AUTOMATIC INERTIA MONITORING AND DATA LOGGING SYSTEM

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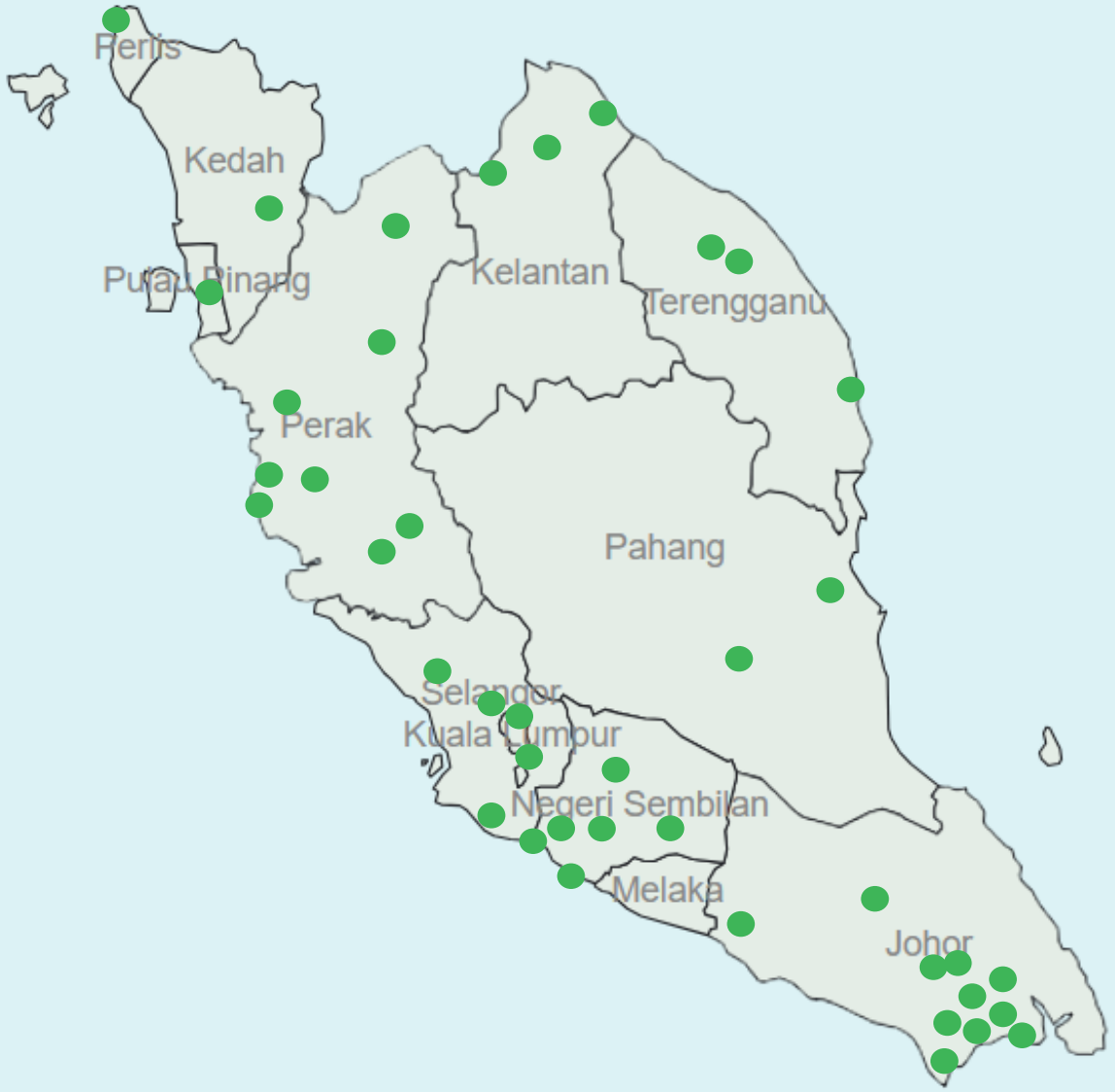
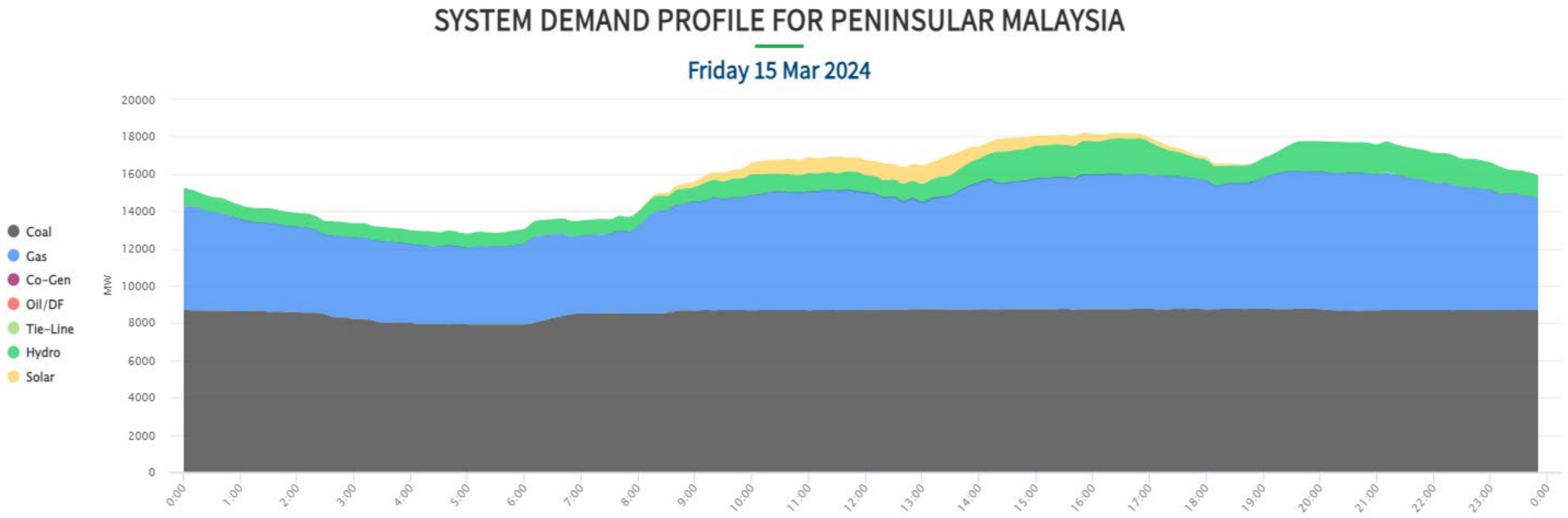
SYNCHROPHASORS IN PENINSULAR MALAYSIA



- The grid system backbone is currently 60-70% observable by WAMS
- Observability of 500kV and 275kV network will reach 90% in upcoming expansion and 100% with LSE
- Number of substations:
  - 500kV: 17
  - 275kV: 109
  - 132kV: 488
- Number of substations with PMU:
  - 500kV: 9
  - 275kV: 48
  - 132kV: 9

