Microgrid Symposium 2022, Singapore

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

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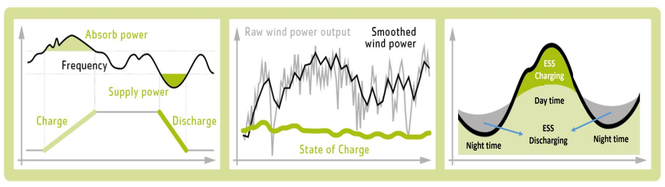
Objectives

- **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 ESS**s
  - 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)

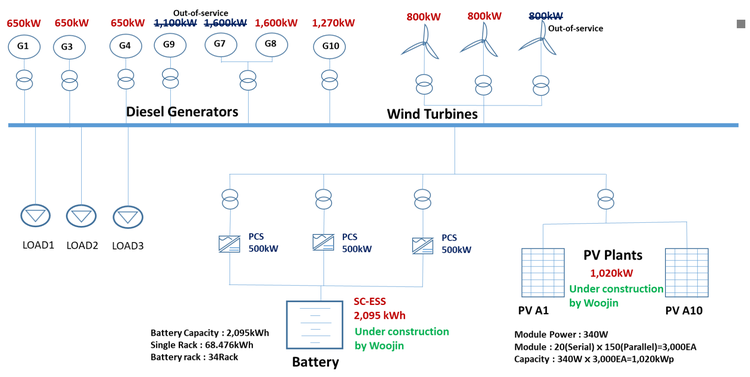
Island	Area (km2)	Population
Santa Cruz	986	15,393
San Cristobal	557	7,475
Isabela	4,670	2,256
Floreana	173	100
Total	6,386	25,224

Research 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

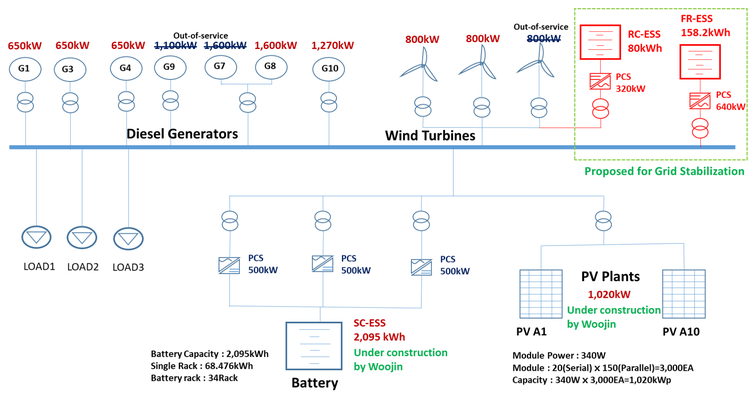
Final System Configuration and Controller Design!

Microgrid Model (in 2020)



- **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 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.

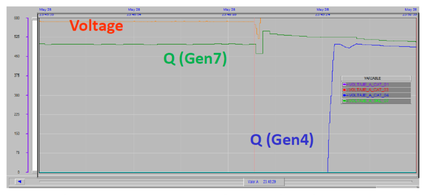
Power System Fault Analysis in 2019/2020

- **Fault analysis for 7 Accident Cases in 2019 and 2020:** Short-circuit faults in distribution lines (3 cases), wind turbine failures (2 cases), and 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

Case	Event	Operation before event	Event propagation
Case 1	WT 1 and WT 2 failure (May/28/2020)	• 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
Case 2	G7 failure caused by WT variations (Jul/11/2020)	• Load: 1.23MW • Power supply: G7(680kW), W1(304kW),W2(248kW	• G7 tripped, and then WT1/WT2 tripped • Blackout for the whole feeder • G1/3/4 turned on to catch up the load • Fault time: 1 hour and 35 min

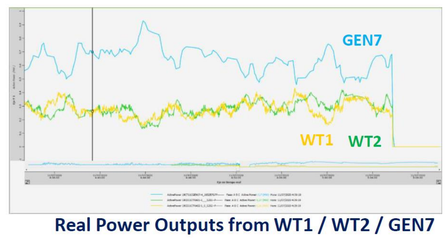
Case 1: Two WT tripped

Real Power Outputs from WT1 and WT2

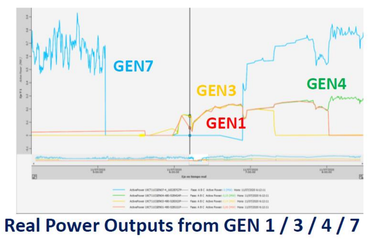


Reactive Power Outputs from Diesel Generators

Case 2: Diesel generator tripped



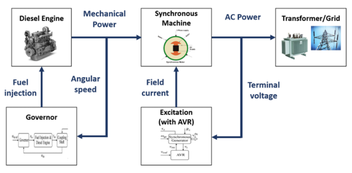
Real Power Outputs from WT1 / WT2 / GEN7



