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Inertial Response of Synchronous Condensers SDG&E Experiences

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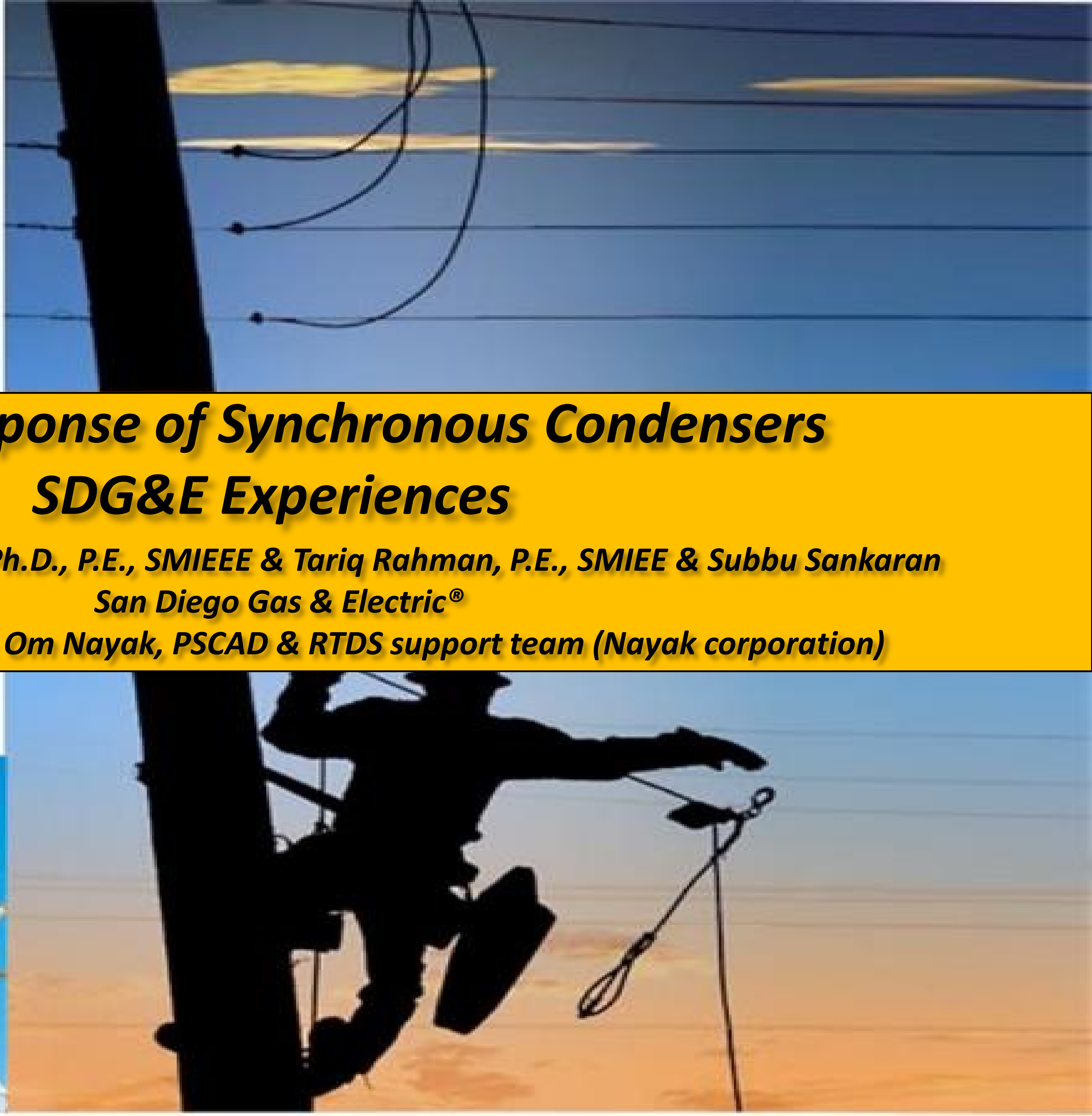

NASPI North American SynchroPhasor Initiative

San Diego, California
April 15-17, 2019

Plant and System Inertia and Inertial Energy

(from a previous joint presentation by SDG&E and Siemens)

- The system inertia of a power system depends on the number of operating rotating machines and the inertia constant of each machine.

$$H_{sys} = \frac{\sum_{i=1}^{N} (S_{ni} H_i)}{S_{sys}}$$

where S_{sys} is selected equal to the total load of system; N is the number of synchronous machines; and S_{ni} and H_i are the nominal apparent power and the inertia constant of i-th synchronous machine.

The initial rate of change of frequency (ROCOF) that depends on the size of the power imbalance and the system inertia is expressed by

$$ROCOF = \frac{f_0}{2H_{sys}} \frac{\Delta P}{S_{sys}}$$

where ΔP is the disturbance size; f_0 is the nominal system frequency.

A higher inertia constant results in a smaller ROCOF.

Synchronous Condensers Overview

(from a previous joint presentation by SDG&E and Siemens)

- SC is a synchronous generator without a prime mover which has been playing an important role in reactive power compensation and keeping voltage stability in power systems.

- SC is a rotational machine, inertia is an inherent feature of SC which is able to enhance the stability of generators located closely.

- The synchronous condenser unit is used for compensation or supply of reactive power in the power system in order to stabilize the grid voltage.
- It is capable to provide short circuit power to stabilize the grid and help maintaining short time frequency and voltage drops.
- The SC provided is started-up with a conventional asynchronous electric motor fed by a variable frequency converter (VFC) from the auxiliary power system.