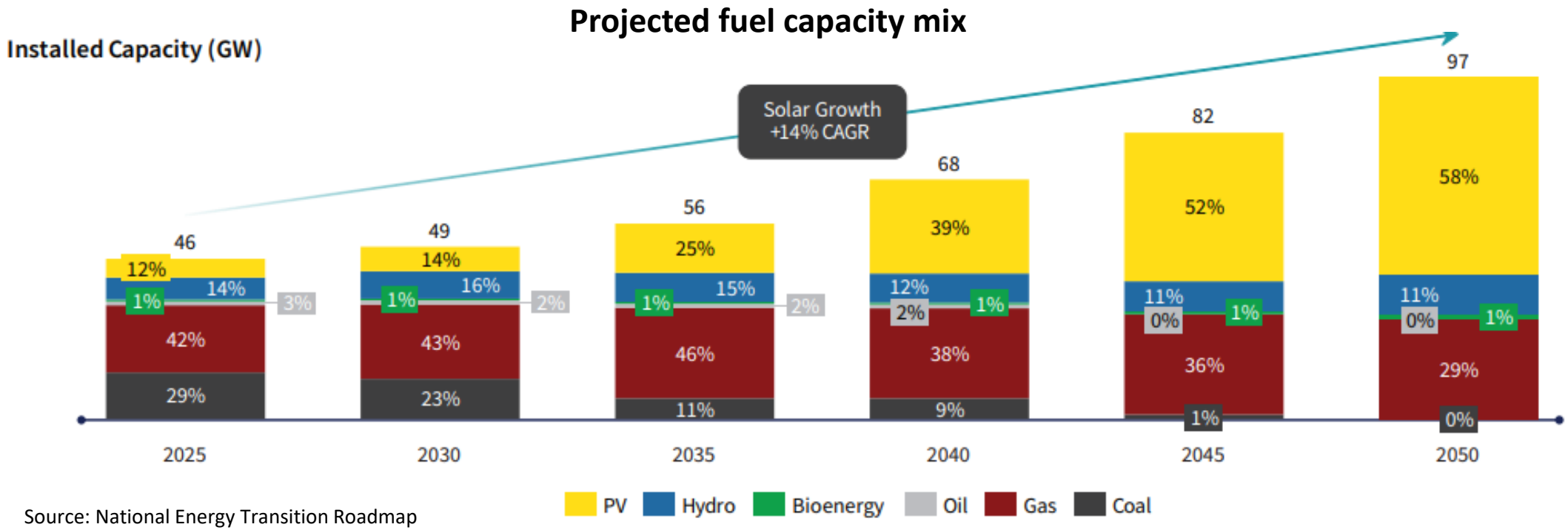
GENERATION MIX



Highest electricity demand: **19.7 GW**
Large scale solar capacity (transmission-connected): **1.5 GW**
Large scale solar capacity (distribution-connected): **0.5 GW**
Rooftop solar capacity: **1.4 GW**

GROWTH OF RENEWABLE ENERGY

- The Malaysia's National Energy Transition Roadmap (NETR) aims to significantly increase the role of renewable energy, which is largely driven by solar photovoltaic installations



Source: National Energy Transition Roadmap

INERTIA CHALLENGES

Disturbance impact with lower system inertia:

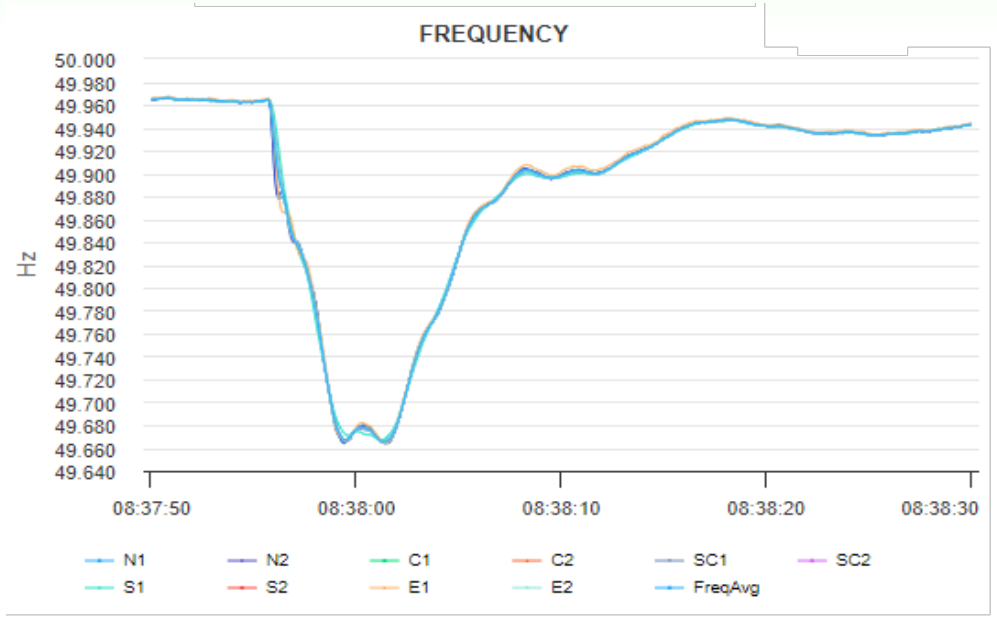
- Increased rate of change of frequency (ROCOF)
- Greater frequency and ROCOF variations across regions
- Decreased nadir frequency
- Extended duration to stabilize frequency (arresting period)
- Shorter duration to reach load shed limit (UFLS)

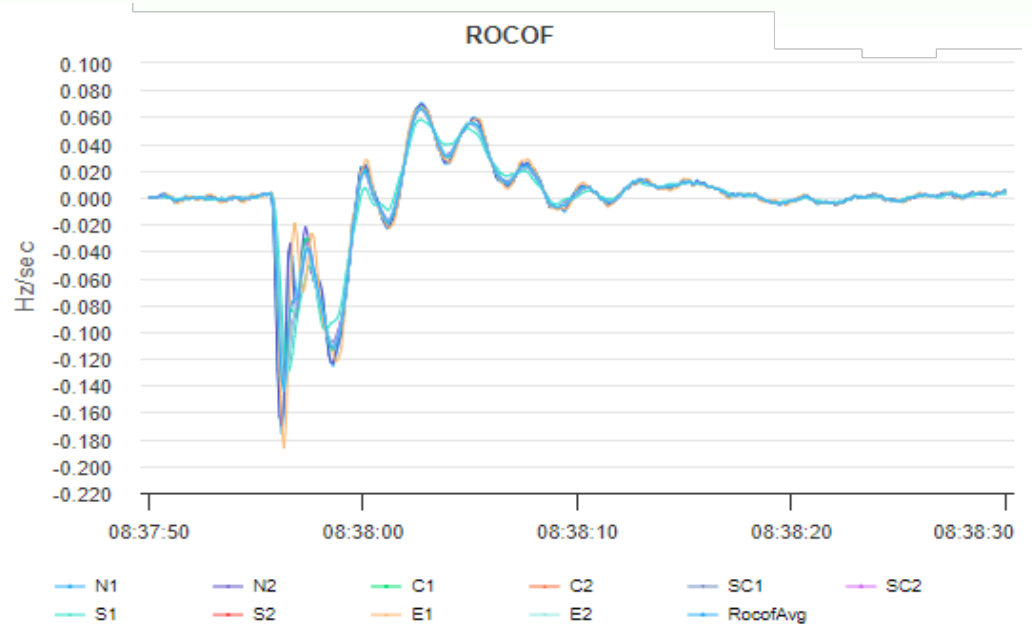
International grid interconnections:

- Malaysia-Thailand interconnected through HVDC lines
- Malaysia-Singapore interconnected through 230kV submarine cables
- Peninsular Malaysia & Singapore peak demand is 27.6 GW collectively

