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A Software Tool for Real-Time Prediction of Potential Transient Instabilities using Synchrophasors

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Outline

- Introduction
- Transient Stability Status Prediction Algorithm
-  Software Tool
- Laboratory-Scale Hardware Setup
- Test Results
- Conclusion


Introduction

- Transient instability: Loss of synchronism of a generator or group of generators after a severe disturbance.
- A very fast phenomenon - Generators can potentially lose the synchronism within a few seconds after the disturbance.
- If transient instability can be recognized in advance, emergency control actions can be initiated to prevent it or minimize its impact.
- Common practice is to provide controls referred as special protection systems (SPSs),
 - Event based control actions designed through offline system studies
 - Could become complicated as the power system expands
- Alternative is the response based emergency control based on synchrophasor measurements.

Preceding work

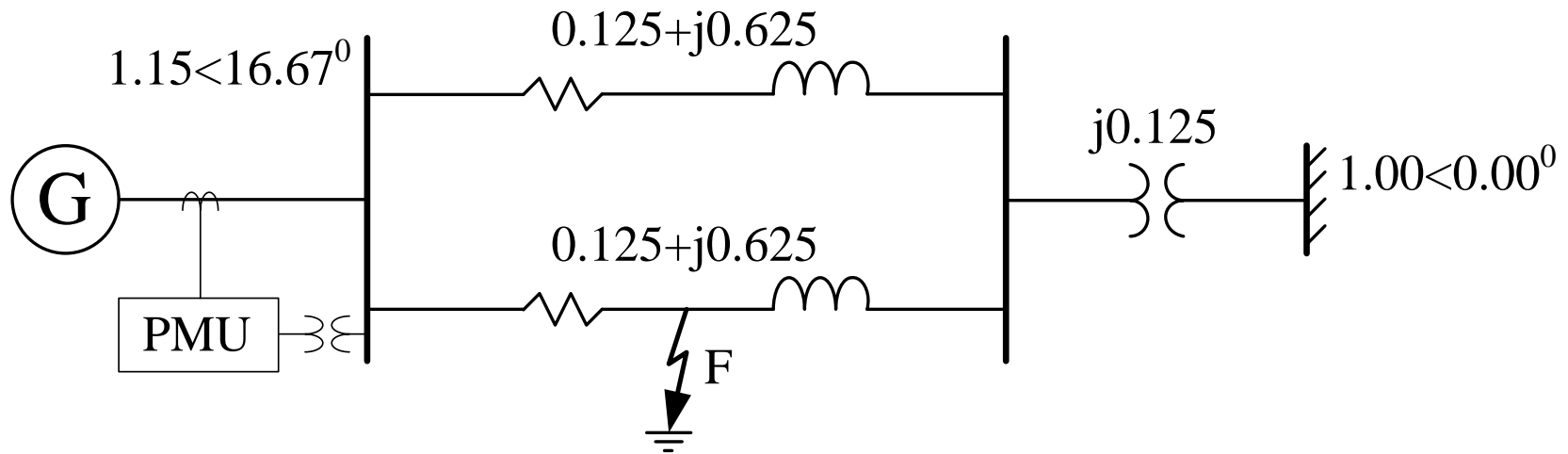
- Rotor Angle Instability Prediction using Post-Disturbance Voltage Trajectories
 - A. D. Rajapakse, F. Gomez, K. Nanayakkara, P. A. Crossley, and V. V. Terzija - IEEE Transactions on Power Systems, Vol. 25-2, May 2010.
 - Fuzzy C-means clustering, template matching & support vector machine classification
- Support Vector Machine-Based Algorithm for Post-Fault Transient Stability Status Prediction using Synchronized Measurements
 - F. R. Gomez, A. D. Rajapakse, U. D. Annakkage, and I. T. Fernando - IEEE Transactions on Power Systems, Vol.26-3, Aug 2011.
 - Support vector machine classification
- Post-Disturbance Transient Stability Status Prediction using Synchrophasor Measurements
 - D. R. Gurusinghe and A. D. Rajapakse - IEEE Transactions on Power Systems, Early Access, 2016.
 - Phase plane of voltage magnitudes

Objective

Implement the recently developed transient stability status prediction algorithm [1], [2] in a real-time software tool () and validate its performance through hardware in the loop simulations.

