Supervisory Parameter Adjustment for Distribution Energy Storage (SPADES) DOE CESER - CEDS Program

Subtask 3.2 - Red Team Attack Tests

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Attack KPIs (Qualitative)

Tier 1

- Power Delivery Disruption
- Instability (Oscillation)
- Voltage Imbalance
- Substation power factor

Tier 2

- Equipment useful life degradation
- Power Quality degradation (poor power factor or over/undervoltage conditions)

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Attacks Associated to Tier 1 KPIs

- Power Delivery Disruption:
  - DER disconnection based on IEEE 1547
  - Line overloading (decrease in DER output or increase in load)
  - Transformer overloading

- Voltage oscillation:
  - Aggressive settings of volt-var, volt-watt curves and interaction with voltage regulators
  - Quick connect/disconnect of DER’s and Loads or change of setpoints
  - Topology reconfiguration
    - Between feeders or within feeders
  - Repeated operation enable/disable regulator, capbanks or tap changes

- Voltage Imbalance:
  - Connect/disconnect single phase DERs/loads to create imbalance

- Substation Power Factor:
  - Connect/disconnect loads, DERs, capbanks

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Attack Tests

Attack Tests Implementation

- Testing of all envisioned attacks have been performed in OpenDSS
  - Validation of attacks and their consequences
- Some of those attacks have also been implemented as prototypes in PyCIGAR
  - Useful for definition of best ways of integrating attacks to the framework
- Functionalities included in PyCIGAR
  - Flexibility to define start and end times independently for multiple devices and multiple attacks of same device
  - Definition of multiple types of attacks to each device
  - Implementation of classes corresponding to hacked devices/controllers
  - Additional input file for defining attacks that may include complex coordination of multiple devices in multiple points in time
  - Wrapper of input parser for processing of attack inputs and integrating them to the simulation
    - Also employed for processing computer network device information and creation of NetJSON representation.

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Topology Reconfiguration Attack

- Attack Scenario:
  - Over/under voltage type PDD attack
  - Step 1: Open normally closed (NC) line or sectionalizing switch
  - Step 2: Close NO switch for radial topology reconfiguration (intra or inter-feeder)
  - Step 3: Repeat 1-2 to cause voltage oscillations (optional)

- Simulation Model (OpenDSS)
  - IEEE 37 bus

- Attack implementation in PyCIGAR
  - ✓ Implementation of Hacked controllers/devices
    - (Hacked switch controller)
  - ✓ Attack parameters: Change topology for defined time
  - ✓ Results: Allow the change of topology based on predefined topologies in PyCIGAR

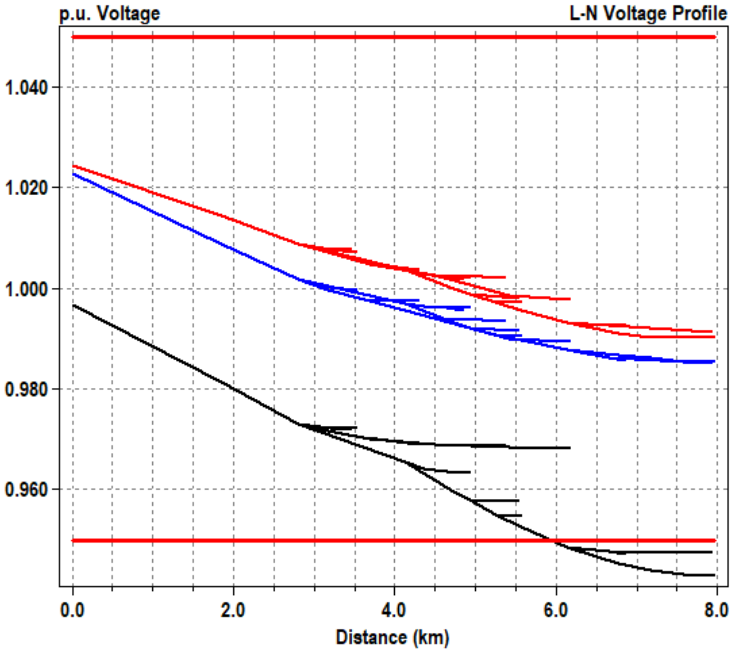
Topology Reconfiguration Attack (Intra-feeder)

