delivery and Maintenance

Planning

Preliminary model delivered 12 months before energisation

Final model delivered 3 months before energization

Model Checklist

Provided in the Appendix

Submitted to the TSO confirming compliance

Model maintenance

Continuous updates required after any plant modification

Updated model must remain compliant with latest TSO specifications

Vendor support required throughout plant lifetime

TSO can request updates for software compatibility

10. Appendix

10.1. Appendix A: Model Checklist

This appendix is a EMT model checklist which must be completed by the plant owner and submitted alongside the EMT model.

Plant model identification	
Model submission Date	
Plant project name	
Primary contact information for model related questions	
List of EMT model files submitted	
List of documents submitted	

Plant model specification checklist		
2. Intended use		**Model Complies? (Y, N, N/A, comments)**
2.1	BESS_INT_1	
2.2	BESS_INT_2	
2.2	BESS_INT_3	
2.2	BESS_INT_4	
2.3	BESS_INT_5	
2.3	BESS_INT_6	
3. Components		**Model Complies? (Y, N, N/A, comments)**
3.1	BESS_COM_1	
3.1	BESS_COM_2	
3.2	BESS_COM_3	

EMT model requirements

Publicly available

https://www.eirgrid.ie/grid/grid-codes-and-compliance-overview/simulation-studies-and-modelling-requirements#EMT-model-specifications

On this page

- Requirements for Power Quality Studies
- Requirements for Fault Ride-Through (FRT) Studies
- Requirements for RMS Models
- EMT Model Specifications

EMT Model Specifications

All users of the transmission system are required to provide electromagnetic transient (EMT) models of their plant.

The documents below provide clear and consistent guidance with regards to the level of detail, model type, model accuracy, performance, usability and interoperability for EMT models.

Users are required to provide EMT models and documentation in accordance with these specifications. In addition, users are required to complete and return the model checklist included in the appendix.

1. EirGrid EMT model specification BESS PPM_v1.0 (July 2025)
2. EirGrid EMT model specification Solar PV PPM_v1.0 (July 2025)
3. EirGrid EMT model specification HVDC _v1.0 (July 2025)
4. EirGrid EMT model specification Wind Power Plants_v1.0 (July 2025)
5. EirGrid EMT model specification Synchronous Generator_v1.0 (July 2025)
6. EirGrid EMT model specification Synchronous Condenser Units_v1.0 (July 2025)
7. EirGrid EMT model specification Converter-based Reactive Support Systems_v1.0 (July 2025)
8. EirGrid EMT model specification Data Centre_V1.0 (May 2026)

Verification Tests and Acceptance Procedures

Carried out by the User as part of the grid connection compliance process

Verification process
Was the model built correctly?

Validation process
Does the model represent the real system adequately for its intended use?

References to be used for verification and validation
The plant harmonic impedance from the Power Quality Assessment report → for verification
FAT results (for HVDC/FACTS, Synchronous generators, Synchronous condensers) → for verification & validation
SAT measurement → for validation

Verification Tests and Acceptance Procedures

Verification table for harmonic impedance

Test initial conditions : **P poc (MW)** **Q poc (Mvar)** **U poc (kV)** **SCL (MVA)** **Connected plant configuration** **Control modes** **Injection signals characteristics**						
Frequency (Hz)	R EMT model (Ω)	X EMT model (Ω)	R reference (Ω)	X reference (Ω)	Error on R (%)	Error on X (%)
200						
250						
…						
2500						

$$\Delta R\ (\%) = \left|\frac{R_{EMT\ model}(k) - R_{reference}(k)}{R_{reference}(k)}\right| < 5\%$$

$$\Delta X\ (\%) = \left|\frac{X_{EMT\ model}(k) - X_{reference}(k)}{X_{reference}(k)}\right| < 5\%$$