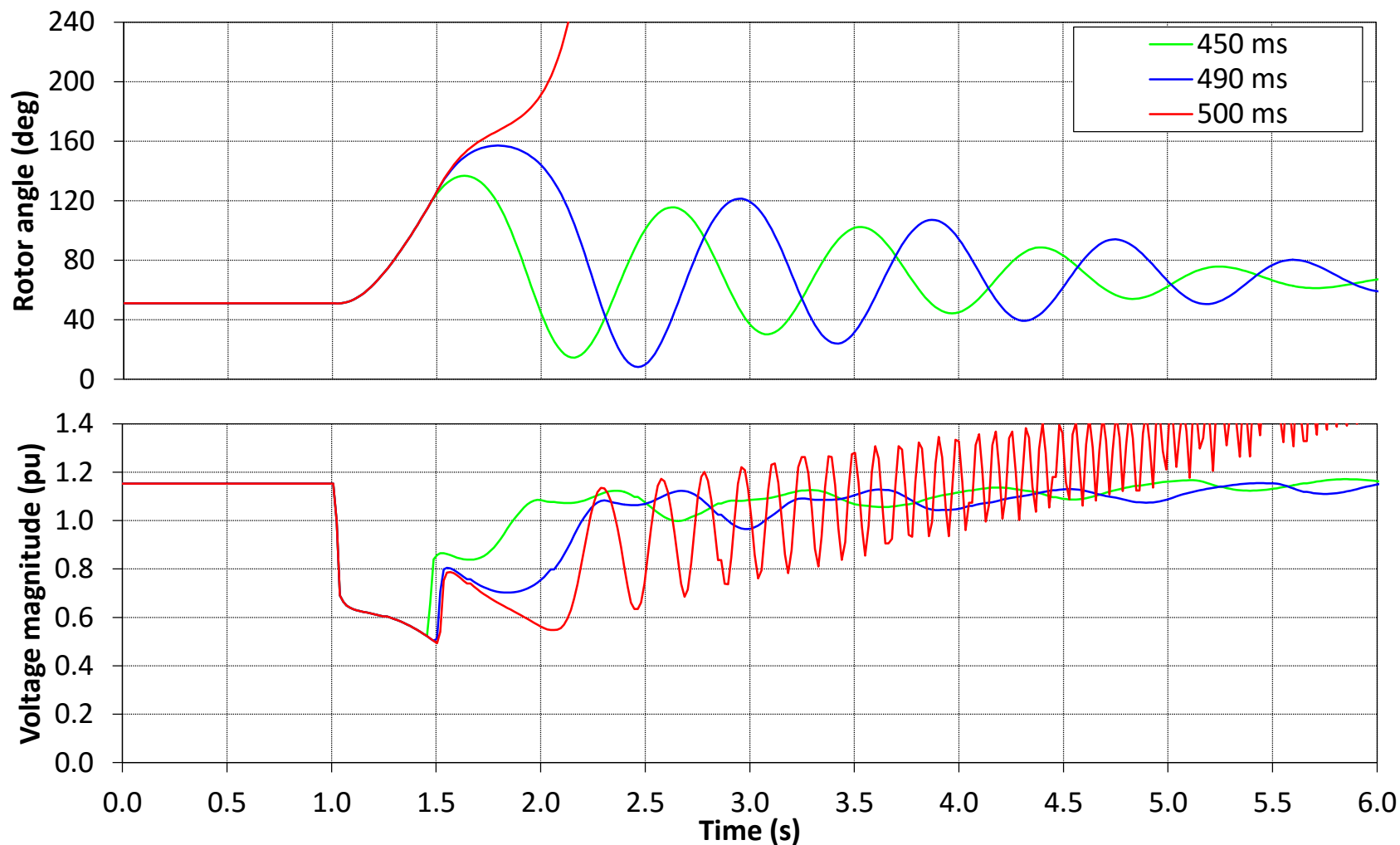
- [1] D. R. Gurusinge and A. D. Rajapakse, "Post-disturbance transient stability status prediction using synchrophasor measurements," *IEEE Transactions on Power Systems* (early access), 2016.
- [2] D. R. Gurusinge, A. D. Rajapakse, D. Ouellette and R. Kuffel, "An application of wide area synchrophasor based transient stability status prediction," presented at The North American Synchrophasor Initiative (NASPI 2015), San Mateo, CA, USA, Mar. 2015.

