

### A High-Fidelity Real-Time Cyber-Power Operation Testbed for Grid Resiliency and Security

Vasavi Sivaramakrishnan, M. Mustafa Hussain, S Basumallik, P Banerjee and Anurag K Srivastava

 Smart Grid REsiliency and Analytics Lab (SG-REAL), West Virginia University, Morgantown, WV, USA







Real-time, data-driven tools supporting wide-area monitoring and providing decision support to control room operators toward better grid performance.



A grid that is resilient to adverse cyber-events

#### Energy Grid – Cyber, Physical, And Existential Events





#### Attacks on US Power Grids Rose to All Fime High in 2022

Physical threats to electric infrastructure climb 77% North Carolina, Washington site attacks triggered blackouts



y <u>Naureen S Malik</u> ebruary 1, 2023 at 9:30 AM EST







### **TO IMPROVE RESILIENCY OF GRID**

#### Tools for Cyber Resiliency

Testbed

- Algorithms and tools for cyber anomaly detection, classification, localization, root cause analytics, and resiliency analysis
- Validate algorithms and tools for deployment



### AGENDA





# POWER SYSTEM MODELING

2023 NORTH AMERICAN RTDS APPLICATIONS & T

# **POWER SYSTEM MODELING**

- Dynamic Model to Represent Field System: Electromagnetic model developed in RTDS
- Realistic Long-Term Dynamic Model in Control Room using PowerSimulator<sup>®</sup> A realistic platform for power system operation and control developed by IncSys and PowerData.
- About PowerSimulator<sup>®</sup>: The Modeling and Simulation Solution with an Operator Training Simulator (OTS).
- Cascadia Test System: A power system model, congruent to the actual grid of Washington State with suitable modifications is also being developed in RTDS.



PowerSimulator<sup>®</sup> web user interface

System Schematic-Cascadia power system model



# **CASCADIA POWER SYSTEM**

#### HIGHLIGHTS

- Total number of sub-stations: 54
- With an overall 21 generating stations (mainly Hydro, Thermal, and Natural Gas)
- The Cascadia deals with power transfer through 115 KV, 230 KV, and 525 KV lines.
- Satsop is the largest generator and is set as the slack bus due to its power generation quantity of 2400 MW.
- The high-power flowlines of Cascadia are Auburn Satsop (1877 MW), Airport- Renton (1503 MW) and etc.



#### Test System Representing Washington State Area



#### WESTERN REGION OF CASCADIA MODELLED IN RTDS



Puget Region of Cascadia on PowerSimulator

Cascadia(Puget) on RTDS via RsCad Fx

Voltage and Power wave forms from Mt Vernon substation in PUGET model on RTDS



#### COMPLETE SYSTEM MODEL WITH MODEL REDUCTION IN RTDS WITHOUT CHANGE IN SYSTEM SIMULATION OUTPUT





# WHY A REDUCED MODEL?

Having all buses at the same voltage level makes it easier to model on RTDS.

It avoids the insertion of transformers there by saves a lot of core space.

> This reduced model is created in such a way that it exactly matches with the original(Incsys), yet it is much simpler.





# HOW IT WAS REDUCED ?

- All parallel lines are eliminated
- Equivalent lines of 115 kV, 230kV and 525 kV is created and the base is kept at 230kV.
- Equivalent lines for all 115kV-230kV and 230kV-525kV transformers is introduced in the place of transformers.

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#### **REDUCED CASCADIA MODEL ON RTDS**

Challenge :

The reactive power limit was not strictly enforced in Incsys which led to power flow discrepancy. Solution :

System modified and reduced for power flow matching between Incsys and Power World.







# **CASCADIA ON RTDS**

- Reduced 42 bus Cascadia system over 2racks (3cores), using rack changing components.
- Actual values calculated from P.U values inputed into RTDS
- Real and Reactive power flow matched up to 2 decimal points.









# PLOT INDICATING THE DIFFERENCE IN VOLTAGE AND ANGLE

• The differences between the original Cascadia and Reduced Cascadia lie on and around zero



# The Communication Network over the Physical power system layer

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#### END TO END DATA CONNECTIVITY, FROM SUBSTATION TO CONTROL CENTER USING NS3



#### SUBSTATION CYBER NETWORK MODEL ENSEMBLE AT SG-REAL LAB





#### AN ENSEMBLE OF S.S DEVICES CONNECTED VIA A NETWORK AND PHYSICAL COUPLING

- Apart from devices connected through NS3, the test bed is also incorporated with the SEL 401 merging unit.
- The coupling with the power system is done using the CVT and CT embedded into the SEL 401.
- The output from the physical system is sent to the merging unit using the GTAO card.
- And the relay is looped back into the physical system using the GTDI input configured with distance protection for the transmission line.





#### CHALLENGES IN CYBER-POWER SIMULATIONS AND POSSIBLE SOLUTIONS

Synchronization between dynamic power system and discreet cyber network system

Interfacing multi vendor hardware & software components

Developing logging & data storage system involving both power and cyber data

Creating real-time cyber-power scenarios to validate monitoring and control tools

Developed Hardware-In-The-Loop testbed using NS3 & SEL SDN switches to exchange data in real time

Worked with SEL, RTDS & GPA products to come up with common supporting standards and protocol

Used a combination of MySQL and Cloud Database along with Splunk to create a real-time logging system

Developing different cyber attack and power system events to create real-time cyber-power scenarios





# DATA GENERATION FOR MACHINE LEARNING AND TOOL DEVELOPMENT

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# DATA GENERATION FOR MACHINE LEARNING AND TOOL DEVELOPMENT

Data generation from IEEE 14 bus, 39 bus, and Cascadia system.

Data generation for control data and various events and switch operations.

Switch operations to emulate unsolicited access and attacks.

Data used in various data analytics and physics involved machine learning algorithms to identify cyber-attacks from rest of the events and operations



## TIME SYNCED DATA STREAMED TO OPEN PDC

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Inputs	Outputs	Actions	Metadata Me	onitoring	Reporting	System				
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6	0.0112	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59,94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31
7	0.012	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31
8	0.0128	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59,94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31
9	0.0136	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
0	0.0144	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
1	0.0152	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
2	0.016	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
3	0.0168	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
4	0.0176	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
5	0.0184	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31
6	0.0192	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
7	0.02	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
8	0.0208	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
9	0.0216	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
0	0.0224	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
1	0.0232	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
2	0.024	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31
3	0.0248	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
4	0.0256	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
5	0.0264	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
6	0.0272	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.3
7	0.028	0.315932069	2829.870836	-1.778460676	2829.874	2.410327	2829.878	0.866667	59.94869	-1.39E-04	0.495233	11066.73	-1.59916	11066.76	2.589627	11066.76	0.777867	4717.716	-1.31

#### SAMPLE OF GENERATED DATA







# **SUMMARY**



Used Real-Time Digital Simulator (RTDS) as a dynamic power system simulator to feed SCADA/PMU data to sensor, network and EMS



Generating Synthetic but realistic data for validation of the algorithms/ tools.



Performing Cyber attacks and creating power events to understand the nature of interdependency within cyber-power system.



Developing Advanced Tools to help operators with better decision making and situational awareness



