Real-Time Operation of Residential PV and Battery Systems for Primary Frequency Response

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Australia User's Group Meeting

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Outline

- **Introduction and Context**
- **Droop-frequency Relationship for Residential Batteries**
- **RTDS Implementation**
- **Case Study and Results**
- **Challenges and Upshot**

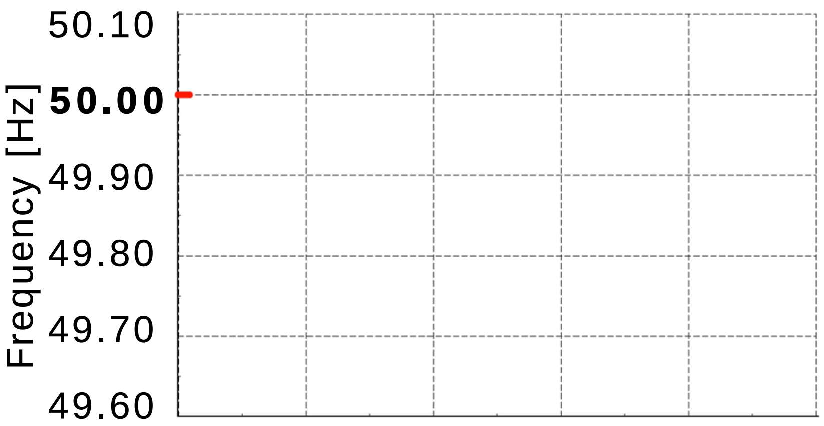
Why Use RTDS?

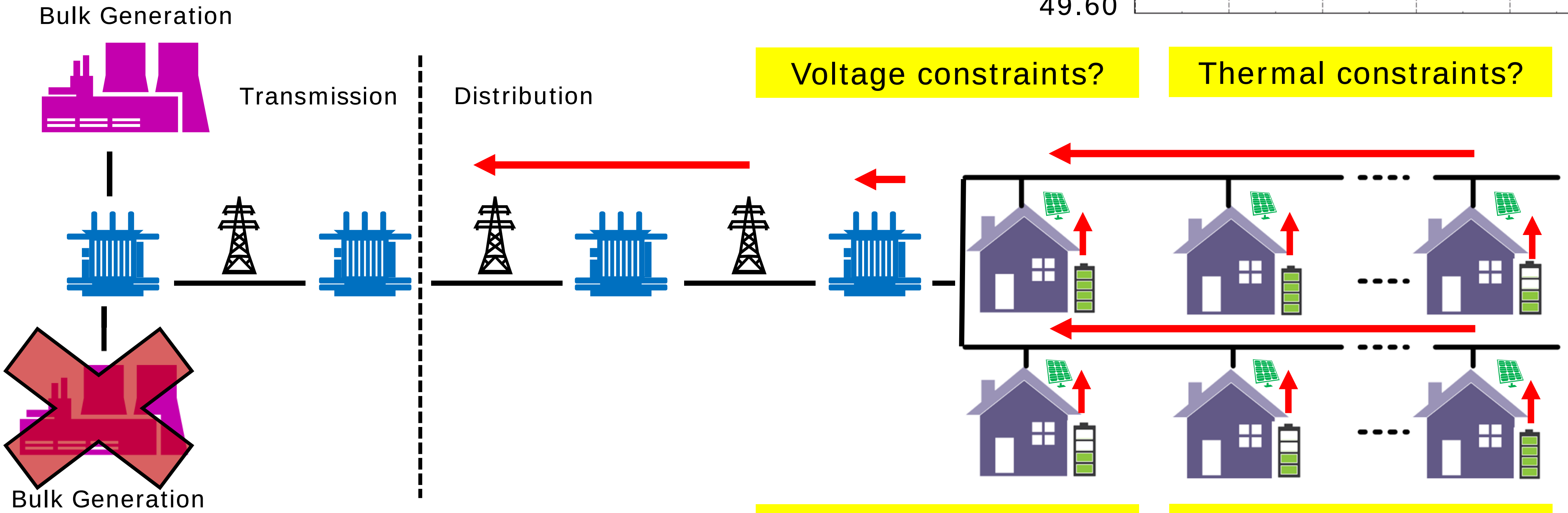
- **Exploring new software packages**
- **Implementation**

- **Student focused**
  - Educational exercises
  - Pushing the limits
  - Future development of power systems

- **Platform to test new ideas**
  - **Controllers**
  - Distributed Energy Resources

Residential Battery Energy Storage Systems for Frequency Response





Voltage constraints?