Expanded Power Plant Model Validation

__Expanded Plant Model Validation__:

- Modeling of Dynamic and non-dynamic systems
- Plant Model Validation (Frequency, Voltage, Real and Reactive flow, Field Voltage and current, and Rotor speed)

__Field Measurements:__

- Measuring V-field and I-field,
- Exciter/PSS Model Validation (Comparing I-field and/or V-field)

__Rotor Measurement:__

- Measuring Rotor speed,
- Governor model validation (Comparing Rotor speed)

Dynamic/non-Dynamic Models

(A typical power system network one-line diagram)

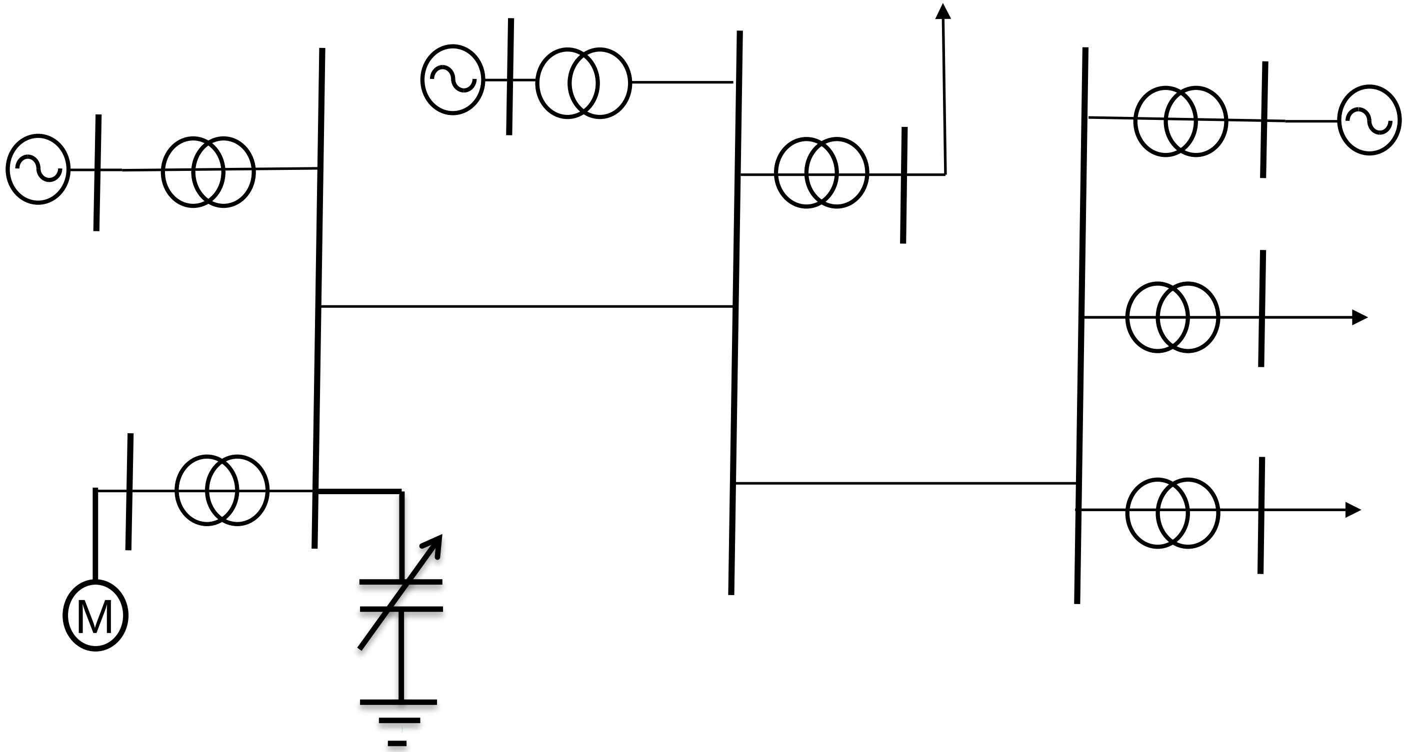

Fig. 1 – Typical power system network

Dynamic Models

(Distinguishing dynamic and non-dynamic elements)

