ANALYZING THE IMPACT OF DISTRIBUTED ENERGY RESOURCES ON DISTRIBUTION SYSTEMS OUTAGE RESTORATION

Konrad Schmitt[1], Manohar Chamana[2], Stephen Bayne[1]
[1]Electrical and Computer Engineering Department, Texas Tech University, Lubbock, USA
[2]National Wind Institute, Texas Tech University, Lubbock, USA
konradkorkschmitt@ieee.org, M.Chamana@ttu.edu, Stephen.Bayne@ttu.edu

INTRODUCTION

Self-healing (SH) provides a solution to partially or entirely restore impacted customers within minutes after the fault occurs. This need for speed does not allow complex analysis of all network aspects, such as Distributed Energy Resources (DERs) participation. Traditionally, SH looks to increase the load supply after an outage, and most of the times, DERs contribution is neglected because of its small levels or lack of data. This study analyzes and discusses the importance of considering DERs generation alongside with consumption in the SH problem to ensure a reliable restoration.

Terminology:

- ***Topology:*** the way the grid is built.
- ***Configuration:*** the way the grid is operated.
- ***Reconfiguration:*** to find a new grid configuration.
- ***Self-healing:*** to find a new grid configuration to restore outages.

METHODOLOGY

The Self-healing algorithm is based on a Mixed-Integer Linear Programming (MILP) that can maintain de-energized the faulted branch while isolating it and reconfiguring the network to restore as many customers as possible. Distribution systems are defined by cells, which are sets of nodes and branches bounded by switches. With that, the outage isolation and restoration is based on energizing and de-energizing cells by optimal switch maneuvers. The problem is formulated using Pyomo Python-based modeling language and Gurobi as solver, which is constrained by operational nodal voltage levels branch current loading.

A. *Mixed-Integer Linear Programming (MILP)*

The cell outage is defined by $C_{ij,t}^{x}$, being 0 as outage and 1 as no outage. The optimal status of each other branch is given by the result of $y_{ij,t}^{b}$, being 1 as energized and 0 as de-energized. Being $U_{i,\phi,t} = \left|V_{i,\phi,t}\right|^{\mathbf{2}}$:

$$min\left[w_1 \cdot \sum_{i\in\Omega_N}\sum_{\phi\in\Omega_\Phi} S_{i,\phi,t}^{d} \cdot \left(1 - y_{i,t}^{n}\right) + \ w_2 \cdot \sum_{ij\in\Omega_{B,S}} \left|y_{ij,t}^{b} - y_{ij,t-1}^{b}\right|\right] \tag{1}$$

$$\sum_{ij\in\Omega_B} S_{ij,\phi,t}^{b} = \sum_{jl\in\Omega_B} S_{jl,\phi,t}^{b} + S_{i,\phi,t}^{d} \cdot y_{j,t}^{n} \tag{2}$$

$$\boldsymbol{U}_{i,t} - \boldsymbol{U}_{j,t} \geq 2 \cdot \left(\boldsymbol{R}_{ij} * \ \boldsymbol{P}_{ij,t} + \boldsymbol{X}_{ij} * \boldsymbol{Q}_{ij,t}\right) - \left(2 - y_{ij,t}^{b} - \ \boldsymbol{\Phi}_{ij}\ \right) \cdot M \tag{3}$$

$$\boldsymbol{U}_{i,t} - \boldsymbol{U}_{j,t} \leq 2 \cdot \left(\boldsymbol{R}_{ij} * \ \boldsymbol{P}_{ij,t} + \boldsymbol{X}_{ij} * \boldsymbol{Q}_{ij,t}\right) + \left(2 - y_{ij,t}^{b} - \ \boldsymbol{\Phi}_{ij}\ \right) \cdot M \tag{4}$$

$$y_{i,t}^{n} \cdot (V^{m})^2 \leq U_{i,\phi,t} \leq y_{i,t}^{n} \cdot \ (V^{M})^2 \tag{5}$$

$$S_{ij,\phi}^{M} \geq \sqrt{\left(P_{ij,\phi,t}^{b}\right)^2 + \left(Q_{ij,\phi,t}^{b}\right)^2} \tag{6}$$

$$\sum_{ij,ji\in\Gamma_i} \left(\beta_{ji,t}^{+} + \beta_{ij,t}^{-}\right) = y_{i,t}^{n} \tag{7}$$

$$\beta_{ij,t}^{+} + \beta_{ij,t}^{-} = y_{ij,t}^{b} \tag{8}$$

$$y_{ij,t}^{b} \leq C_{ij,t}^{x} \tag{9}$$

B. *Distribution System Network*

As a test case, the MV Oberrhein test system is used in the analysis and has its data available through the Pandapower python package. Figure 1 shows this 177-node network, with 63.3 MVA and 21.75 MW of installed load and generation, as well as 29 normally closed and 6 normally open switches.