Thermal constraints?

How much Frequency Response is possible?

Controls? SOC constraints?

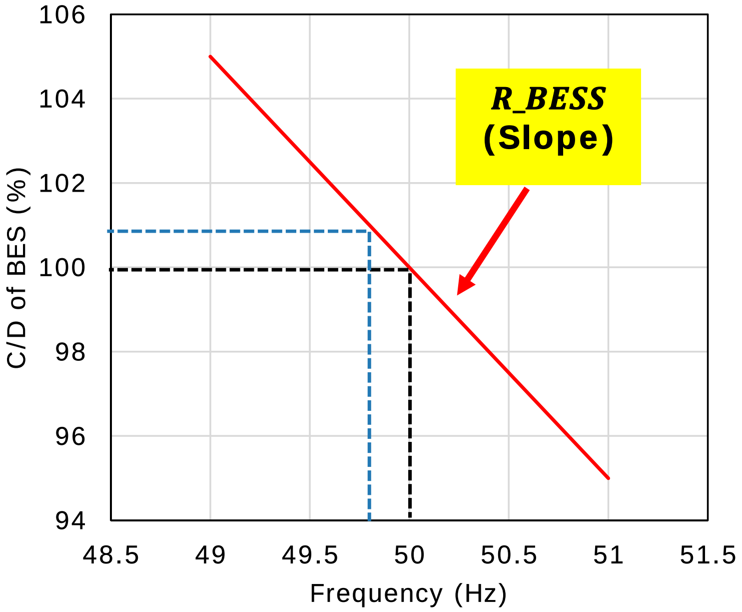
Concept of Control [Droop]

- Quasi steady-state frequency (QSSF) $:= \boldsymbol{\Delta f} = \dfrac{\Delta \mathrm{P_L}}{\frac{1}{R_{eq}} + D + \frac{1}{R_{BESS}}}$

- Solving for $\boldsymbol{R_{BESS}}$ → $\dfrac{1}{R_{BESS}} = \left(\dfrac{\Delta P_L}{\Delta f}\right) - \left(\dfrac{1}{R_{eq}}\right) - (D)$

NOFB Limit of 49.85 Hz

- **Droop response** of residential batteries can be deduced to **limit** $\boldsymbol{\Delta f}$ within some value



From profiles → Unit Commitment → Battery Droops

$P^{RDnet}_{i,t} = P^{D}_{i,t} - P^{PV}_{i,t} + P^{BES}_{i,t} \quad \forall t \in T \; i \in I$	Residential Net Demand per customer	**Profiles**
$P^{RDnet}_{t} = \sum_{i \in I} P^{RDnet}_{i,t}$	Residential Net Demand Total	
$P^{NRDnet}_{t} = \sum_{k \in K} P^{NRDnet}_{k,t}$	Same for Non-Residential Demand	
$\mathrm{Min} \sum_{j \in J} \sum_{t \in T} c^{P}_{jt} + c^{u}_{jt} + c^{d}_{jt}$	Sum them up and run UC	**Unit Commitment**
$\Delta P_t = \max\{P_{jt}\}_t$	Extract the largest Generator	
$R^{B}_{eq_t} = \dfrac{1}{\dfrac{\Delta P_t}{\Delta f_{max}} - \dfrac{1}{R^{G}_{eq_t}} - D_t}$	Calculate time based droop for a QSSF (e.g. 49.85 Hz, NOFB in Australia)	**BES Droops**

