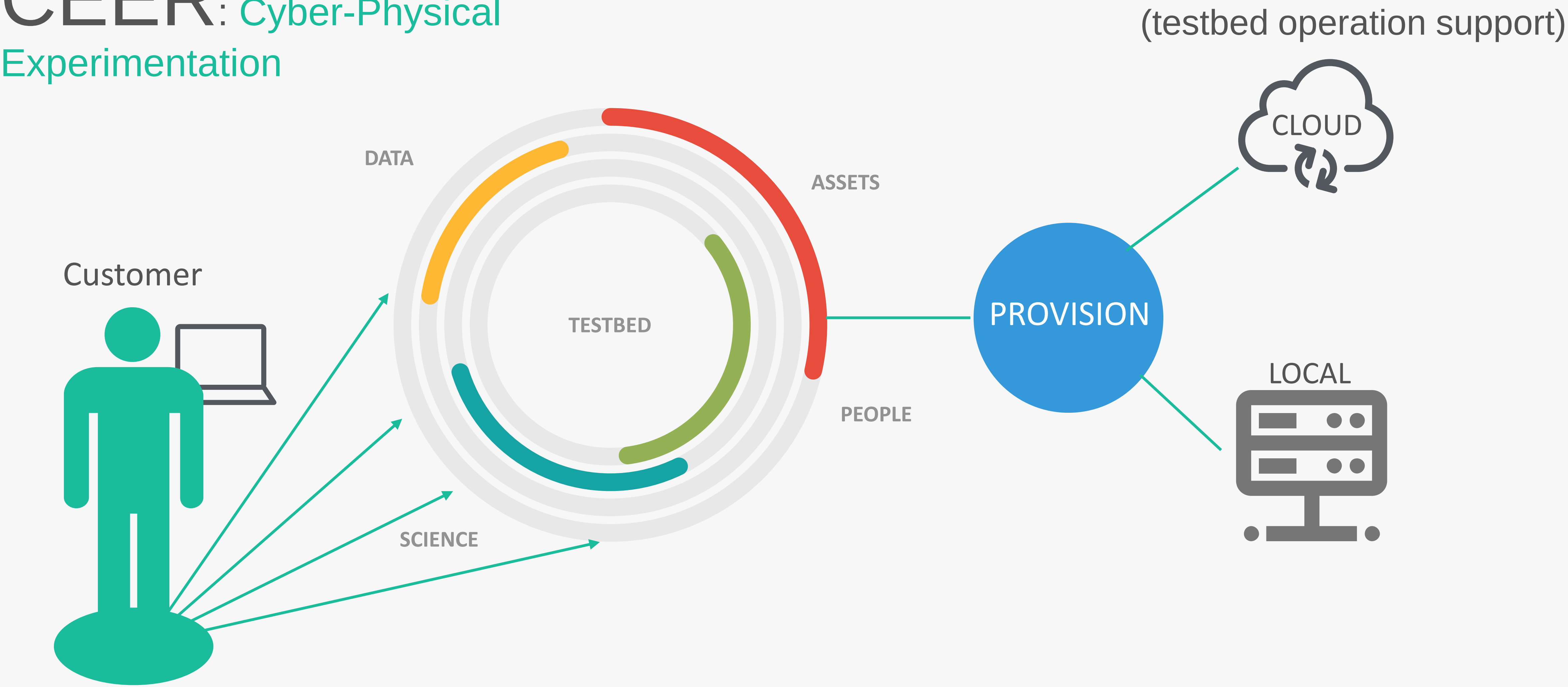
Illinois Testbed

An Overview of Resource Availability

CEER: Cyber-Physical Experimentation



People

Edmond

Ashwini

Yu

Prosper

Steve

Jeremy

David

Richard

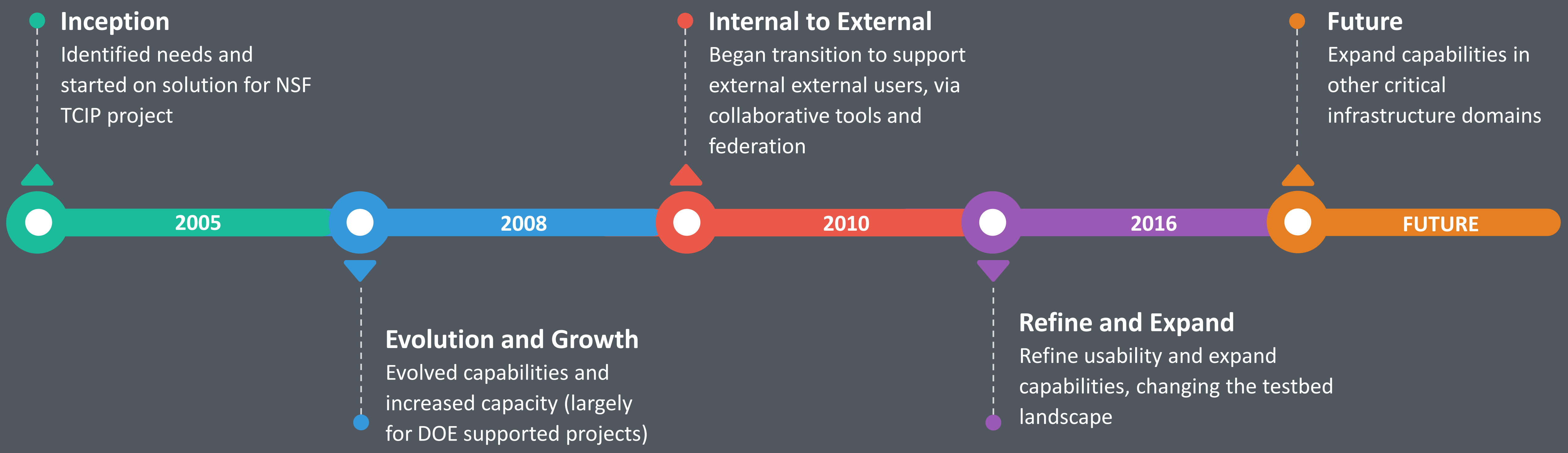
Shane

Tim

Ziping

CEER Lineage

An Evolution



Inception

Identified needs and started on solution for NSF TCIP project

Evolution and Growth

Evolved capabilities and increased capacity (largely for DOE supported projects)

Internal to External

Began transition to support external external users, via collaborative tools and federation

Refine and Expand

Refine usability and expand capabilities, changing the testbed landscape

Future

Expand capabilities in other critical infrastructure domains

The reason

Mission critical technology must be proven to be effective before we need it

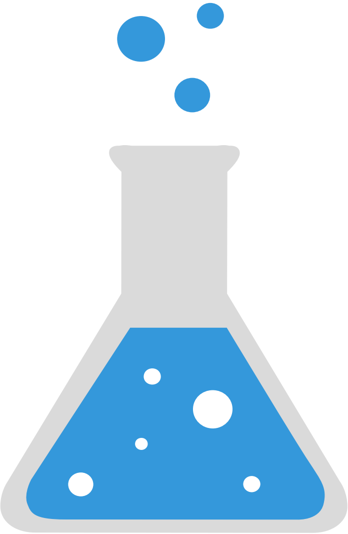
The capabilities to fully prove out this technology are not available today.

A realistic, recomposable, and well instrumented testbed is essential.

Our approach

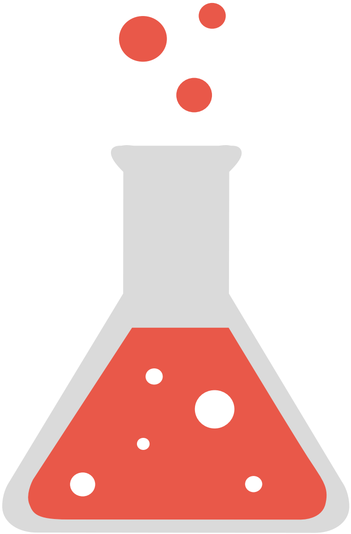
Driven Models

Scalable, accurate, and encompassing cyber and physical models that adapt to exercise needs based on performer input



Modularity

Adaptable composition, configuration, and deployment of testbed assets to accomplish exercise goals



Instrumentation

Appropriate and accurate instrumentation to capture needed assessment knowledge without affecting results

Knowledge

Blend of academic, enterprise, manufacturing, and asset owner knowledge to ensure a multi-dimensional approach

What’s available to those that need it TODAY?

10,000 Mile View

- Physical testbed access
- Dedicated (isolated) office space on site
- Dedicated remote access
- ICS software and equipment
- Computation and Storage support (within reason)
- Capacity to bring in special software and equipment

Network Overview

- 10GigE Uplinks and Fabric
- SDN-enabled
- Isolation and segregation
- Dedicated VPN access

Capabilities

- Full end-to-end Smart Grid capabilities
- Deployed Advanced Metering Infrastructure (AMI)
- Solar research platforms
- Real, emulated, and simulated hardware/software for scalability
- Real data from the grid, Industry partners, etc.
- Power simulation, modeling, and optimization of various forms
- Network simulation, modeling, and visualization of various forms
- Advanced hardware-in-the-loop cyber-physical simulation
- WAN/LAN/HAN integration and probes
- Security and protocol assessment tools (static/dynamic analysis, test harnesses, fuzzing)
- On-grid testing capabilities via Ameren TAC facility (with fiber optic interconnects to our primary testbed)

Hardware/Software Overview

- RTDS, PowerWorld, PSSE, PSCAD, PSLF, DSAtools, DynRed
- RINSE, tstBench, LabView, OSI PI, OSIi Monarch, SEL suites, PGDA
- Full range of open source power grid tools (openDNP3, openPDC, openPG, openXDA/openFLE, openHistorian, SIEGate)
- GPSs, substation computers, relays, PMUs, testing equipment, PLCs, security gateways, NI platforms
- Power analysis tools, PDCs, data analytics
- Full AMI deployment, TCIPG Smart Meter Research Platform
- RTUs, F-Nets, inverters, oscilloscopes, firewalls, embedded devices, sensors, spectrum analyzers, SIEMs, IDSs
- Home EMS, energy and environmental monitoring devices, zigbee, automation
- Display wall, visualization platforms (STI, RTDMS), training platforms
- Mu Dynamics, Fortify, security research tools, IBM Tivoli suite
- Cyber-physical extension via federation

Control Center

- OSIi Monarch EMS
- OSIsoft PI data historian
- Space Time Insight STAS system
- RTDMS and Phasor Grid Dynamics Analyzer
- Secure Information Exchange Gateway (SIEGate)
- Open Phasor Gateway (openPG)
- Open Phasor Data Concentrator (openPDC)
- Open Historian (openHistorian)

Generation

- Isolated Solar Test Lab
    - Single panel isolation for assessing behavior of solar in controlled conditions
- External Solar Array
    - 20kw array split into 5 separate strands
    - Varying technology of micro inversion, DC optimization, etc for each strand
    - Feeds into operational building for energy offset

Transmission and Distribution

- ABB
  - Relays (18 x REF 615)
  - Substation Gateway (2 x COM 600), plus virtualization
- Arbiter
  - PMU
- GE
  - D60 (Qty 2) – one upgraded to an N60 for 61850 support
  - F60
- Novatech
  - 8 x Orion LX
- Eaton/Cooper
  - 2 x SG4250 Substation Gateway

Transmission and Distribution

- Schweitzer Engineering
  - GPS Clocks (4 x SEL-2407, 2 x SEL-2488)
  - Substation Computers (SEL-1102, SEL-3351, 3 x SEL-3354, 1 x 3355)
  - Relays (3 x SEL-351S, 5 x SEL-421)
  - Adaptive Sources (5 x SEL-AMS)
  - Automation Controller (SEL-RTAC, SEL-3555)
  - Encrypting Devices (2 x SEL-3022, 4 x SEL-3025)
  - Network Switches (2 x SEL-2730M)

Advanced Metering

- Itron
  - 22 Openway Meters
  - 4 Cell relays
  - 1 MDMS Itron Enterprise
- Trilliant tstBench Meter Emulation
  - Allows for scaling meter assets
- TCIPG Smart Meter Research Platform
  - Custom research board built from the ground up to research AMI unencumbered
- Full protocol stacks (C12.22 and DLMS/COSEM)