SYSTEM INERTIA DURING IMBALANCE EVENTS

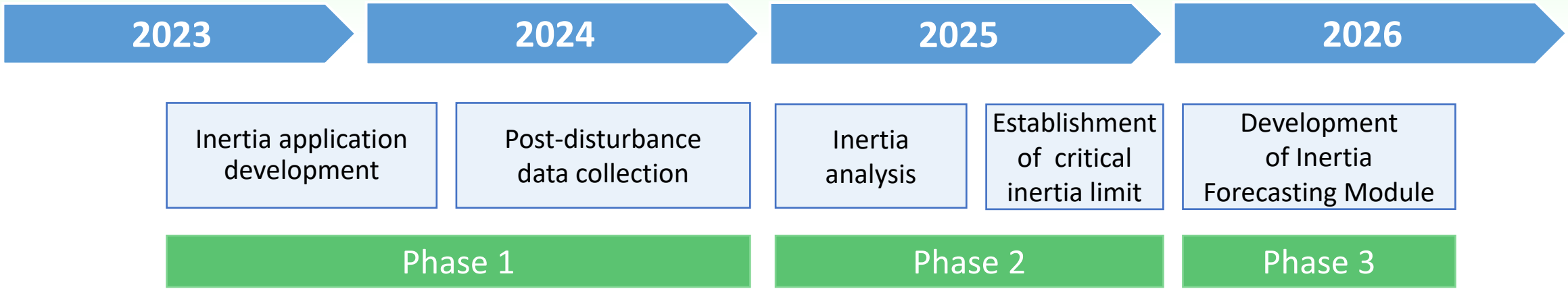
Loss of a 1,000MW coal unit in the Northern Region at 8:37am





Region	Time	Gen Loss	ROCOF	Nadir frequency	Freq change	Arresting period
North	08:37:56.20	1000	-0.195	49.669	-0.334	5.4
South	08:37:56.90	1000	-0.169	49.671	-0.332	5.25
Average	08:37:56.30	1000	-0.145	49.673	-0.330	5.3

INERTIA MONITORING SYSTEM DEVELOPMENT

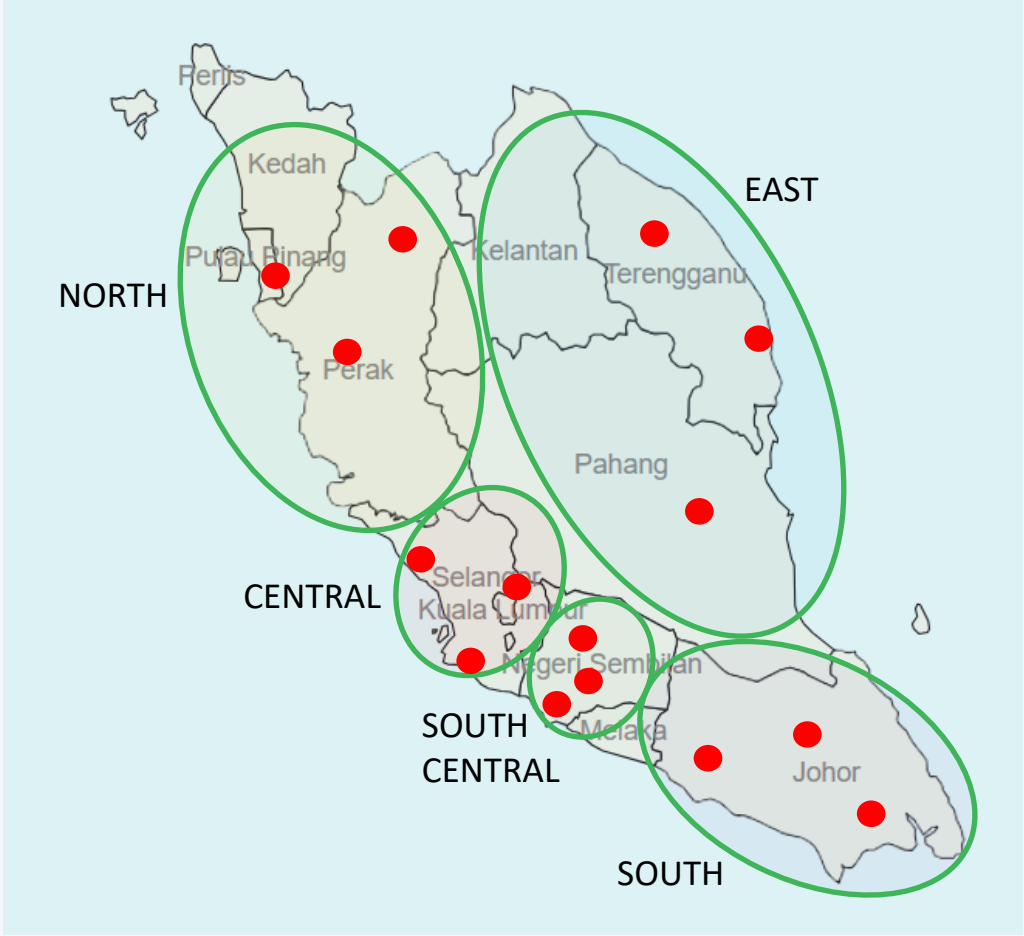


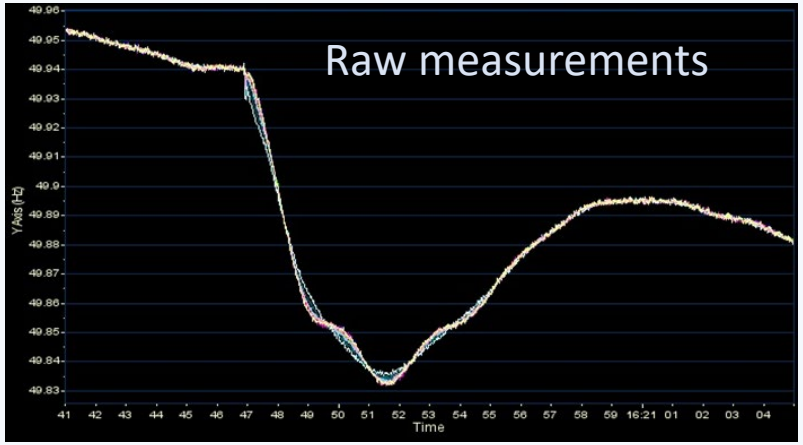
OBJECTIVES

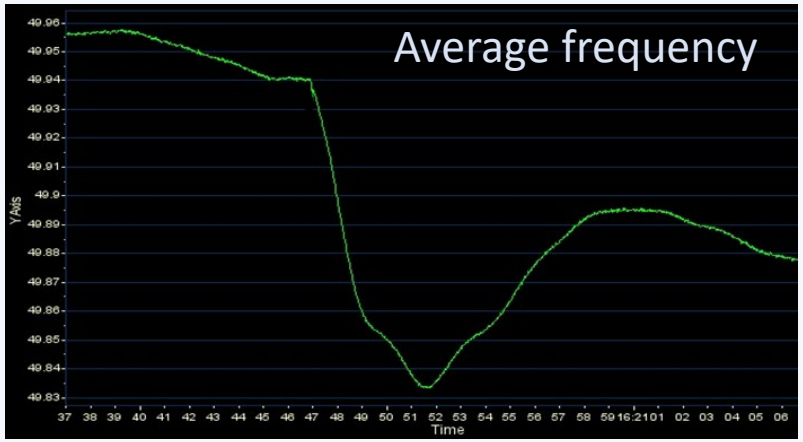
- To assess the current system inertia
- To study how increasing solar PV capacity impacts system inertia
- To identify critical inertia limit for Peninsular Malaysian grid
- To collect data for future development of machine learning inertia estimation
- To make data easily accessible to system operators