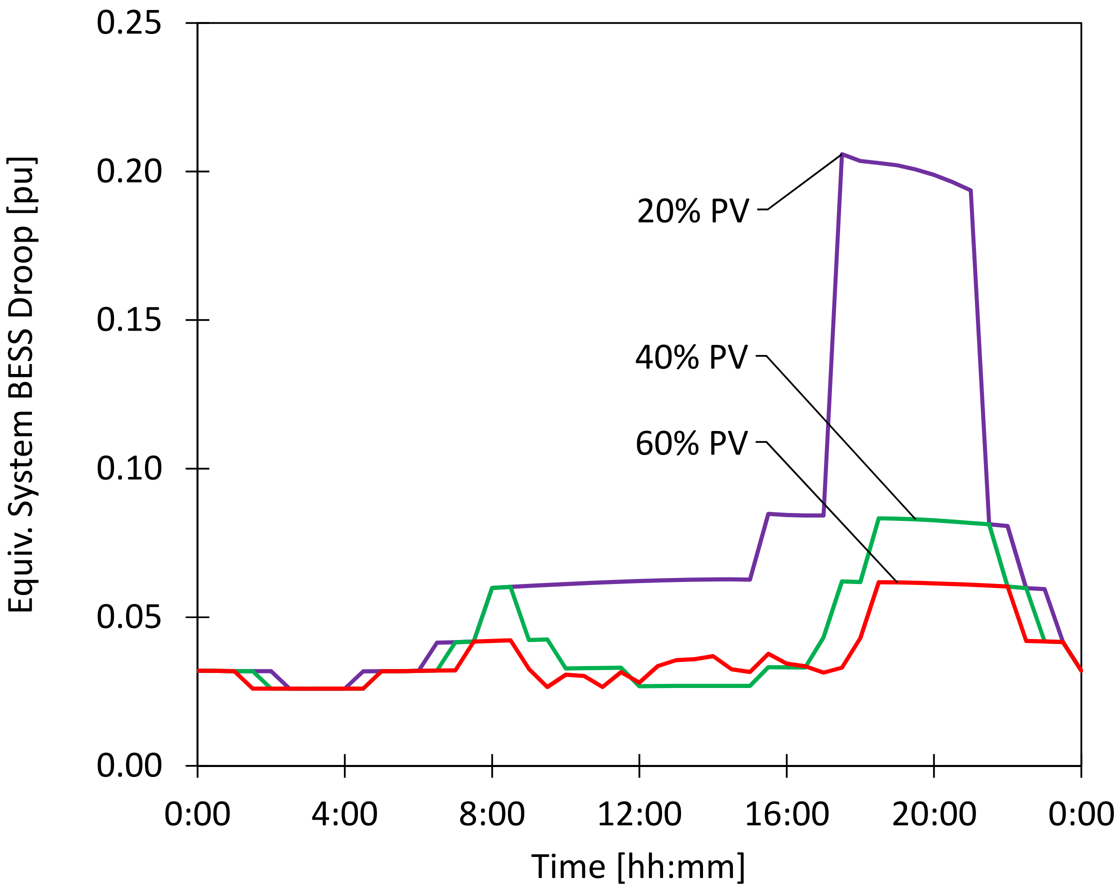
D. Jaglal, W. J. Nacmanson and L. F. Ochoa, "Quantification and Verification of Residential Battery Response for Frequency Regulation in PV-Rich Power Systems," in IEEE PowerTech, Milano, 2019

Quantification of BESS Droop

- Looks something like →
- Re: inverse droop and active power relationship

- Increased PV → Displaces Conventional generators → More response required from BESS

- **% Represents percentage of residential customers with PV & BESS**



The idea now, is that we try to implement this using RTDS

System Overview

RTDS

- **Power System**
  - Generators
  - Controllers
  - Loads
  - Batteries
  - PV Systems

Communication Infrastructure

- **Network Measurements**
  - Voltage
  - Powers
  - Frequency
  - Generator States