RESULTS

As shown in Fig. 2, for a fault downstream Switch 2, the entire feeder is de-energized by the Switch 2 tripping. The isolation is then made by maintaining Switch 2 open and also opening Switch 30. The actual system's load and generation levels are 0.5 p.u. of their nominal installed demand/capacity. Being the power demand used in the MILP problem defined by:

$$S_{i,\phi,t}^{d} = S_{i,\phi,t}^{c} - S_{i,\phi,t}^{g} \tag{10}$$

Where the demand, $S_{i,\phi,t}^{d}$, is the difference between the consumed, $S_{i,\phi,t}^{c}$, and generated, $S_{i,\phi,t}^{g}$, power in each node. Even though the actual system is operating with 0.5 p.u. of load and generation, the case study I neglects any level of generation in the SH optimization, while Case II considers the actual power generation from the DERs generation.

- ***Case I:*** disregards generation levels in the SH ($S_{i,\phi,t}^{g} = 0\ p.u.$).
- ***Case II:*** uses actual generation levels in the SH ($S_{i,\phi,t}^{g} = 0.5\ p.u.$).

The main goal of this comparison is to analyze the restoration solution proposed by the SH and its power quality and reliability aspects when applied to the actual system.

Figures 3 and 4 present the restoration solution for Cases I and II, respectively. Table 1 summarizes the results for each case and compare them with the initial and outage network states.

