Microgrid Symposium 2022, Singapore

Design and Control of Energy Storage System for Stand-alone Microgrids to Mitigate Renewable Energy Variation

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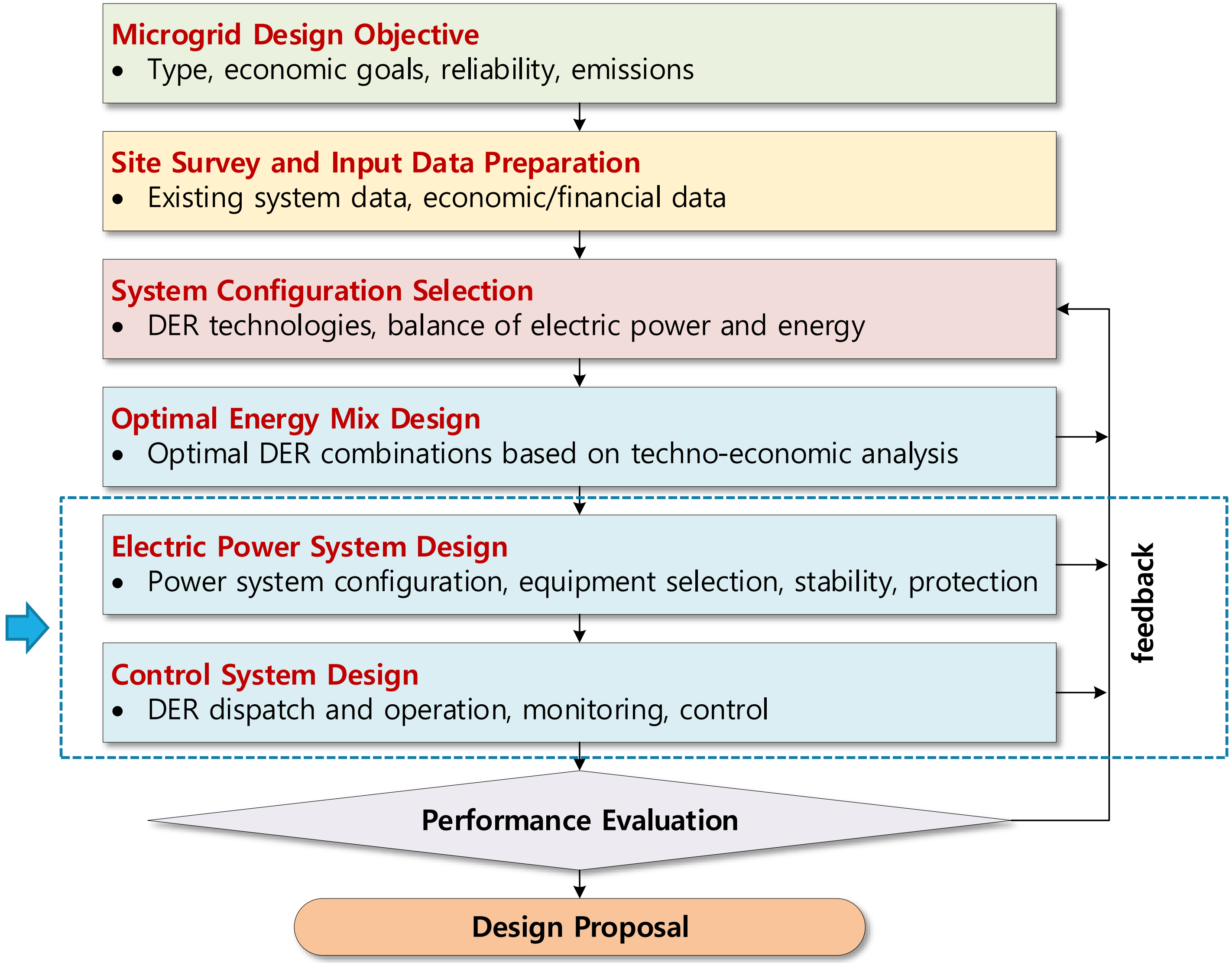
Microgrid Planning and Design Procedure

This presentation



Objectives

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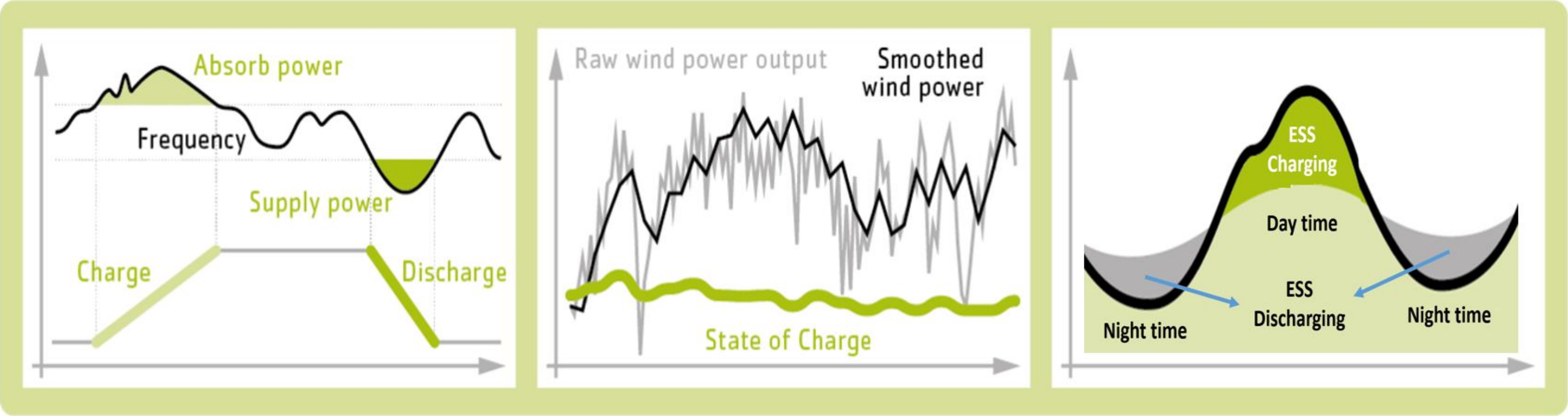
- **Research Objectives**
  - **Power system stabilization using ESSs** against variations in renewable energy resources (RESs), specifically, wind turbines for a stand-alone island
  - Design and simulation analysis of **three types of ESSs**
    - ESS for power system **frequency regulation (FR-ESS)**
    - ESS for **ramp-rate control** of RESs **(RC-ESS)**
    - ESS for **surplus energy charging (SC-ESS)**



Frequency Regulation **(FR-ESS)**

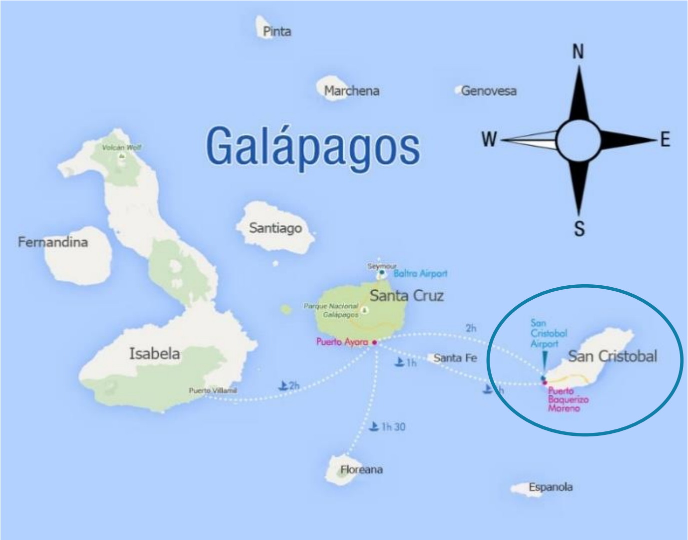
Solar/Wind Ramp Rate Control **(RC-ESS)**