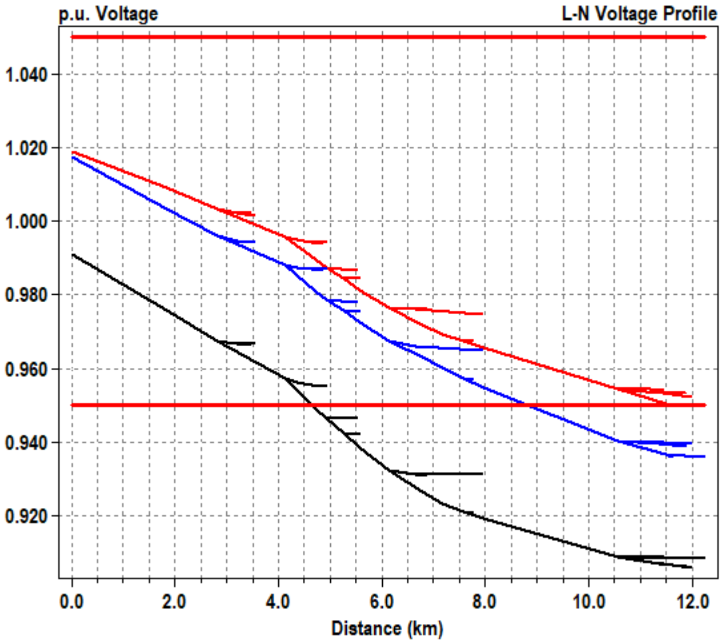
Tests Performed

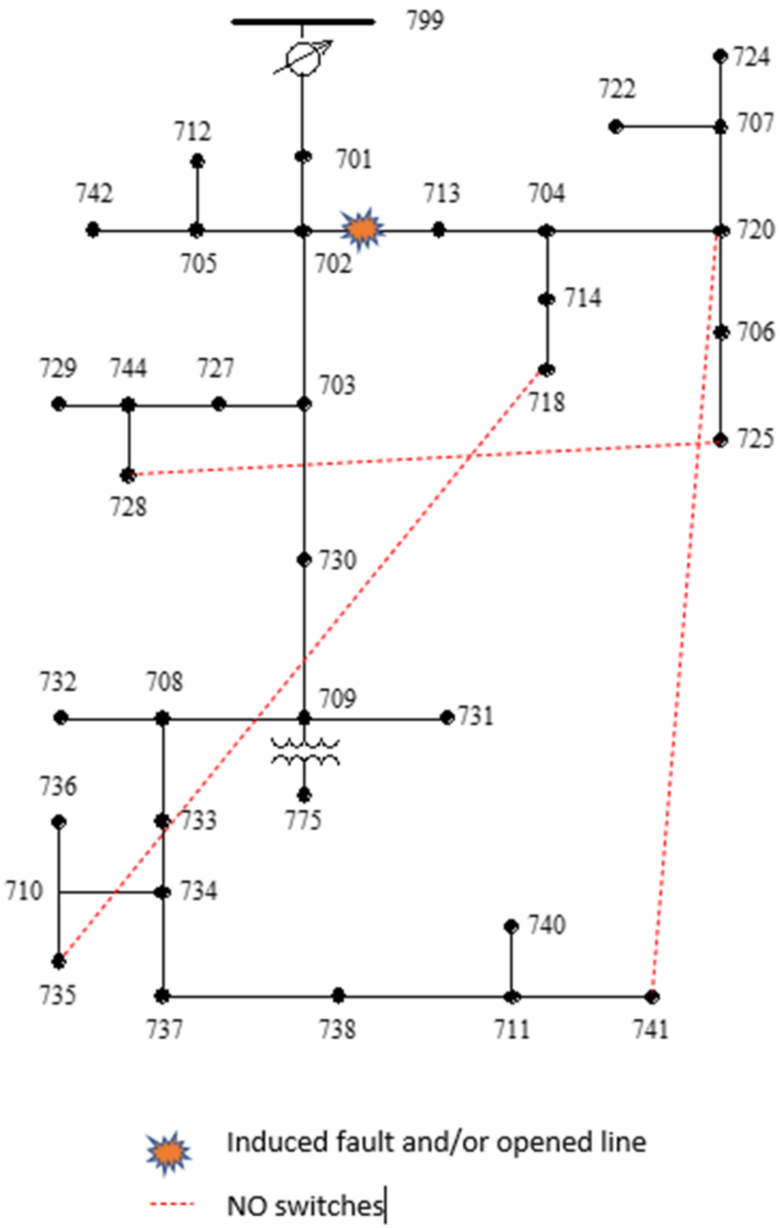
- Close 741-720 and Open 702-713

Test Results (explanation, outcome of tests)

- Feeder is longer after reconfiguration and experiences lower voltages towards the end of the feeder







Topology Reconfiguration Attack (PyCIGAR)

Tests Performed

Modify basic topology of IEEE 3 network by utilizing a hacked switch

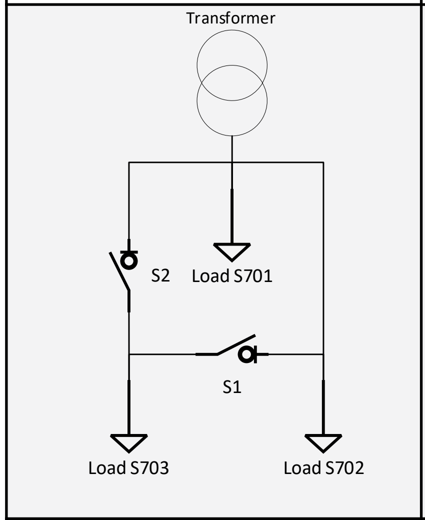
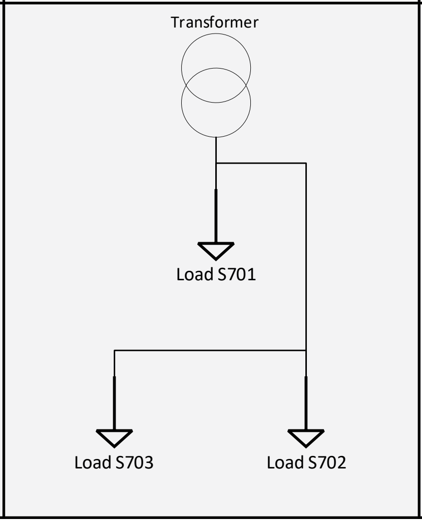
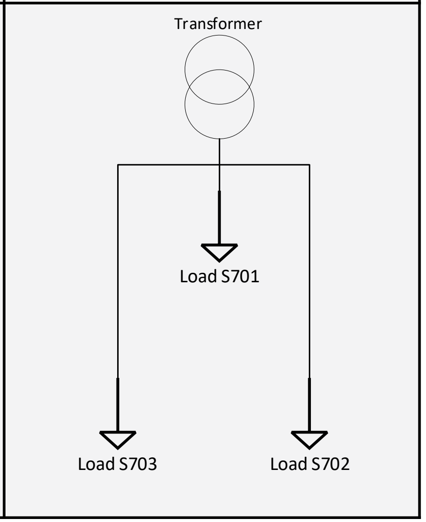
- Close Switch S2 and open Switch S1

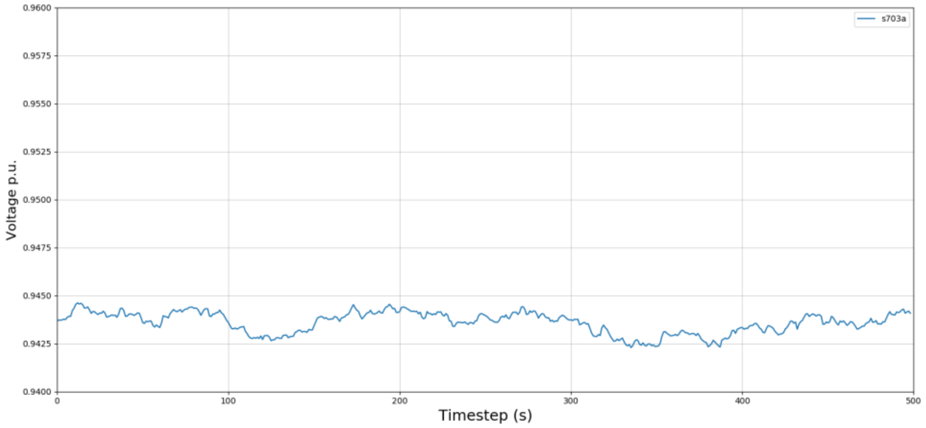
Attack is executed twice

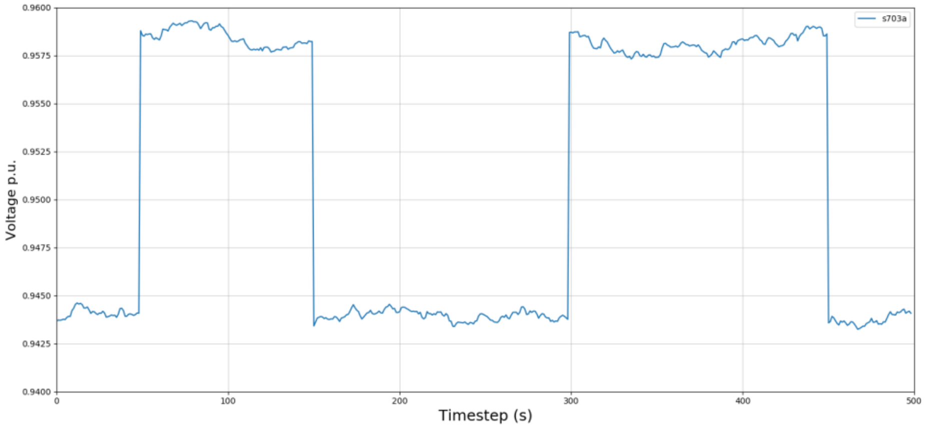
Test Results (explanation, outcome of tests)