User Interface

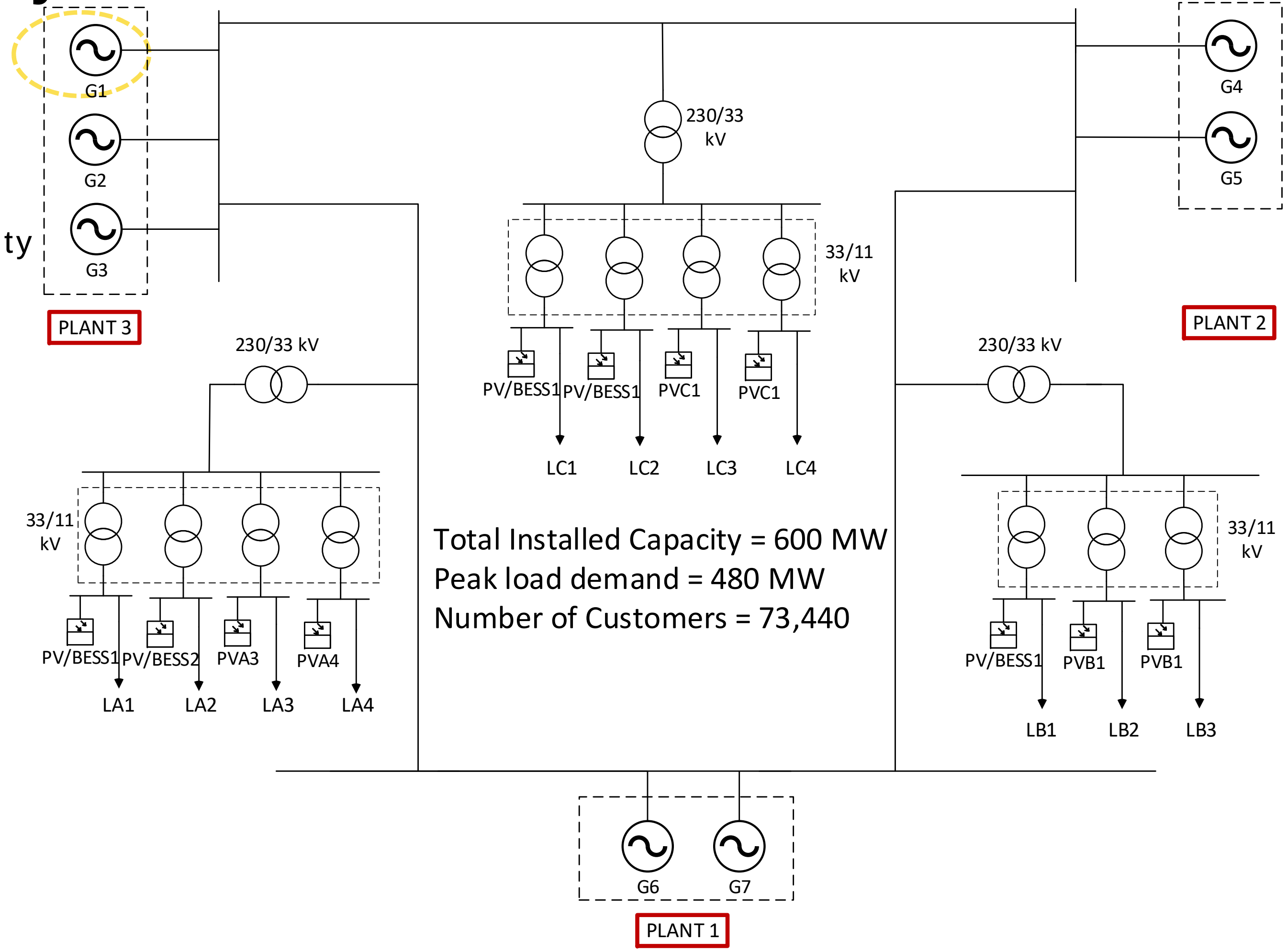
SCADA

- **SCADA**
  - Data Translation
  - Visualization of Network Measurements

Case Study – Modified IEEE 9-Bus

- **Generation**
  - 7 Synchronous generators
  - 600 MW / 660 MVA total installed capacity
  - 4% Droop on all generators
- **Residential PV and Batteries**
  - Aggregated to Tx Level
- **Load**
  - Static
- **Contingency**
  - Loss of 20 MVA Generator
- **BESS with droop to meet target frequency of ~49.85 Hz**

$$R^{B}_{eq_t} = \frac{1}{\frac{\Delta P_t}{\Delta f_{max}} - \frac{1}{R^{G}_{eq_t}} - D_t}$$