Surplus energy charging **(SC-ESS)**

Project Summary

- **Project summary**
  - (**2019/20 KSP-IDB Joint Consulting**) The Grid Stabilization and Optimization Support in Galapagos Islands of Ecuador Using ESS
  - Target Area: **San Cristobal Island** of the Galapagos Islands
  - Project Period: April ~ October 2020 (6 months)

- **Project work items**
  - **Power system modeling**
    - Power distribution system modeling using Power Factory
    - Energy resources modeling: diesel generators, wind turbines, solar PV plants and ESSs
  - **Power system analysis**
    - Power flow analysis
    - Short-circuit analysis
    - Dynamic transient analysis for RES variations
    - Power system stabilization studies using ESSs



Island	Area (km2)	Population
Santa Cruz	986	15,393
San Cristobal	557	7,475
Isabela	4,670	2,256
Floreana	173	100
Total	6,386	25,224

Microgrid Model (in 2020)

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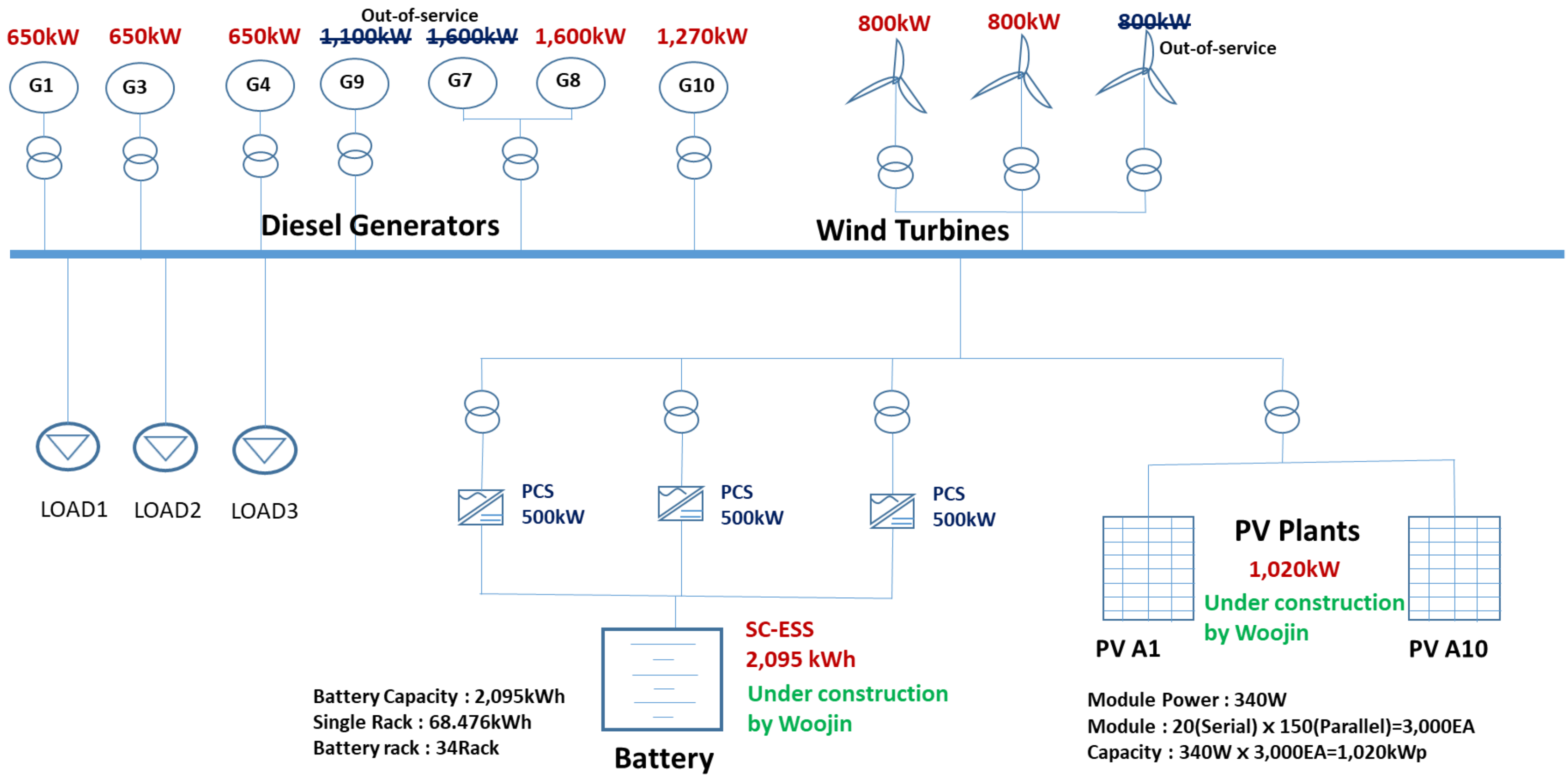
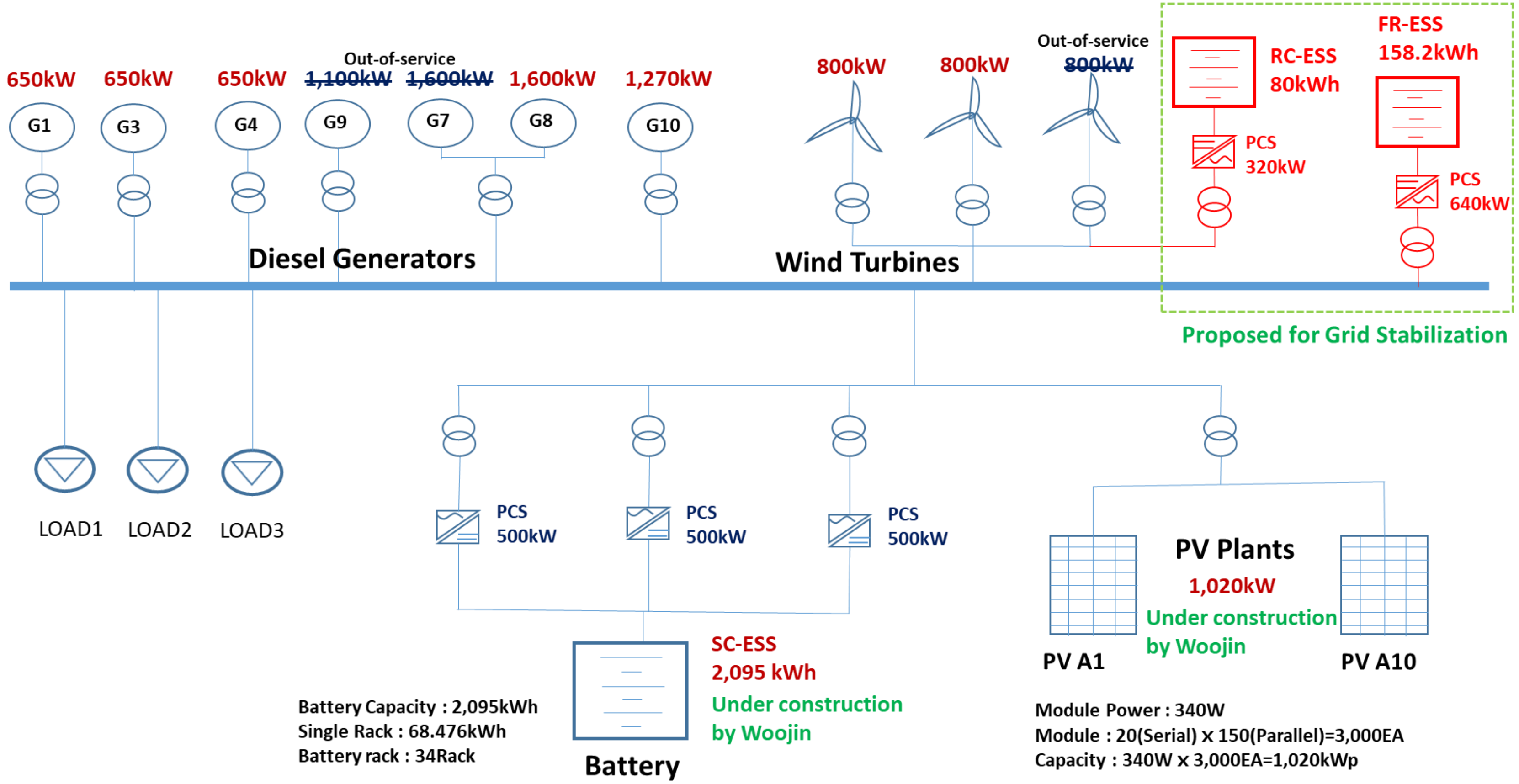
- **Microgrid Operation Data**
  - Peak demand: 2,994 kW in 2015 and expected to 3,589 kW in 2020 (with 4% annual increase)
  - Three 800 kW wind plants are constructed on the hilly sections about 20 minutes away from the city. However, one of them is stopped because the hydraulic pitch controller is broken.