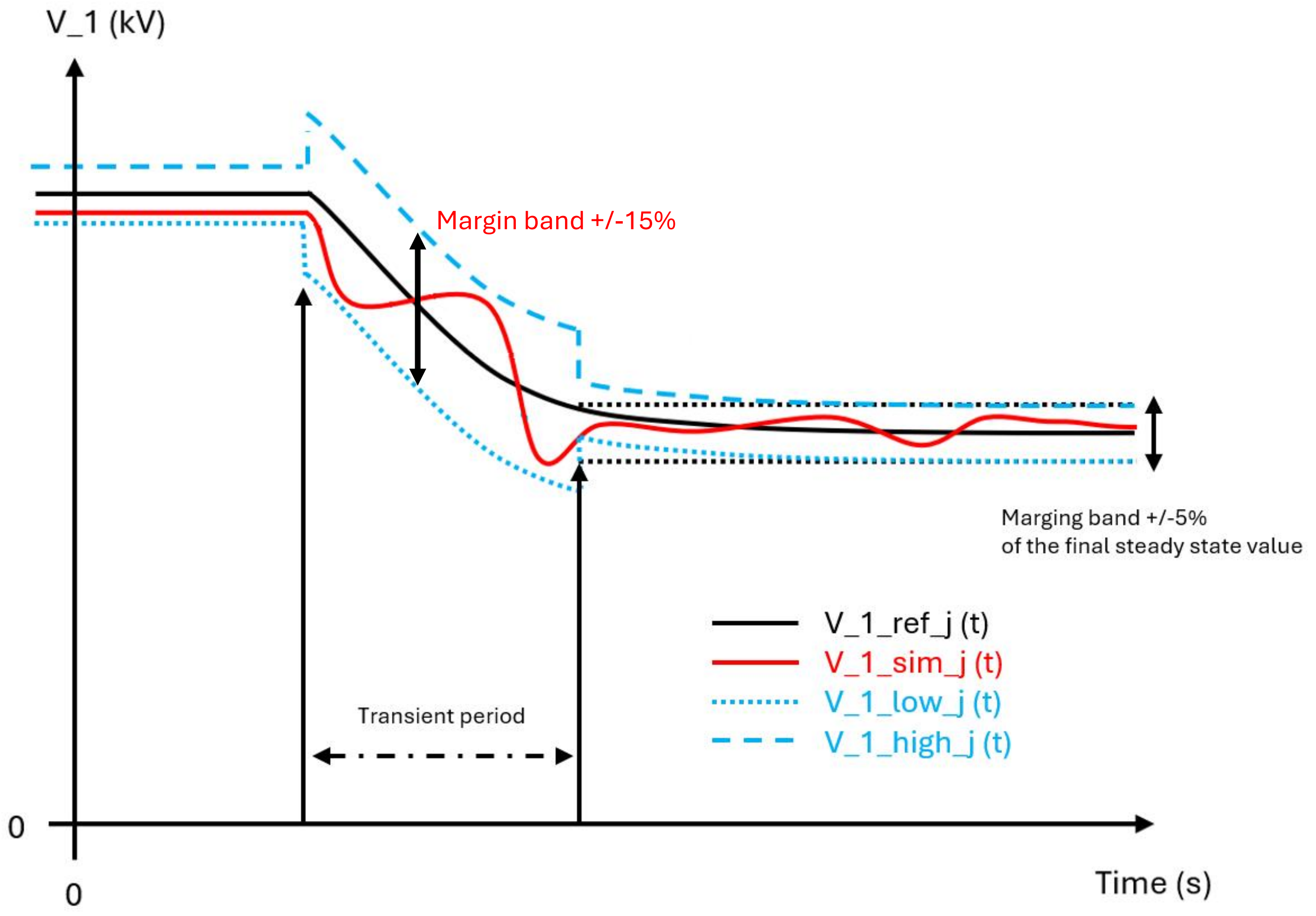
Verification Tests and Acceptance Procedures