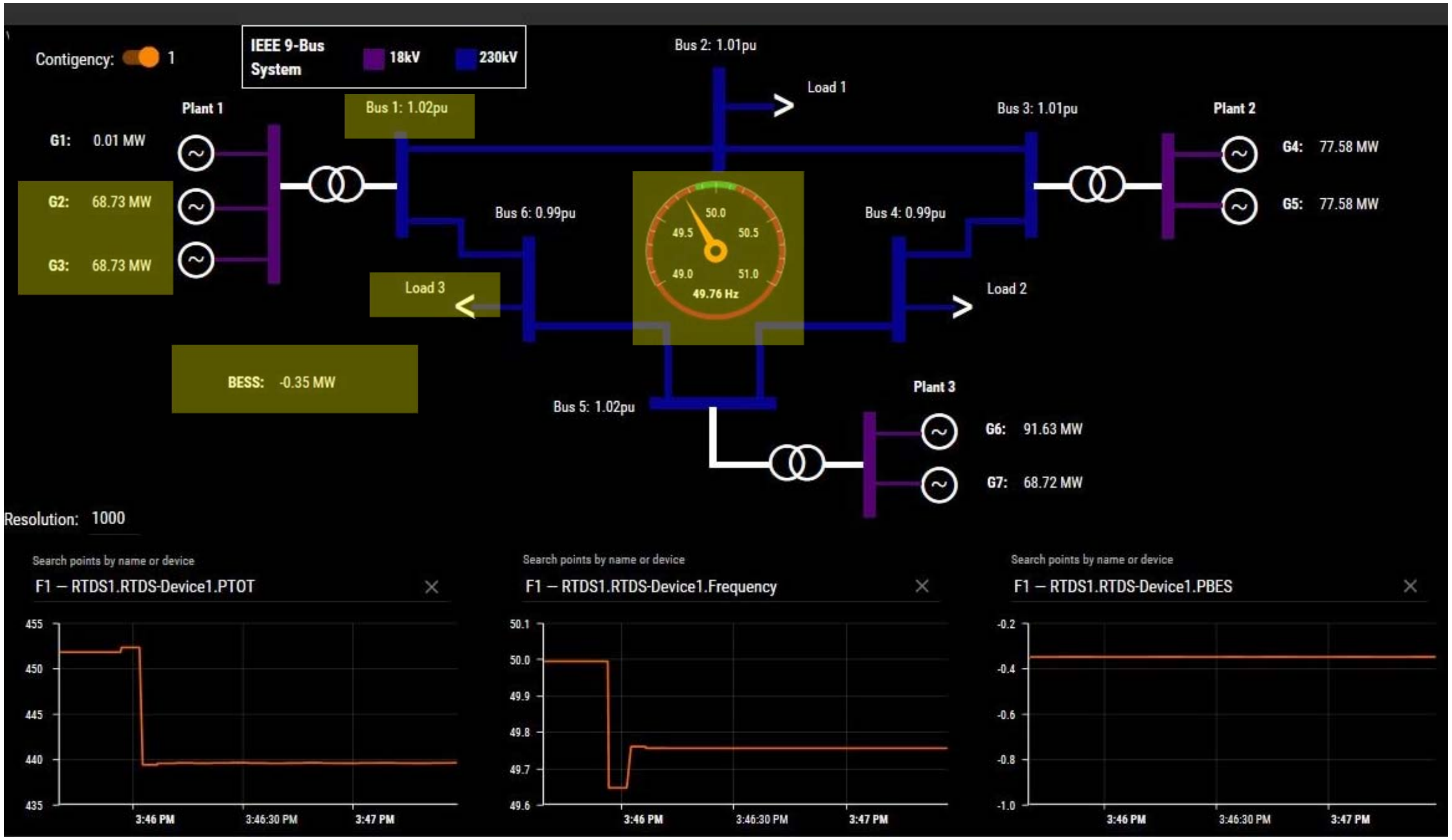
Total Installed Capacity = 600 MW
Peak load demand = 480 MW
Number of Customers = 73,440

Introduction to the Dashboard – Modified IEEE 9-Bus Test Network

- Generator Active Powers
- Bus Voltages
- Frequency
- Loads
- Aggregated BESS

Line Graphs

- Generator power (Total)
- Frequency
- BESS response


Contigency: 1

Resolution: 1000

Search points by name or device: F1 – RTDS1.RTDS-Device1.PTOT

Search points by name or device: F1 – RTDS1.RTDS-Device1.Frequency

Search points by name or device: F1 – RTDS1.RTDS-Device1.PBES

Three Snapshot Cases

- Case 1 → Base Case – No PV or BESS
- Case 2 → PV and BESS | **[No Droop]**
- Case 3 → PV and BESS | **BESS implemented with droop**