Microgrid Stabilization with FR / RC ESSs

- **Microgrid Stabilization with ESSs**
  - To stabilize the variations from WTs, RC-ESS and FR-ESS are proposed.
  - The purpose of the project is to evaluate the performance of RC-ESS and FR-ESS in terms of power system stabilization.



Power System Faults Analysis

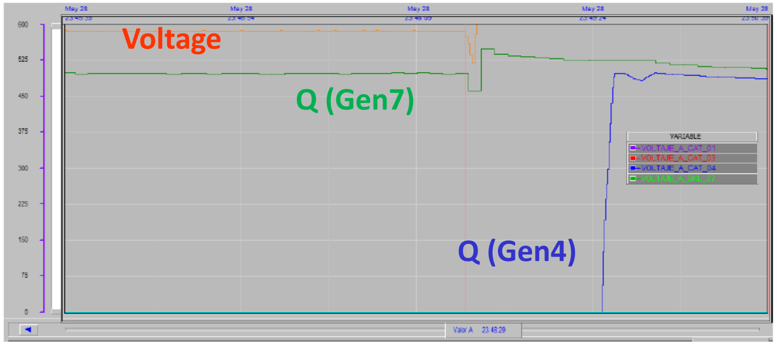
- **Fault Analysis for 7 Accident Cases in 2019 and 2020**
  - An overview of the analysis of the seven accident cases in 2019 and 2020
    - Short-circuit faults in distribution lines: 3 cases
    - Wind turbine failures: 2 cases
    - Unknown reasons : 2 cases
  - Wind turbine failures cause blackouts.
    - The diesel generators tripped out due to frequency fluctuation and the recloser operation.
    - Lack of countermeasures for wind turbine failure or variations
    - Lack of the concept of operation reserve for generator trip

Event	Date	Event	Operating condition before event	Event propagation	Report
Case 1	May/28/2020	WT 1 and WT 2 failure	• Load: 1,830 kW • Power supply: G7(933kW), WT1(320.8kW), WT2(576.2kW) • G1/3/4/10: cold reserve	• WT1/WT2 tripped • R/C off (underfrequency) • 80% of the load curtailed • Fault time: 49 min	Report including detailed process
Case 2	Jul/11/2020	G7 failure (caused by WT variations)	• Load: 1.23MW • Power supply: G7(680kW), W1(304kW),W2(248kW)	• G7 tripped • WT1/WT2 tripped • Blackout for the whole feeder • G1/3/4 turned on • Fault time: 1 hour and 35 min	Report including detailed process

Power System Faults Analysis

- **Case 1: Two WT tripped**
  - An overview of the analysis of the seven accident cases in 2019 and 2020

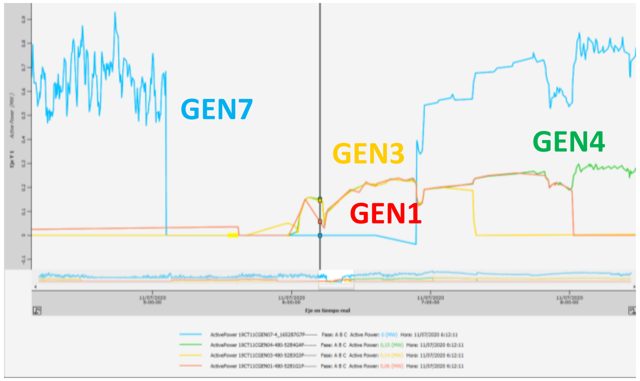
Real Power Outputs from WT1 and WT2



Reactive Power Outputs from Diesel Generators

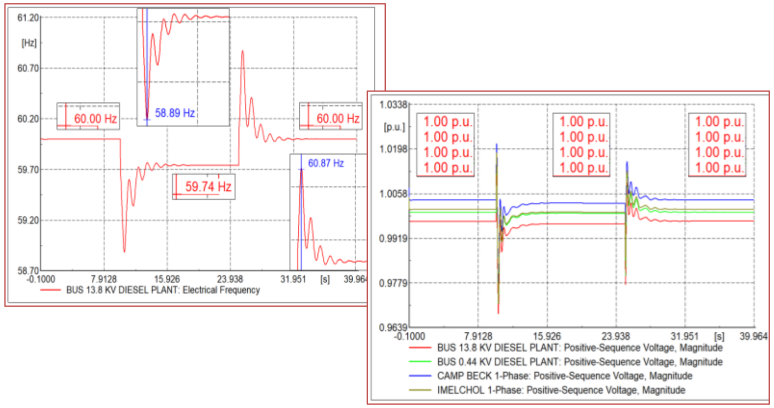
- **Case 2: Diesel generator tripped due to WT faults**
  - An overview of the analysis of the seven accident cases in 2019 and 2020