Illustration of compliance analysis with SAT results

Signals for quantitative comparison
0/1/2 sequence Voltage and Current

Signals for qualitative comparison
Instantaneous Voltage and Current

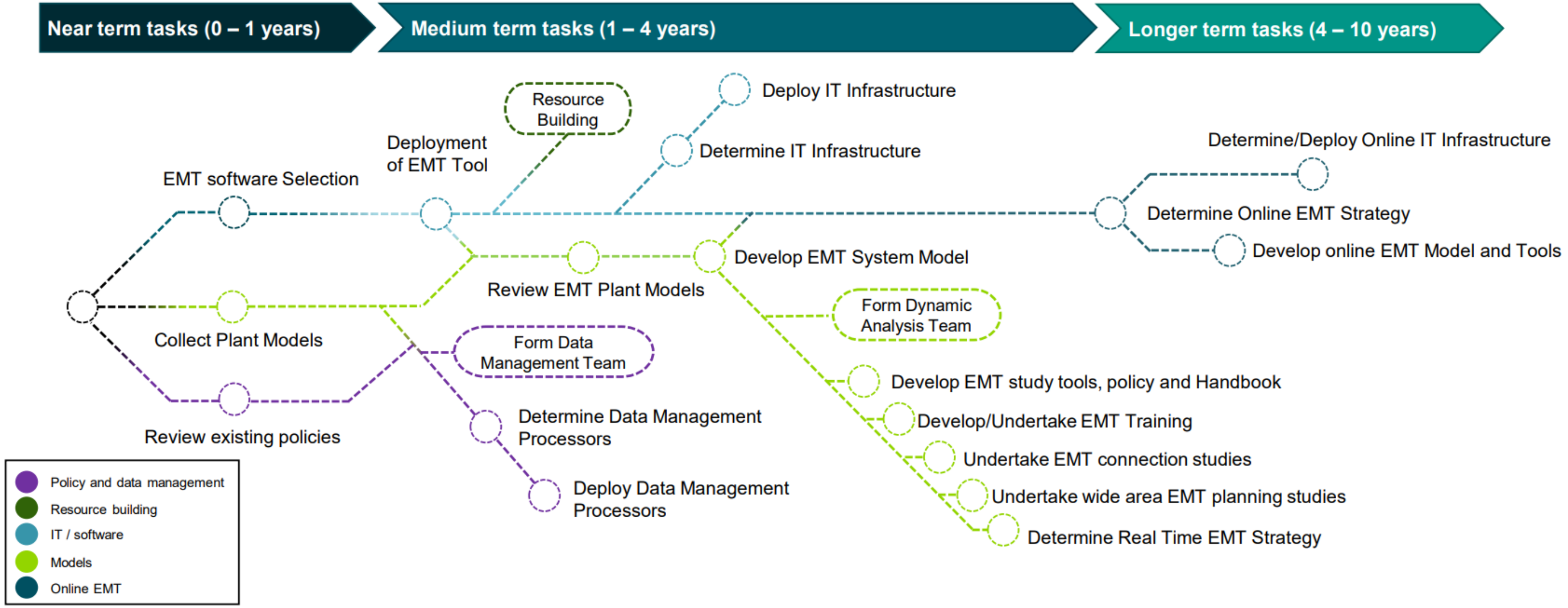
EMT model setup
All test conditions shall be documented
Simple AC model or playback method



EMT Roadmap : Overview

High-level implementation roadmap

The need for EMT deployment in EirGrid is evident and this high-level roadmap has been developed based on findings from interviews and in-house knowledge.



EMT Models in EirGrid

GRID CODE COMPLIANCE REQUIREMENT

EMT Model to be submitted by customers as part of the grid code compliance requirement.

INTERNAL MODEL VERIFICATION

1. A two step approach is adapted to verify the model structure and its dynamic behaviour.
2. Non-compliance with these tests will require the customer to provide an updated model to achieve the Energization Operational Notification (EON).

MODEL VALIDATION

Customer to validate the EMT model against site data and provide a final model before the Final Operational Notification (FON).

WIDE AREA NETWORK MODEL

The final model will then be then integrated with the wider area network. pre-connection studies, transmission network planning, operational studies, system incident investigations.

EMT Model Timeline

PREMINARY MODEL	MODEL VERIFICATION AND ACCEPTANCE TEST	ENERGISATION	MODEL VALIDATION	FINAL MODEL

PREMINARY MODEL

- To be submitted **12 months** before first energization.
- A simplified model and documents are submitted with preliminary settings of the plant.
- Additionally, the customers are required to submit a completed checklist provided in the specification annexure.

MODEL VERIFICATION AND ACCEPTANCE TEST

- The submission of models and documents is verified against the published specifications.
- Furthermore, the provided model is run through **a series of compliance tests** to assure it is fit for purpose.