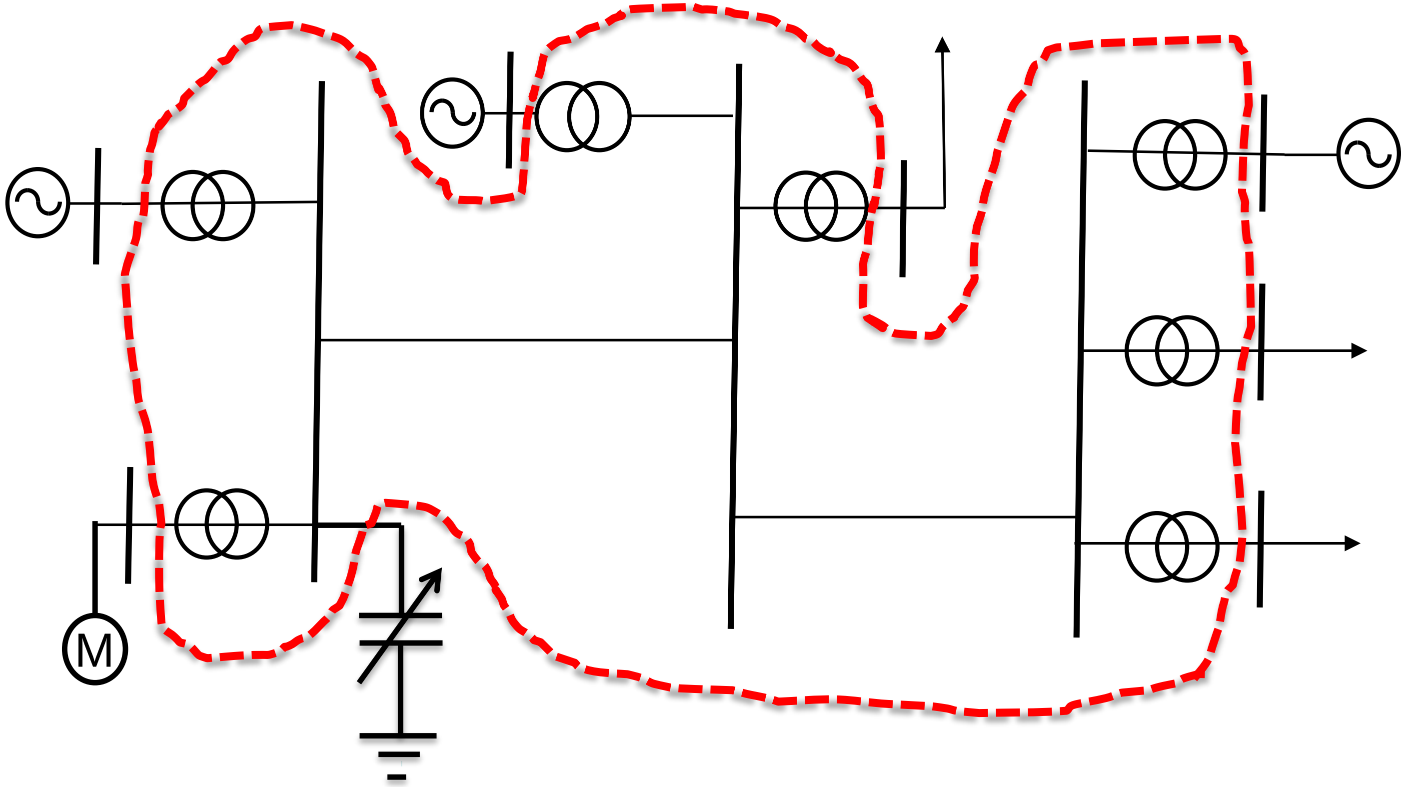

Fig. 2 – Distinguishing dynamic and non-dynamic elements

Dynamic Models (Synchronous Machines)

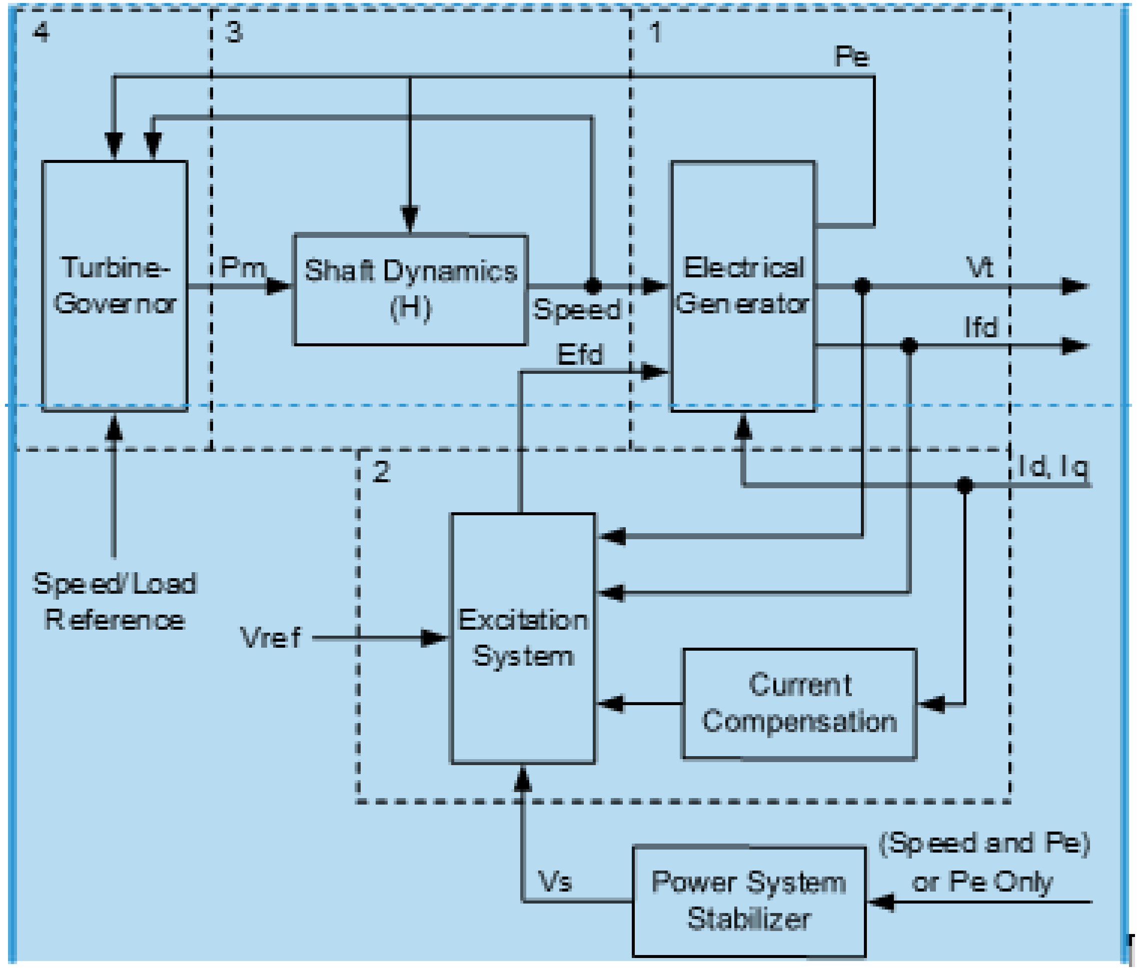

Fig. 3 – Typical Machine Model Interactions

*See "Power Plant Model Validation for Achieving Reliability Standard Requirements Based on Recorded On-Line Disturbance Data" by EPRI (P. Pourbeik, et al.)