Real Power Outputs from WT1 / WT2 / GEN7



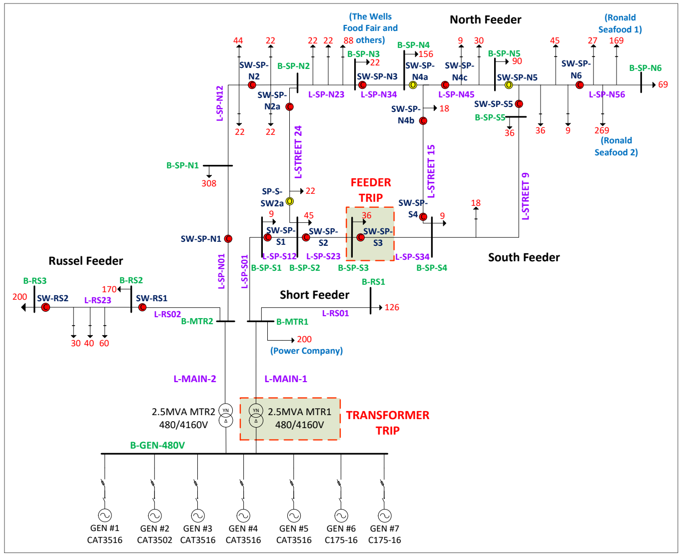
Real Power Outputs from GEN 1 / 3 / 4 / 7

Power System Modeling and Analysis



Power System Modeling

- Single-line diagram
- Sizing of PVs, ESSs, Diesel generators
- Possible installing locations of PVs, ESSs
- Controllers for ESSs, Diesel generators
- Possible grid expansion



Power System Analysis

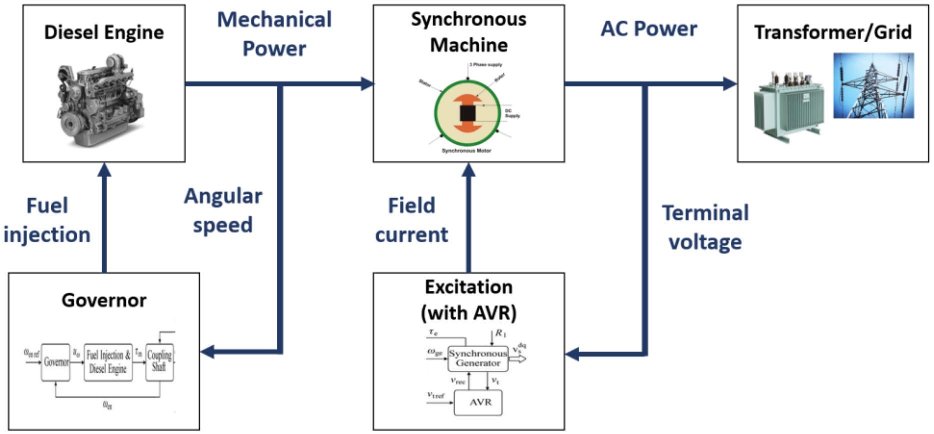
- Normal operating conditions: power, voltage, frequency
- Abnormal operating conditions: faults, severe load variations, machine-trip events, black start
- Voltage stability under different dynamic conditions
- Frequency stability under different dynamic conditions

Final System Configuration and Controller Design!

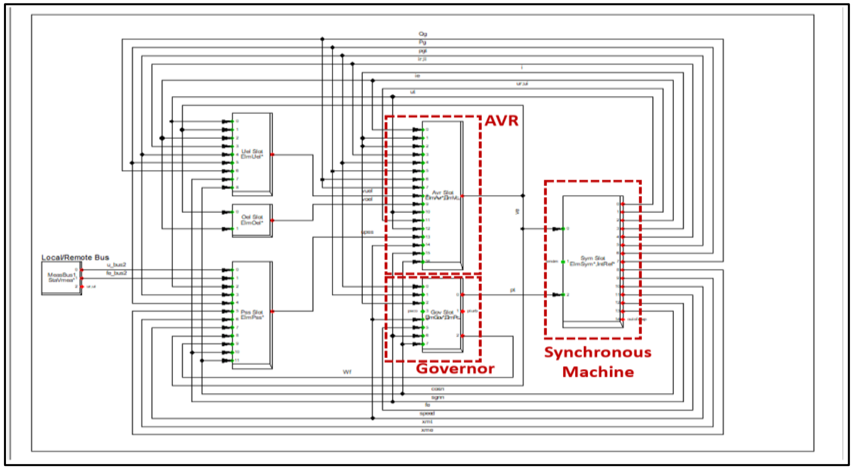
- **S/W Tool: Power Factory**

Power System Modeling
Diesel Generator and Controller

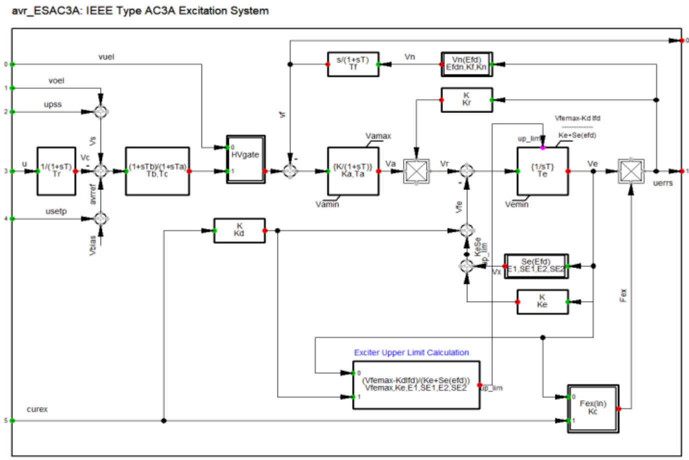
- The dynamic parameters of diesel generators are provided by ElecGalapagos.



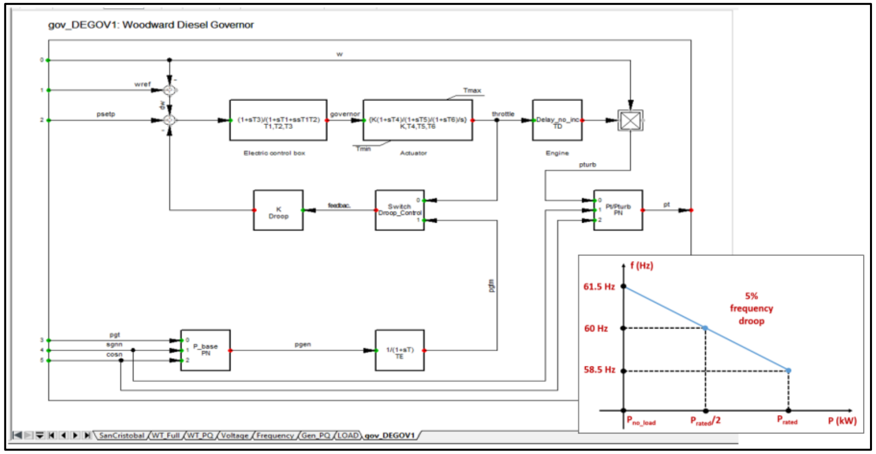
Simplified block diagram of diesel generator model