Power System Protocols

- Protocols (binary/source)
  - C37.118
  - 61850 (and 61850-90-5)
  - DNP3
  - ICCP
  - Modbus
  - AMI (C12.22, DLMS/COSEM)
  - Zigbee/Zwave
  - Proprietary
- Test harnesses and more

Modeling

- Power
  - Opal-RT 5700 fully loaded
  - Real Time Digital Simulator (RTDS)
    - 2 chassis units, well optioned with various protocol packages
    - Allows for hardware in the loop, pure simulation, and emulation
    - Doble F6350e, 2 x F2100
    - Pacific Power 112AMX
  - PowerWorld, PSSE, PSLF, PSCAD, *SAT, DynRed
  - OpenDSS, GridLabD
- Cyber
  - RINSE/SSF, NS{2,3}, Emulab/DETER, etc

Security Specific

- ICS Security Vendor Commercial Products
- Secure Software Analysis Tools (Commercial and Open)
- Mu Dynamics MU-8000 + Mu Studio
  - Security scale testing and fuzzing
- Tofino SCADA Firewall (old and current gen)
- Bayshore SCADA Firewall
- Sonicwall, Cisco, and Firewall1 Firewalls
- Custom Linux VPN and Cisco ASA 5510
  - VPN/Firewall for lab facilities
- IDS and SIEM systems
- IBM Tivoli product suite
- Openflow switching and Layer 3+ switches
  - IP routing and segregation for lab facilities
  - 10GE uplinks on core switches

Computation

- 60+ High-end servers
    - Provide computational support, experimentation set up and teardown, etc.
    - Currently hosting hundreds of VMs supporting research
- Latest Virtualization and Container Capabilities
- Federation of assets and internal provisioning of both cyber and physical assets
    - Professional enterprise-class range provisioning and management platforms being integrated

Miscellaneous

- F-Net (Qty. 11)
    - Wall outlet “PMU”s
- Osiris RTU
    - Connects server with legacy devices
- Semikron Inverters (Qty 4)
    - DC inverters for voltage stability framework
- National Instruments DAQ and PXI chassis
    - Analog/Digital Taps
    - National Instruments LabView
        - Programmable logic for A/D taps
- Arduino, Beagleboards, Raspberry PI, etc
- Misc. Software to utilize the hardware
- Advanced display wall for visualization and research

Unique Integration

- Special builds of various software
- Custom tools to integrate cyber-physical systems
- Custom tools to automate experimentation
- Programmatic control of a variety of the assets
- Software Defined Radio capabilities
- Full lab packet capture

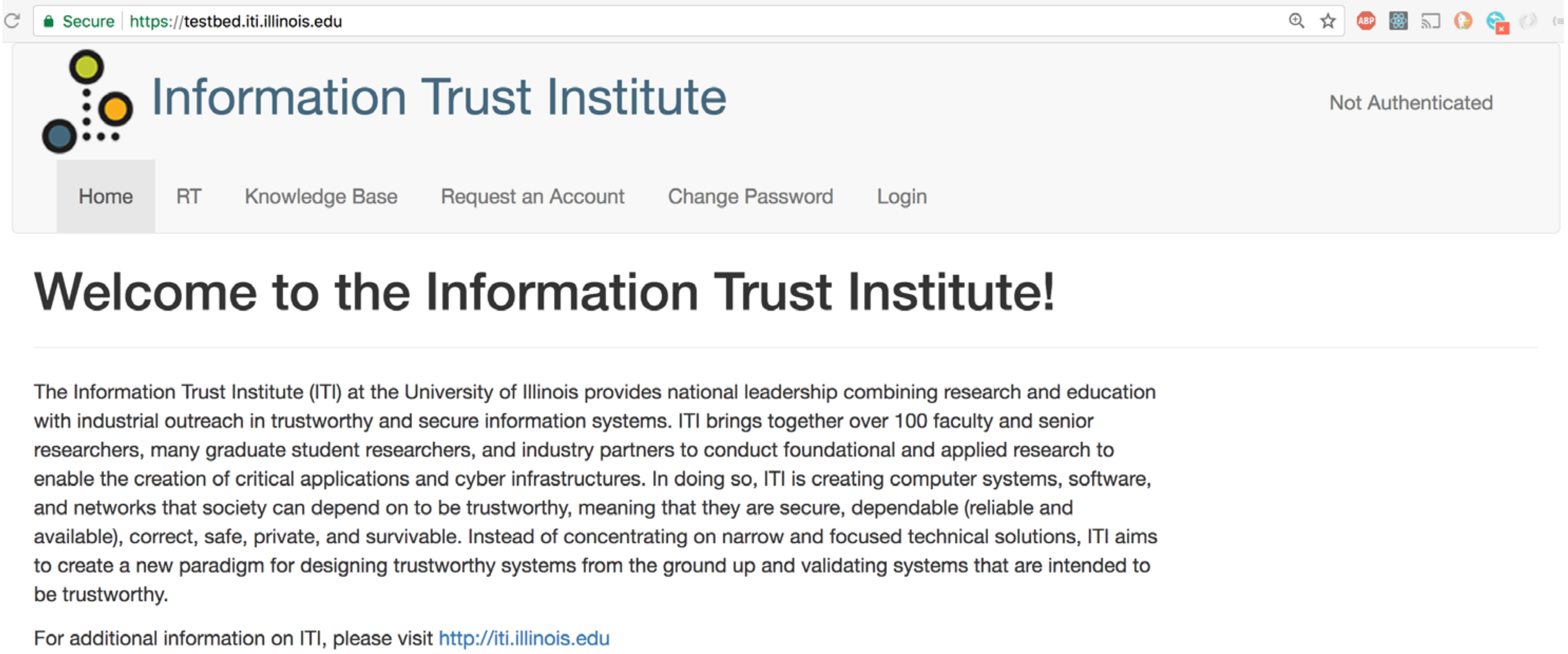
Accessing the Testbed

Things to know

- Getting Access
- The Testbed Portal
- Knowledge Base
- Remote Access
- On Site Access
- Getting Help

Getting Access To The Testbed

- The Testbed Portal (https://testbed.iti.illinois.edu)



Welcome to the Information Trust Institute!

The Information Trust Institute (ITI) at the University of Illinois provides national leadership combining research and education with industrial outreach in trustworthy and secure information systems. ITI brings together over 100 faculty and senior researchers, many graduate student researchers, and industry partners to conduct foundational and applied research to enable the creation of critical applications and cyber infrastructures. In doing so, ITI is creating computer systems, software, and networks that society can depend on to be trustworthy, meaning that they are secure, dependable (reliable and available), correct, safe, private, and survivable. Instead of concentrating on narrow and focused technical solutions, ITI aims to create a new paradigm for designing trustworthy systems from the ground up and validating systems that are intended to be trustworthy.

For additional information on ITI, please visit http://iti.illinois.edu

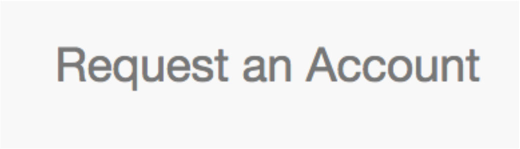
CEER Testbed Portal

- Account Onboarding
- Account Maintenance
- Project Access Approvals
- FAQ
- Basic Help Queries

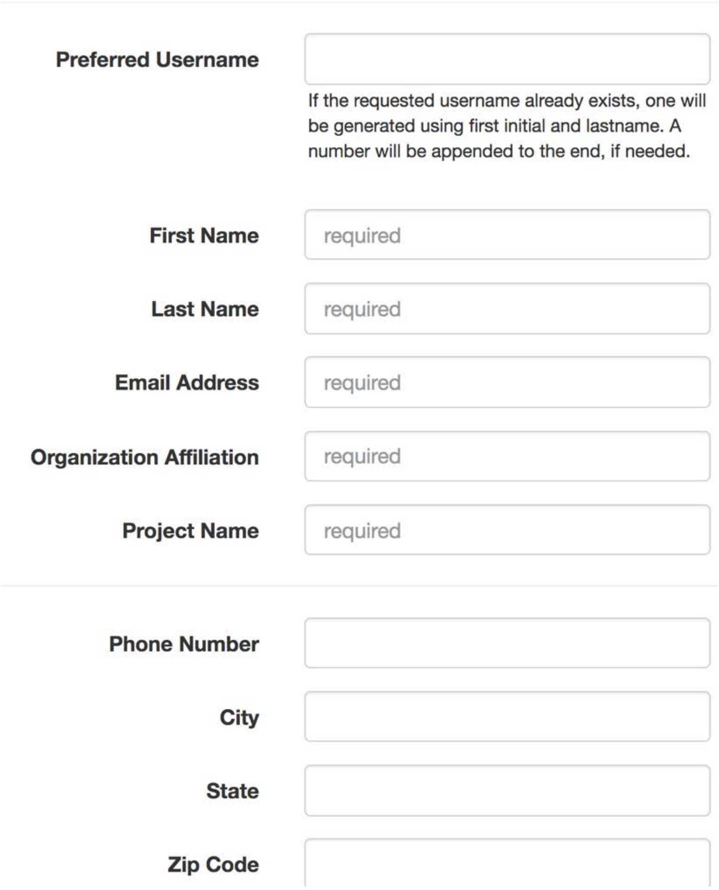
- Continuous development
  - More features coming

python™
Flask
web development,
one drop at a time
B
HUGO
A Fast & Modern Static Website Engine

Request an Account


Request an Account

- To assure proper routing for approval, be sure to have the correct Project Name.
  - Project manager will get an email after submitting your request.
  - You will get an email when the request is approved.
- Email link is time sensitive,
  - if past the time, use the forgot password link to get a new password.


Preferred Username

If the requested username already exists, one will be generated using first initial and lastname. A number will be appended to the end, if needed.

First Name: required

Last Name: required

Email Address: required

Organization Affiliation: required

Project Name: required

Phone Number

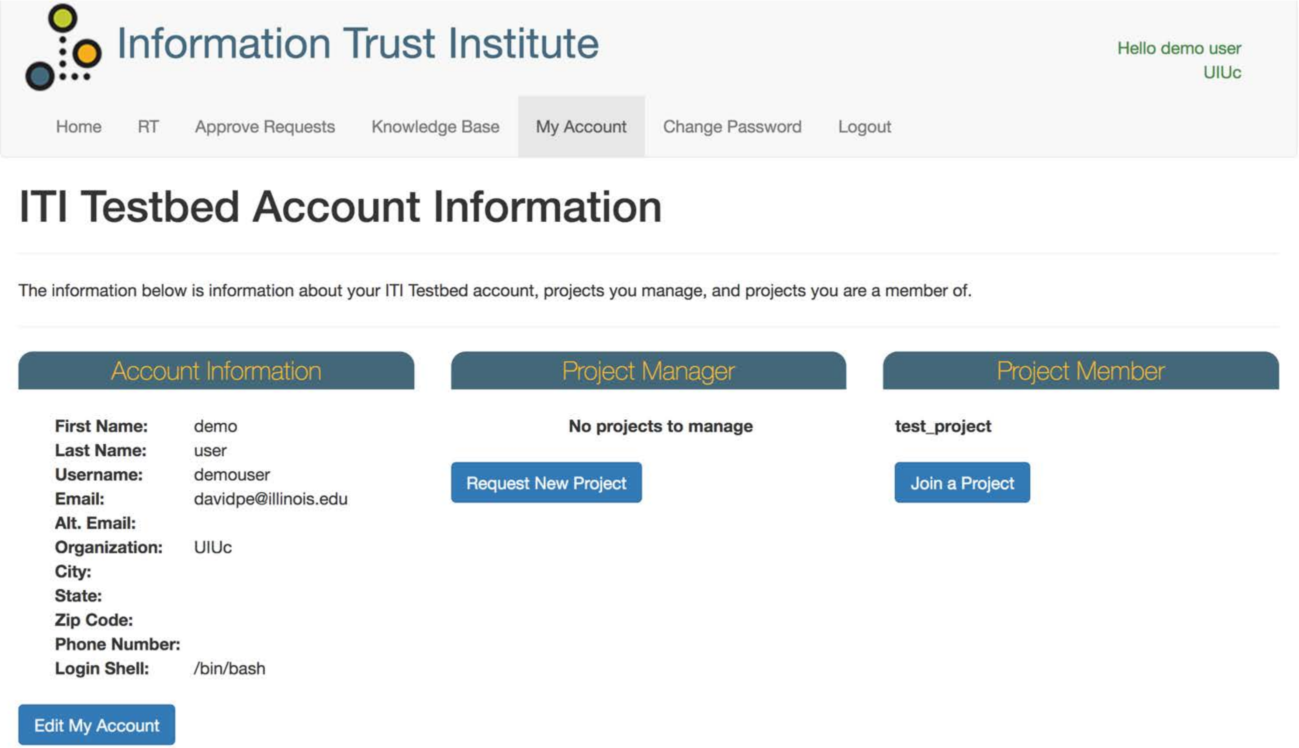
City

State

Zip Code

Project Members

- Update Account Information
- List Project Membership
- Change password
- View non-authenticated and authenticated KB
- Request new projects



ITI Testbed Account Information

The information below is information about your ITI Testbed account, projects you manage, and projects you are a member of.