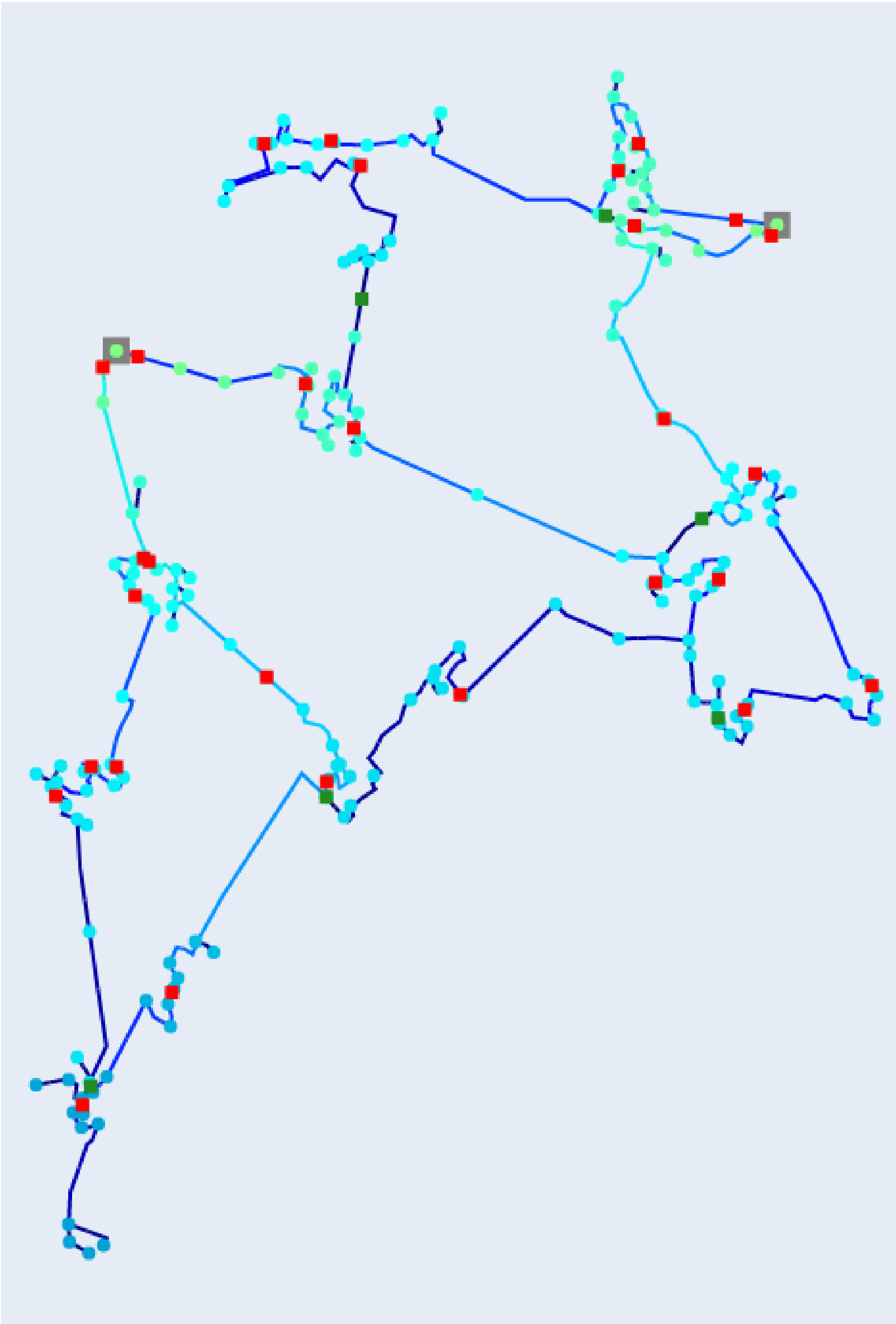

Figure 1. Initial System.