Dynamic model of diesel generator in PowerFactory library

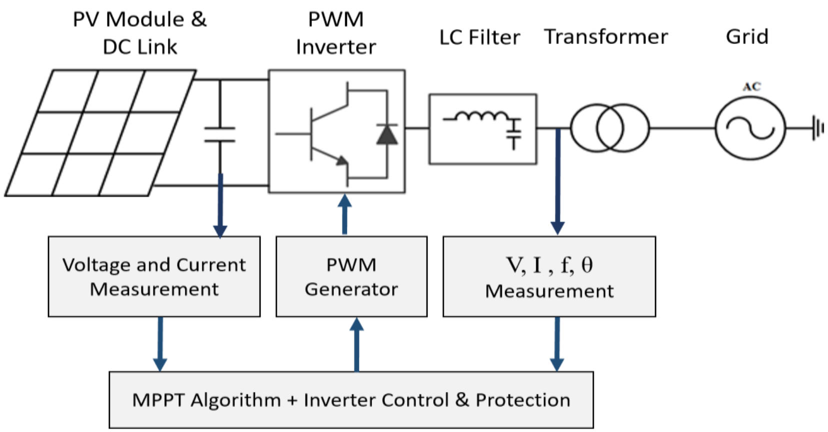


Exciter modeling in PowerFactory

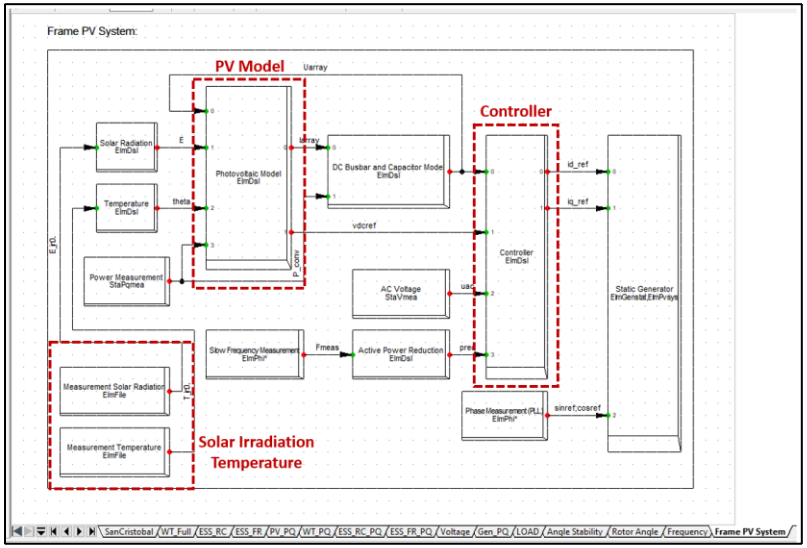


Governor modeling in PowerFactory

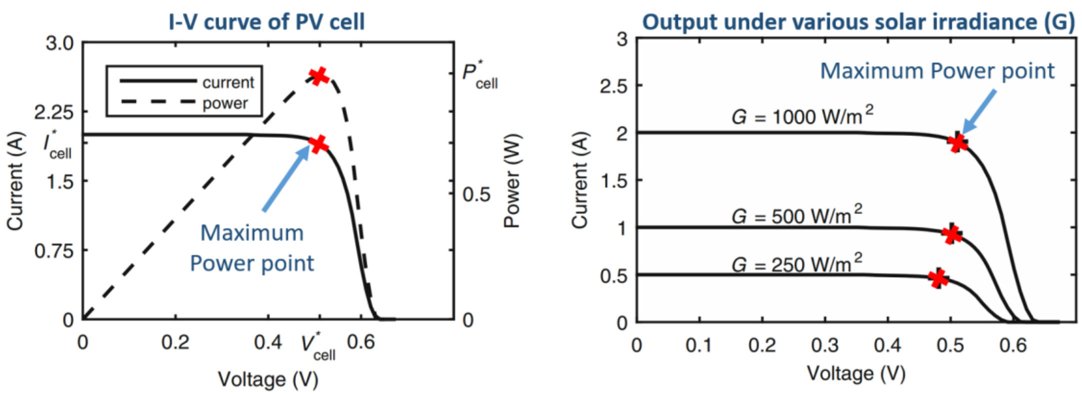
Power System Modeling
PV and Controller



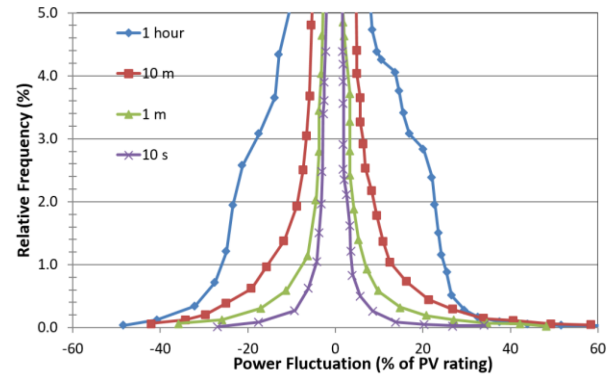
PV System and Controller



PV inverter controller implemented in PowerFactory



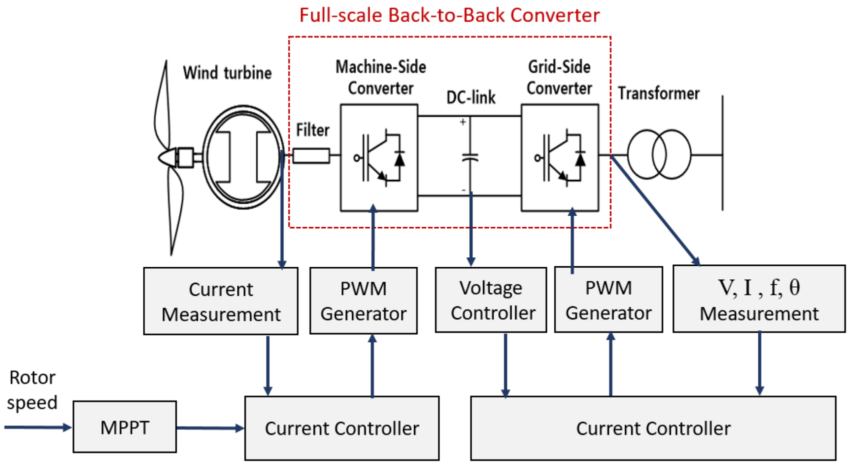
Concept of MPPT Control of PV Inverter



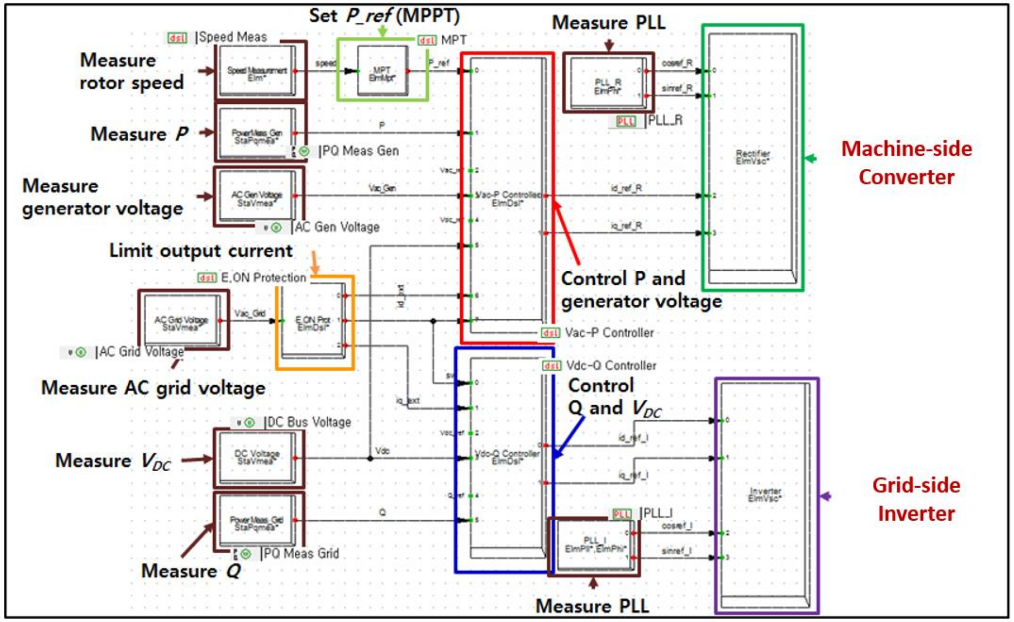
Variations in PV output

Power System Modeling
WT and Controller

- **WT Model**
  - Includes a wind turbine model, a permanent magnet synchronous generator (PMSG), and a full-scale back-to-back converter, which is composed of a machine-side converter (MSC), a DC link capacitor, and a grid-side inverter (GSI).