Account Information

First Name:	demo
Last Name:	user
Username:	demouser
Email:	davidpe@illinois.edu
Alt. Email:	
Organization:	UIUc
City:	
State:	
Zip Code:	
Phone Number:	
Login Shell:	/bin/bash

Project Manager

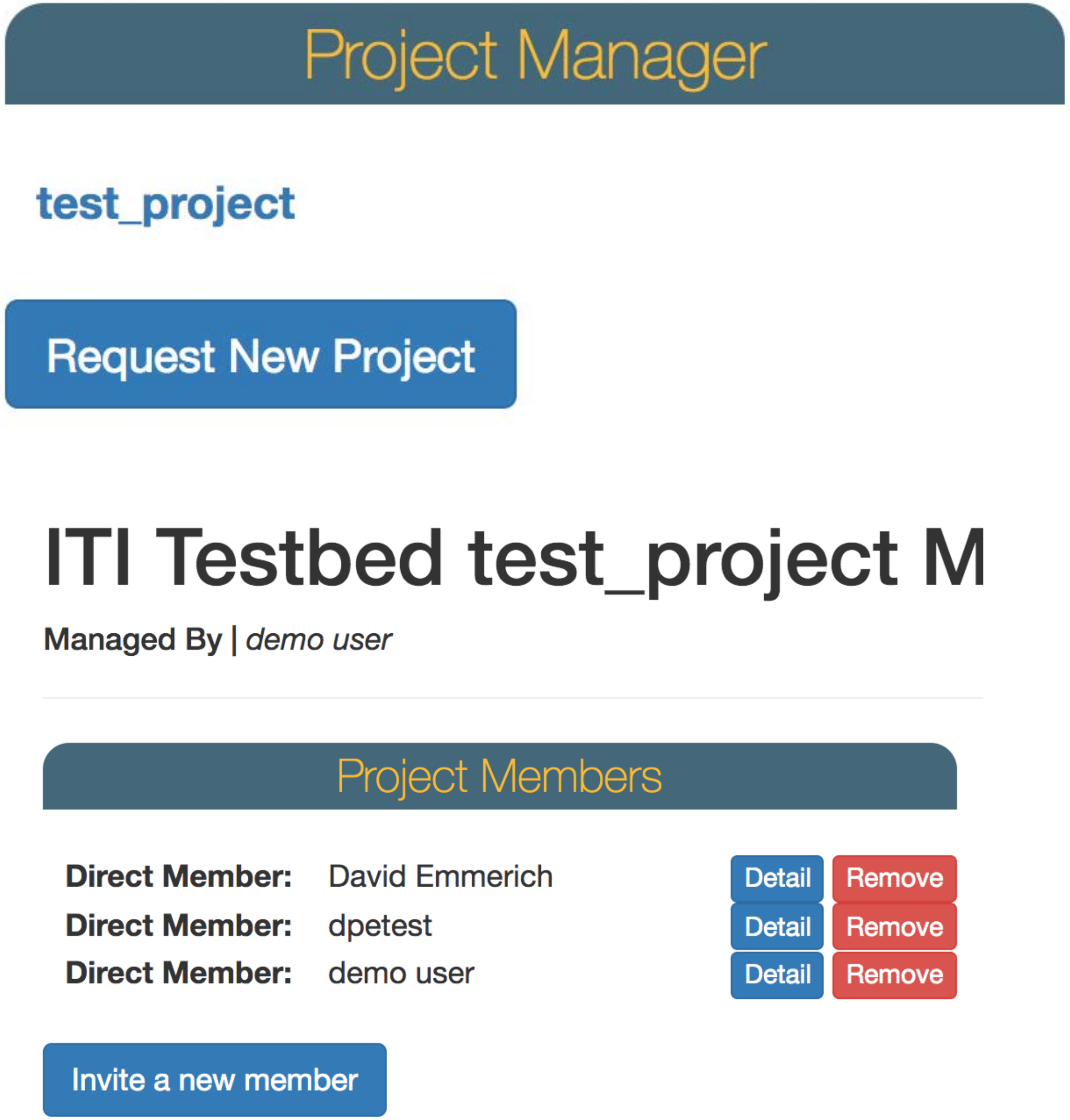
No projects to manage

Project Member

test_project

Project Managers

- Everything a Project Member can do
- Approve account requests
  - Only projects they manage
- View and remove project members
- View basic details of project members
- Invite new project members



Project Manager

test_project

ITI Testbed test_project M

Managed By | *demo user*

Project Members

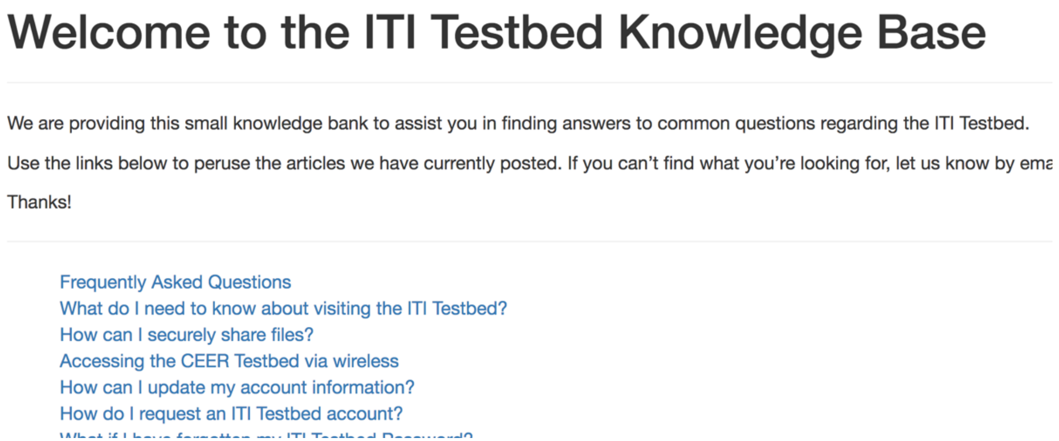
Direct Member: David Emmerich

Direct Member: dpetest

Direct Member: demo user

Knowledge Base

- Basic FAQ-type questions and answers
- Updated regularly as new services and queries arise
- 3-tier access
  - Anonymous
  - Authenticated
  - Developer
  - *additional tiers are being developed
- Categorization is being developed



Welcome to the ITI Testbed Knowledge Base

We are providing this small knowledge bank to assist you in finding answers to common questions regarding the ITI Testbed.

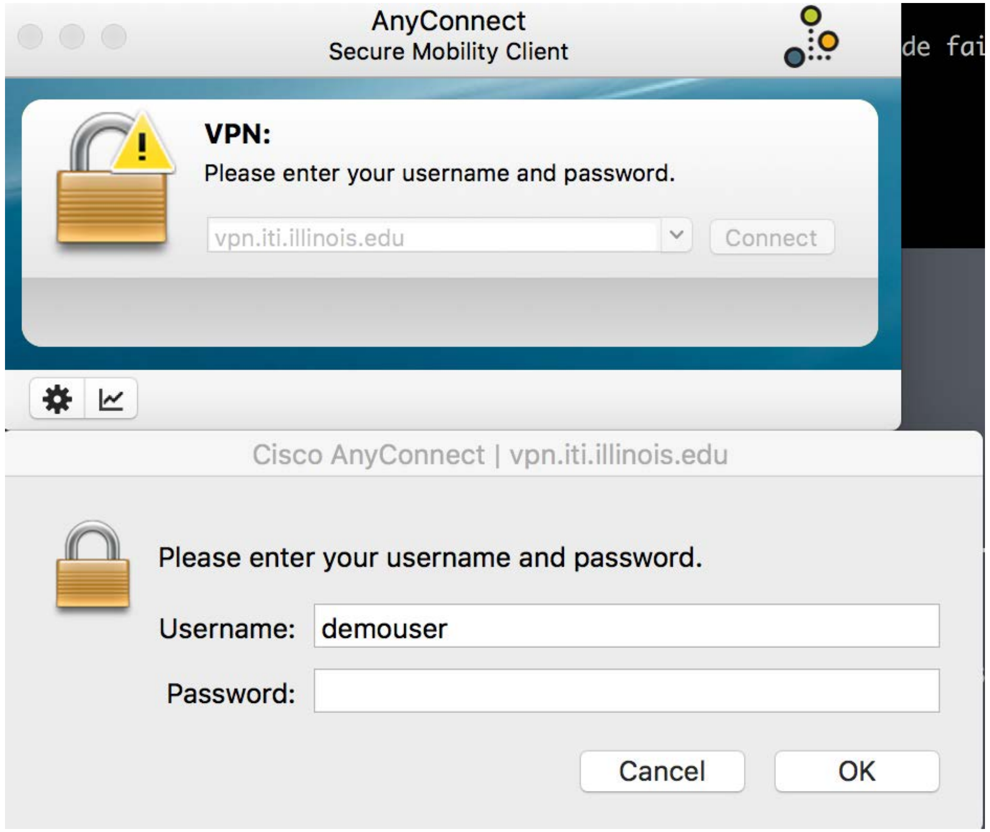
Use the links below to peruse the articles we have currently posted. If you can't find what you're looking for, let us know by ema

Thanks!

- Frequently Asked Questions
- What do I need to know about visiting the ITI Testbed?
- How can I securely share files?
- Accessing the CEER Testbed via wireless
- How can I update my account information?
- How do I request an ITI Testbed account?
- What if I have forgotten my ITI Testbed Password?

Remote Access using Cisco ASA

- Must have a testbed account
- Go to https://vpn.iti.illinois.edu
- Login with testbed credentials
- Select AnyConnect from left navigation menu
- When connecting you will be given an option to download the client
- Login the VPN with your testbed credentials



AnyConnect
Secure Mobility Client

VPN:
Please enter your username and password.

vpn.iti.illinois.edu

Cisco AnyConnect | vpn.iti.illinois.edu

Please enter your username and password.

Username: demouser
Password:

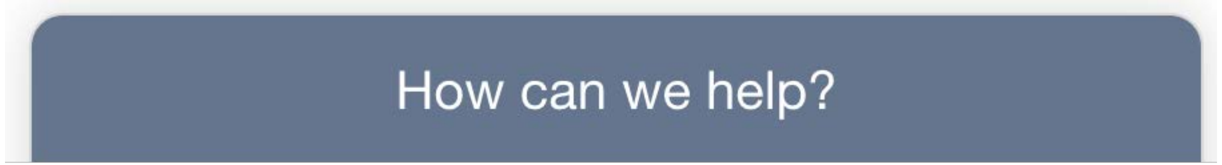
More details | https://testbed.iti.illinois.edu/kb/priv/2.html

Accessing on Site

- On site access in CSL Studio
- CEER Testbed Wifi
  - Requires Testbed Account
  - Additional SSID’s in cases for guests that do not have an account
- Direct network access in CEER Workroom
- Some Workstations available upon request

Getting Help

- How Can We Help?
  - Chat at https://testbed.iti.illinois.edu
  - Goes direct to a slack support channel
  - Help available during regular working hours
  - Please include name and alternative contact in case we need continue work at later time or through different means.