Dynamic Model Simulation

(Steps in Numerical Simulation)

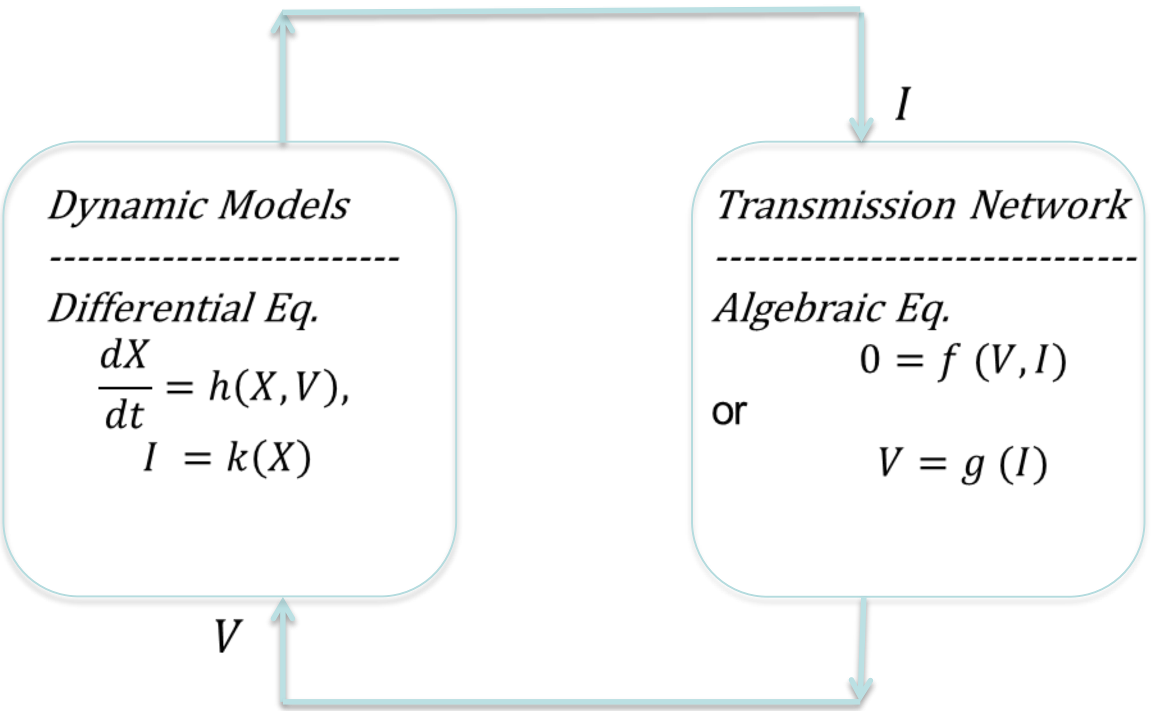

Fig. 4 – Steps in Numerical Simulation

Basic Plant Model Validation Using PMU Data

(Courtesy of BPA , based on the methodology proposed by Dmitry Koserev and Steve Yang)

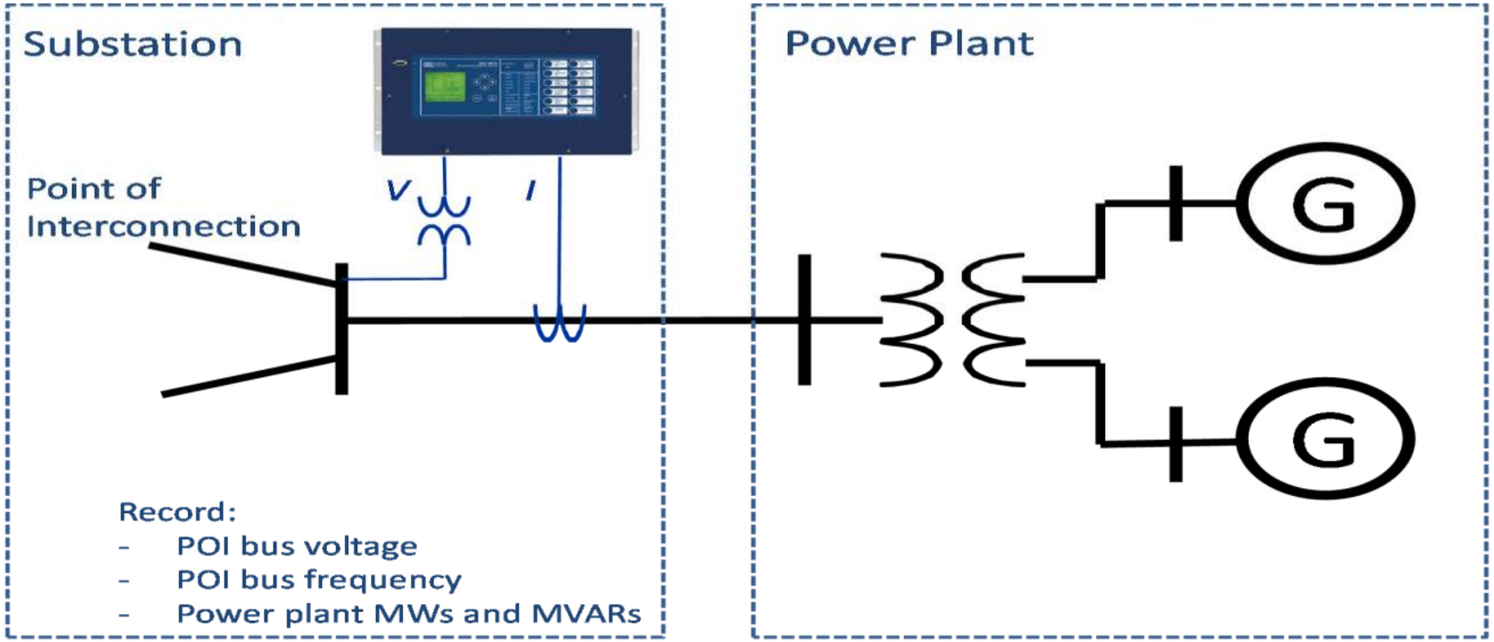

Fig. 5 – PMU needs to be placed at Power Plant POI

Expanded PSLF Power Plant Model Validation Using PMU Data

(This is based on the methodology proposed by Dmitry Koserev and Steve Yang from BPA)