- Load S703 is connected to Transformer

➢ Voltage of Load S703 increases

Layout	Topology before attack	Topology after attack
		





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Load/DER Disconnect Attack

- Attack scenario
  - Voltage Imbalance type attack
  - Selective load shedding/increase on a single phase to worsen phase imbalance
  - Repeated actions could also cause oscillations (optional)

- Simulation Model (OpenDSS)
  - IEEE 37 bus

- Attack implementation in PyCIGAR
  - ✓ Implementation of Hacked controllers/devices
    - ▪ (Hacked Load Device and Hacked load controller)
  - ✓ Downscale load in IEEE 3 bus system
  - ✓ Attack parameters: scaling of load according to provided scaling factor for a defined time
  - ✓ Result: Allow the scale loads at any node in PyCIGAR

  To be done:
  - Discuss and implement phase specific downscaling
  - Test implementation for single phase downscaling

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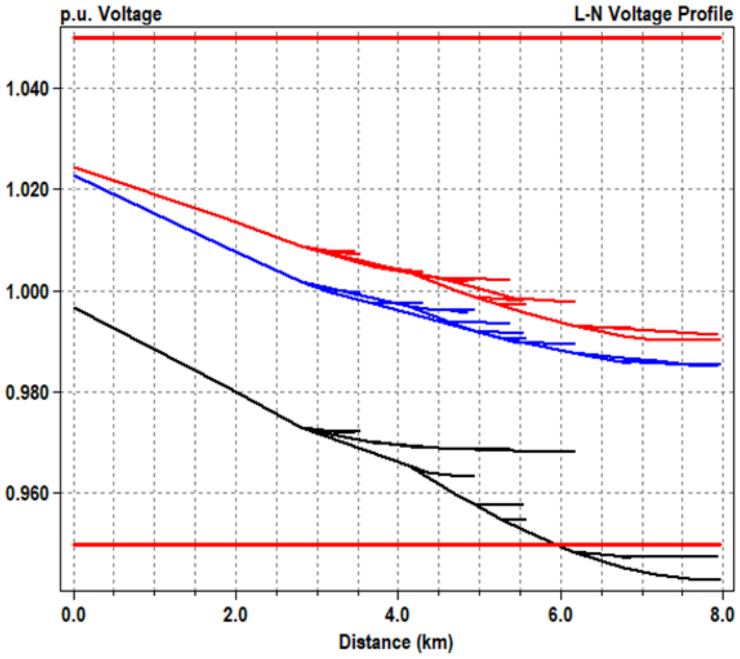
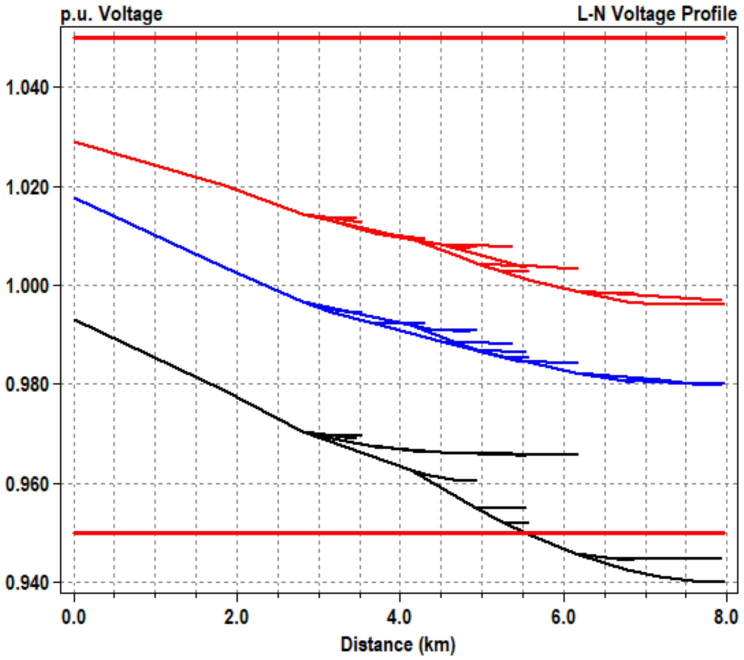
Load Disconnection Attack - Voltage Imbalance

Tests Performed
- Open S701a, S714a, S738a

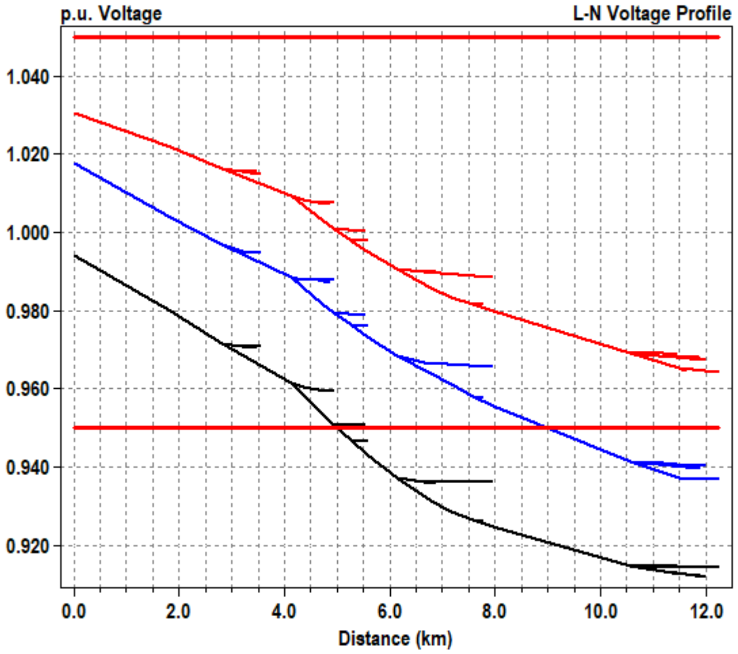
Test Results
- Disconnecting several large single-phase loads worsens imbalance between red and blue phases. Combining with topology reconfiguration also degrades the voltage.



Original



Disconnecting large load on one phase



Disconnecting large load on one phase + Topology reconfiguration

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Load/DER Disconnect Attack – Load scaling in PyCIGAR

Tests Performed

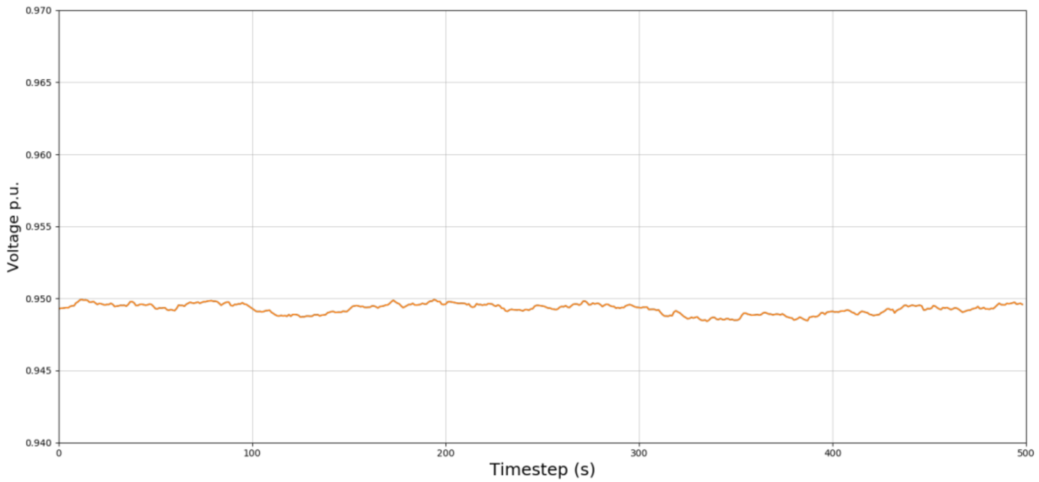
- Downscale the load of Load S701 in the IEEE 3 network according to the attack input
- Attack input is a scaling factor of 0.9 in the first attack and 0 in the second attack