Power System Modeling

Power System Modeling

- To support the advancement of research, verification, and validation of smart grid cyber tools
- Capability to **generate realistic power grid scenarios** derived from real data but without conveying sensitive information
- Capability to **support communications traffic** that models the real systems
- Capability to **interface and drive hardware devices** in the loop

Power System Modeling Tools

- In general power system modeling tools are categorized into two parts:
  - Electromechanical transient tools (millisecond time scale)
    - PowerWorld
    - Siemens PSS/E
    - GE PSLF

    Transmission level
    3 phase balanced

    - OpenDSS
    - GridLab-D

    Distribution level
    Phase unbalance
  - Electromagnetic transient tools (microsecond time scale)
    - Real Time Digital Simulator (RTDS)
    - Opal-RT
      - Hypersim
      - RT-Lab (interface with Matlab Simulink)
      - eFPGAsim (detailed power electronic converters, nano-second scale)
  - Opal-RT ePhasorsim (millisecond time scale)

  Real-Time fidelity
  3 phase balanced
  Phase unbalance

Communication Tools

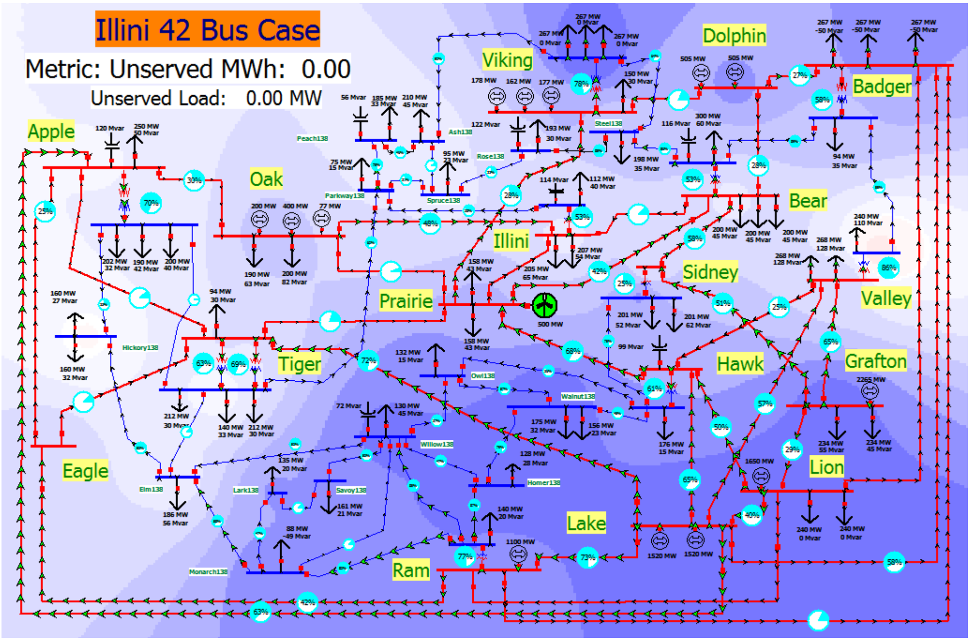
- Communication tools are needed to communicate realistic telemetry and control signals from and to the power grid simulation scenarios
  - RTDS GTNET Interface
  - Opal-RT Communication Cards
  - Protection relays (SEL and ABB)
  - Substation Automation (ABB, Novatech, SEL)
  - SCADA/EMS (OSI Monarch)
- Capability to speak number of different protocols generally used in the field
  - DNP3
  - IEC61850
  - Modbus etc.

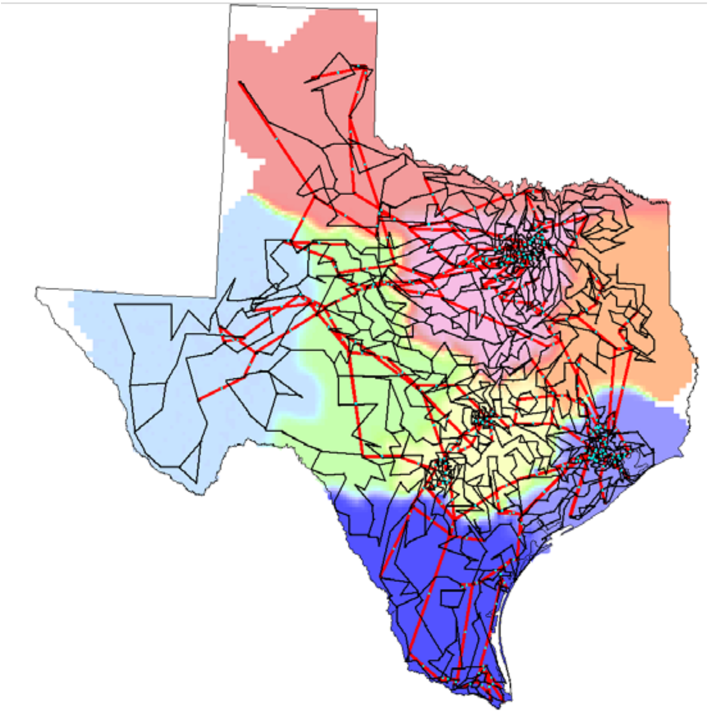
Modeling Cases

- For **non-real time simulators**, publicly available IEEE test cases are modeled for different simulators:

  http://icseg.iti.illinois.edu/power-cases/

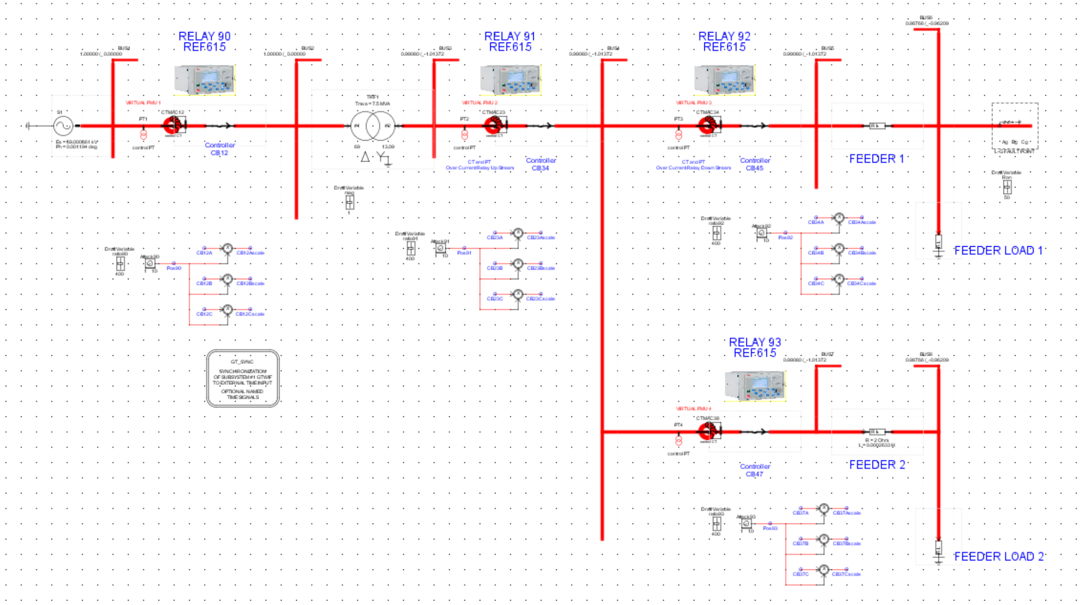
- Publicly available synthetic cases modeling behavior of real grid are also available:



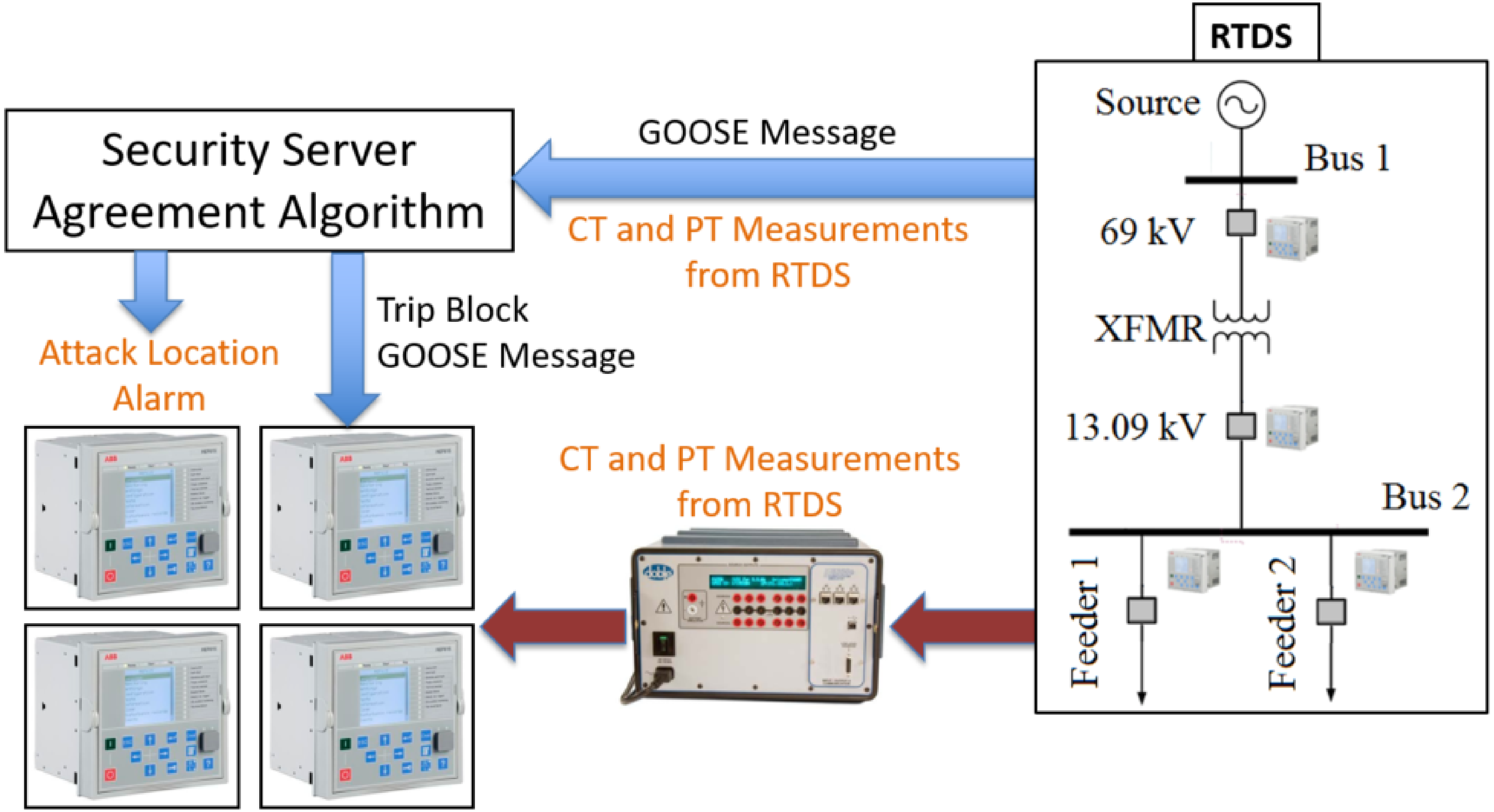


Real Time Digital Simulator (RTDS)

- Currently capable of modeling high fidelity real time power system simulation up to 60 nodes
- Capable of interfacing with external hardware devices like protection relays
- Capable of communicating number of different protocols like DNP3, IEC61850 GOOSE and SV, C37.118 etc.