ENERGISATION / MODEL VALIDATION

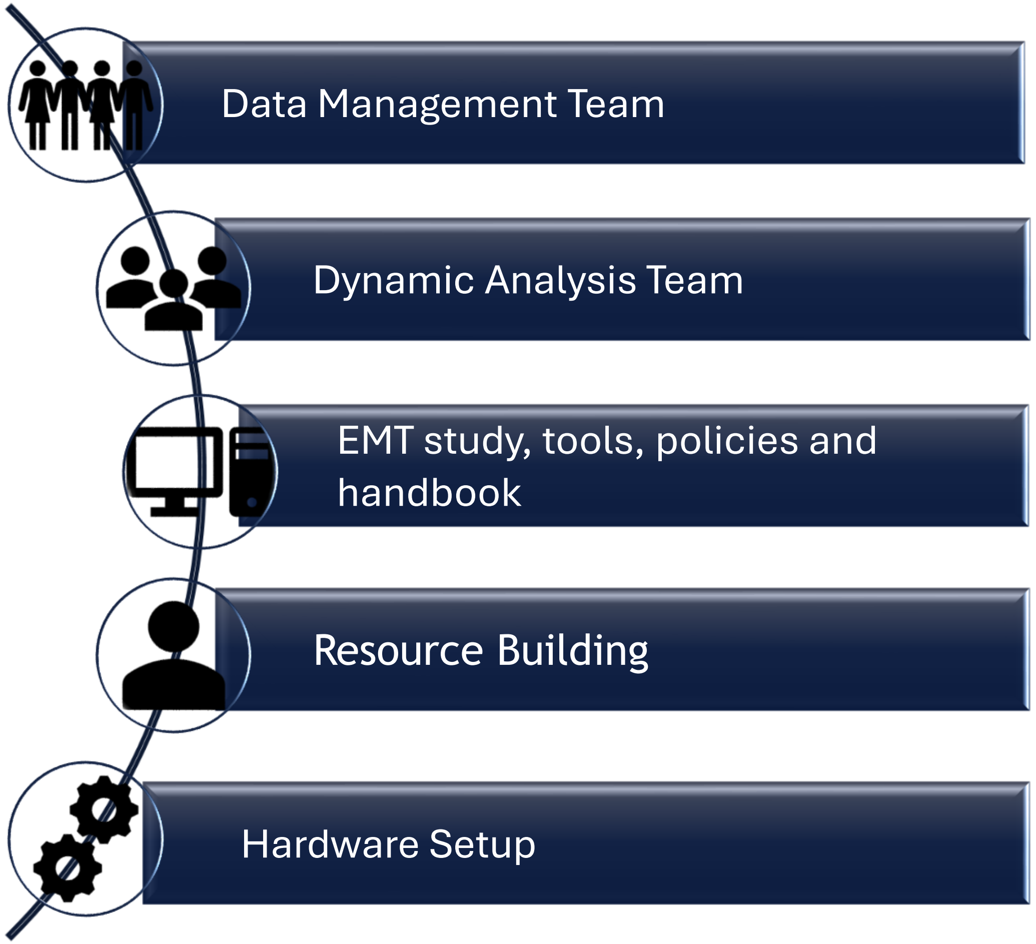
- The energization is approved only if the EMT model provided by the customer is accepted by the TSO.
- Customer uses the Sit Acceptance Tests (SAT) results for model validation **(part of the grid connection compliance process).**

FINAL MODEL

- This model should be submitted **3 months** before the first energization of the plant.
- The model can be **fully aggregated or fully detailed** (as applicable).
- The model should have **final settings** as implemented on site.

Next Steps

- EirGrid is actively engaging with industry to implement the feedback received on model specifications for all technologies and data centres.
- The TSO is in the process of gathering updated EMT models from customers.
- All the new connections are mandated to abide by the Grid Code and the EMT model specifications.
- EirGrid is also working with the industry and customers to discuss and further refine the EMT Model Validation guidelines.
- The larger plan is to develop a wide area network suitable for conducting system planning, studies and forecasting in the EMT domain.

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HVDC Supervisory Control Technology from the System Operator's Perspective

Gumin Kwon
Senior Researcher, KEPCO Research institute

Agenda

1. Changes in the Korean Power System Environment
2. Concept of KEPCO’s BTB HVDC Supervisory Control System
3. Yangju BTB HVDC Analysis Case & HILS Test Environment
4. Future Plan & Main Challenges