Test Results

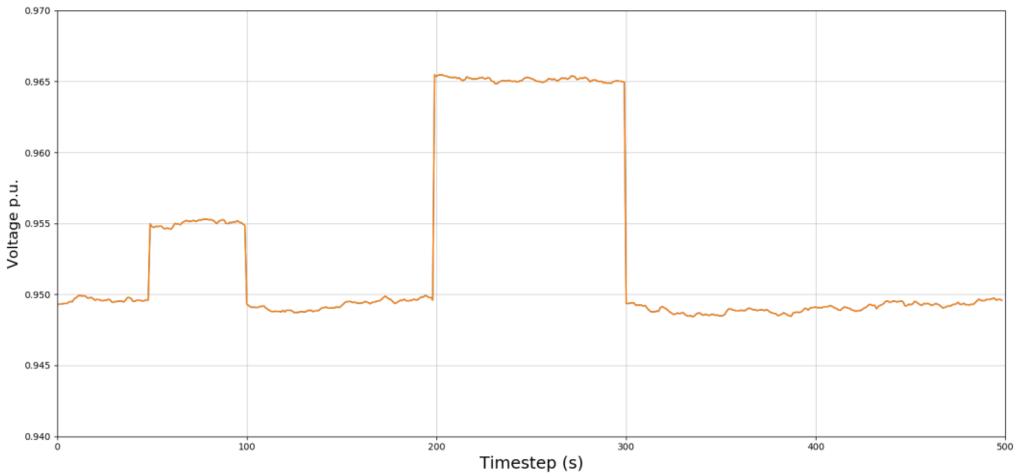
- ➢ Voltage on node S701 increases depending on the amount of down scaling.
- ➢ Second attack represents a load drop.

Next steps:

- Explore Load scaling for different phases



Original Simulation (IEEE 3 with no initial scaling factors applied and 500 simulation steps)



Simulation with Downscaling attack on node S701. (IEEE 3 with no initial scaling factors applied and 500 simulation steps)

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Regulator Attack

- Attack scenario
  - Over/under voltage type PDD attack
  - Disable regulator, or reverse delay settings for multiple regulators
  - Repeated actions could also cause oscillations (optional)

- Simulation Model (OpenDSS)
  - IEEE 37 bus, IEEE 123 bus

- Attack implementation in PyCIGAR

  To be done:
  - Extend regulator class
  - Implement hacked component classes
  - Extend red team parser
  - Define attack parameters
  - Test attacks

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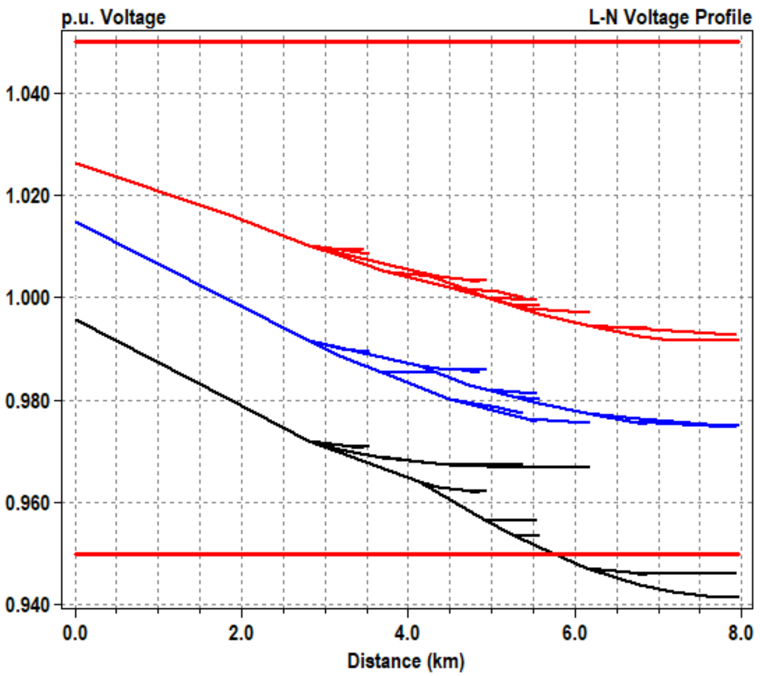
Regulator Attack (Disable)

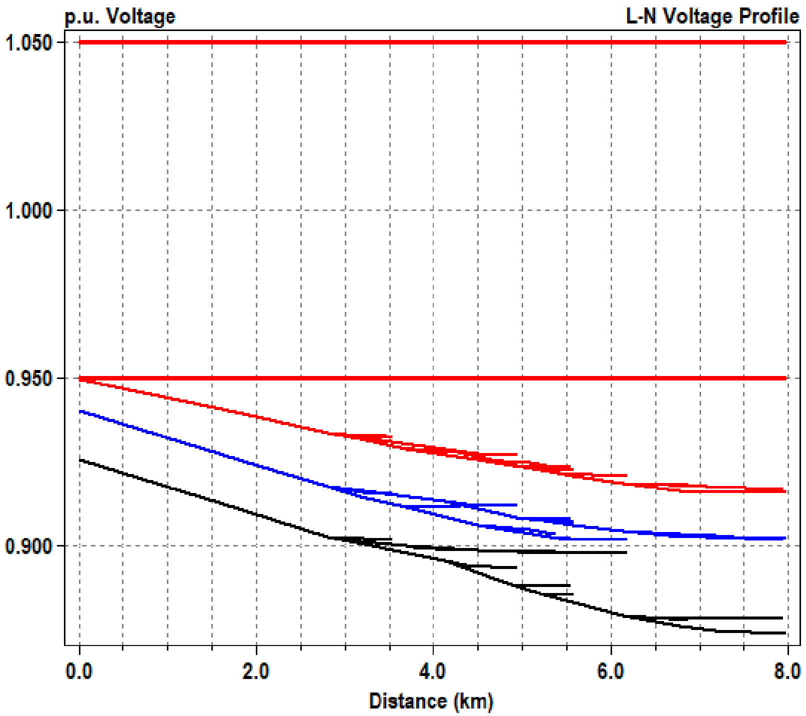
Tests Performed

- Disable regulator

Test Results (explanation, outcome of tests)

- Disabled regulator brings down the voltages for the entire feeder (IEEE 37 Bus)