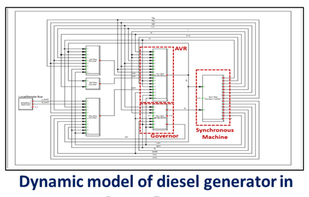
Real Power Outputs from GEN 1 / 3 / 4 / 7

Power System Modeling

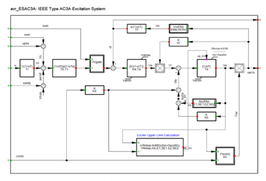
- **Diesel Generator and Controller**



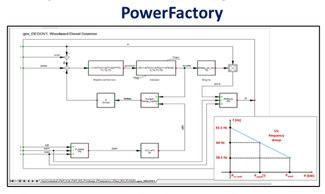
Block diagram of diesel generator model



Dynamic model of diesel generator in PowerFactory

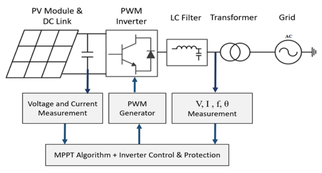


Exciter modeling in PowerFactory

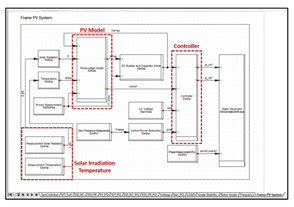


Governor modeling in PowerFactory

- **PV and Controller**

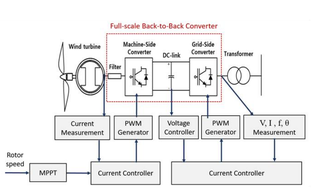


PV System and Controller

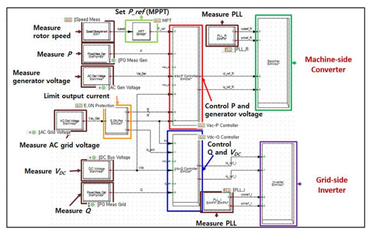


PV inverter controller in PowerFactory

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

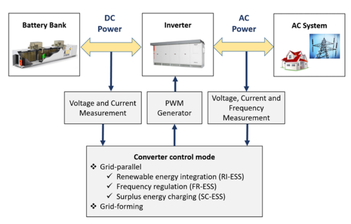


Block diagram of WT and controller

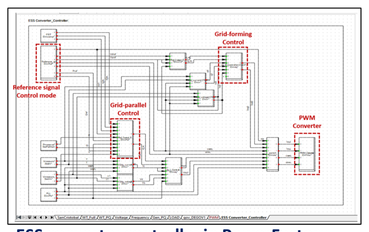


WT full-scale back-to-back converter controller implemented in PowerFactory

- **ESS and Controller**
  - ESS inverters should have bi-directional power control capability.
  - For higher renewable energy penetration, ESS should have grid-forming capability so that all diesel generators can be turned off.



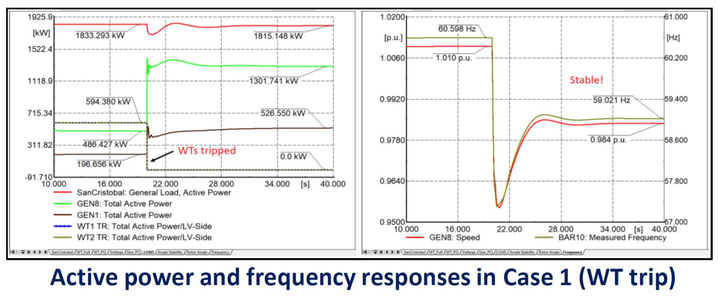
Block diagram of ESS and controllers



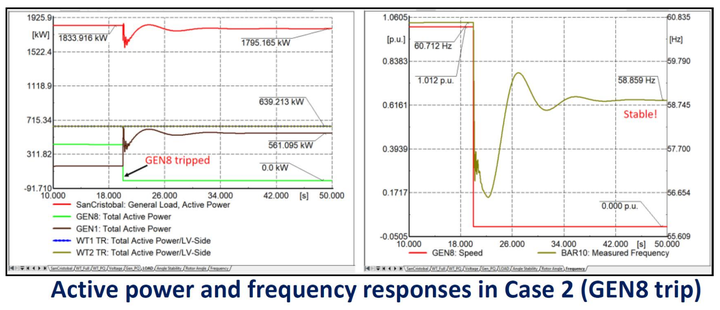
ESS converter controller in PowerFactory

Suggestions of Two Solutions for System Stabilization

- **To have sufficient operation reserve with (N-1) contingency criteria and consideration of WT variations**
  - Diesel generators must provide sufficient operating reserve considering the (n-1) contingency and WT variations.
  - 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)

ESS Application for MG Stabilization

ESS can provide operation reserve instead of diesel generators and reduce the curtailment on WTs by storing surplus power.

- FR-ESS balances power mismatch in short time period against WT variations
- RC- ESS limits WT variations
- SC-ESS supplies operation reserve for generator trip (replacing diesel generators)