Changes in the Korean Power System Environment

Rapid Expansion of Renewable Energy

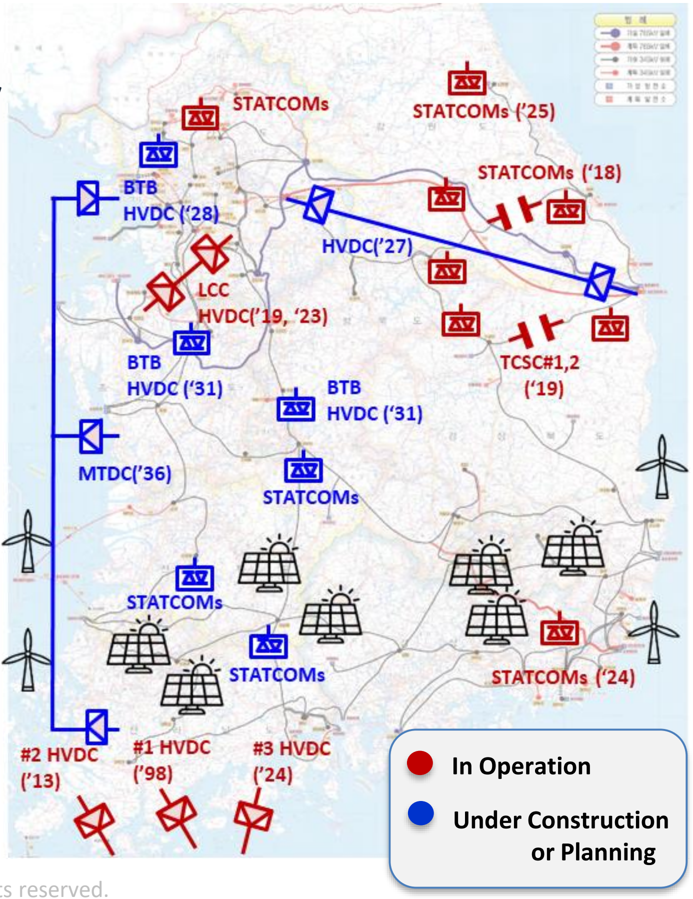
Large-scale grid integration of solar and wind generation leads to reduced system inertia, increased voltage fluctuations, and growing power system instability

Growing Installation of HVDC & FACTS

Continuous increase in HVDC transmission links and FACTS devices (SVC, STATCOM, TCSC, etc.) for grid stabilization

Growing Need for Precise EMT Analysis

Growing penetration of power-electronics-based devices exposes the limitations of conventional RMS analysis → increasing importance of EMT (Electromagnetic Transient)-based precise simulation



HVDC

Large-Scale Power Transfer to the Seoul Metropolitan Area

STATCOM

Dynamic reactive power supply, voltage regulation

TCSC

Real-Time Control of Transmission Line Impedance

Changing Trends in HVDC Projects in Korea

PAST - LCC HVDC

Primary Objective
- Bulk Power Transmission

Representative Projects
- Jeju #1/#2
- Bukdangjin-Godeok
- East Coast HVDC

Characteristics
- Unidirectional Power Transfer
- Independent HVDC Control
- Point-to-Point Transmission

PRESENT - VSC BTB HVDC

Primary Objective
- Power System Flexibility

Representative Projects
- Yangju BTB HVDC
- Shin-Bupyeong BTB HVDC
- Seo-Sejong BTB HVDC

Characteristics
- Flexible Bidirectional Power Control
- Mitigation of Power System Issues Through Active Control
- Coordinated Control with Adjacent DC Facilities

Why Do We Need a BTB HVDC Supervisory Control System?

01 Challenge

- Increasing power system variability
- Frequent operating point adjustments required
- Increasing Number of Controllable DC Assets

02 Operator Limitation

Manually determining and adjusting the optimal operating point in real time is practically impossible for system operators

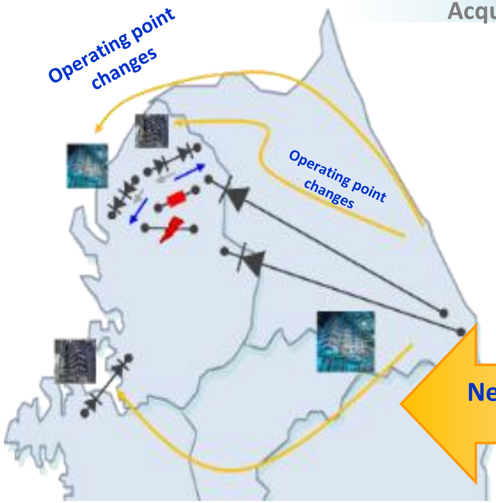
→ OUR SOLUTION

BTB HVDC Supervisory Control System

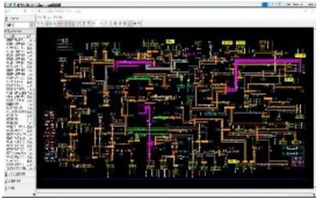
- Real-time system monitoring
- Automatic operating point calculation
- Remote control execution
- Operator decision support