- With regulator
- Regulator disabled

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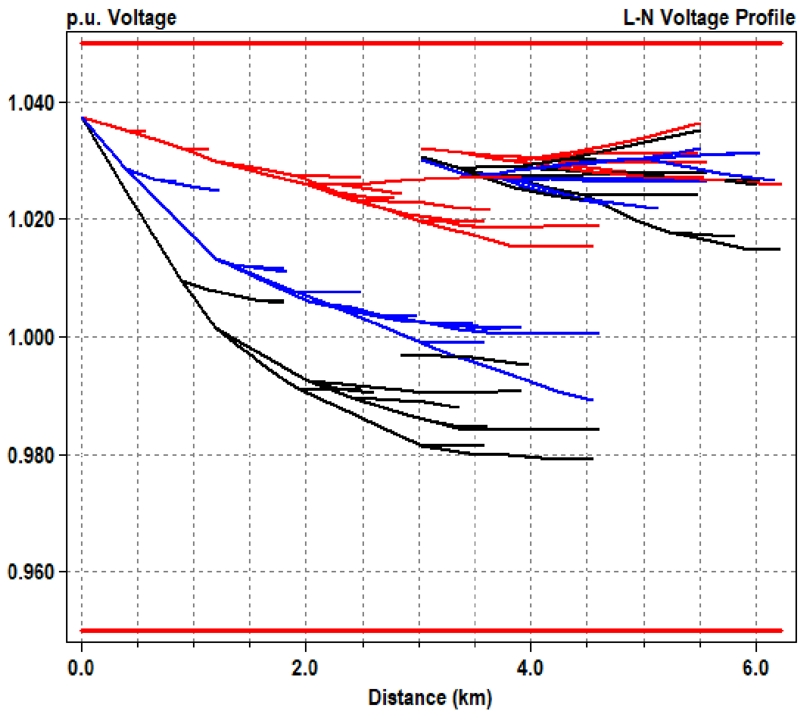
Regulator Attack (Reverse time delay)

Tests Performed

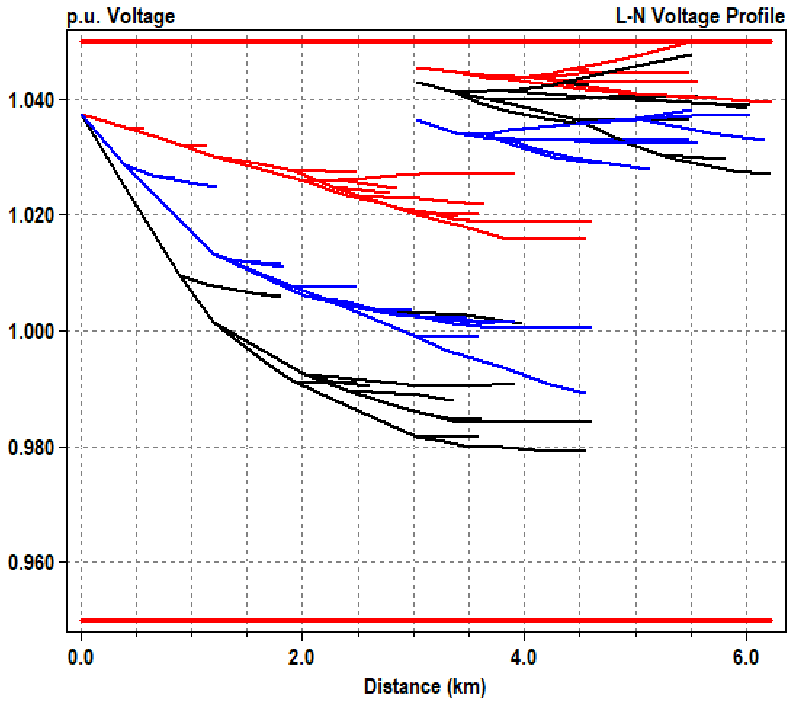
- Change the delay setting of substation LTC to act after line regulators

Test Results (explanation, outcome of tests)

- Reverse delay, ie., substation LTC has a longer delay than line regulators raise voltages



- With regulator



- Reverse delay on regulator

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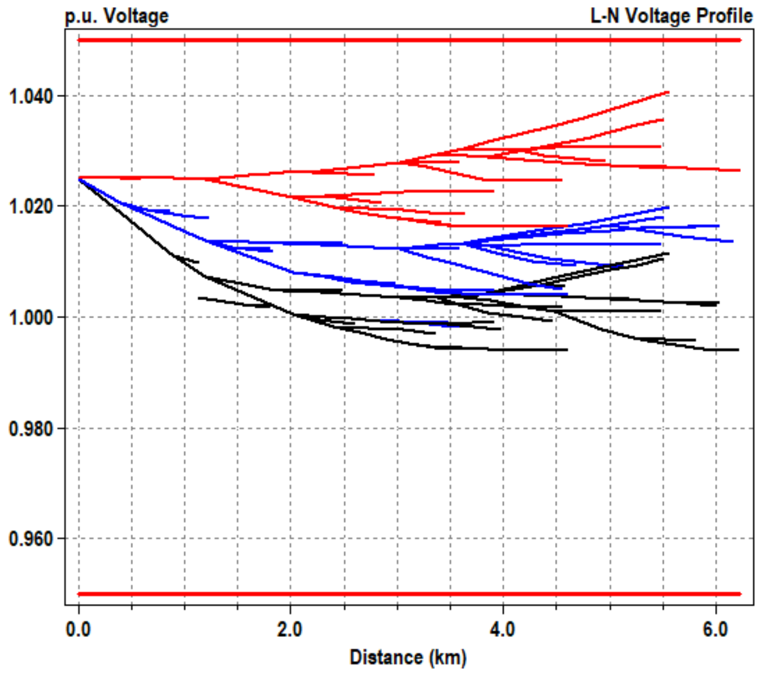
Regulator Attack (Reverse power)

Tests Performed

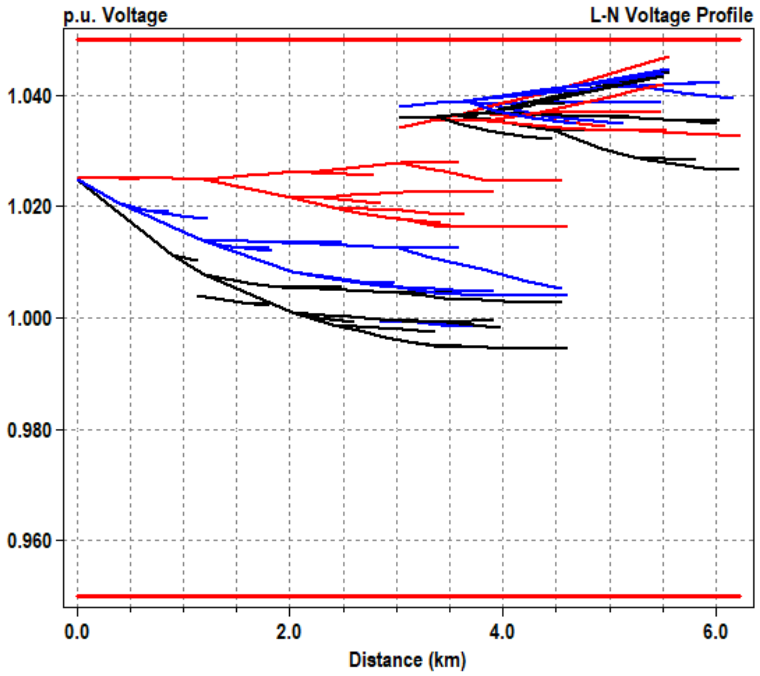
- Reverse power flow through regulator (RevRegTest.dss)