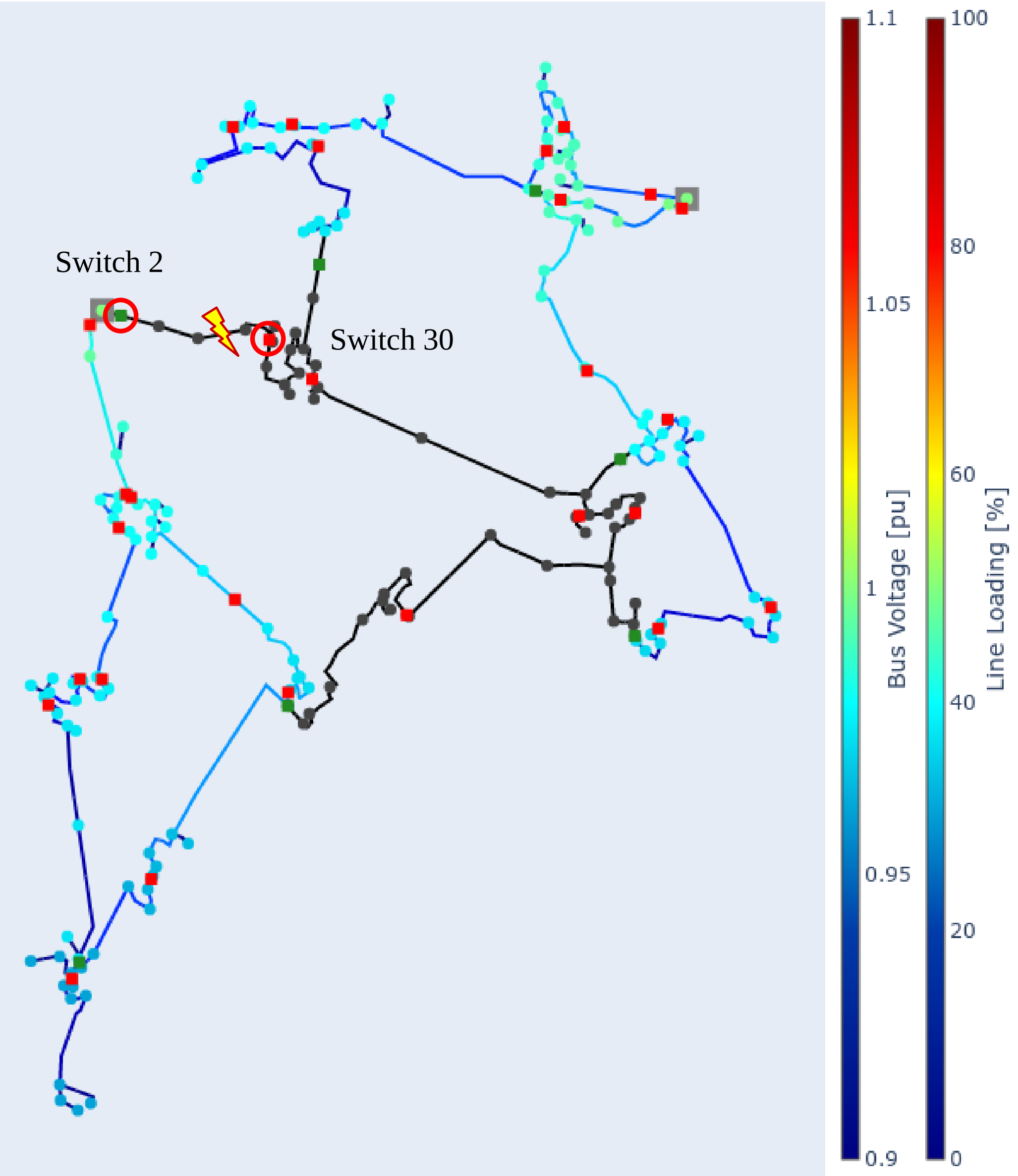

Figure 2. Outage System.

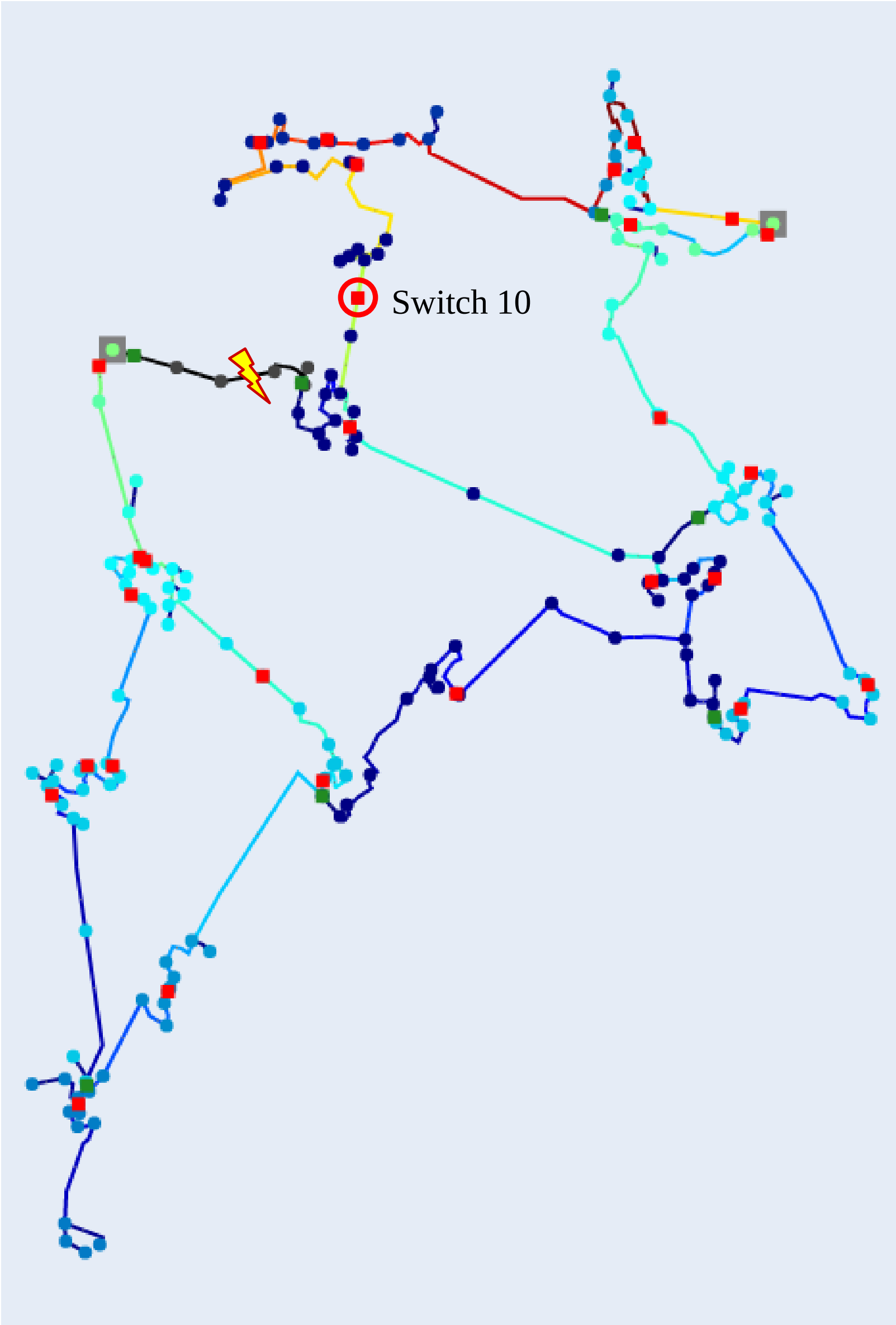

Figure 3. Case I Restoration.