Summary of steps in Extended Power Plant model validation in GE PSLF:

1. Select a disturbance of significant magnitude
2. Extract the measured data from PI database for Voltage, Frequency, Active Power, and Reactive Power at the point of interconnection
3. Create a local Power flow and dynamic model for the machine as seen at Point of Interconnection
4. Using the playback feature of PSLF, simulate the dynamic behavior of the machine for the measured voltages and frequencies
5. Compare the measured values of active and reactive power at the Point of Interconnection, **field voltage and current and rotor measurements** with the simulation results

PSCAD Power Plant Model Validation Using PMU Data

(Newly Proposed Methodology by SDG&E)

Summary of steps in PSCAD Power Plant model validation :

1. Select a disturbance of significant magnitude
2. Extract the measured data from PI database for Voltage, Frequency, Active Power, and Reactive Power at the point of interconnection
3. Create a local model for the machine as seen at Point of Interconnection in PSCAD
4. Using the playback feature of PSCAD, simulate the dynamic behavior of the machine for the measured voltages and frequencies. (using measured phase angles didn’t work due to wrapping of the angles.)
5. Compare the measured values of active and reactive power at the Point of Interconnection with the simulation results

Inertial Energy of a Synchronous Condenser Plant

Summary of steps in calculating Inertial Energy of a Syncon Plant:

1. Select a frequency event of significant magnitude
2. Validate the PSLF positive sequence model by its PSCAD EMT model *(as required by NERC guideline)*
3. From the plant MW response, calculate the Inertial Response (MW*sec)
4. From the WECC model, calculate the Total System Inertial Energy
5. Estimate the impact of the given synchronous condenser plant in system ROCOF