RTDS Use Case

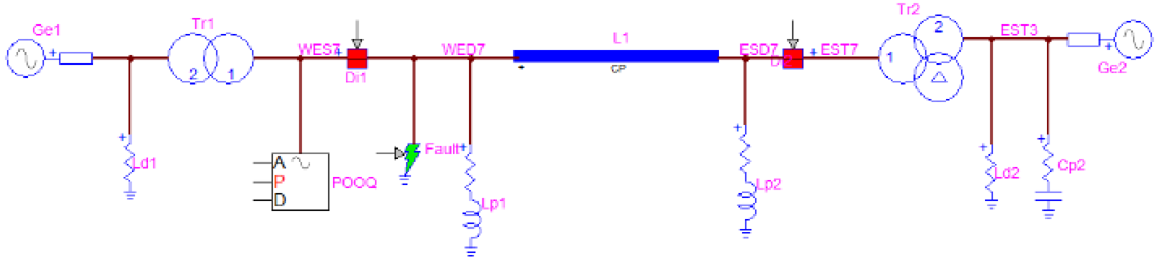


Detection of Data injection attacks in the Distribution Substation Automation System

- Communications setup using IEC61850 GOOSE
- Hardware-in-loop connection to the ABB REF615 Feeder Protection IEDs
- System solved at a 50 microseconds time scale

Opal-RT Real Time Simulator

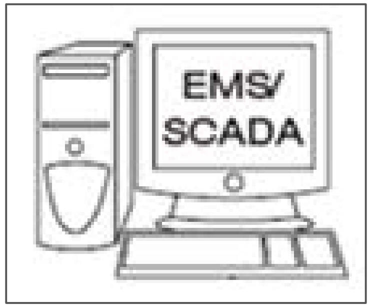
- Capable of modeling up to 8000 system to be able to run high fidelity real time power system simulations
- Capable of interfacing with external devices
- Capable of communicating via multiple protocols simultaneously
- Nano-second scale Power Electronics modeling
- Electromechanical Transient time scale simulator capable of running a real time power system scenario

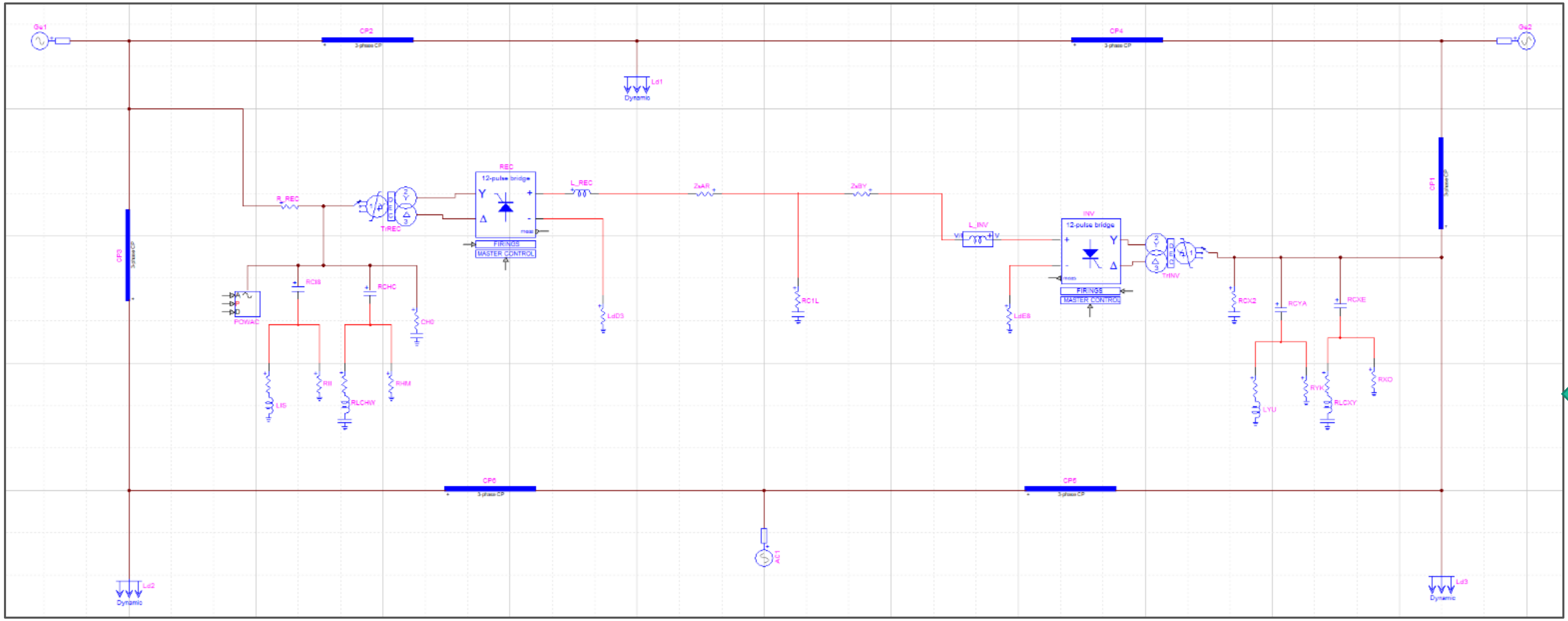


Opal-RT Hypersim Use case

Detection of false command injection on the HVDC converter station

- An HVDC system embedded in an IEEE 9 Bus system
- Communications to the control center using DNP3 protocol
- ABB COM600 used as the converter station RTU

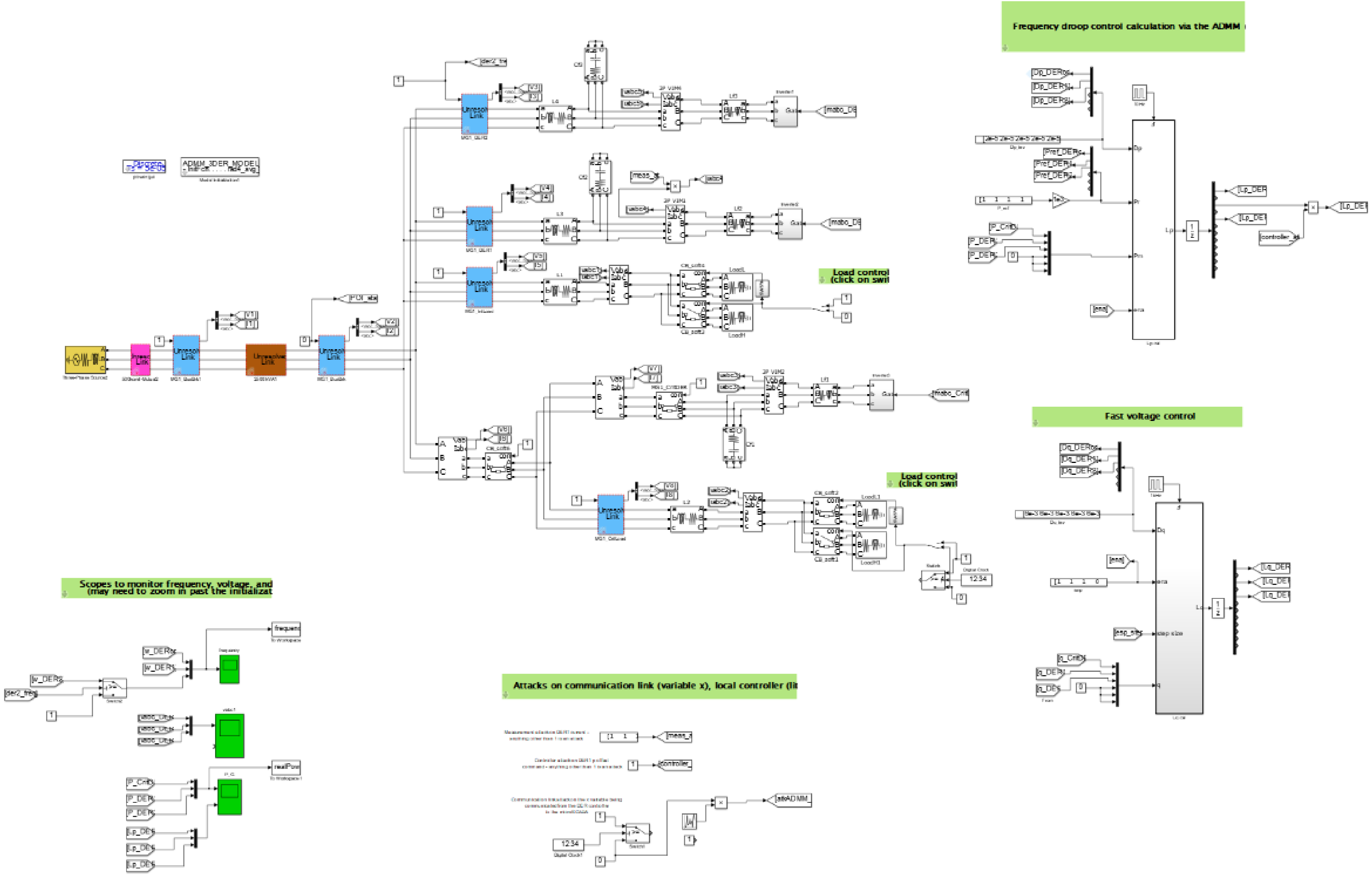




DNP3
Communication

DNP3
Communication

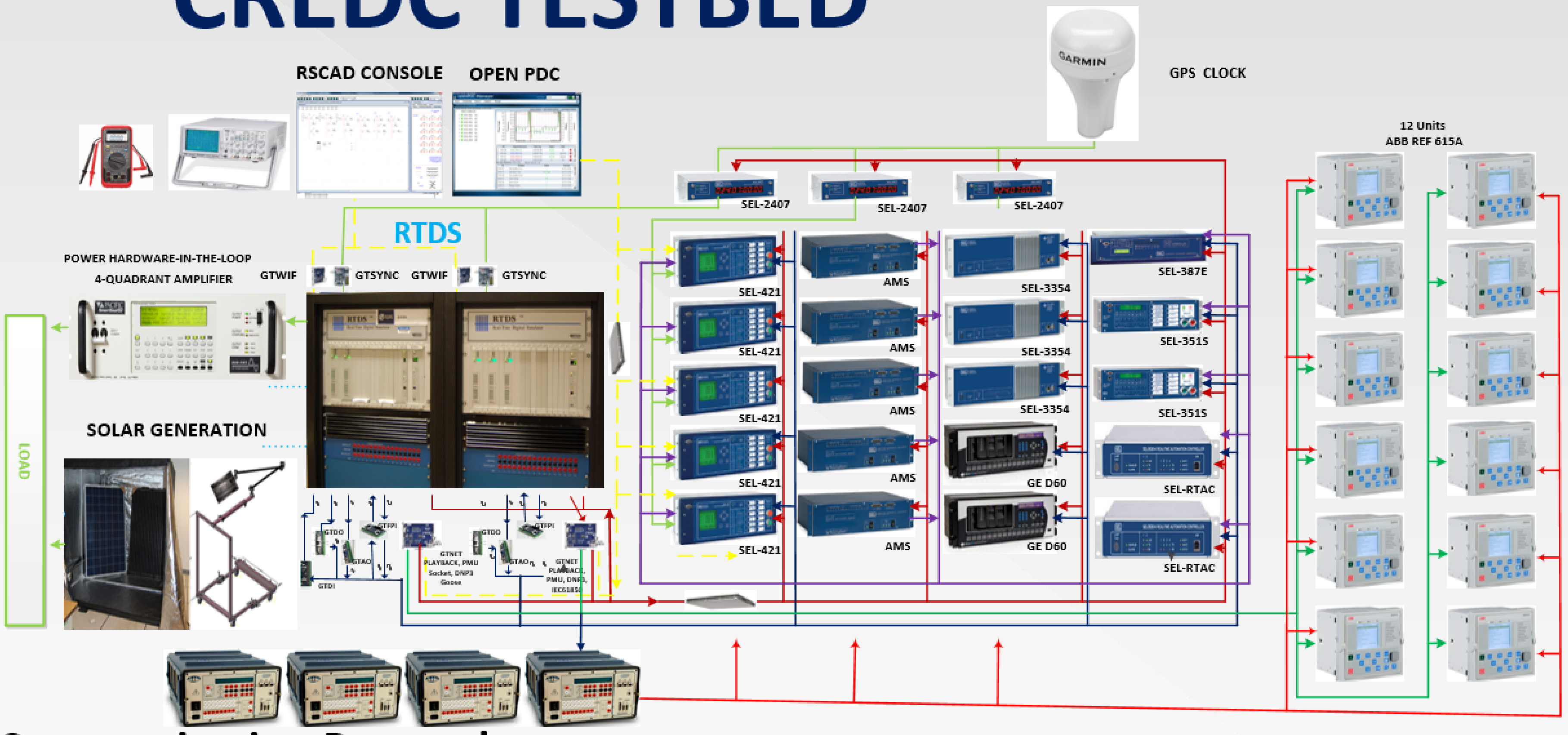
Opal-RT RT-Lab Use Case


Frequency droop control calculation via the ADMM
Fast voltage control
Load control (click on swi
Load control (click on swi
Scopes to monitor frequency, voltage, and (may need to zoom in past the initializat
Attacks on communication link (variable x), local controller (li
ADMM_3DER_MODEL
Unresol Link
12:34