Test Results (explanation, outcome of tests)

- Reverse power through regulator pushes up voltages if reversible setting for regulator is not enabled



- With regulator, reversible=yes, revneutral=yes



- Reverse power through regulator, no reverse regulator setting

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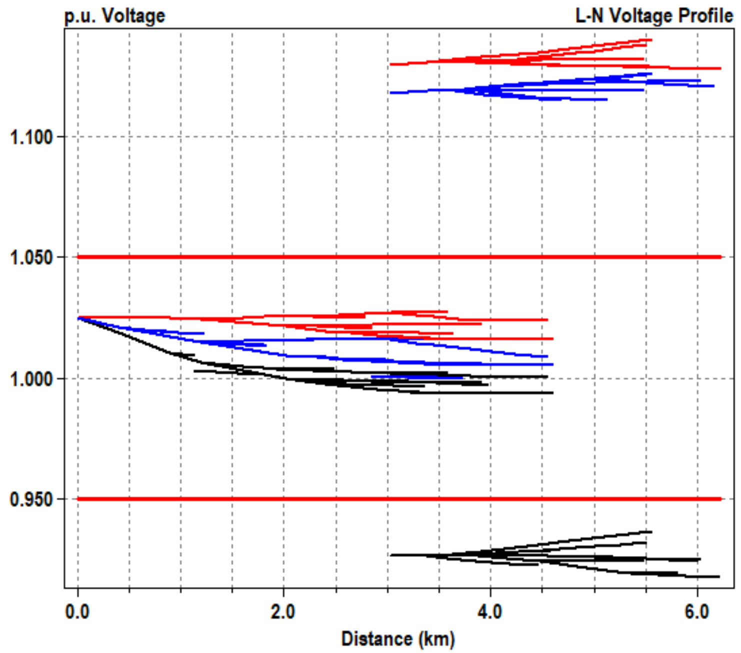
Regulator Attack (Reverse power)

Tests Performed

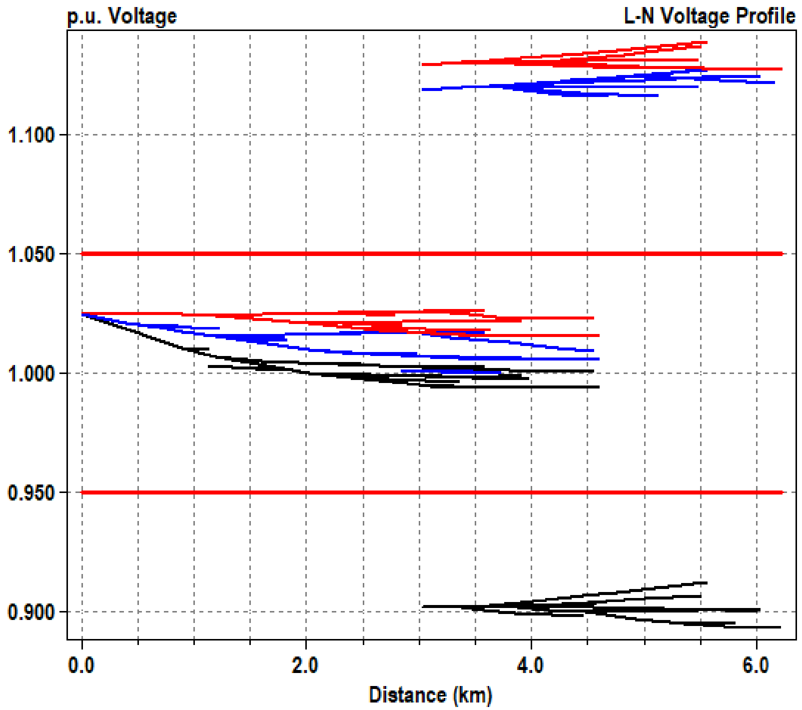
- Reverse power flow through regulator (RevRegTest.dss)

Test Results (explanation, outcome of tests)

- Reverse power through regulator changes voltages drastically if reversible=yes for regulator, but revneutral=no



- With regulator, reversible=yes, revneutral=no



- With regulator, reversible=yes, revneutral=no + reverse delay

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Capbank Attack

- Attack scenario
  - Over/under voltage type PDD attack
  - Disable regulator, or reverse delay settings for multiple regulators
  - Repeated actions could also cause oscillations (optional)

- Simulation Model (OpenDSS)
  - IEEE 123 bus

Attack implementation in PyCIGAR

To be done:

- Identify and define or extend the necessary classes
- Implement hacked component classes
- Extend red team parser
- Define attack parameters
- Test attacks

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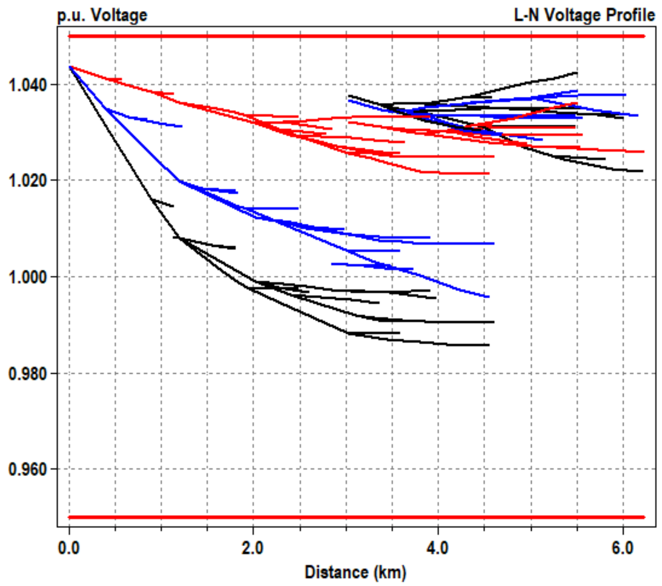
Capacitor Attack (Disable)