Concept of the Proposed Technique



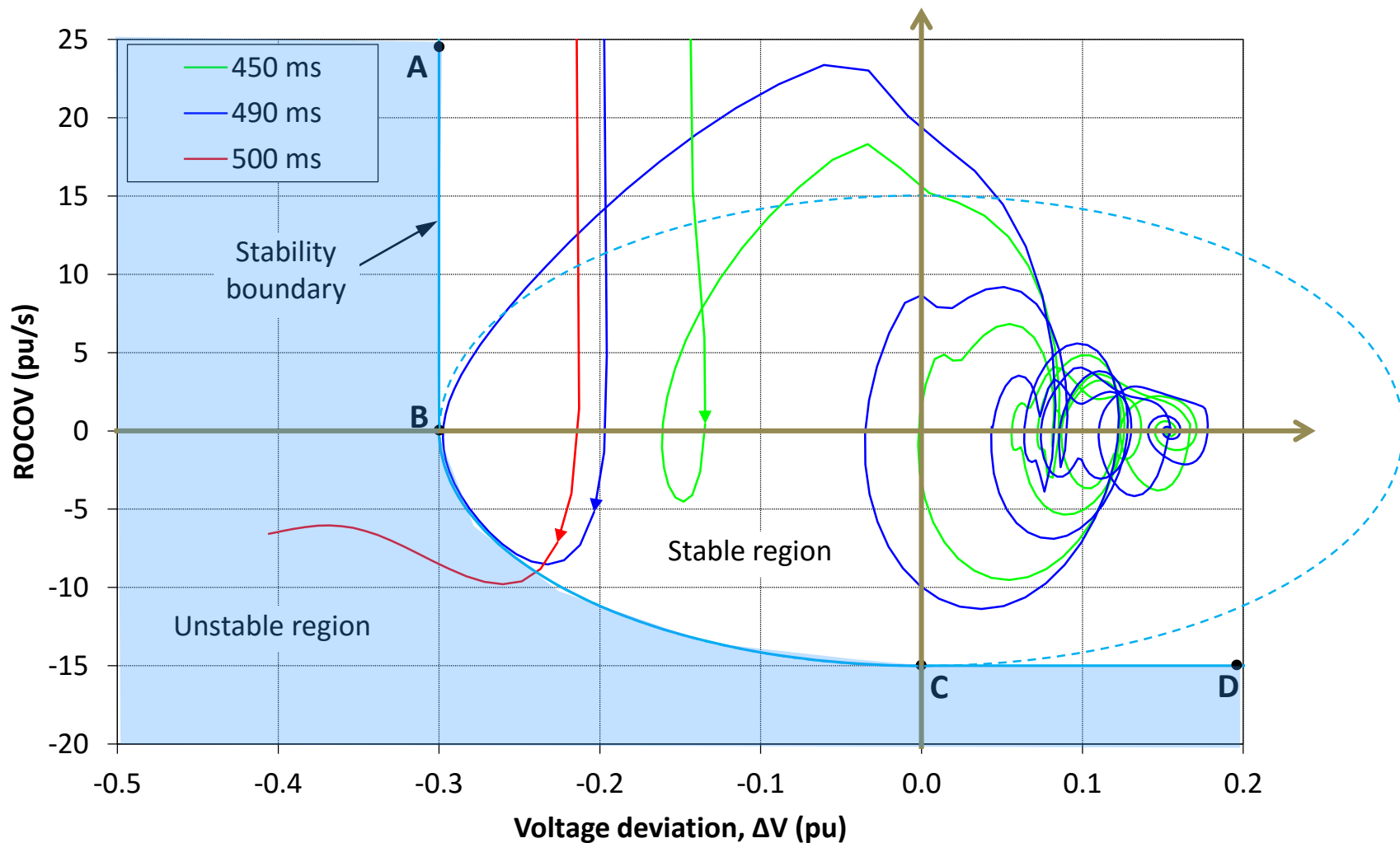
One machine to infinite bus (OMIB) system with the initial steady-state power flow solution

Concept of the Proposed Technique



Variations of rotor angle and voltage magnitude following a fault

Concept of the Proposed Method



Plot of ROCOV vs. ΔV following a fault

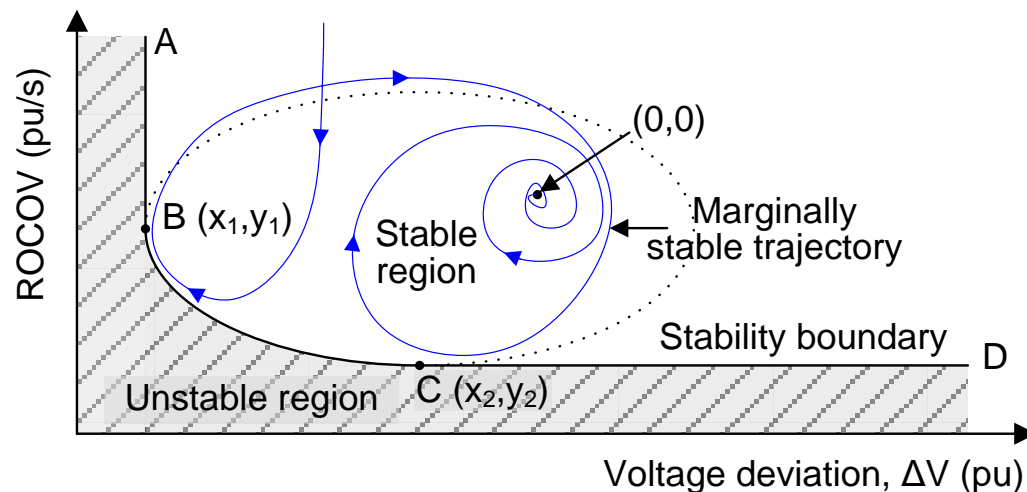
Implementation of Algorithm

- **Off-line design**

1. Identification of contingencies that makes generator marginally unstable through off-line dynamic simulations.
2. Determination of stability boundary for each generator

- **Real-time operation**

1. Detection of severe disturbances and triggering the transient stability status prediction algorithm.
2. Prediction of transient stability status, and trigger emergency control actions



- Developed at the intelligent Power Grid Laboratory of the University of Manitoba, Canada as a tool for testing synchrophasor applications
 - Implement synchrophasor application programs using an output data stream from a PDC
 - Check the availability of real-time data stream, determine the data configuration and connect.
 - Display/plot selected phasors with geographical information.
 - Record an event log, and save data for a specified duration upon triggered by an event specified by the user.
 - Retrieve and plot recorded data
 - Applications: Transient stability monitoring, line parameter estimation, oscillation monitoring