Detection of false spoofed data attack on the Microgrid control system

- MG system modeled in Matlab Simulink and run in real-time environment on Opal-RT
- IEC 61850 communication with with ABB COM600 Substation Automation Controller
- Hardware-in-loop connection with ABB REF 615 IEDs at certain locations in the MG system

CREDC TESTBED



Communication Protocols

RTDS Rack 1
Goose
PMU
Socket
Sample Values

RTDS Rack2
PMU
Socket
DNP3
Goose

— HARDWIRE

— TCP/IP

— AMS EMULATED SIGNAL

— DNP3, IEC 61850, Goose, PMU

} DIGITALS AND ANALOG LOW LEVEL SIGNAL

— HIGH VOLTAGE SIGNALS

} POWER LEVEL SIGNALS

Data Generation

DNP3 Protocol Generator

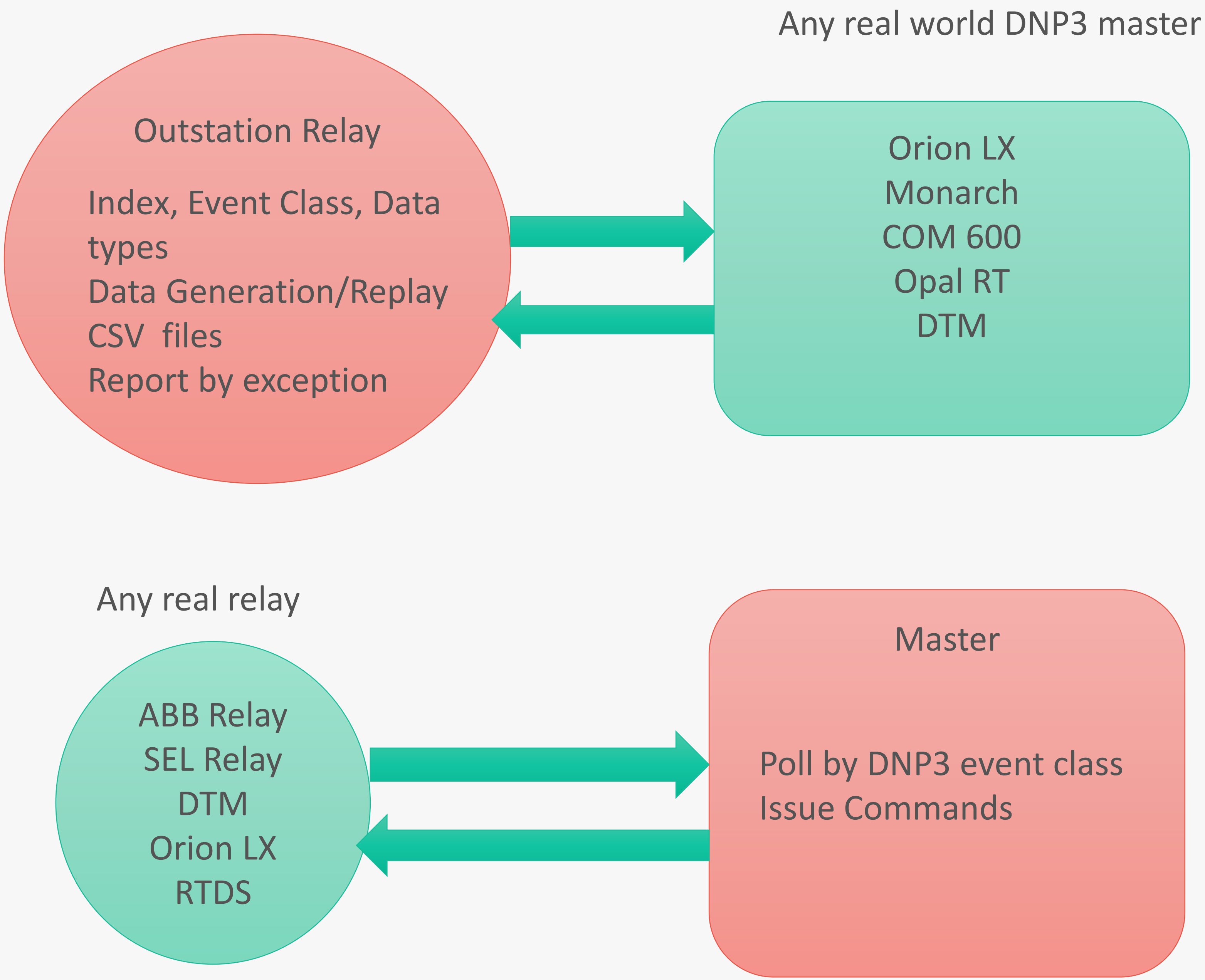
- Based on OpenDNP3 open source under Apache license
- Can simulate masters, outstations or both
- Can be deployed on virtual machines, Docker containers or Raspberry Pi
- Linux based application
- Write your own data generation rules
- Replay real power simulation csv files

Modbus Protocol Generator

- Based on Pymodbus open source under BSD license
- Similar in capabilities to DNP3 Generator
- Cannot replay csv files yet

Distributed Test Manager (Triangle Microworks, Inc)

- Proprietary license
- Windows based software
- Has GUI, simpler to set up
- Visual representation of your system
- DNP3, Modbus, IEC 61850, IEC 60870-5 protocols
- Data generation and visuals are scriptable via Javascript



Any real world DNP3 master

Outstation Relay

Index, Event Class, Data types
Data Generation/Replay
CSV files
Report by exception