INERTIA MONITORING METHODOLOGY

15 WAMS frequencies with 10Hz resolution are taken across 5 regions

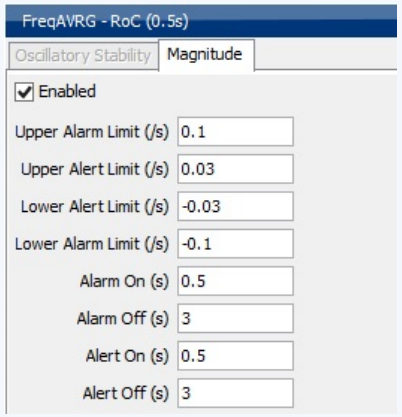






INERTIA MONITORING METHODOLOGY

Alert limit -0.03 Hz/s is set for the rate of change of average frequency

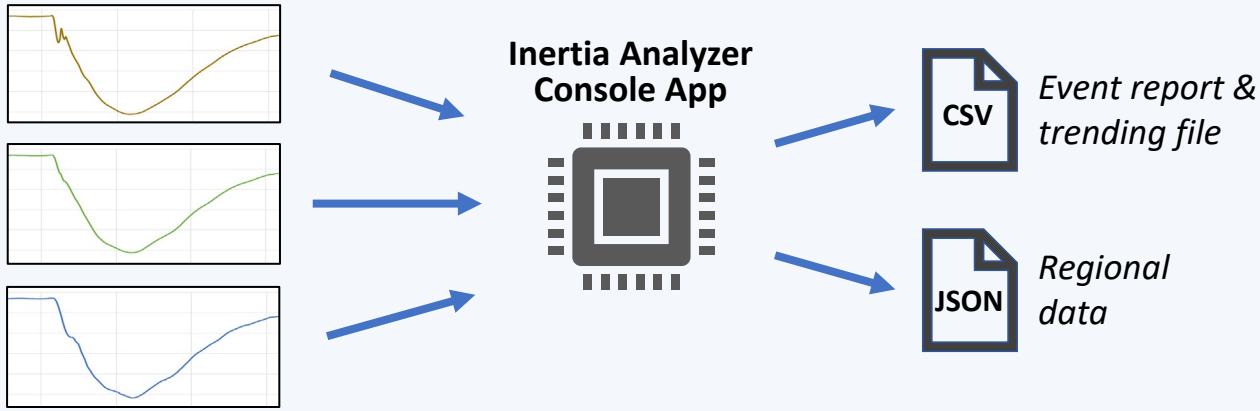


Inertia Analyzer application runs every 5 minutes to scan for ROCOF violation, which indicates a sudden generator outage

Source Date	Source Time	Synchronous Area
11/27/20	09:02:24.980	Synchronous Area 1
11/27/20	09:02:24.980	Synchronous Area 1
11/27/20	09:02:18.900	Synchronous Area 1
11/27/20	09:02:11.480	Synchronous Area 1
11/27/20	09:02:04.980	Synchronous Area 1
11/27/20	09:02:04.980	Synchronous Area 1
11/27/20	09:02:03.900	Synchronous Area 1
11/27/20	09:01:59.980	Synchronous Area 1
11/27/20	09:01:59.980	Synchronous Area 1

Upon disturbance event detection, Inertia Analyzer executes the following tasks:

- **Frequency Analysis:** Pulls individual frequency measurements from WAMS database, computes ROCOF and analyzes inertia-related parameters
- **Generation Data Extraction:** Pulls the total conventional and solar generation data from SCADA
- **Inertia Calculation:** Computes effective inertia from the gathered data
- **Data Tabulation:** Organizes inertia and related parameters for analysis
- **Report Generation:** Produces event report in CSV and JSON formats

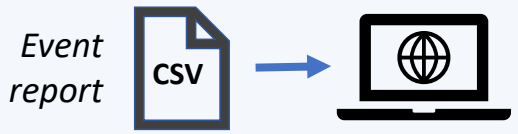


**Data analysis and storage are performed for each region*

$$System\ Inertia\ [MWs] = \frac{Power\ Imbalance[MW]}{2\ x\ ROCOF\ [\frac{Hz}{s}]} x\ nominal\ frequency\ [Hz]$$

INERTIA MONITORING METHODOLOGY

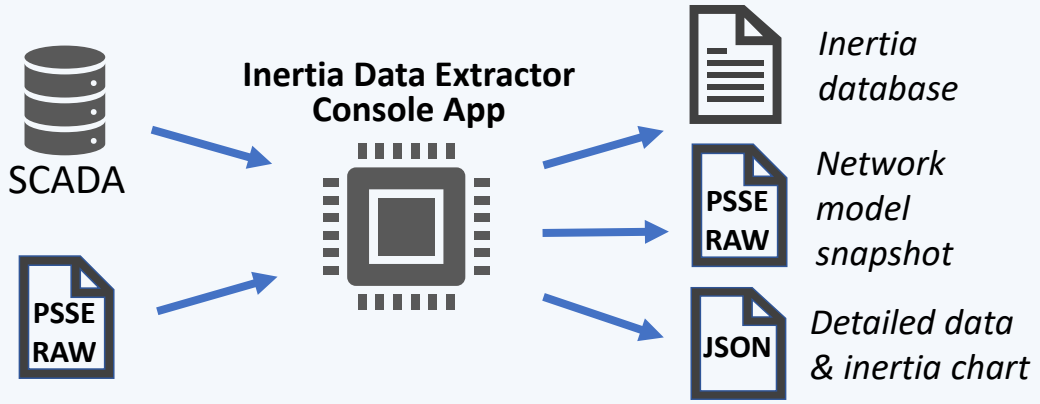
Event report is manually validated via a web interface