Features of



A screenshot of the PhasorEye software interface. The interface is displayed within a window with a standard operating system title bar. On the left side, there is a vertical navigation menu with four buttons: "Connection Status", "Analysis Tools", "View Event Log", and "Return Home". The "Return Home" button is highlighted with a blue border. The main content area of the window displays the "PhasorEye" logo in red, followed by the text "Synchrophasor Applications For Monitoring & Control of Power Systems" and "Intelligent Power Grid Laboratory University of Manitoba" in blue. At the bottom of the window, there is a status bar containing the text "Version: 1.5", "Intelligent Power Grid Laboratory - University of Manitoba", a red "Offline" indicator, and a "Recording Off" indicator. In the bottom left corner of the window, there is a logo for the Intelligent Power Grid Laboratory (IPGL) at the University of Manitoba.

Features of



The screenshot displays the PhasorEye software interface. On the left is a navigation sidebar with buttons for 'Connection Status', 'Analysis Tools', 'View Event Log', and 'Return Home'. The main area is titled 'Connection Information' and shows the following details:

- IP Address: 192.168.100.80
- Port: 4719
- ID: 2
- Stop button
- Display Window Size: 600 Data Points

Below this, the 'Staton Name' is set to 'Gen30' and 'PHASOR CH 1:V1'. A 'Refresh' button is present. A table lists data for various generators:

| Generator | Frequency | ROCOF |
|-----------|-----------|-------------|
| Gen30 | 59.995 Hz | 0.0001 Hz/s |
| Gen31 | 59.995 Hz | 0.0001 Hz/s |
| Gen32 | 59.995 Hz | 0.0001 Hz/s |
| Gen33 | 59.995 Hz | 0.0001 Hz/s |
| Gen34 | 59.995 Hz | 0 Hz/s |
| Gen35 | 59.995 Hz | 0 Hz/s |
| Gen36 | 59.995 Hz | 0.0001 Hz/s |

To the right of the table is a phasor diagram showing a red vector pointing towards the 90-degree mark on a circular scale with 0, 90, 180, and 270-degree labels.

At the bottom left is the 'iPGL' logo (Intelligent Power Grid Laboratory). The bottom status bar shows 'Version: 1.5', 'Intelligent Power Grid Laboratory - University of Manitoba', an 'Online' indicator (green bar), and a 'Recording Off' indicator (red bar).

Features of



GraphicConsole
- □ ×

Browse Background
Clear Background

PMU Components Decks:

Lock Components

Reset Position

PMU: connect to PMU:

Add Connection Clear Connection

Close all Sub Window

Bird's eye / Road Map

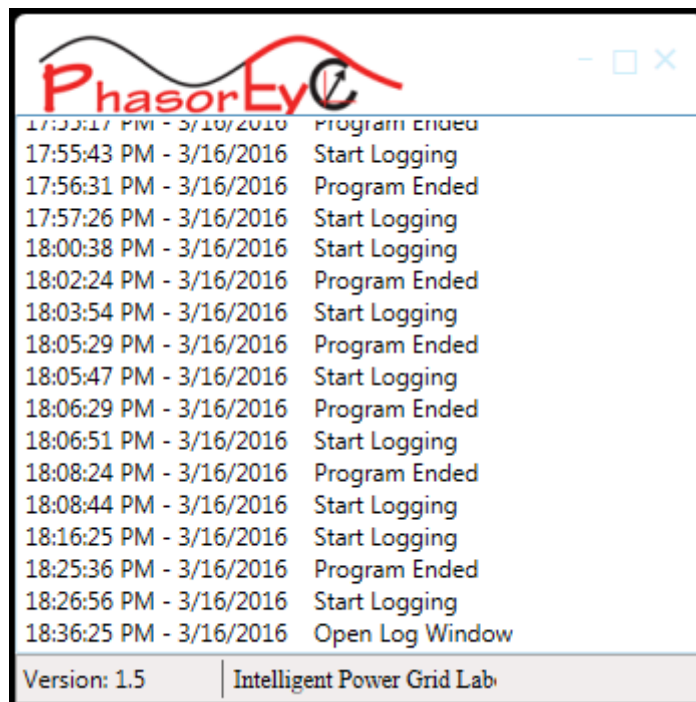
Version: 1.5 | Intelligent Power Grid Laboratory - University of Manitoba