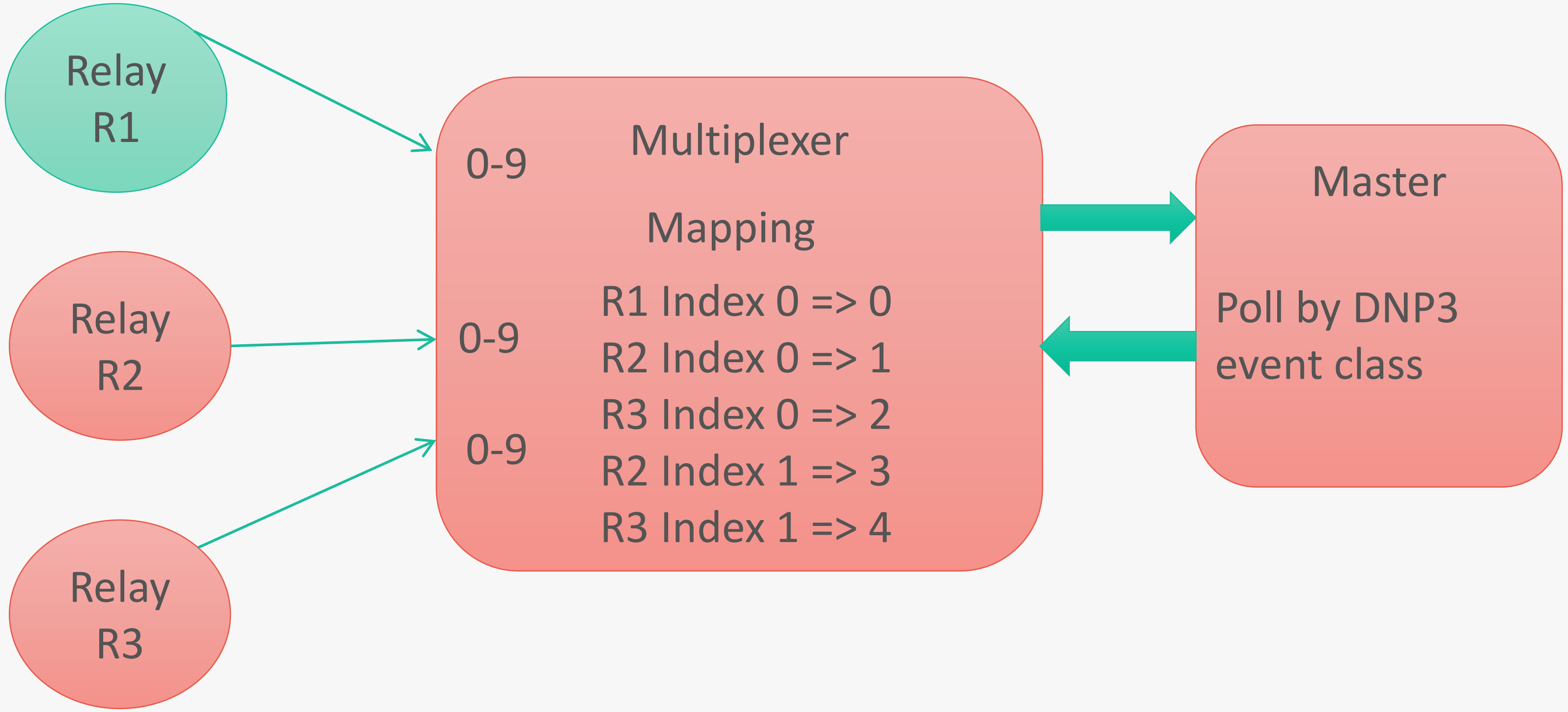
Orion LX
Monarch
COM 600
Opal RT
DTM

Any real relay

ABB Relay
SEL Relay
DTM
Orion LX
RTDS

Master

Poll by DNP3 event class
Issue Commands



Relay R1

Relay R2

Relay R3

0-9

0-9

0-9

Multiplexer

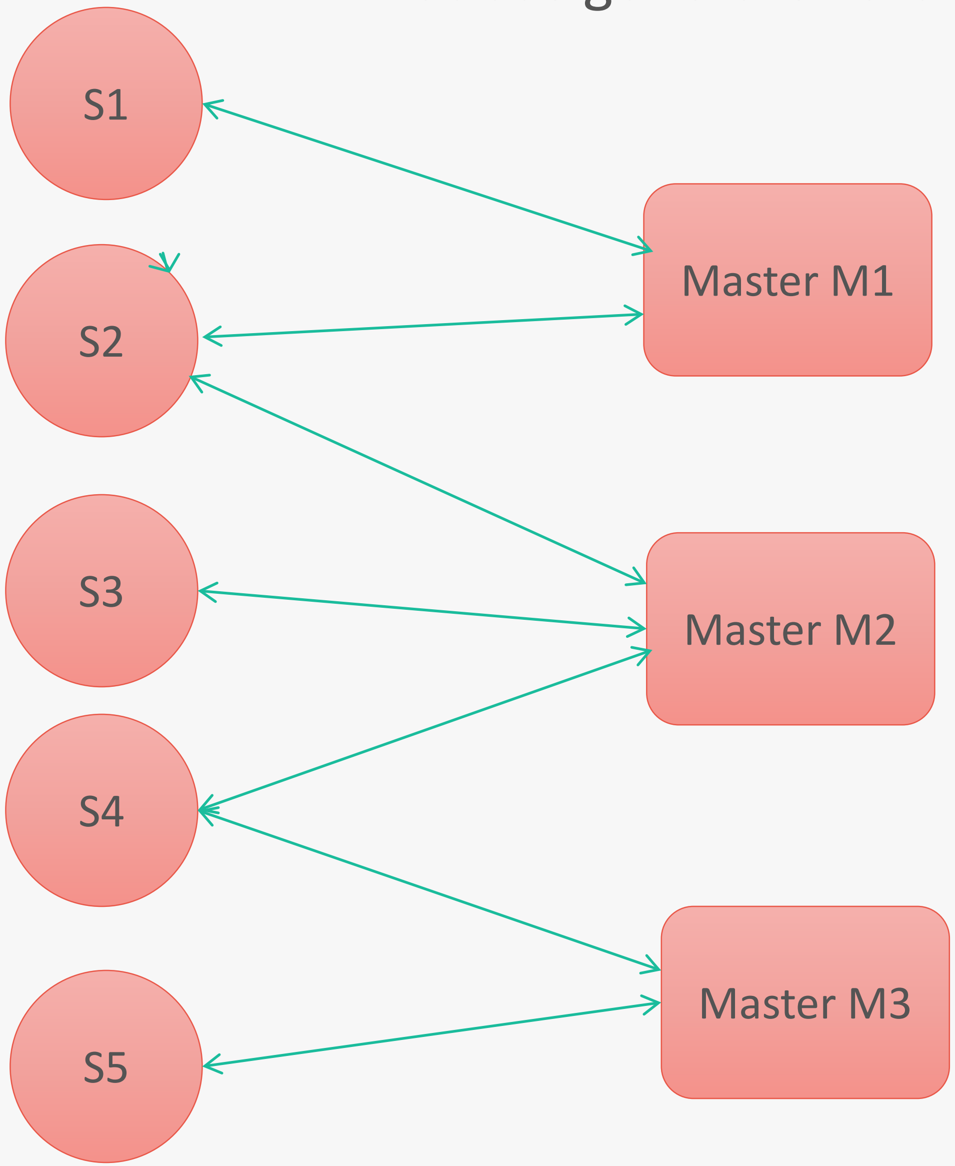
Mapping

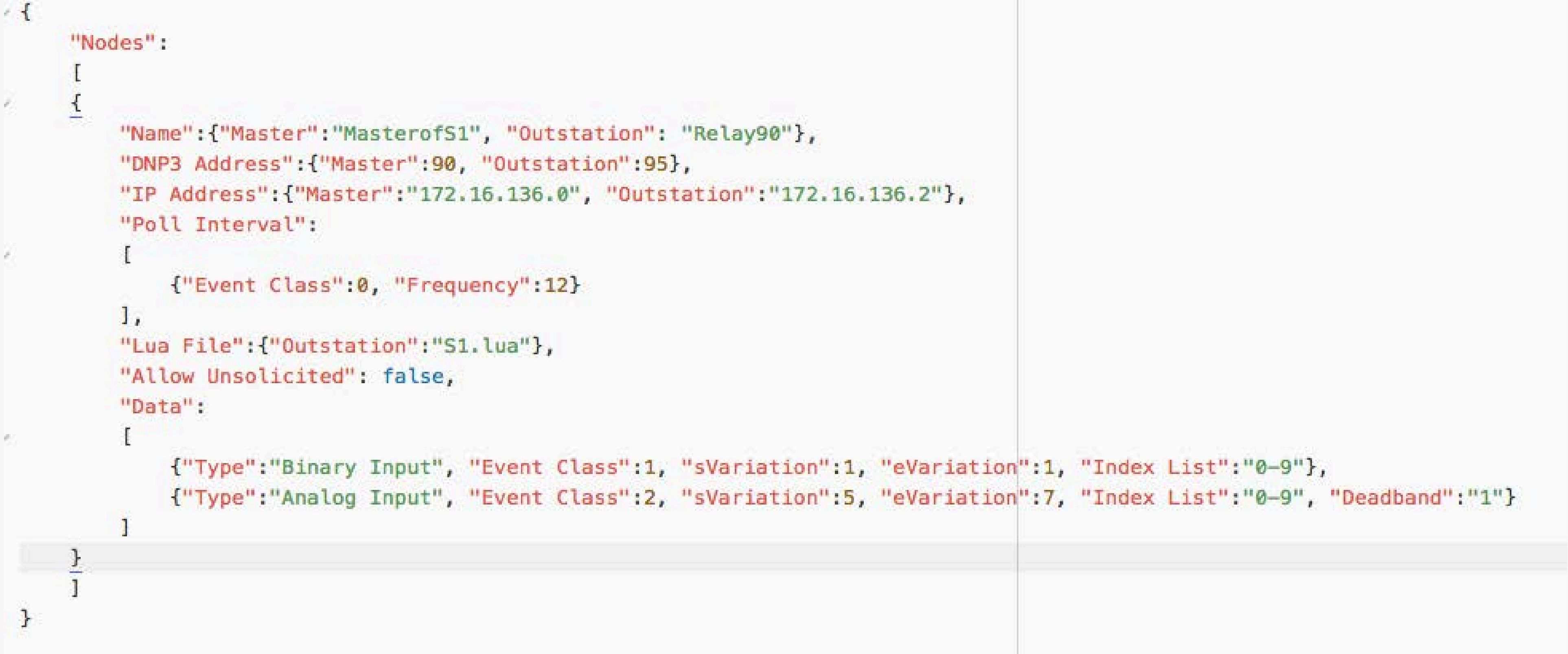
R1 Index 0 => 0
R2 Index 0 => 1
R3 Index 0 => 2
R2 Index 1 => 3
R3 Index 1 => 4

Master

Poll by DNP3 event class

Modbus generator example layout





```
{
    "Nodes":
    [
    {
        "Name":{"Master":"MasterofS1", "Outstation": "Relay90"},
        "DNP3 Address":{"Master":90, "Outstation":95},
        "IP Address":{"Master":"172.16.136.0", "Outstation":"172.16.136.2"},
        "Poll Interval":
        [
            {"Event Class":0, "Frequency":12}
        ],
        "Lua File":{"Outstation":"S1.lua"},
        "Allow Unsolicited": false,
        "Data":
        [
            {"Type":"Binary Input", "Event Class":1, "sVariation":1, "eVariation":1, "Index List":"0-9"},
            {"Type":"Analog Input", "Event Class":2, "sVariation":5, "eVariation":7, "Index List":"0-9", "Deadband":"1"}
        ]
    }
    ]
}
```

Lua is a lightweight, embeddable scripting language

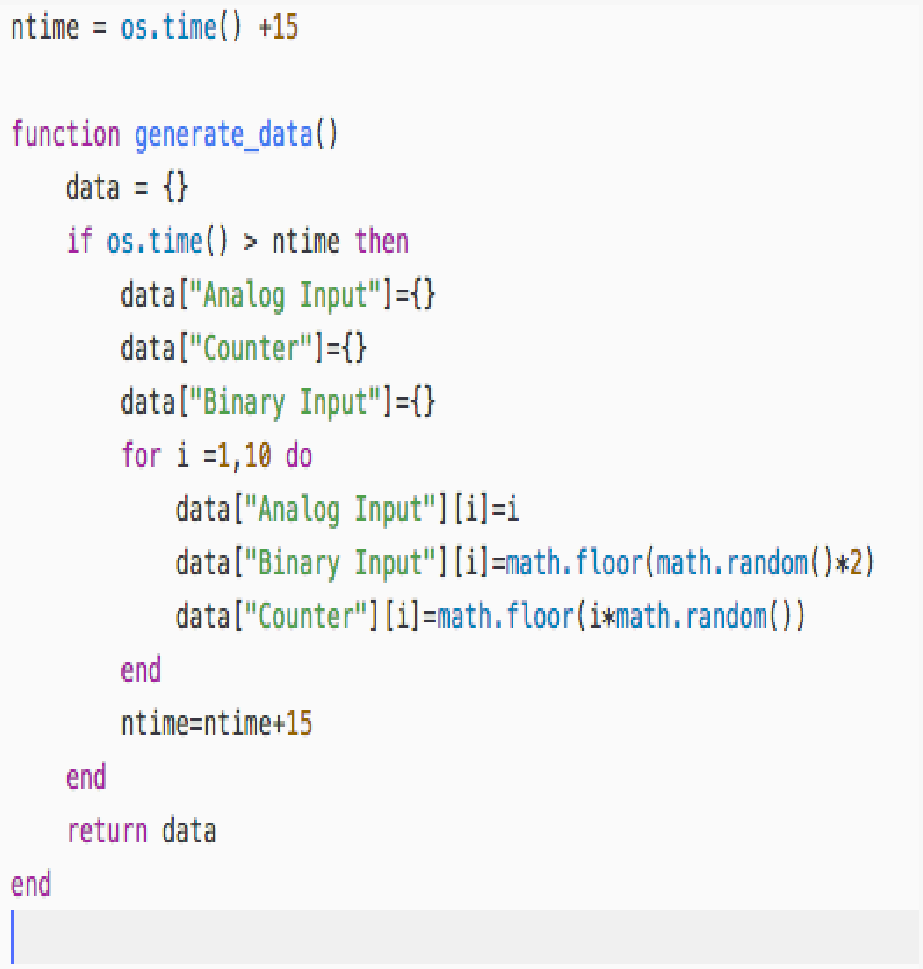
Lua Script files are used for

- Data generation/replay of csv files
- Sending Commands to outstations
- Inject/modify data in multiplexer

Minimally, need to supply

- Configuration file in JSON format describing topology
- Lua script (if simulating an outstation)

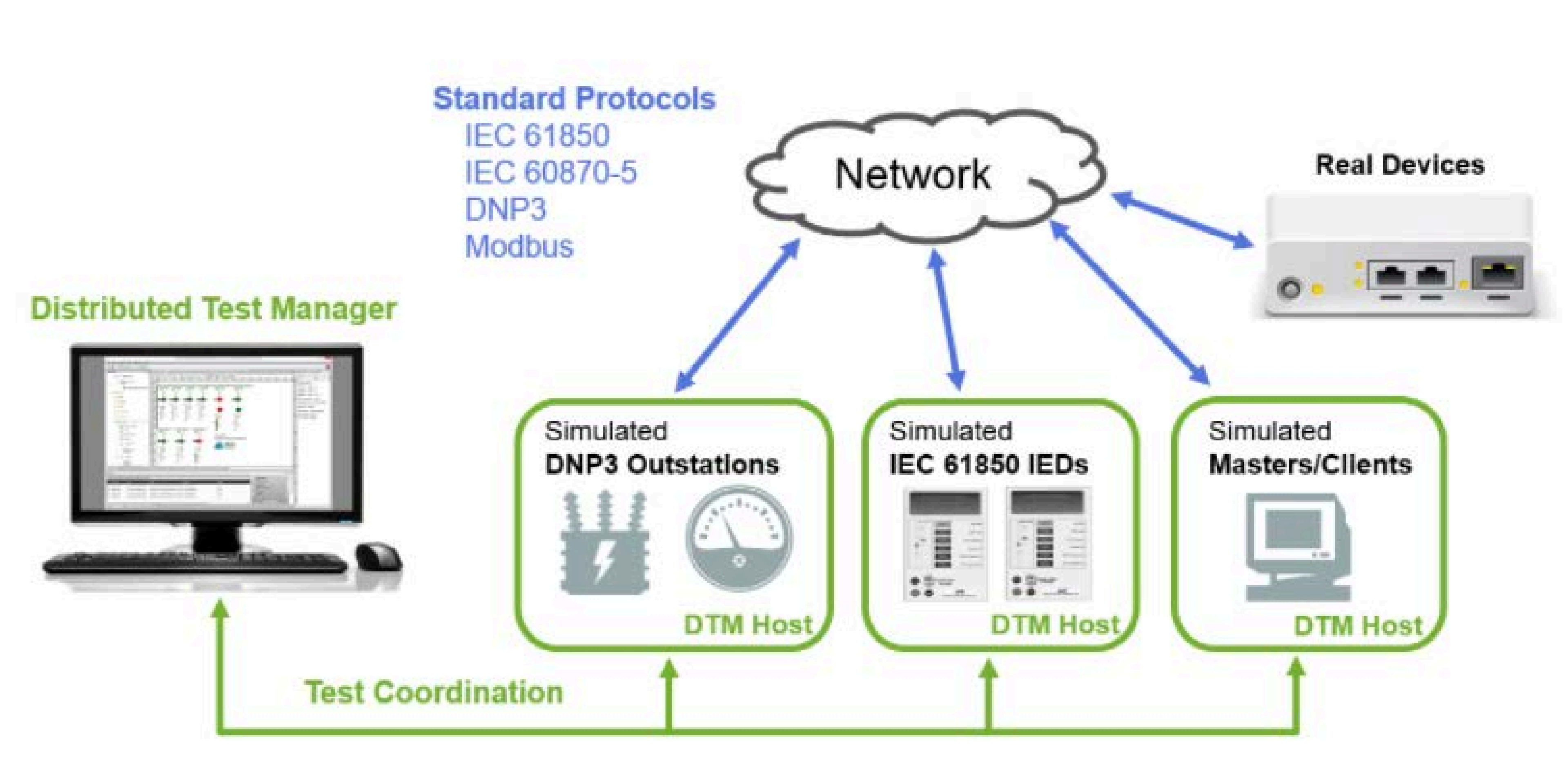
Each outstation can use its own custom lua script
OR point to a single lua script that is run independently for each outstation.