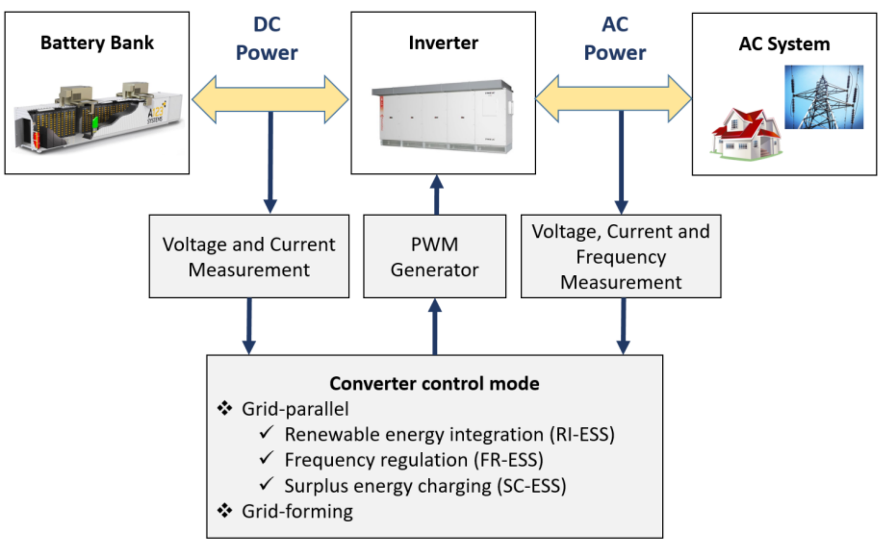
Simplified block diagram of WT and controller



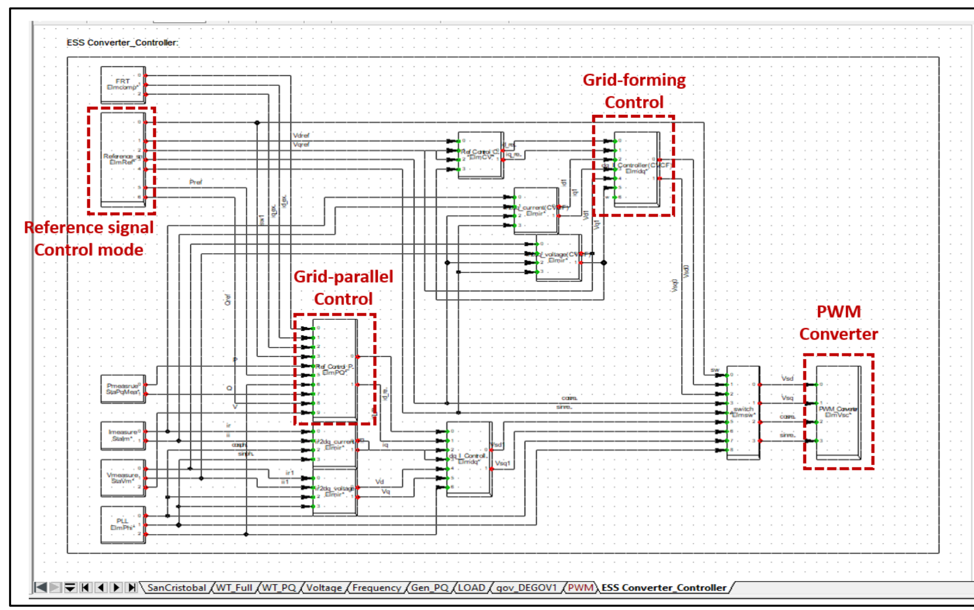
WT full-scale back-to-back converter controller implemented in PowerFactory

Power System Modeling
ESS and Controller

- **Features of ESSs**
  - Because of the charging and discharging characteristics of batteries, ESS inverters should have bi-directional power control capability.
  - Control modes: grid-parallel mode and grid-forming modes
    - For higher renewable energy penetration, ESS should have grid-forming capability so that all diesel generators can be turned off.



Simplified block diagram of ESS and controllers

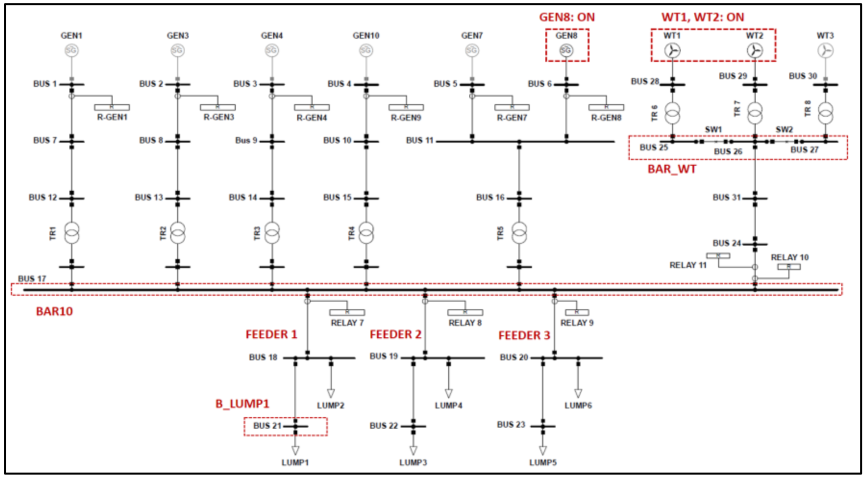


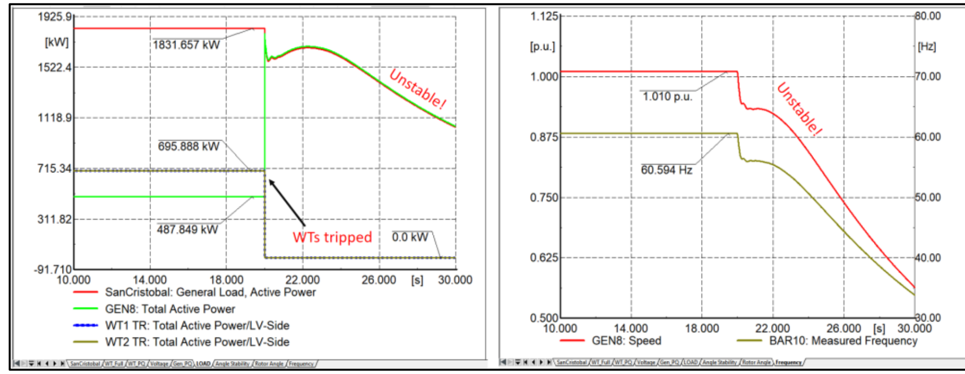
ESS converter controller implemented in PowerFactory