SynCon MW Response to Frequency Events

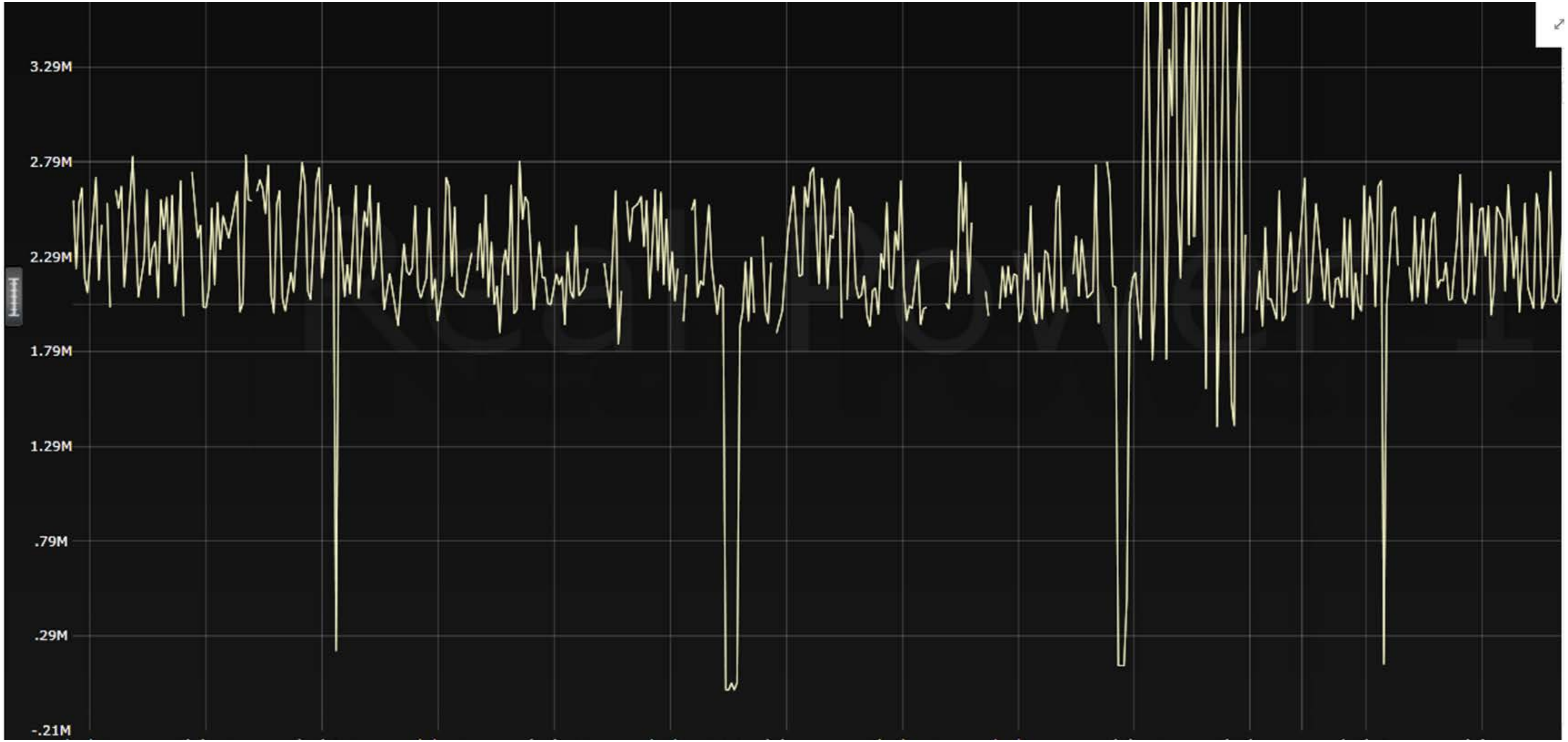

Fig. 6 – Typical 2-year period SynCon MW Response

SynCon MW Response to Frequency Events

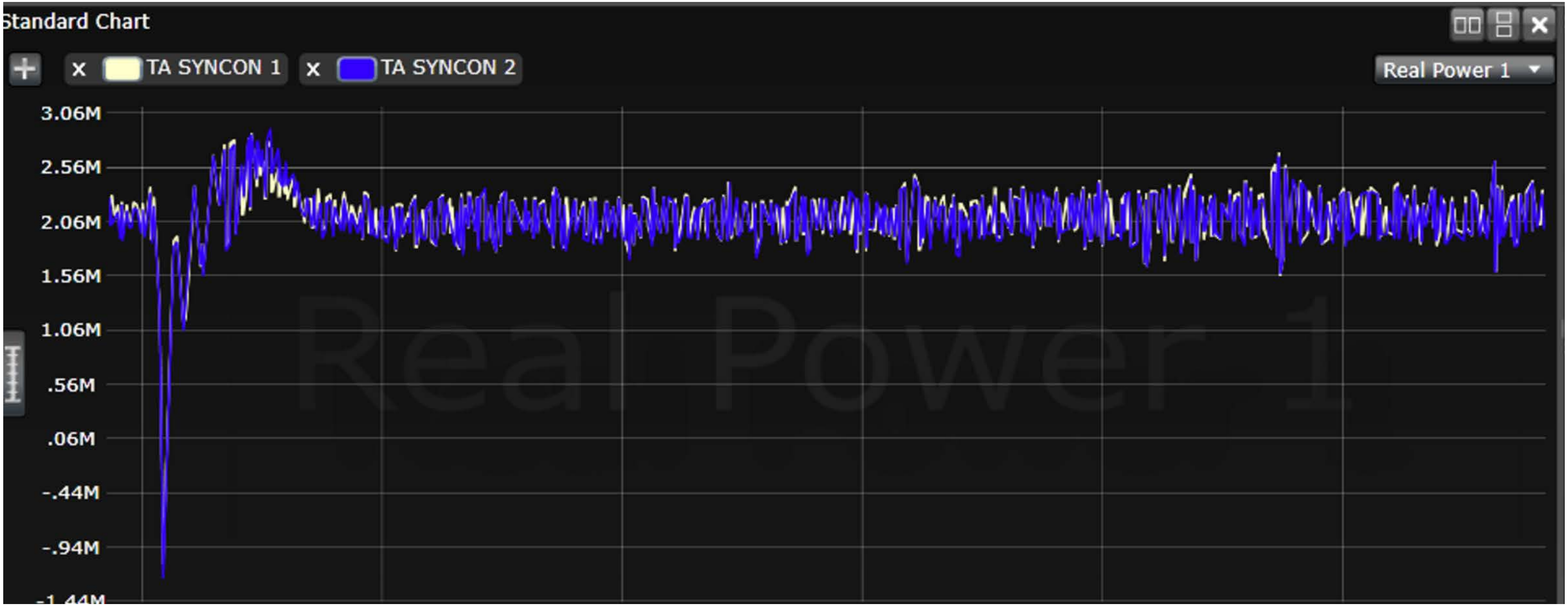

Fig. 6 – Typical 30-sec Syncon MW Response to a frequency event (Actual synchrowave Central PMU Measurements)