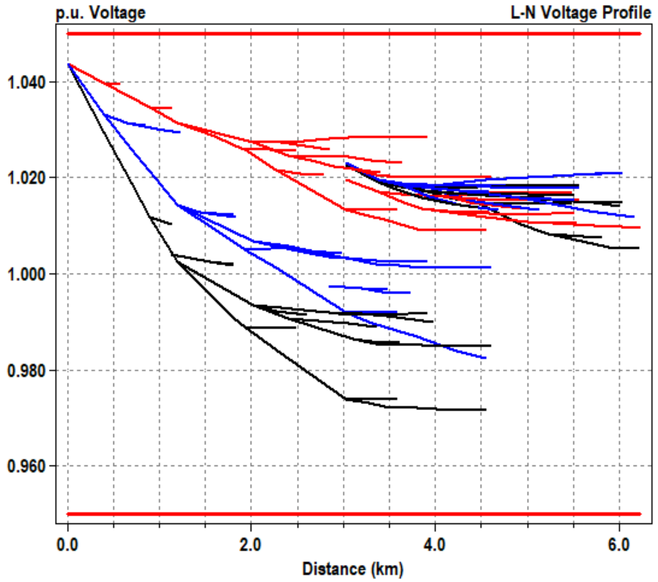
Tests Performed

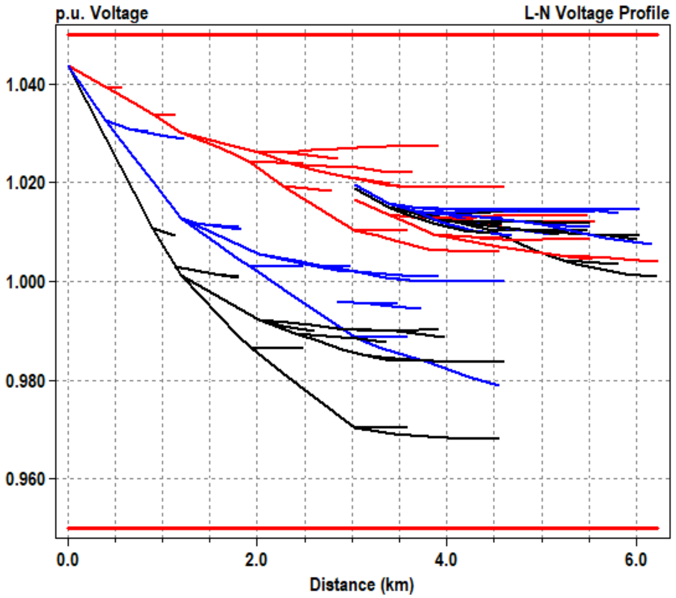
- Disable capbank – can modify capcontrols as well, IEEE 123 bus

Test Results (explanation, outcome of tests)

- Disabling capbank reduces feeder voltage







- With capbank
- Capacitor disabled

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Energy Storage Attack

- Attack scenario
  - Manipulate active/reactive power setpoints

- Simulation Model (OpenDSS)
  - TBD

- Attack implementation in PyCIGAR
  - ✓ Implementation OF hacked classes
  - ✓ Extended red team parser

  To be done:
  - Define attack parameters and scenarios
  - Integrate attack specifics in hacked classes
  - Test attacks

Attack Costs/Budget

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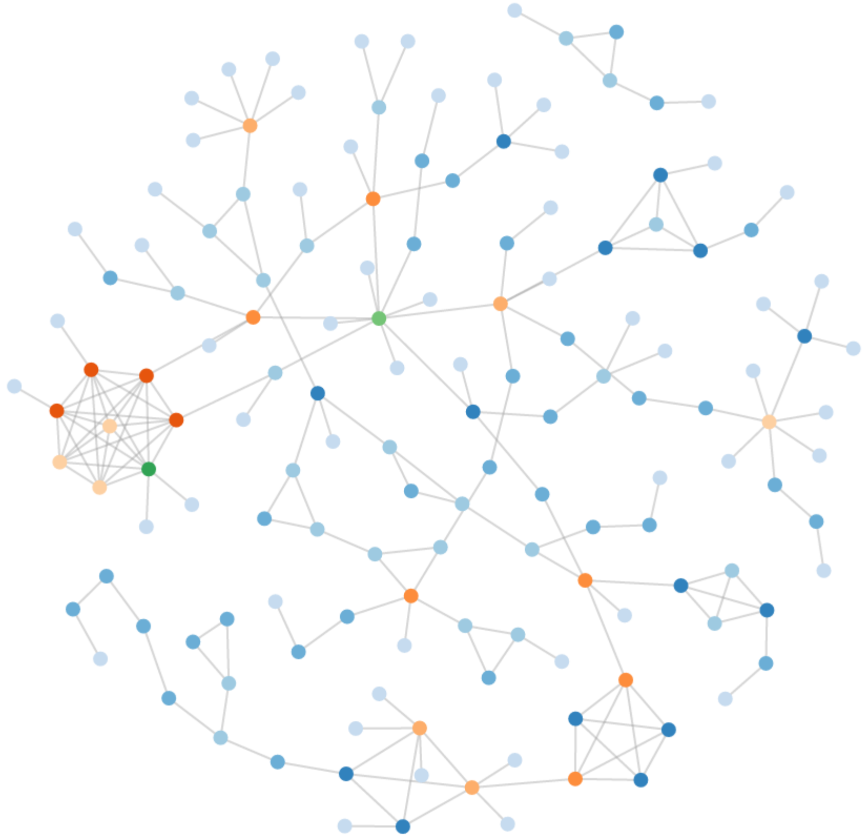
NetJSON to overlay Computer Network information

- Features
  - Configuration of devices
  - Monitoring data
  - Network topology
  - Routing information
- Adds the ability to define the IP network communication paths and firewall/access rules



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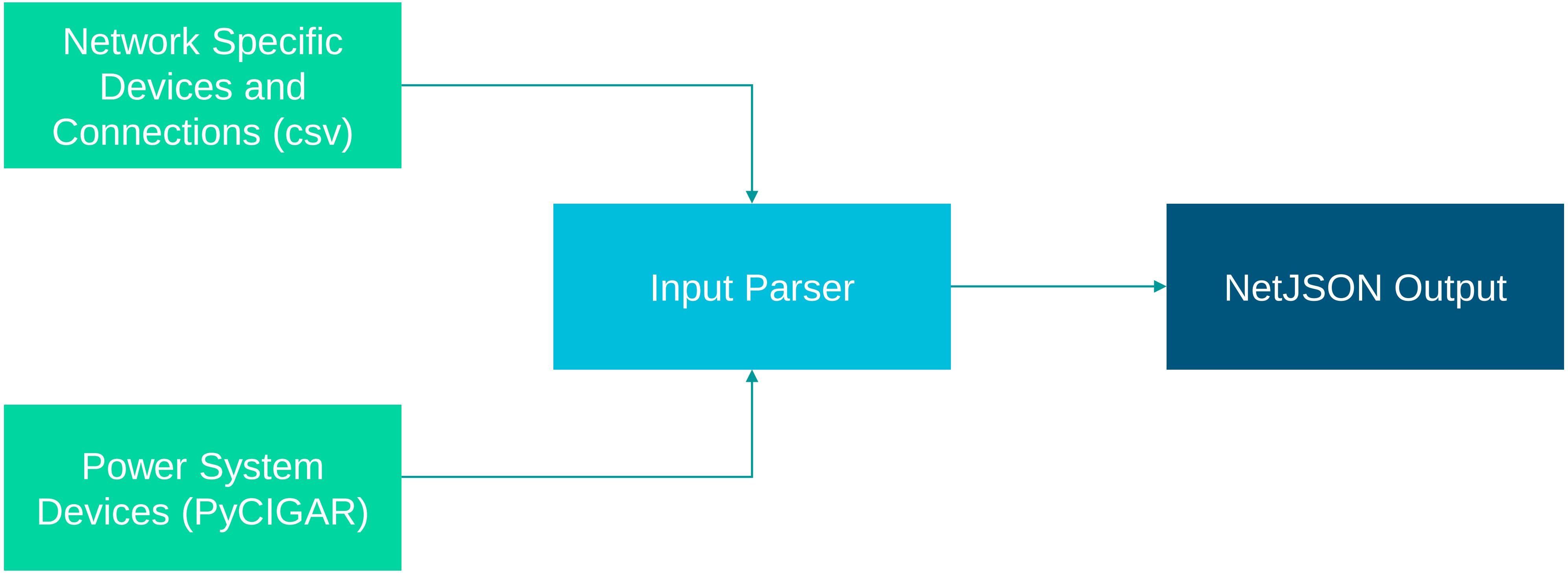
NetJSON Generation