PMU 0

Station Name : Gen30
 ID Code : 1
 Phasor 0 Name : PHASOR CH 1:V1
 Phasor 1 Name : PHASOR CH 2:I1
 Phasor 2 Name : ANALOG CH 0

| | | | | | |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 |

Features of

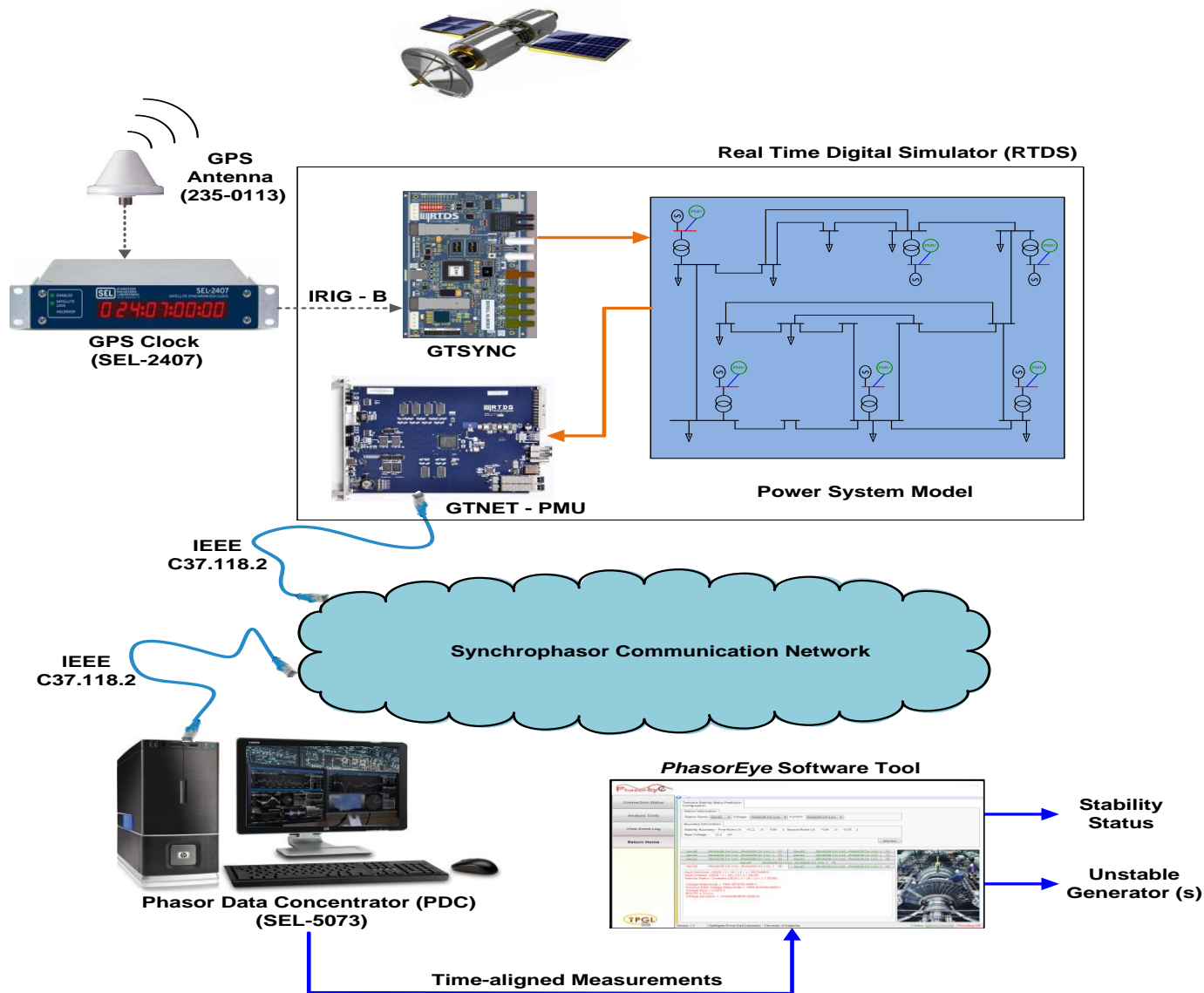


The screenshot shows a window titled "PhasorEye" with a standard Windows-style title bar (minimize, maximize, close buttons). The window contains a log of events. The log entries are as follows:

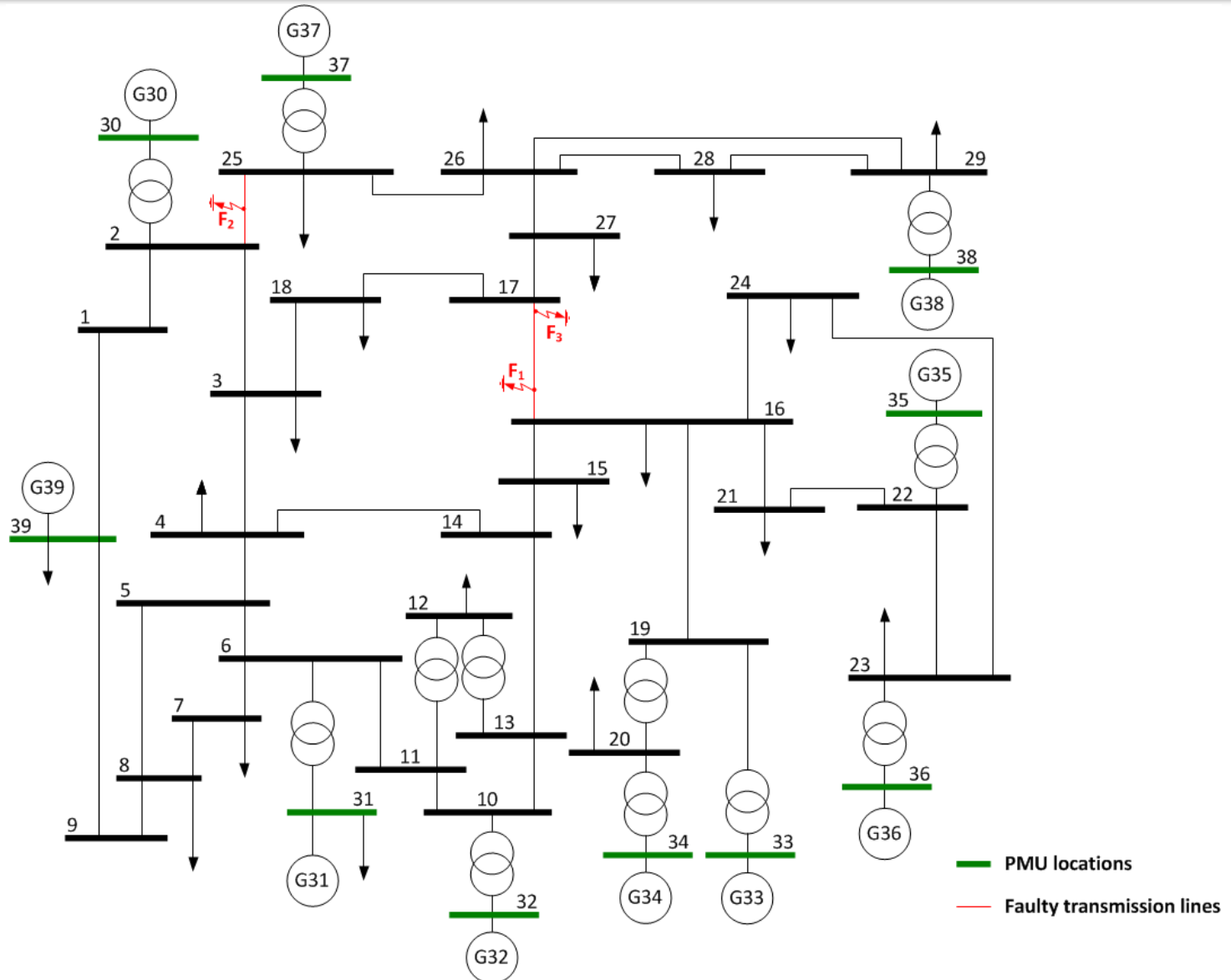
| Time | Date | Action |
|-------------|-----------|-----------------|
| 17:55:17 PM | 3/16/2016 | Program ended |
| 17:55:43 PM | 3/16/2016 | Start Logging |
| 17:56:31 PM | 3/16/2016 | Program Ended |
| 17:57:26 PM | 3/16/2016 | Start Logging |
| 18:00:38 PM | 3/16/2016 | Start Logging |
| 18:02:24 PM | 3/16/2016 | Program Ended |
| 18:03:54 PM | 3/16/2016 | Start Logging |
| 18:05:29 PM | 3/16/2016 | Program Ended |
| 18:05:47 PM | 3/16/2016 | Start Logging |
| 18:06:29 PM | 3/16/2016 | Program Ended |
| 18:06:51 PM | 3/16/2016 | Start Logging |
| 18:08:24 PM | 3/16/2016 | Program Ended |
| 18:08:44 PM | 3/16/2016 | Start Logging |
| 18:16:25 PM | 3/16/2016 | Start Logging |
| 18:25:36 PM | 3/16/2016 | Program Ended |
| 18:26:56 PM | 3/16/2016 | Start Logging |
| 18:36:25 PM | 3/16/2016 | Open Log Window |

At the bottom of the window, there is a status bar with the text "Version: 1.5" on the left and "Intelligent Power Grid Lab" on the right.

Laboratory-Scale Hardware Setup



Simulation Results : IEEE 39-Bus Test System



Simulation Results : Stable Case

PhasorEy

Connection Status

Analysis Tools

View Event Log

Return Home

Transient Stability Status Prediction Configuration

Station Information

Station Name: Gen30 Voltage: PHASOR CH 1:V1 Current: PHASOR CH 1:V1

Boundary Information

Stability Boundary - First Point { X: -0.11 ,Y: 0.00 } Second Point { X: -0.04 ,Y: -0.35 }

Base Voltage : 13.2 kV

Monitor

| | | | |
|-------|-----------------------------------|-------|-----------------------------------|
| Gen38 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen37 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen36 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen35 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen34 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen33 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen32 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen31 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |

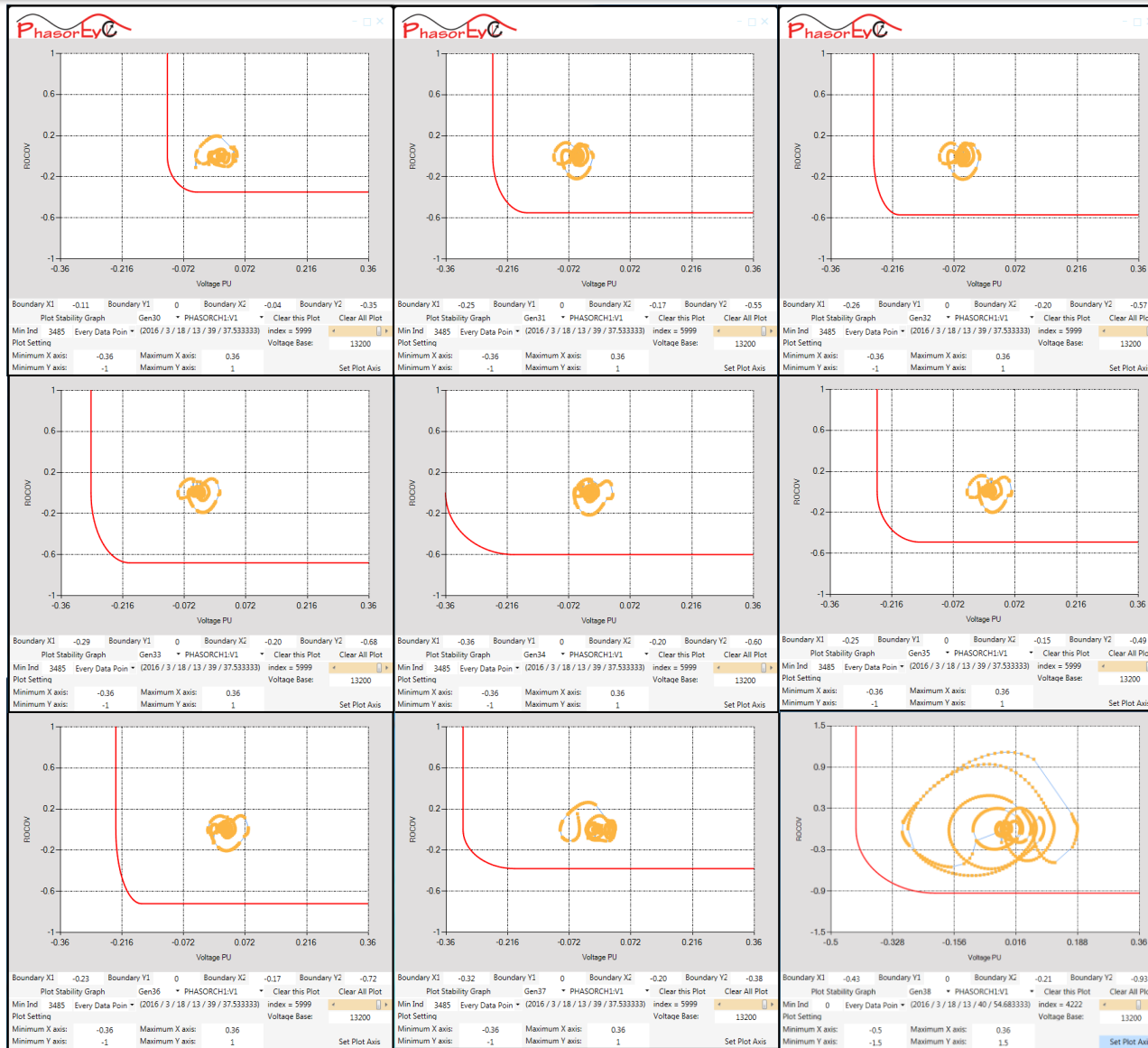
Gen30 (PHASOR CH 1:V1 /PHASOR CH 1:V1)

Fault Detected : (2016 / 3 / 18 / 13 / 40 / 40.8333333)
Fault Cleared : (2016 / 3 / 18 / 13 / 40 / 40.9333333)

Time : (2016 / 3 / 18 / 13 / 41 / 26.9333333)
Stability Boundary : First point { -0.11 ,0}
Second point { -0.04 , -0.35}
Voltage (PHASOR CH 1:V1) : 13306.16 < 19.59
Current (PHASOR CH 1:V1) : 13306.16 < 19.59
Counter : 5917

Version: 1.5 | Intelligent Power Grid Laboratory - University of Manitoba | Offline | Recording Off

Simulation Results : Stable Case



Simulation Results : Unstable Case

PhasorEy

Connection Status

Analysis Tools

View Event Log

Return Home

Transient Stability Status Prediction Configuration

Station Information

Station Name: Gen30 Voltage: PHASOR CH 1:V1 Current: PHASOR CH 1:V1

Boundary Information

Stability Boundary - First Point { X: -0.11 ,Y: 0.00 } Second Point { X: -0.04 ,Y: -0.35 }