Trigger Generation Contingency

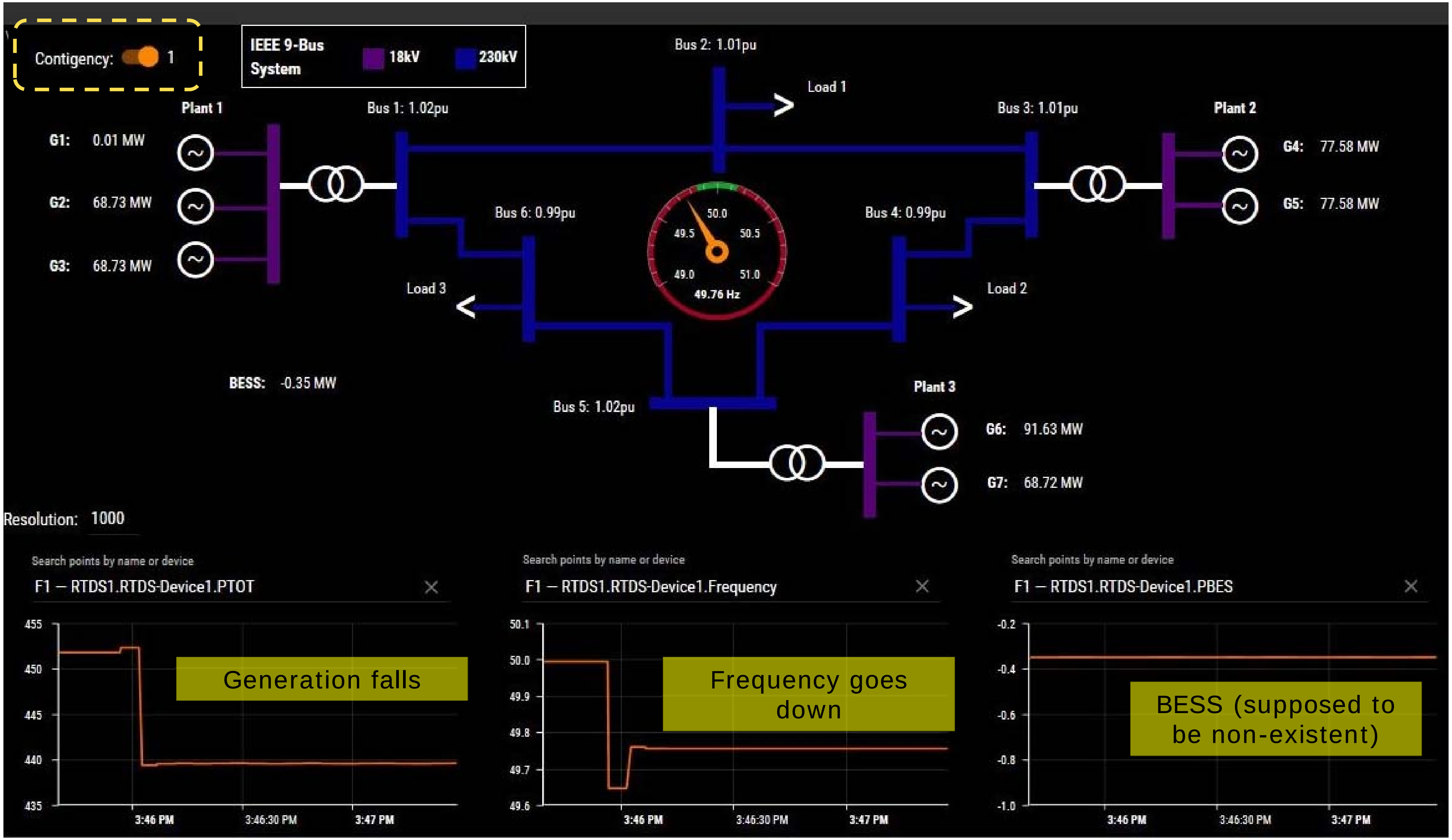
→

Observe

- Generators response
- System Frequency
- BESS response

Case 1 → Base Case – No PV or BESS