Sample Input and Output

Sample input files

Devices:

```
device,property_dict
controlcenter,{"type":"control_center"}
network_switch1,{"type":"switch"}
network_ids1,{"type":"ids"}
network_firewall1,{"type":"firewall"}
network_switch2,{"type":"switch"}
network_firewall2,{"type":"firewall"}
network_switch3,{"type":"switch"}
network_firewall3,{"type":"firewall"}
ntp_clock1,{"type":"ntp_clock"}
hackme_wifi,{"type":"wifi_router"}
```

Connections:

```
device_a,device_b,property_dict
inverter_s701a,network_switch1,{"type":"wired"}
network_switch1,network_ids1,{"type":"wired"}
network_ids1,network_firewall1,{"type":"wired"}
network_firewall1,controlcenter,{"type":"wired"}
inverter_s702a,network_switch2,{"type":"wired"}
network_switch2,network_firewall2,{"type":"wired"}
network_firewall2,controlcenter,{"type":"wired"}
inverter_s703a,network_switch3,{"type":"wired"}
network_switch3,network_firewall3,{"type":"wired"}
network_firewall3,controlcenter,{"type":"wired"}
ntp_clock1,network_switch1,{"type":"wired"}
hackme_wifi,network_switch1,{"type":"wireless"}
```

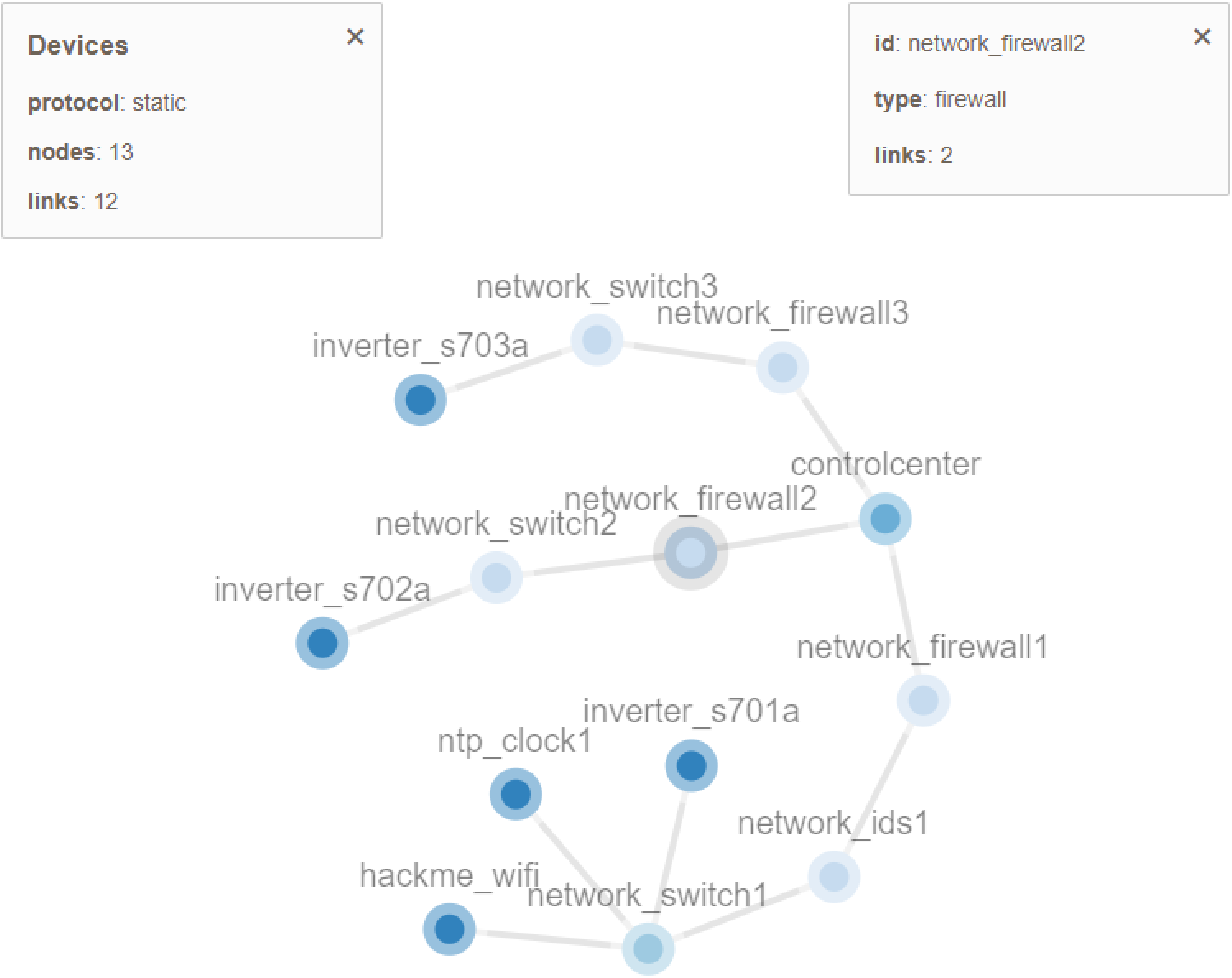
Resulting NetJSON (Output)

```
{
  "type": "NetworkGraph",
  "label": "Devices",
  "protocol": "static",
  "version": null,
  "metric": null,
  "nodes": [
    {
      "id": "inverter_s701a",
      "properties": {
        "type": "pv_device"
      }
    },
    {
      "id": "inverter_s702a",
      "properties": {
        "type": "pv_device"
      }
    },
    {
      "id": "inverter_s703a",
      "properties": {
        "type": "pv_device"
      }
    },
    {
      "id": "controlcenter",
      "properties": {
        "type": "control_center"
      }
    },
…
```

```
…
],
  "links": [
    {
      "source": "inverter_s701a",
      "target": "network_switch1",
      "properties": {
        "type": "wired"
      }
    },
    {
      "source": "network_switch1",
      "target": "network_ids1",
      "properties": {
        "type": "wired"
      }
    },
    {
      "source": "network_ids1",
      "target": "network_firewall1",
      "properties": {
        "type": "wired"
      }
    },
    {
      "source": "network_firewall1",
      "target": "controlcenter",
      "properties": {
        "type": "wired"
      }
    },
…
]}
```


Sample NetJSON Node Graph

- Node graph created based on the sample input file
  - Contains devices and link
  - In practical applications, device properties will contain information such as:
    - Attack costs
    - Communication paths
    - Firewall rules



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