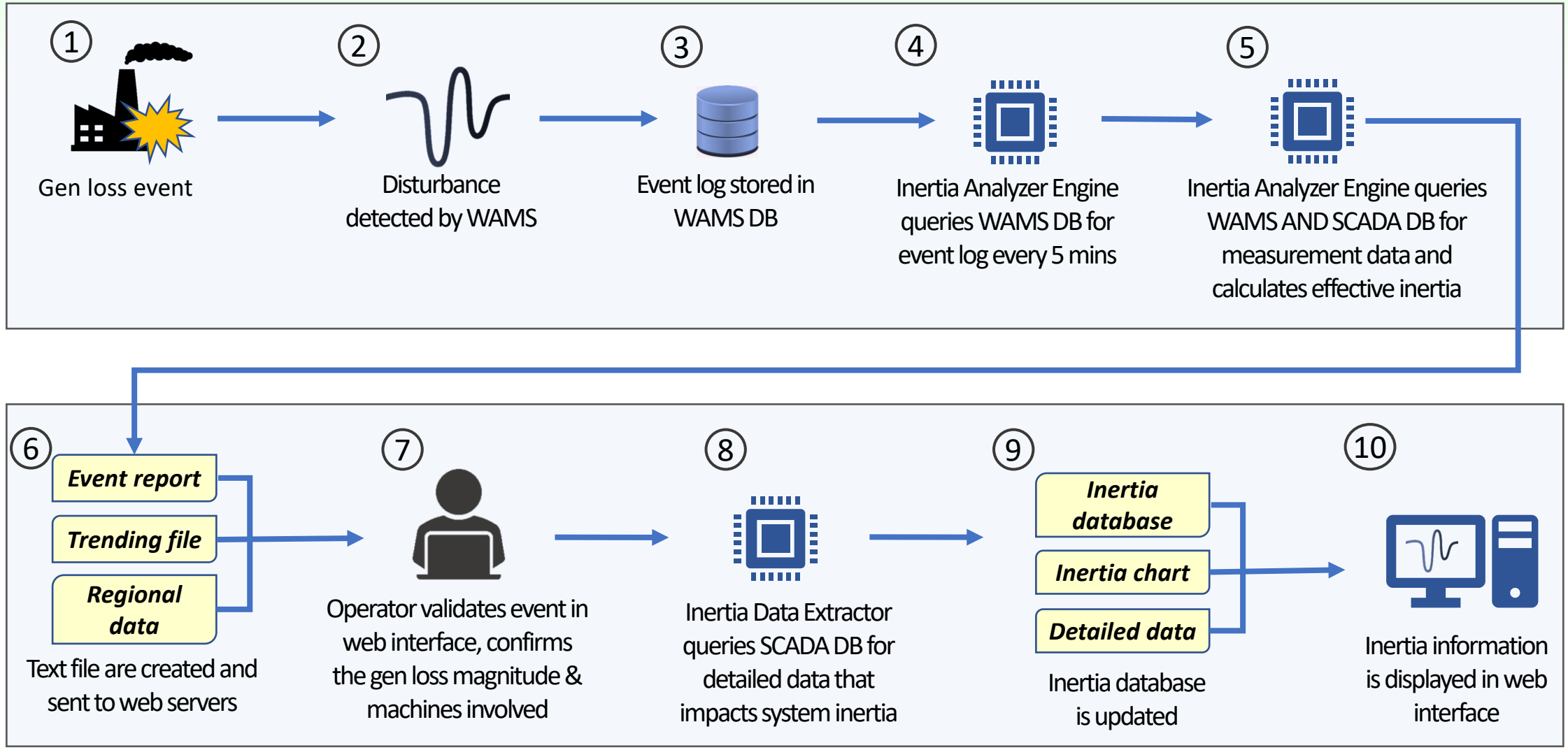
**For event validation, operator must enter megawatt loss and specify tripped machine*

Upon validation of event, Inertia Data Extractor executes the following tasks:

- **Generation Data Extraction:** Pulls individual generator loading from the SCADA database
- **Inertia Data Extraction:** Pulls available SCADA parameters that influences system inertia e.g. interface loading, battery energy storage system, regional load
- **Inertia Calculation:** Recalculates the effective inertia (if different from first estimation)
- **Network Model Extraction**: Saves a copy of the EMS model snapshot (.raw)
- **Data Logging:** Inserts event report in main inertia database
- **Data Storage:** Saves gathered data for future use *e.g. advanced analytics and machine learning*



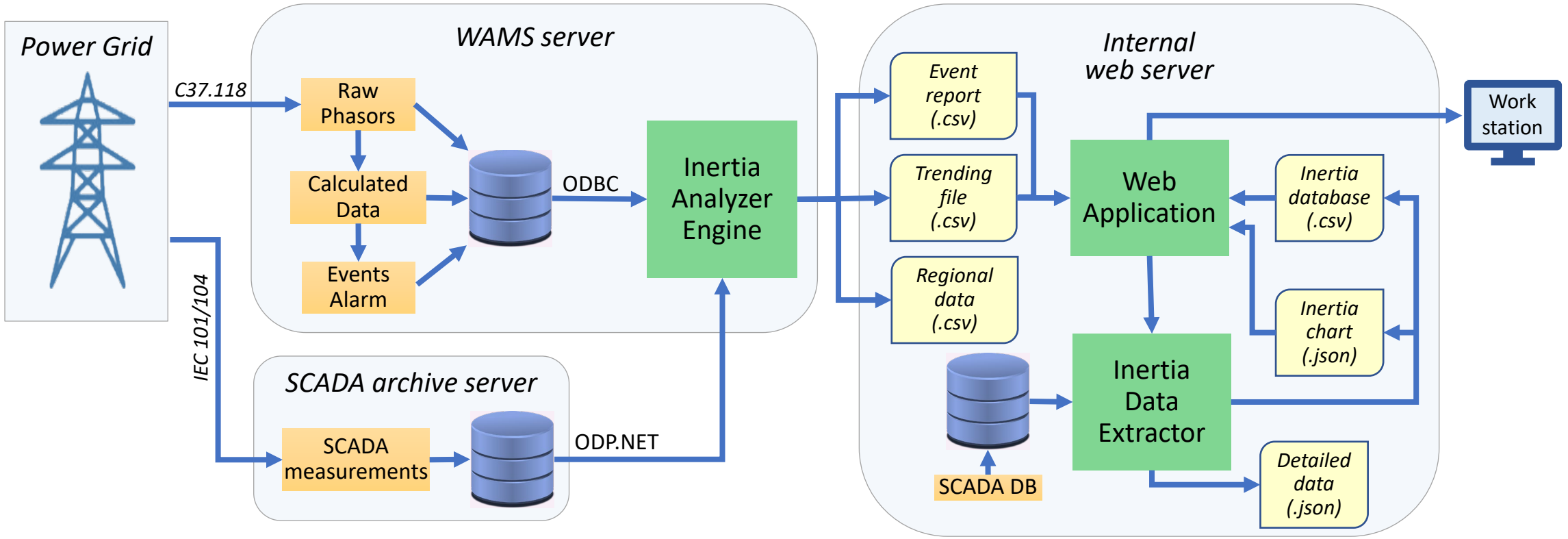
EVENT REPORTING PROCESS



DATA FLOW DIAGRAM

The inertia monitoring system consists of three components:

- Inertia Analyzer Engine
- Inertia Data Extractor
- Web Application



INERTIA DATABASE AND LOG FILES

Preliminary event report

- Produced the moment generation outage disturbance event is detected

CSV file
Event report

- Effective inertia
- ROCOF
- Arresting period
- Nadir frequency
- System demand
- Solar generation
- Megawatt loss

CSV file
Regional Data

- Regional inertia
- Regional ROCOF
- Regional arresting period
- Regional nadir frequency

CSV file
Trending file

- Frequency trend
- ROCOF trend

Main database & detailed report

- Produced when operator validates each generator outage event
- Objectives:
  1) To analyze the system inertia and related parameters
  2) To gather data for machine learning model training

CSV file
Inertia database

- Effective inertia
- Rotating inertia
- ROCOF
- Arresting period
- Nadir frequency
- Tripped machine
- Megawatt loss
- Total demand
- Tie-line loading
- Solar generation

JSON file
Detailed data

- Full generation data
- BESS load
- Regional rotating inertia
- Regional load
- Regional solar PV
- FFR resources