SynCon MW Response to Frequency Events

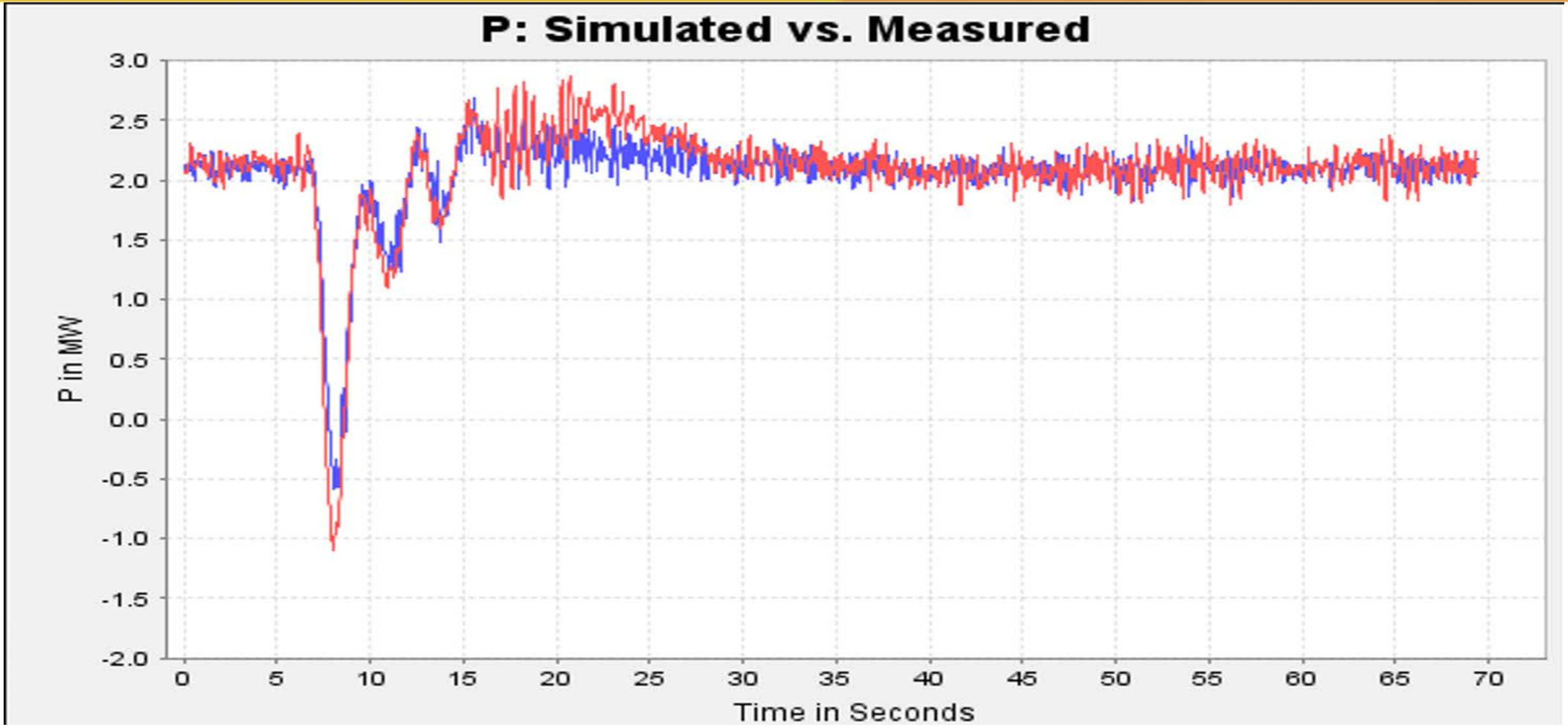

Fig. 6 – Typical 30-sec SynCon MW Response to a frequency event - PSLF MW simulation (blue) matching the measurements (red)

SynCon MW Response to Frequency Events

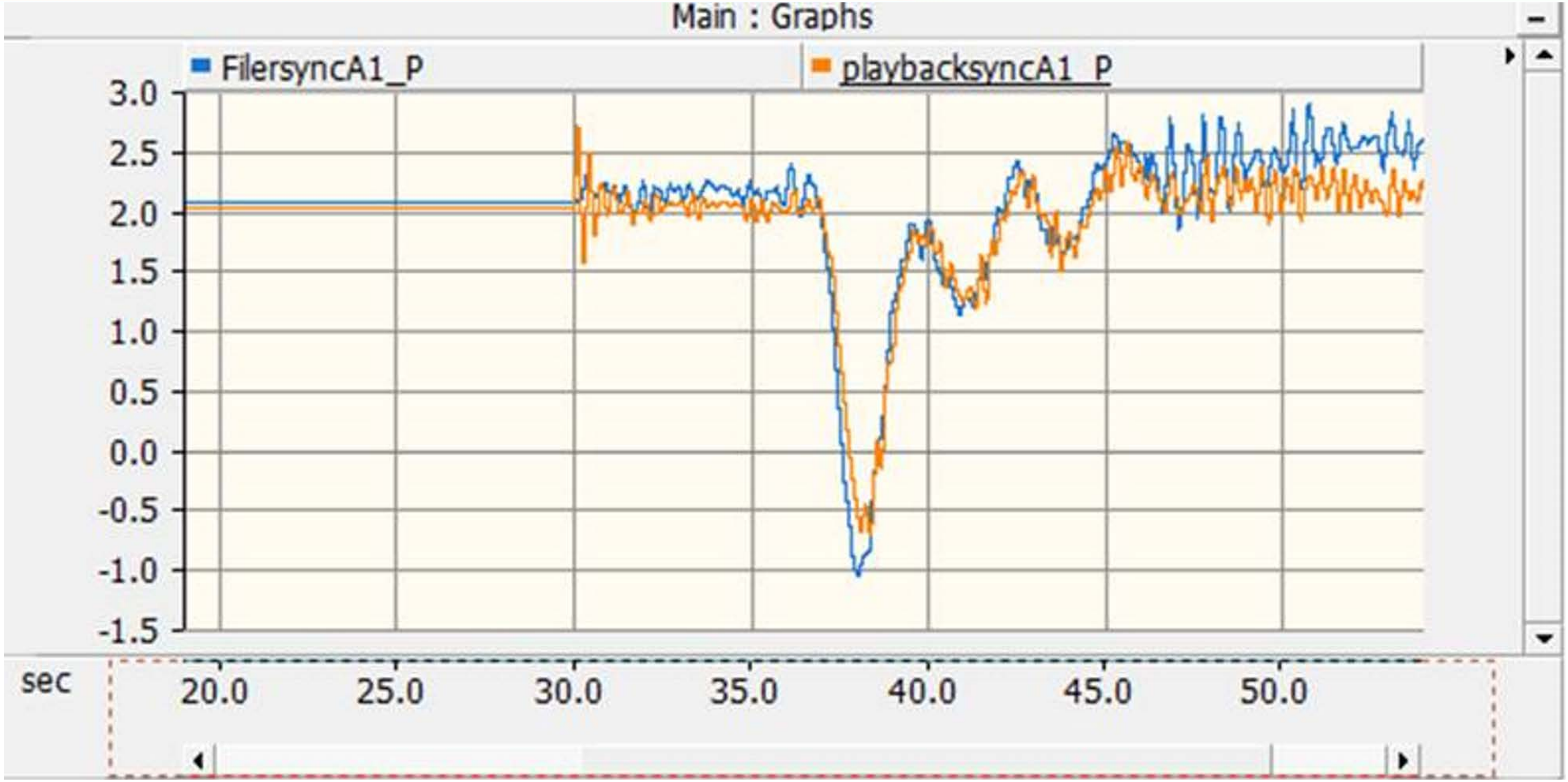

Fig. 6 – Typical 30-sec Syncon MW Response to a frequency event - PSCAD MW simulation (Orange) matching the measurements (blue)

System Inertia Energy

Area	Nominal Inertial Energy	MVA
A	76844.88	22017.49
B	117218.2	27377.26
C	68392.7	16533.78
D	8982.03	2288.44
E	11434.46	2969.72
F	12932.23	2428.85
G	27512.07	7596.19
H	16040.62	3597.94
I	9242.58	2720.84
J	31043.27	7602.86
K	12743.87	3650.73
L	159105.6	41865.06
M	39878.02	11817.75
N	149549.1	36801.77
O	43850.96	11036.09
P	21655.25	6710.08
Q	12808.11	3503.88
R	87116.78	22224
S	3138.21	1141.31
T	29449.09	9371.75
U	290.69	121
V	21113.32	4828.17
Total	**960342.1**	**248205**