Base Voltage : 13.2 kV

Monitor

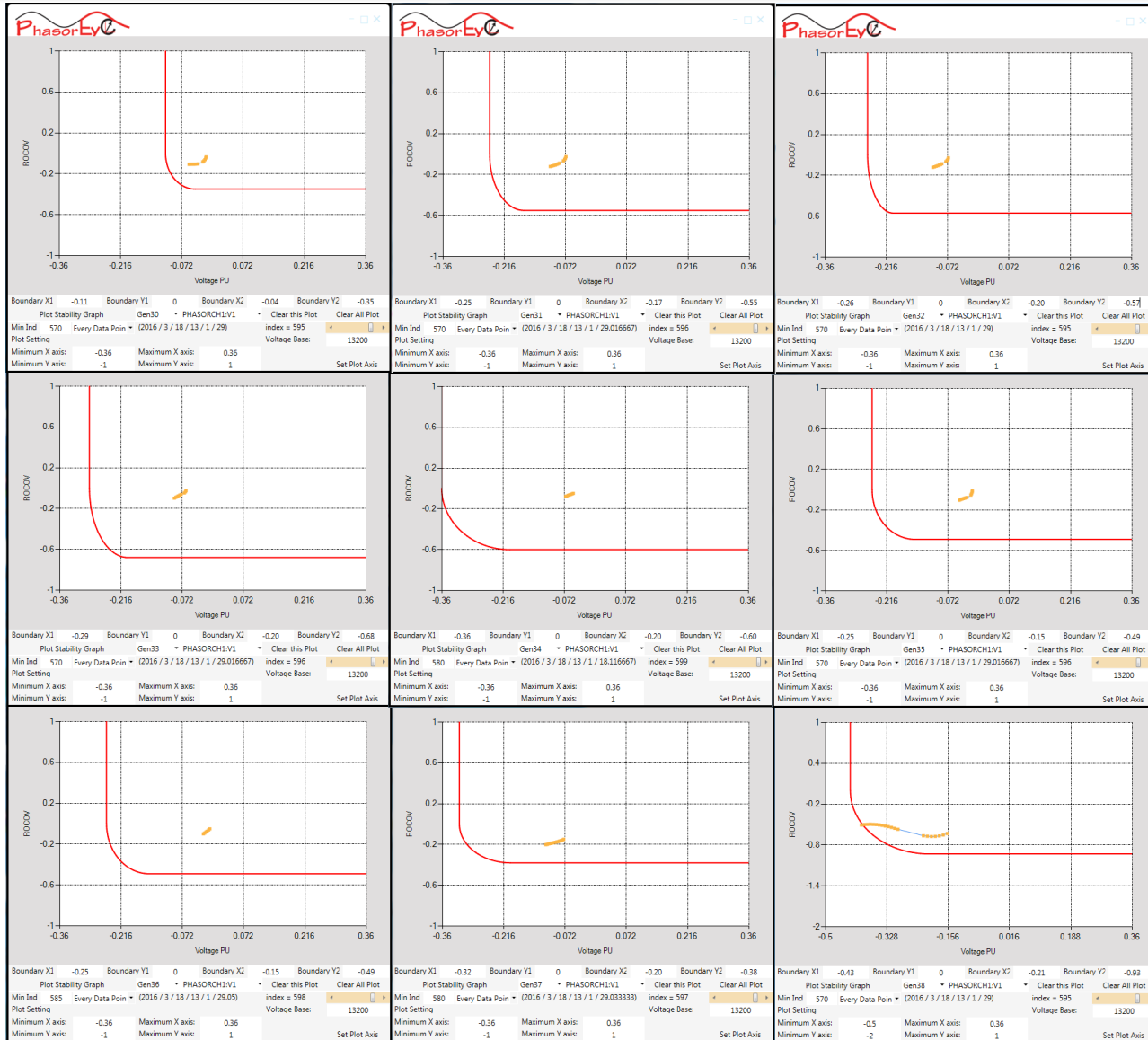
| | | | |
|---|-----------------------------------|-------|-----------------------------------|
| Gen36 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen35 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen34 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen33 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen32 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen31 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |
| Gen30 (PHASOR CH 1:V1 /PHASOR CH 1:V1) | | | |
| Gen38 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) | Gen37 | (PHASOR CH 1:V1 /PHASOR CH 1:V1) |

Fault Detected : (2016 / 3 / 18 / 13 / 1 / 28.316667)
Fault Cleared : (2016 / 3 / 18 / 13 / 1 / 28.45)
Stability Status : Unstable (2016 / 3 / 18 / 13 / 1 / 29.05)

Voltage Magnitude = 7465.30763913649 V
Previous Data Voltage Magnitude = 7465.30763913649 V
Voltage Base = 13200 V
ROCOV = 0 Pu/s
Voltage Deviation = -0.434446390974509 Pu

Version: 1.5 | Intelligent Power Grid Laboratory - University of Manitoba | Online | Recording Off

Simulation Results : Unstable Case



Conclusion

- A synchrophasor based transient stability status prediction algorithm was implemented in a standalone software tool.
- The effectiveness and practical implementation aspects of the transient stability prediction algorithm was evaluated in a laboratory scale test setup with the RTDSTM simulator.
- We hope to present how the transient stability predictions can be used to initiate emergency control actions in a future NASPI meeting.
 - Load shedding
 - Generator shedding
 - HVDC control

Thank you

Q & A