JSON file
Inertia chart

- Inertia database in JSON format for data visualization in web application

WEB APPLICATION INTERFACE

GRID SYSTEM OPERATOR

WIDE AREA MONITORING SYSTEM

OVERVIEW | TUTORIALS | SETTINGS | STABILITY | INERTIA | ADMIN LOGS | DOCUMENTATION | ACTIVITIES

Generation Loss Event Logging

Preliminary Generation Loss Report

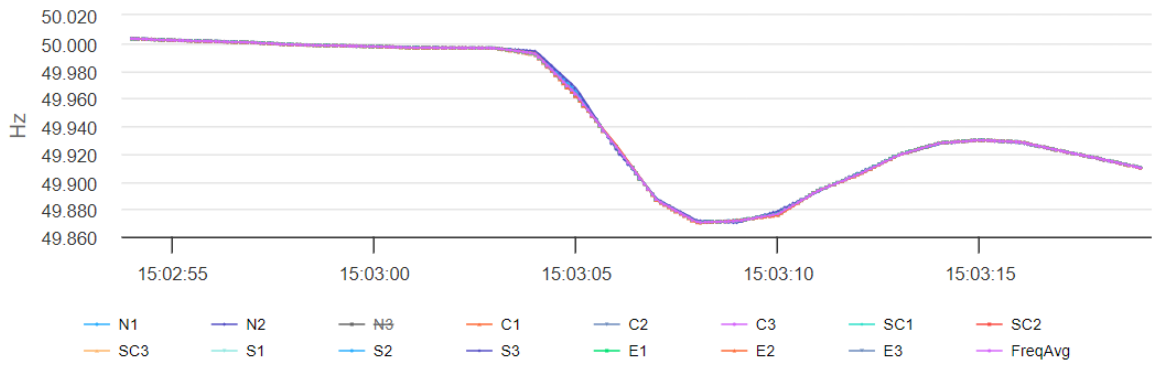
Inertia Log

Select	Time of tripping	ROCOF (Hz/s)	Bottom Freq (Hz)	Arresting period (sec)	Effective Inertia (MWs)	Gen loss (MW)	1st tripped unit	Total gen (MW)	Solar gen (MW)
◉	2023-11-30 08:37:56.30	-0.145	49.669	5.4	172413	1000	COAL_G1 U3	15560	124
○	2023-12-01 11:02:23.54	-0.072	49.726	4.9	157912	570	GAS_G2 BLK2	17840	1870
○	2023-12-01 13:02:04.90	-0.132	49.810	4.8	149930	282	GAS_G1 BLK1	18233	2702
○	2023-12-01 15:44:12.29	-0.13	49.92	4.2	189576	150	HYDRO_G5 U2	17301	2390

Frequency

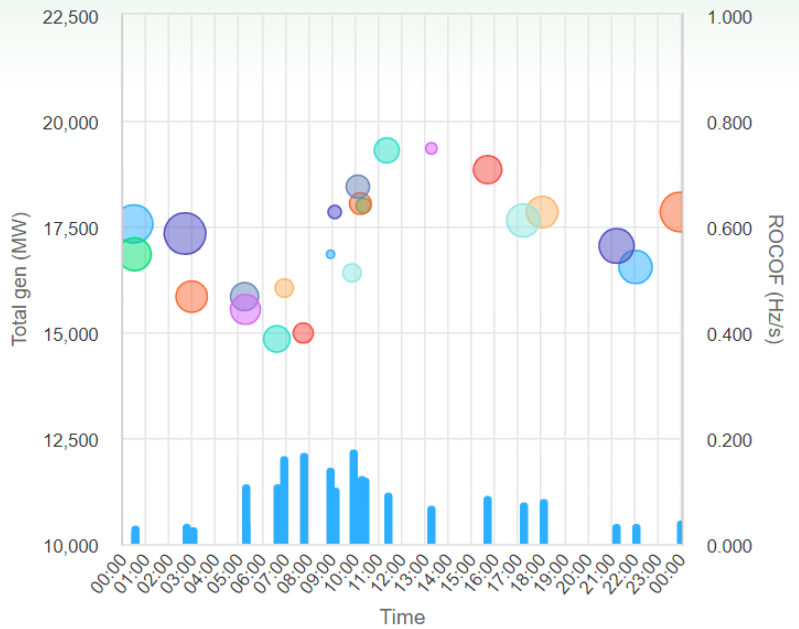
Highlight chart area to zoom in, hold 'Ctrl' to pan

Toggle Freq-ROCOF:



Download data: Main Log | Regional Log | Detailed Log | Event Trending

Inertia Chart | Power BI Chart



Scatter plot: Total gen

Circle size: Inertia

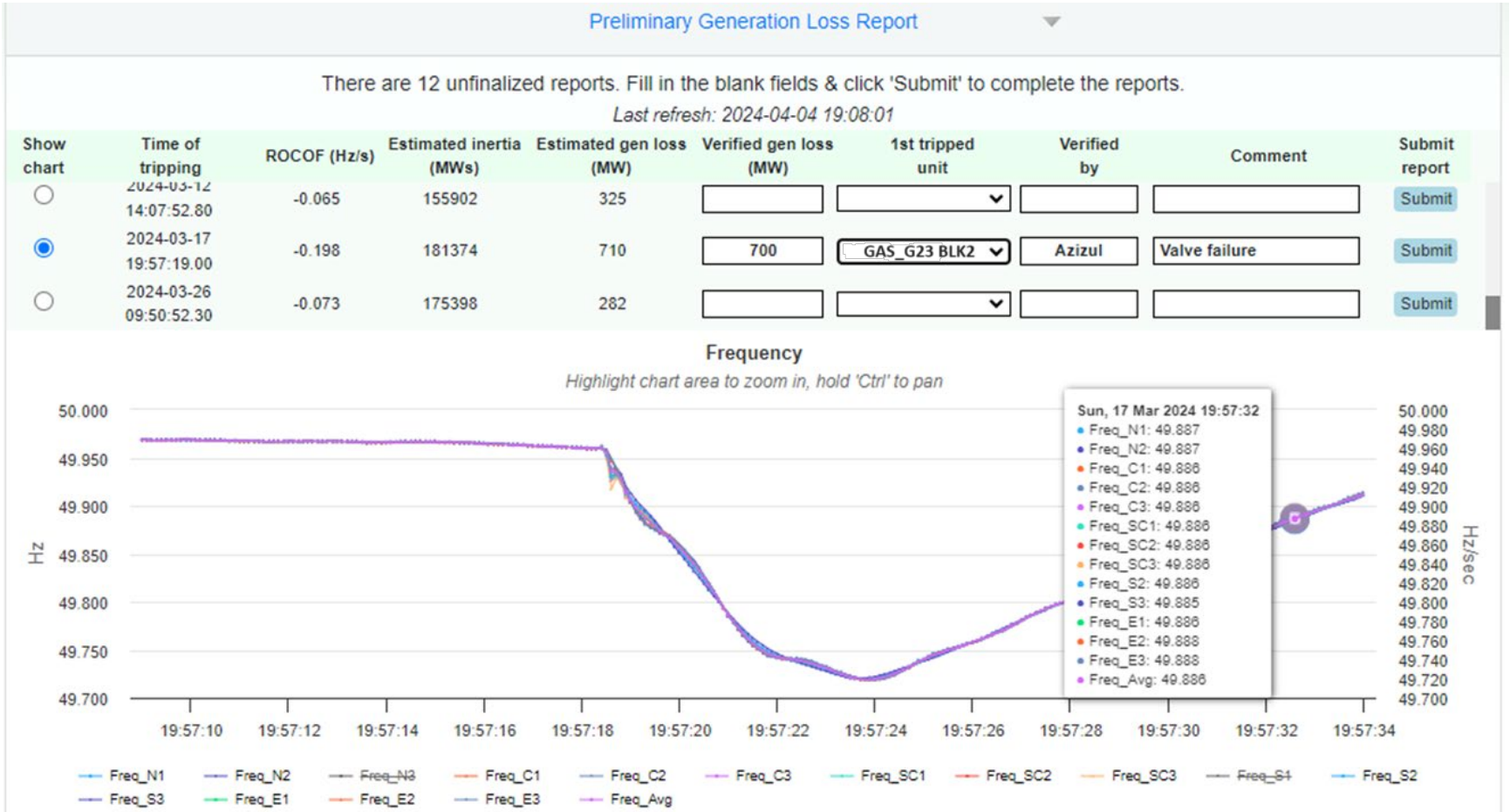
Bar height: Rocof

Default

WEB APPLICATION INTERFACE

Event report

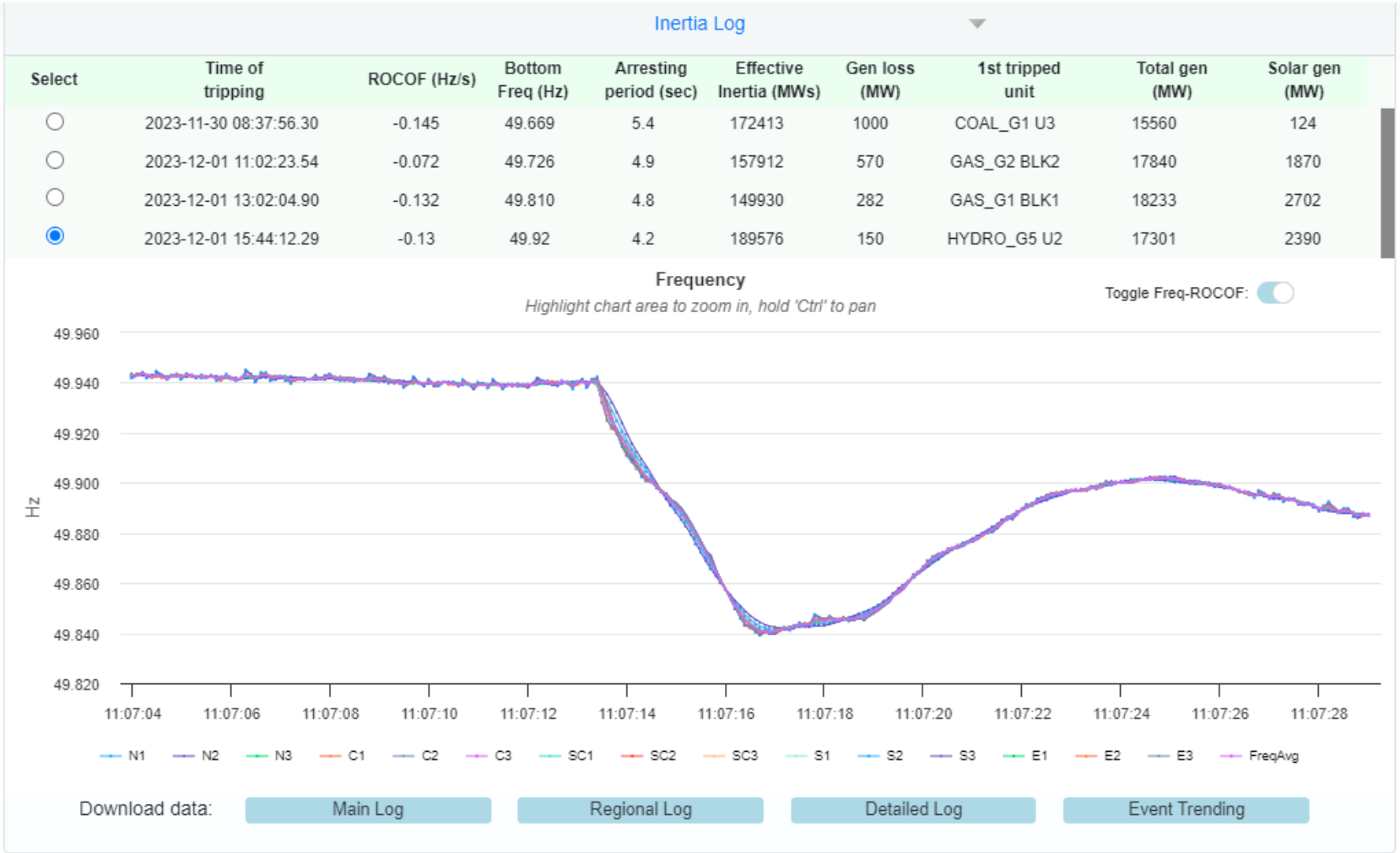
- Contains event report from automatic disturbance detection
- Requires operator to validate event by entering the amount of megawatt loss and specify tripped machine



WEB APPLICATION INTERFACE

Inertia Database

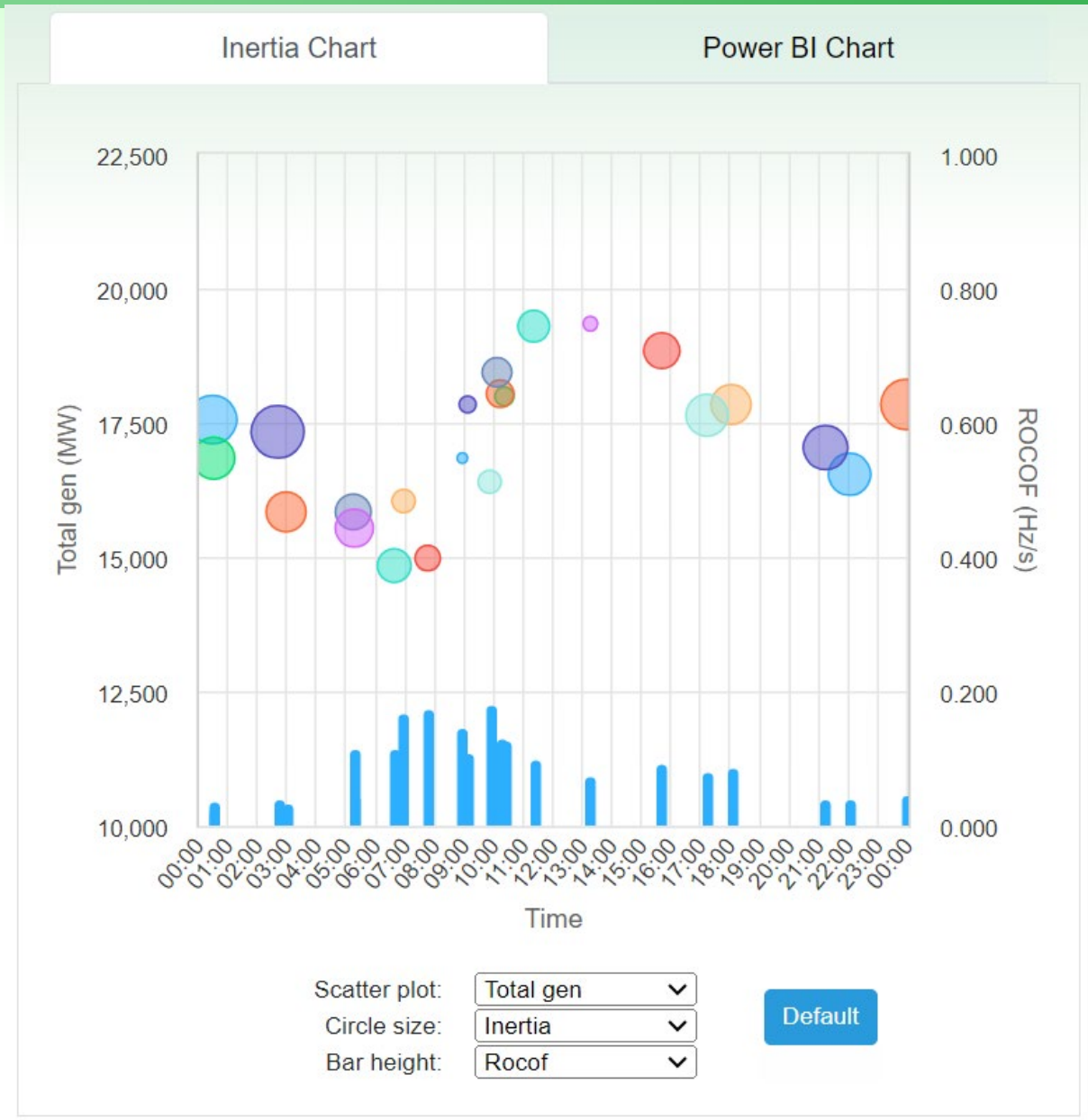
The main database of generator outage disturbance events and inertia-related parameters