The BTB HVDC Supervisory Control System was developed to automatically determine and apply optimal operating points under continuously changing power system conditions

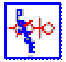
Concept of KEPCO's Supervisory Control System



Power System Data Acquisition



SCADA
(Grid Operating Status)



PSS/E DB

New BTB Operating point
(Direction, Pdc, Vref, etc)

Supervisory Control System

Power System Operational Variability

- Contingency
- Load Variations
- Renewable Generation Fluctuations
- GT Generator Start-up/Shutdown

Active and Automated
BTB HVDC Control Response

Enhanced Flexibility of BTB HVDC Control &
Reliable and Secure Power System Operation

BTB HVDC Supervisory Control System: Concept & Key Functions

CONCEPT

Preventive control through contingency analysis — Optimizing BTB HVDC operating points based on anticipated system conditions and contingencies, rather than providing fast corrective actions after disturbances occur

1

Optimal P-Q Operating Point Calculation

Calculation of optimal active and reactive power operating points based on a PSS®E-based power system operation database

2

Remote BTB HVDC Control

Real-time monitoring and remote control of BTB HVDC operating points

3

Local Power System Monitoring (Every 5 Minutes)

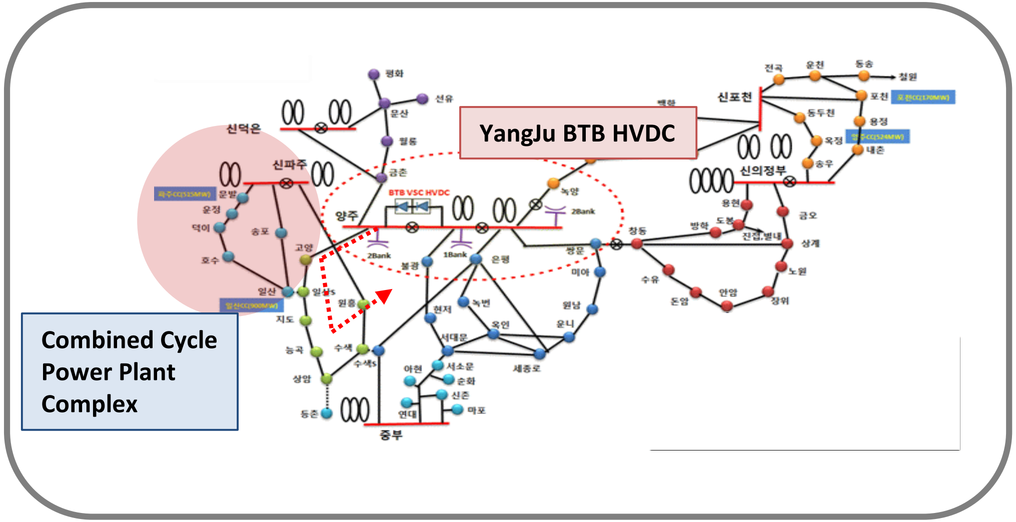
Monitoring of transmission line overloads and bus over-/under-voltage conditions

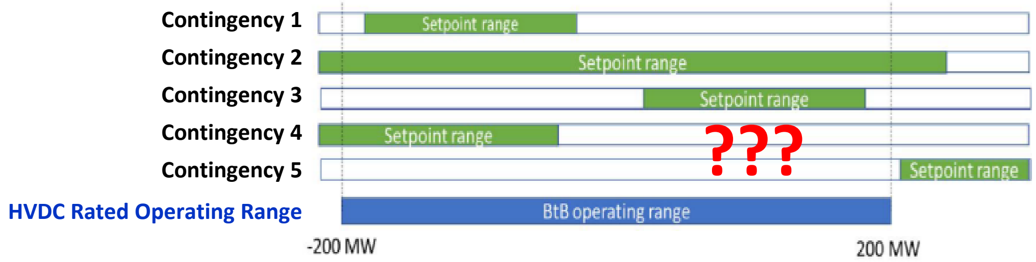
4

Security Operating Region Assessment Based on Contingency Analysis

Verification of secure operating regions through contingency-based power system studies