Power System Analysis

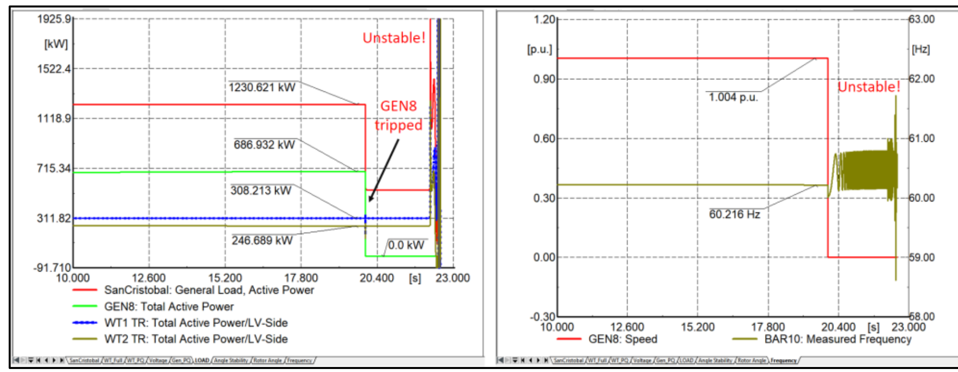
Dynamic Transient Analysis

- **Simulation studies for two fault cases**





Active power and frequency responses in Case 1 (WT trip)



Active power and frequency responses in Case 2 (GEN8 trip)

Scenario	Simulation settings	Simulation event
Case 1 (WT trip)	Load of 1.83 MW supplied by GEN8, WT1, and WT2.	While GEN8 (1,600kW rated), WT1 (800kW rated) and WT2 (800kW rated) are supplying the total load, both WT1 and WT2 are suddenly tripped together.
Case 2 (GEN8* trip)	Load of 1.23 MW supplied by GEN8 (55% of the load), WT1 (25% of the load), and WT2 (20% of the load).	GEN8 (1,600kW rated) is suddenly tripped.

*** GEN8 is used instead of GEN7, which are identical to each other.**

Power System Analysis

Dynamic Transient Analysis

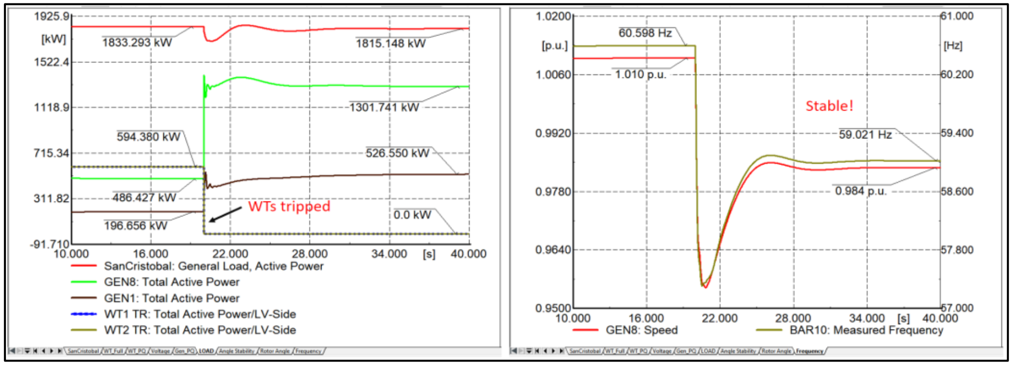
- **Two possible solutions for the current microgrid**

➢ **Sufficient operation reserve with (N-1) contingency criteria and WT variations**

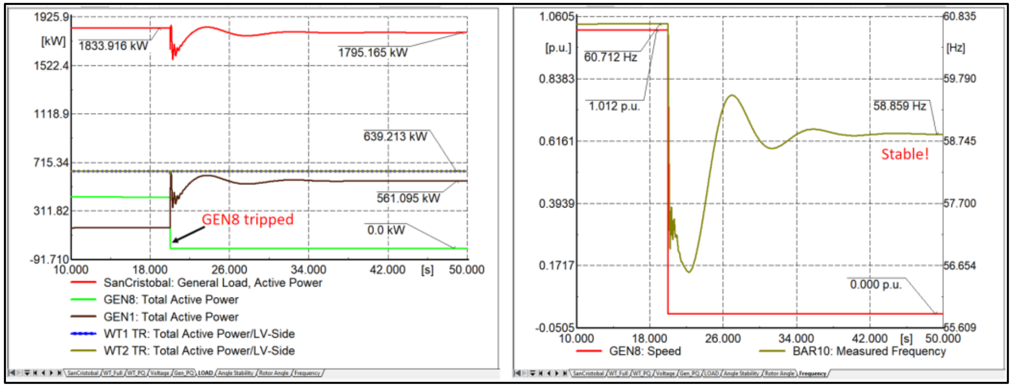
- As the case of diesel generator trip, other diesel generators must provide sufficient operating reserve considering the (n-1) contingency and WT variations.
- WTs cannot be considered to replace diesel generator in terms of (n-1) criteria.
- Therefore, at least two diesel generators must operate at any time in this microgrid.

➢ **WT power control for curtailment**

- Based on loading conditions, the central controller should be able to limit the maximum power of WTs so that diesel generators do not operate below the minimum load requirement (30% of the generator rating) and also avoid over-generation problem.



Active power and frequency responses in Case 1 (WT trip)



Active power and frequency responses in Case 2 (GEN8 trip)

These solutions can stabilize the microgrid but are not efficient because of additional DG operation and WT curtailment.

ESS can provide operation reserve and store the surplus power from WTs.