WEB APPLICATION INTERFACE

Inertia Chart

- Inertia data visualization to analyze the trends of inertia-related parameters
- Y-positions, circle sizes & bar heights can be configured to display:
  - Inertia
  - Rocof
  - Arresting period
  - Frequency change
  - Total generation
  - Total solar gen
- Embedded Power BI chart is added for more advanced chart visualization



INERTIA FORECAST BY MACHINE LEARNING

In the project's next phase, a machine learning (ML) algorithm will be used to forecast system inertia

TRAINING

Col A	Col B	Col C	Col D	Col E	Col F	Col G
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…

Historical data

PREDICTION

Col A	Col B	Col C	Col D	Col E	Col F	Col G
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…

Planning and forecast data *Prediction*

INERTIA FORECAST BY MACHINE LEARNING

Nadir frequency prediction with ML gradient boosting algorithm

Time	Northern Gen Inertia	Central Gen Inertia	Southern Gen Inertia	Eastern Gen Inertia	Tie-line	BESS	Solar Forecast	…
08:00	35,512	3,202	39,950	22,703	95	12	450	…
08:15	39,905	3,202	46,301	25,722	95	12	565	…
08:30	41,302	4,590	51,102	29,450	95	3	582	…
08:45	42,400	5,355	52,207	34,477	95	-9	635	…
09:00	44,125	5,355	55,535	36,444	120	-12	739	…

ML model

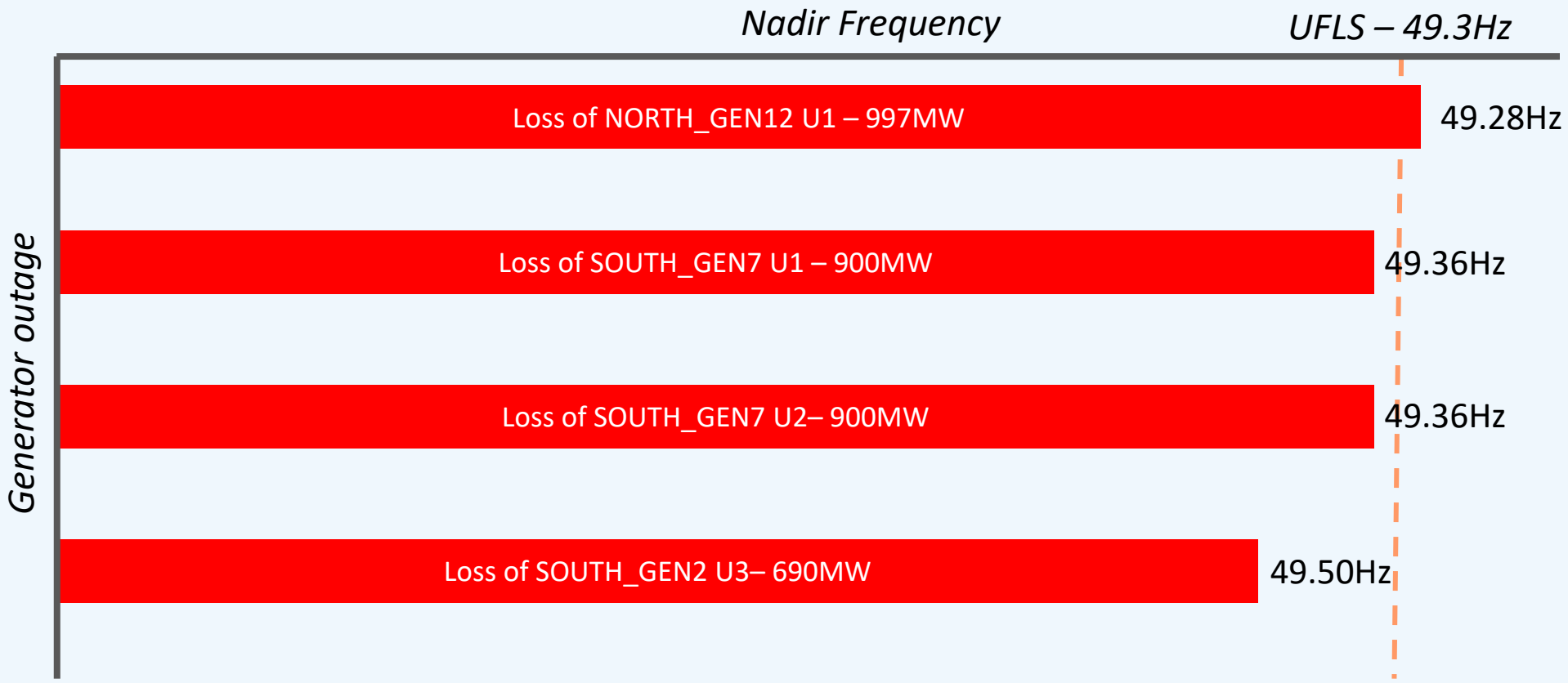
Nadir Frequency
49.69
49.71
49.72
49.75
49.76

*Parameters provided to ML model may also include other influencing factors with available data such as regional load, network configuration, fast frequency response resources etc.

INERTIA FORECAST BY MACHINE LEARNING

Potential use of machine learning application

Inertia-Based Real-Time Contingency Analysis (RTCA)



TECHNOLOGY USED IN SYSTEM DEVELOPMENT

WAMS data recording and event detection

GE PhasorPoint

Average frequency:
Calculated Data

Event logging:
Alarm & event

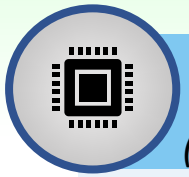
Event query and inertia analysis *(Inertia Analyzer)*

.NET6 Console App

DB access:
OdbcDataReader

Analysis & parameter search:
LINQ

Report creation:
StreamWriter



Detailed data logging *(Inertia Data Extractor)*

.NET Core Web App

DB access:
SqlDataReader

Report creation:
StreamWriter

Web application

HTML, CSS & JavaScript

Backend:
.NET Core web application

Data storage

Plain text files

Format:
CSV and JSON

Machine learning

ML.NET (C#) and XGBoost (Python)

Algorithms:
Gradient boosting

CONCLUSIONS

- **Elegant Monitoring Solution:** We have successfully developed and demonstrated a simple yet effective system for monitoring system inertia
- **Comprehensive Data Integration:** Our approach ensures comprehensive collection and organization of all available inertia-related data. This enables operators and power system analysts to access and utilize critical information more efficiently
- **Future-Ready and Scalable:** This system not only meets current needs but is also scalable to accommodate more advanced analyses and machine learning techniques

Value creations

Ease of inertia data access	Better dispatch planning	Enhanced awareness on stability risk
Innovation and technology development	Basis of future strategic planning	Increased grid resilience

TENAGA NASIONAL

GRID SYSTEM OPERATOR

Thank you for your attention

Q & A