Fig. 7 – Calculating Total System Inertial Energy

SynCon MW Response to Frequency Calculating SynCon Inertial Energy During an EventEvents

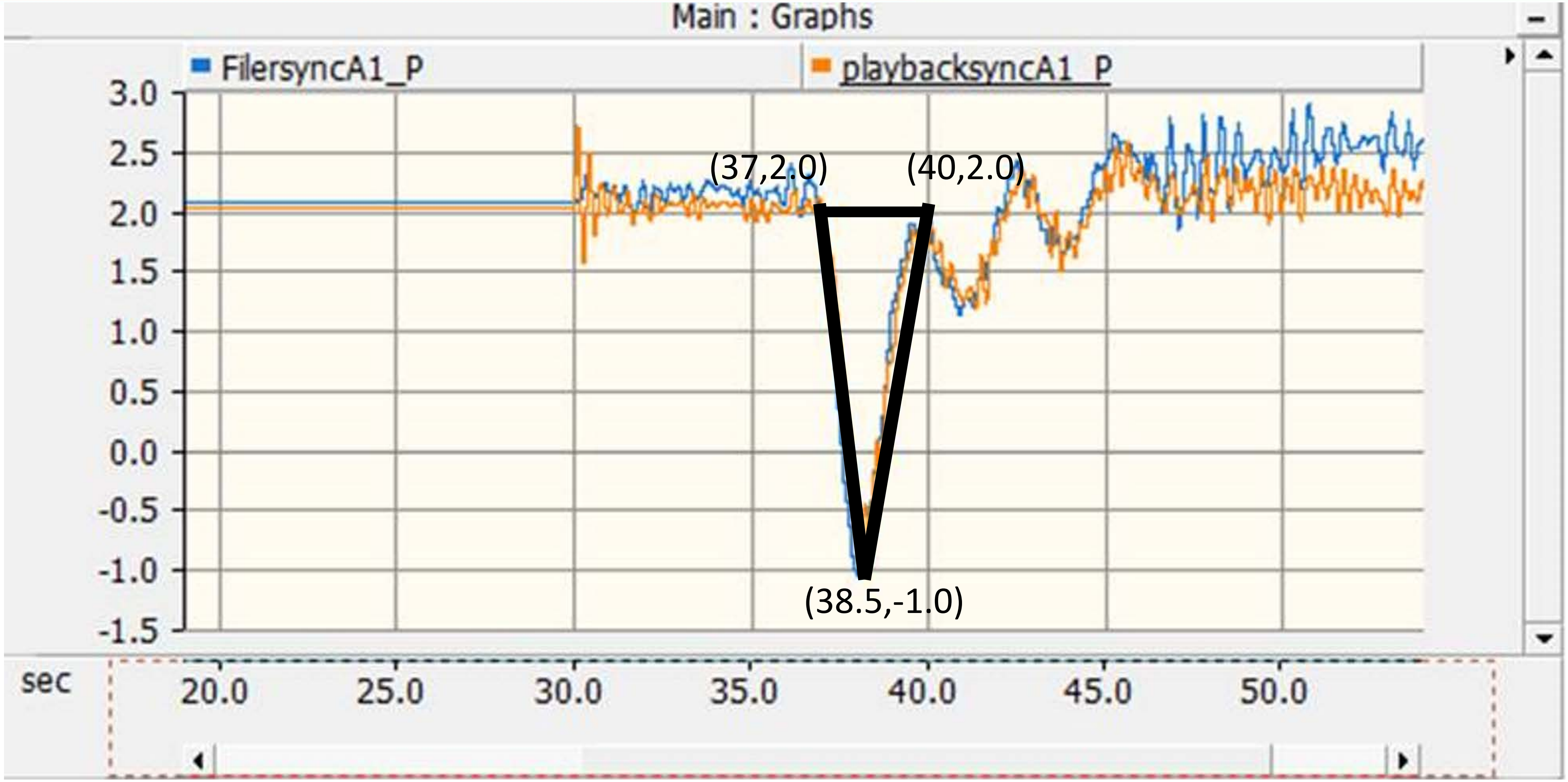

Fig. 7 – Typical calculation of inertial energy that is delivered by a syncon during a frequency event

Calculating SynCon Inertial Energy During an Event

Sample calculation

- **syncon inertial energy delivered during the event**

$$\frac{1}{2}(40-37)(2.0+1.0) = 4.5 \text{ MW.sec} = 4.5 \text{ Mega Joules}$$

- **Total available syncon energy**

H * MVA = 2.122 *225 = 477.45 Mega Joules

- **Almost 1% of the energy is delivered to the network during first 3 seconds of the frequency event**.
- **System inertial energy is about 2000 times of the syncon inertial energy. So the system frequency will not be impacted that much with the inertial energy of a single syncon, but almost all will react together and the total is a large number.**
- **Simulation confirms that the generators in the vicinity of the syncon will see lesser rate of drop of speed. I.e., less fatigue on the shaft.**

Conclusions

- Both positive sequence and EMT model validation of power plants are discussed.
- A sample calculation of synchronous condenser inertial power is demonstrated and its impact on ROCOF is calculated.

The main requirements for above calculations are the following:

- To have PMU measurements at the terminal of any dynamic units (conventional generators, wind turbine, solar PV, synchronous condensers, SVC, HVDC Converters, etc.)
- To know the right settings for the controllers (e.g., voltage, reactive, or power factor control) for validating PSLF and PSCAD models

Thank You! ☺