Power System Analysis

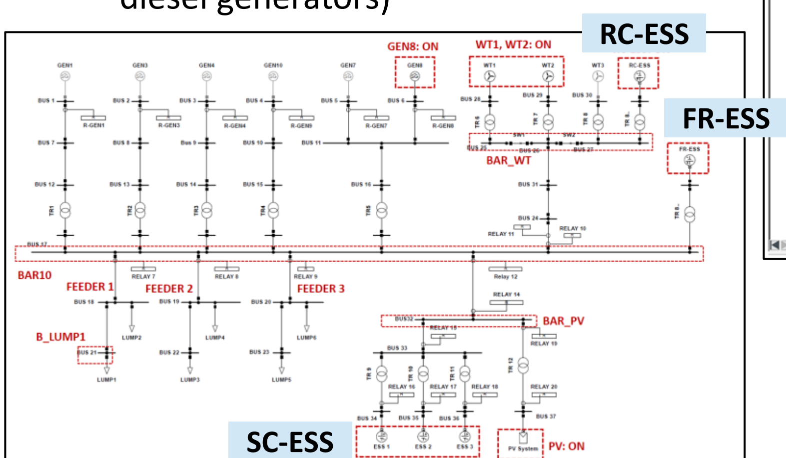
Dynamic Transient Analysis

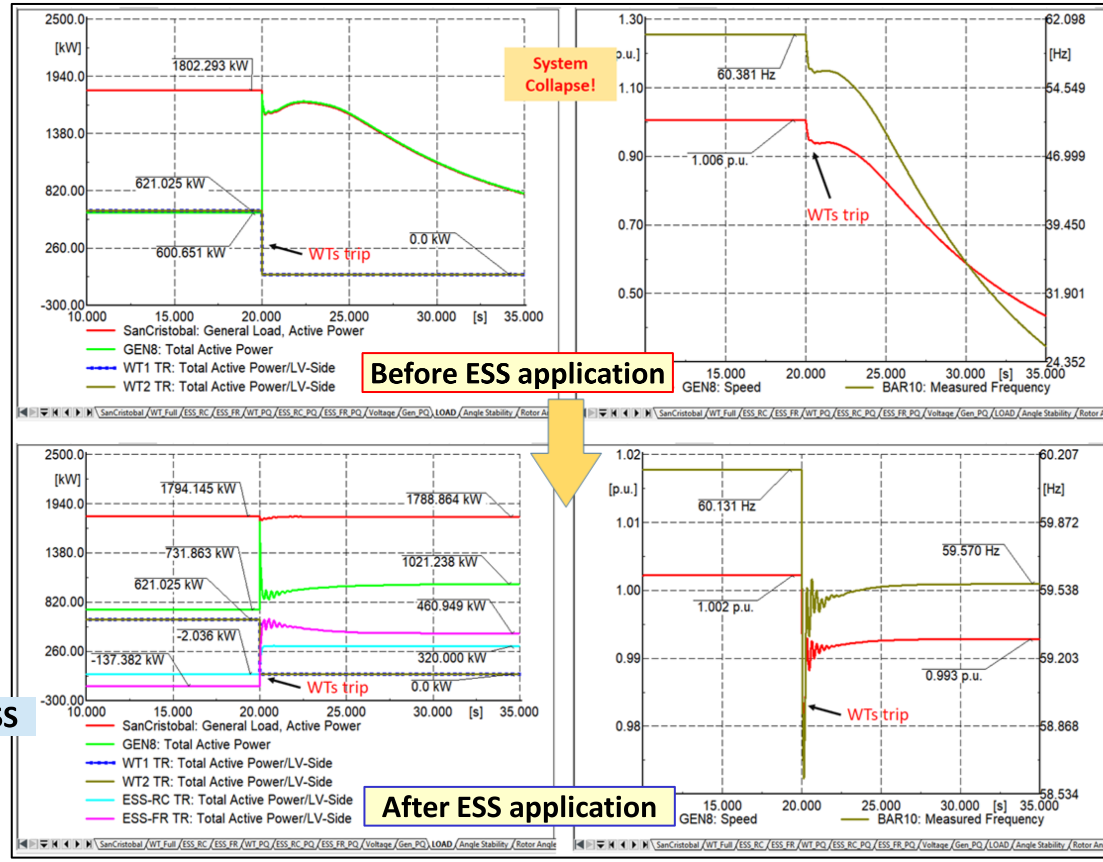
- **ESS applications for microgrid stabilization**

➢ **FR-ESS: Frequency Regulation**
- To balance power mismatch in short time period against WT variations

➢ **RC-ESS: Ramp-rate Control**
- To limit WT variations

➢ **SC-ESS: Surplus WT energy Control**
- To supply operation reserve for generator trip (replacing additional diesel generators)





Active power and frequency responses in Case 1 (WT trip)

Conclusion

- **Power system design and simulation for a stand-alone microgrid**
  - **Power system modeling and simulations**
  - **Power system stabilization using ESSs**
    - ESS for power system **frequency regulation (FR-ESS)**
    - ESS for **ramp-rate control** of RESs **(RC-ESS)**
    - ESS for **surplus energy charging (SC-ESS)**

- **Future extensions**
  - **Microgrid controller design and simulations**
  - **Optimal coordinated control of ESS and other DERs**

Grid Interactive Control Functions
(Area EPS Control, Spot Market, DMS, TSCADA, Connection to other grids)

Supervisory Control Functions
(Forecasting, Data Management and Visualization, Volt/Var Optimization, Economic Dispatch, Dispatch, State Estimation, Emergency Handling, Generation Smoothing, Spinning Reserve, Topology Change Management, Black Start, Protection Coordination)

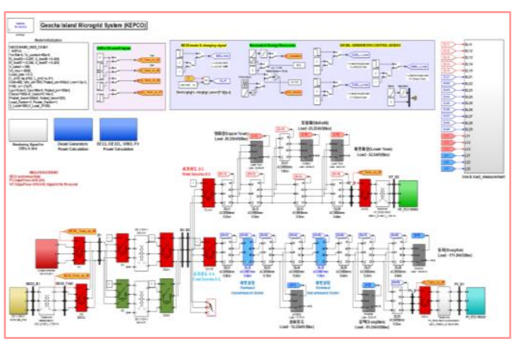
Local Area Control Functions
(Sequence Logic/Status Control, Load Management, AGC, Load Shedding, Resynchronization, Disturbance Recording)

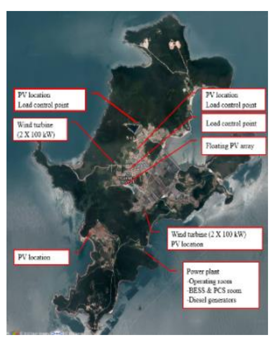
Device Level Control Functions
(Voltage/Frequency Control, Reactive Power Control, Electric Vehicle Control, Energy Storage Control, Load Control, Generation Control, Islanding Detection, Fault Protection)

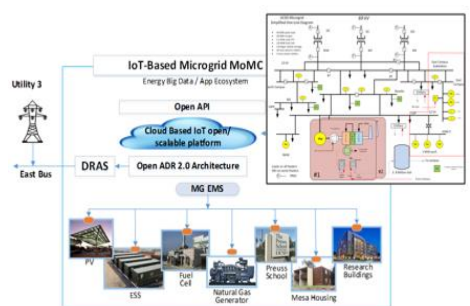
MG Design Project Portfolio

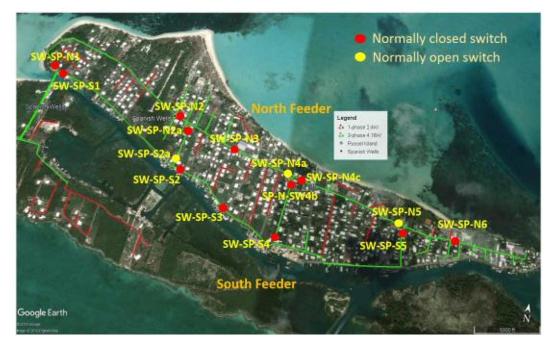
http://smartgrid.kookmin.ac.kr

- **Stand-alone Microgrid in South Korea**
  - Gasa, Geocha, and Ulleung Islands
- **Campus Microgrid Design**
  - Seoul National University, University Campuses in California
- **Stand-alone Microgrid in Pacific and Caribbean Ocean, and South America**
  - Remote sites in Palau, Bahamas, Bolivia, Chile, Ecuador, and Honduras
- **Microgrid Design Support Tool (MDS Tool)**
  - Techno-economic analysis using state-of-the-art DER control technologies









Thank you

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