This triggers the fault

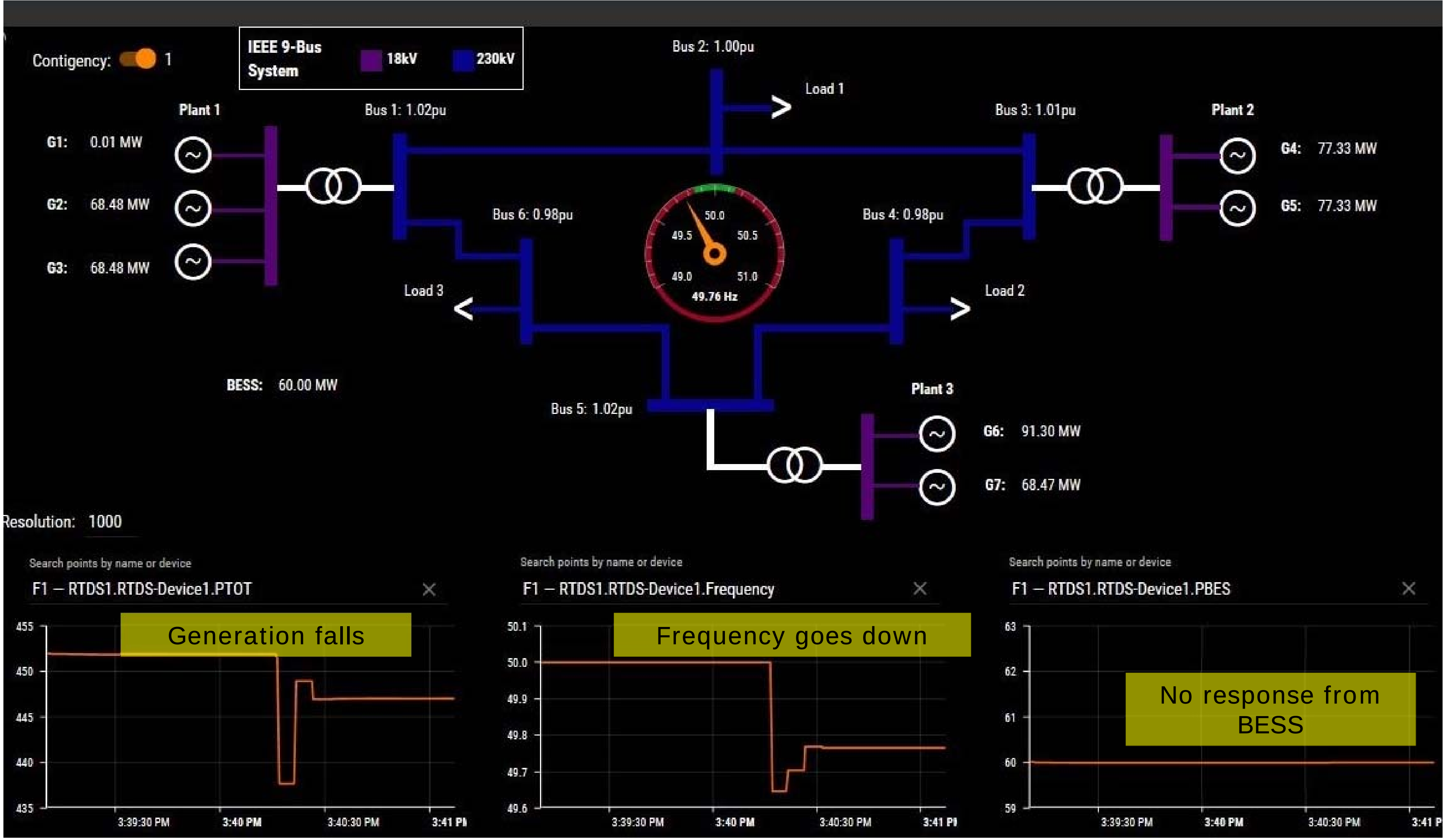


Generation falls

Frequency goes down

BESS (supposed to be non-existent)

Case 2 → PV and BESS [no Droop]