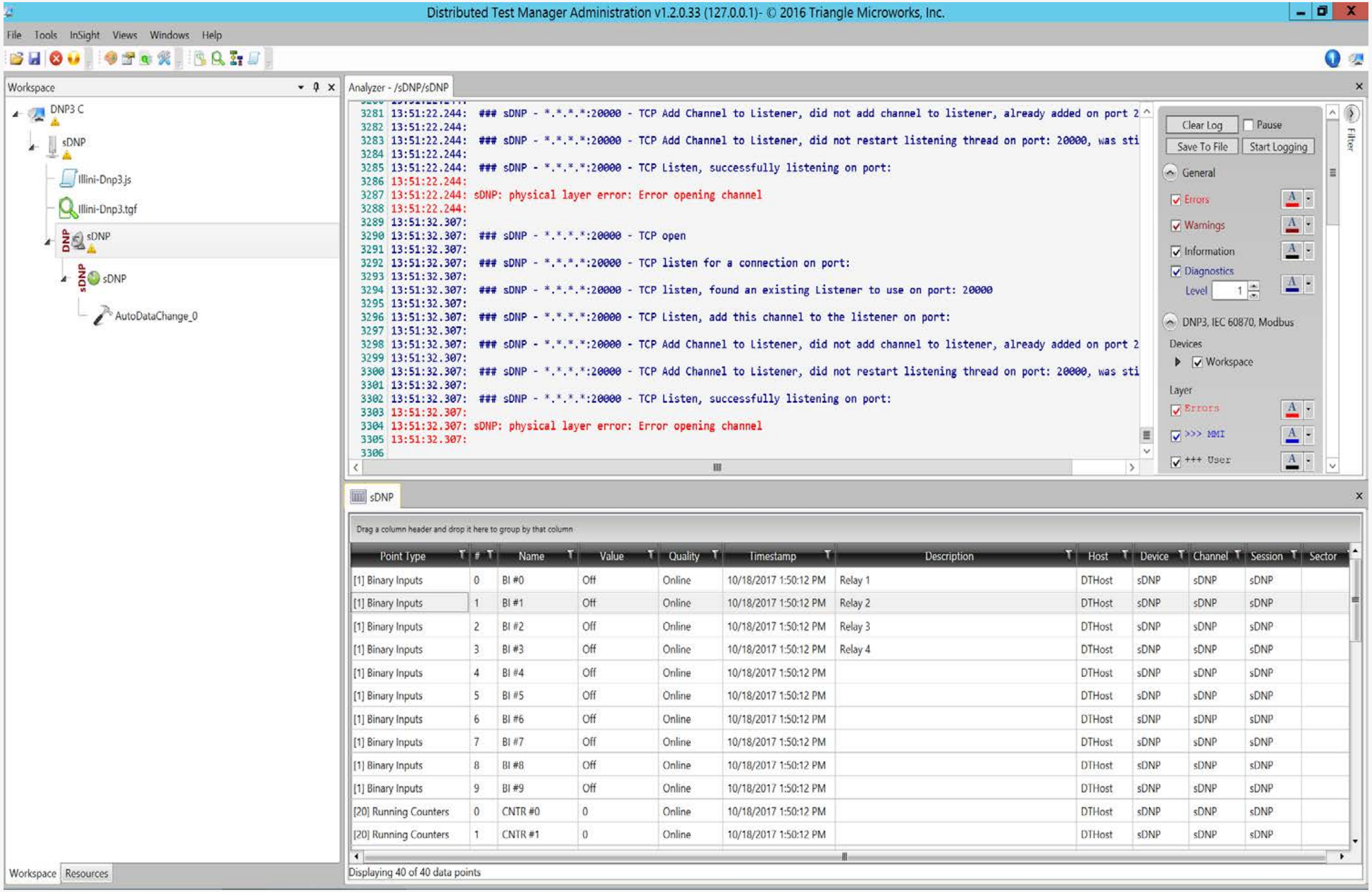


```lua
ntime = os.time() +15

function generate_data()
    data = {}
    if os.time() > ntime then
        data["Analog Input"]={}
        data["Counter"]={}
        data["Binary Input"]={}
        for i =1,10 do
            data["Analog Input"][i]=i
            data["Binary Input"][i]=math.floor(math.random()*2)
            data["Counter"][i]=math.floor(i*math.random())
        end
        ntime=ntime+15
    end
    return data
end
```

DTM example layout



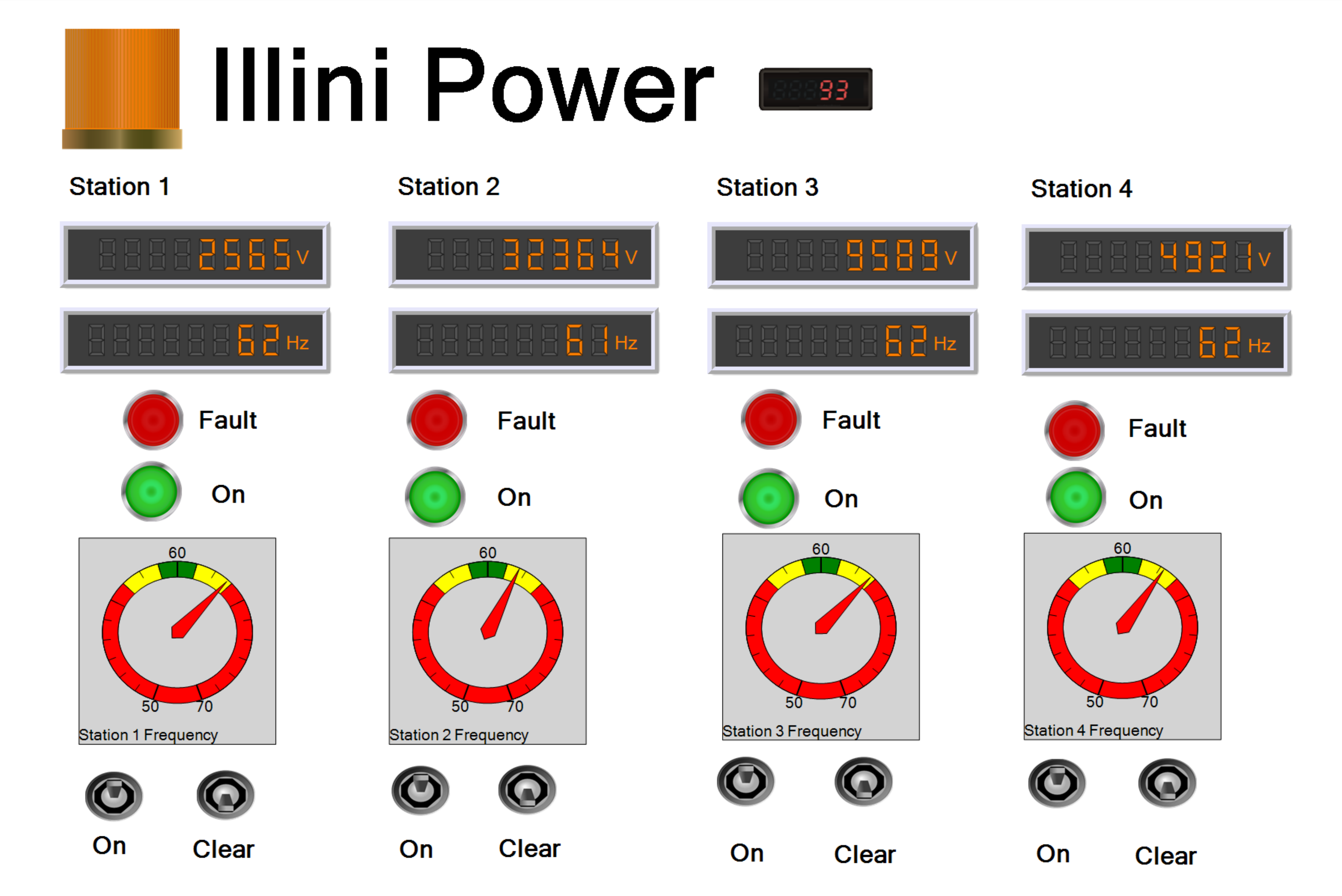


```
13:51:22.244:  ### sDNP - *.*.*.*:20000 - TCP Add Channel to Listener, did not add channel to listener, already added on port 2
13:51:22.244:
13:51:22.244:  ### sDNP - *.*.*.*:20000 - TCP Add Channel to Listener, did not restart listening thread on port: 20000, was sti
13:51:22.244:
13:51:22.244:  ### sDNP - *.*.*.*:20000 - TCP Listen, successfully listening on port:
13:51:22.244:
13:51:22.244: sDNP: physical layer error: Error opening channel
13:51:22.244:
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP open
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP listen for a connection on port:
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP listen, found an existing Listener to use on port: 20000
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP Listen, add this channel to the listener on port:
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP Add Channel to Listener, did not add channel to listener, already added on port 2
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP Add Channel to Listener, did not restart listening thread on port: 20000, was sti
13:51:32.307:
13:51:32.307:  ### sDNP - *.*.*.*:20000 - TCP Listen, successfully listening on port:
13:51:32.307:
13:51:32.307: sDNP: physical layer error: Error opening channel
13:51:32.307:
```

Drag a column header and drop it here to group by that column

Point Type	#	Name	Value	Quality	Timestamp	Description	Host	Device	Channel	Session	Sector
[1] Binary Inputs	0	BI #0	Off	Online	10/18/2017 1:50:12 PM	Relay 1	DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	1	BI #1	Off	Online	10/18/2017 1:50:12 PM	Relay 2	DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	2	BI #2	Off	Online	10/18/2017 1:50:12 PM	Relay 3	DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	3	BI #3	Off	Online	10/18/2017 1:50:12 PM	Relay 4	DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	4	BI #4	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	5	BI #5	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	6	BI #6	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	7	BI #7	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	8	BI #8	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[1] Binary Inputs	9	BI #9	Off	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[20] Running Counters	0	CNTR #0	0	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	
[20] Running Counters	1	CNTR #1	0	Online	10/18/2017 1:50:12 PM		DTHost	sDNP	sDNP	sDNP	

Displaying 40 of 40 data points


Illini Power
93
Station 1
2565 V
62 Hz
Fault
On
60
50
70
Station 1 Frequency
On
Clear
Station 2
32364 V
61 Hz
Fault
On
60
50
70
Station 2 Frequency
On
Clear
Station 3
9589 V
62 Hz
Fault
On
60
50
70
Station 3 Frequency
On
Clear
Station 4
4921 V
62 Hz
Fault
On
60
50
70
Station 4 Frequency
On
Clear

A little on vision…

A Sneak Peak

Overall, we seek to…

- Advance the state of art for cyber experimentation
- Increase usability through tailored tools and seamless integration
- Focus on development and integration of modular re-usable pieces
- Drive models and their conditions from real telemetry
- Incorporate and extend the work done by other researchers
- Document and package experiments

- Drive research with reproducible, releasable, and recreate-able experiments
- Develop environments that aid learning, research understanding, and translate to operational advancement

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