Analysis of the Power System near the “YangJu” BTB HVDC





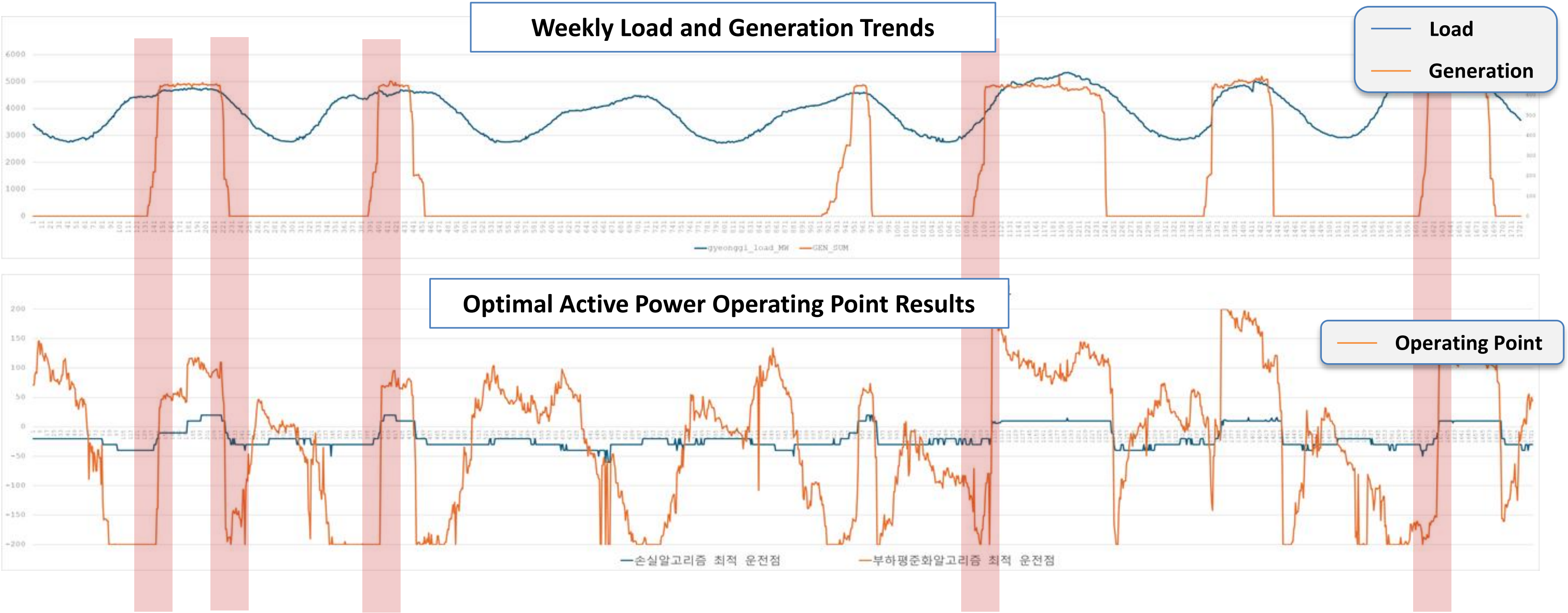
Changes in System Operating Conditions:

- Combined-Cycle Power Generation Operating Conditions
- Load Levels
- Nearby Transmission Line Faults

No Common Operating Region Exists

The Operating Point must be adjusted According to System Conditions

Analysis of the Power System near the "YangJu" BTB HVDC



Need for BTB HVDC Power Flow Control Due to Generator Output Variations

HILS-based System Verification Environment


Yangju BTB HVDC Replica Controller


Replica Controller Operation HMI (Local Control)


Supervisory Control System (Remote Control)


Real-Time Digital Simulator (RTDS)

Future Plan & Main Challenges

Future Work

- Field deployment of the Supervisory Control System
  - Validation of system effectiveness under actual power system operating conditions
- Assessment of the economic benefits of the Supervisory Control System
- Expansion of the Supervisory Control System to other BTB HVDC Projects

Main Challenges

- Ensuring the Reliability and Quality of Input Data (Garbage In, Garbage Out)
- Coordination of Multiple DC Facilities
  - How should coordinated control be implemented among nearby DC facilities (e.g., BTB HVDC and STATCOM)?
- Establishment of Common Integration Standards
  - Development of common control policies, cybersecurity requirements, and communication protocols for integrating equipment from different vendors into a single Platform(Supervisory Control System)

Thanks for listening

Questions?

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KEPCO