Resolution: 1000

Search points by name or device
F1 – RTDS1.RTDS-Device1.PTOT

Search points by name or device
F1 – RTDS1.RTDS-Device1.Frequency

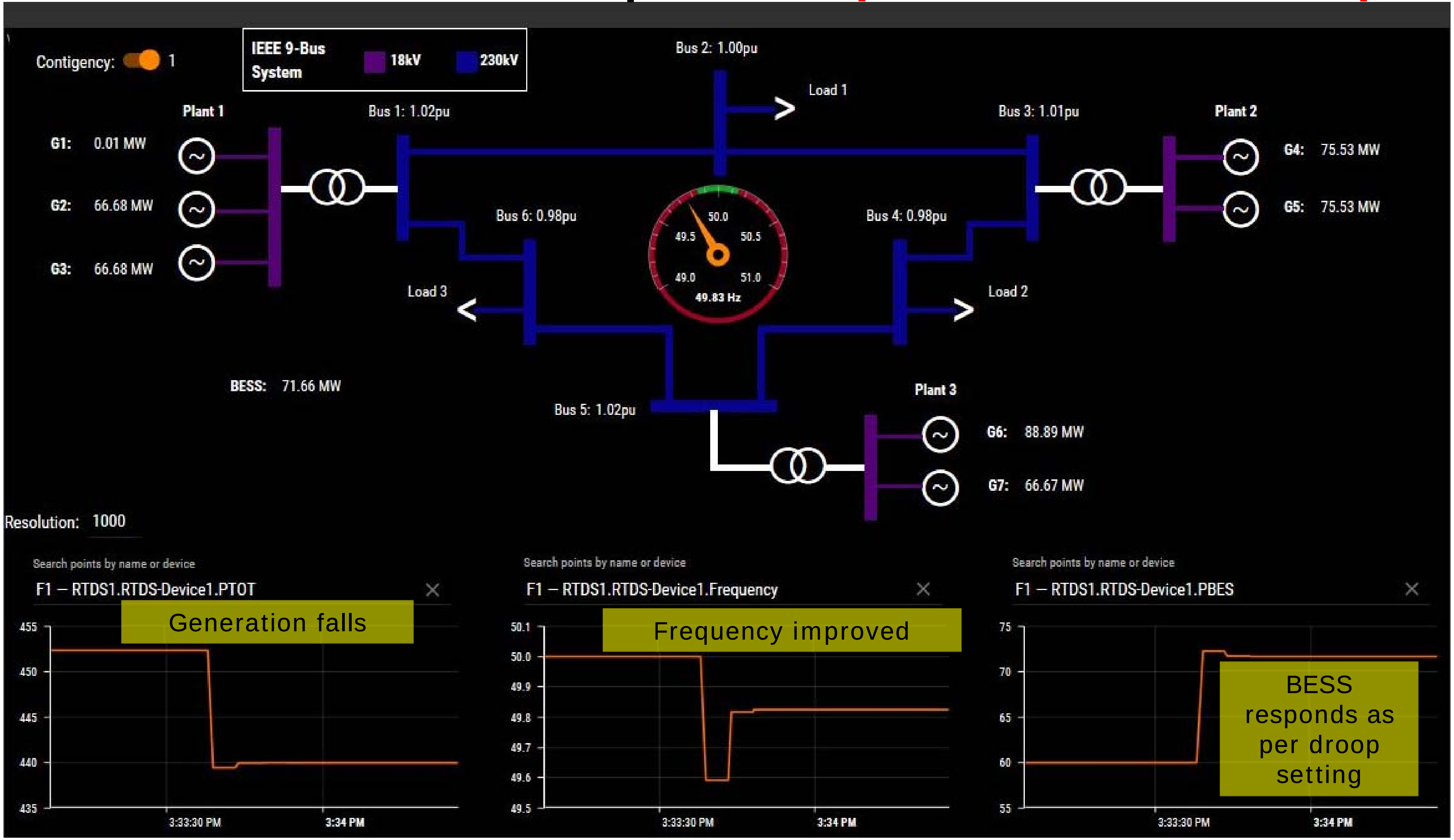
Search points by name or device
F1 – RTDS1.RTDS-Device1.PBES

Generation falls

Frequency goes down

No response from BESS

Case 3 → PV and BESS | BESS implemented with droop



Contigency: 1

Resolution: 1000

Search points by name or device
F1 – RTDS1.RTDS-Device1.PTOT

Search points by name or device
F1 – RTDS1.RTDS-Device1.Frequency

Search points by name or device
F1 – RTDS1.RTDS-Device1.PBES

Generation falls

Frequency improved

BESS responds as per droop setting

Challenges

- Properly implementing the BESS at the distribution level
- Higher resolution data to be sent to dashboard for visualisation
- Dynamic simulations a bit tricky to visualise using Open Source platforms
    - SCADA
    - Server

Upshot

- Very much the start of the Journey
- Its possible to implement simple BESS controllers to manage frequency deviations
- This type of work makes a more realistic environment for students to have a feel for concepts

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