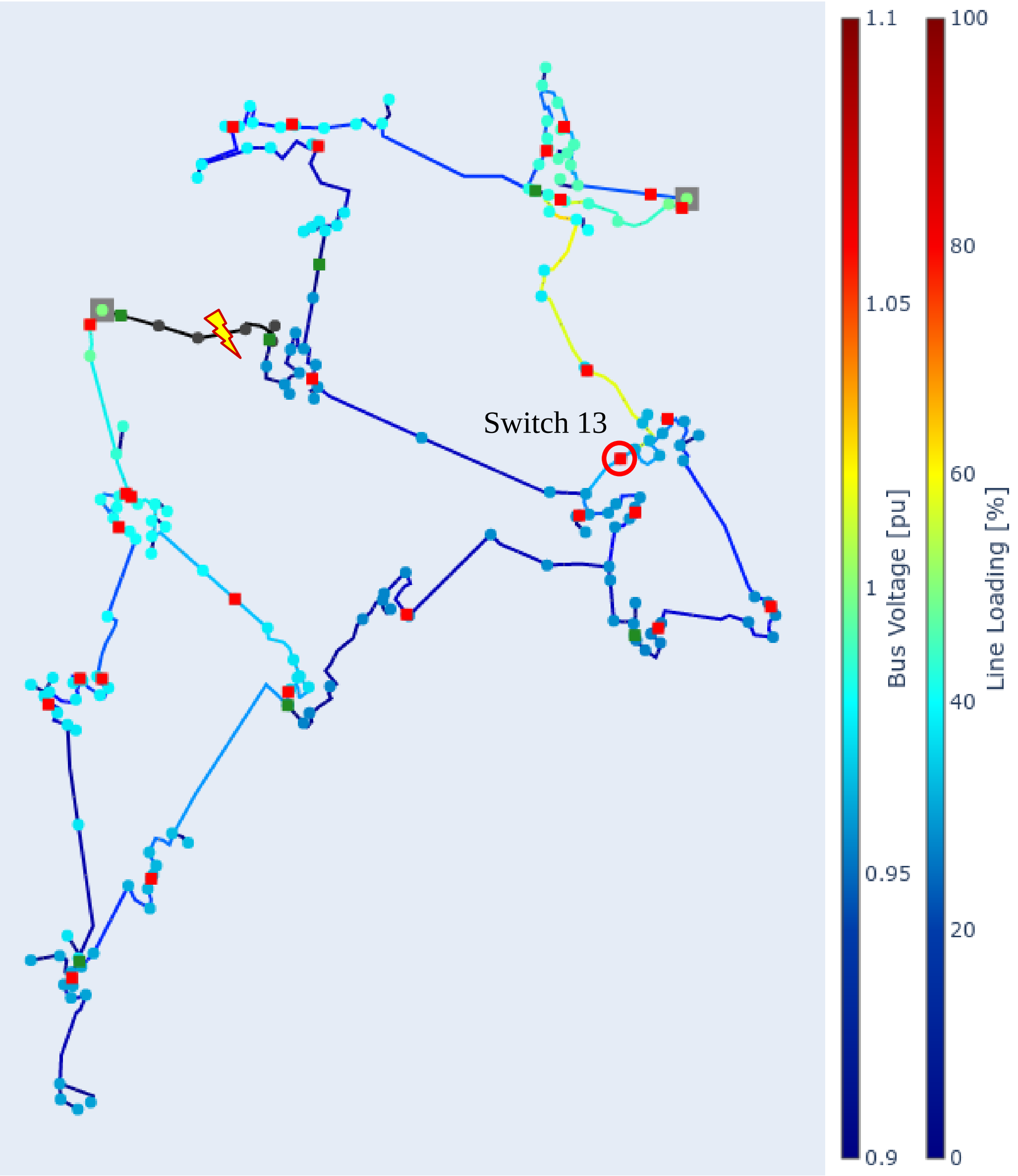

Figure 4. Case II Restoration.

It is possible to observe that by misleading the SH optimization with neglecting the DERs generation, the provided solution stresses some branches with high loading and consequently, low voltage levels. In the other hand, when the actual DER generation values are provided to the restoration, the proposed solution is capable to ensure a reasonable loading and voltage levels in all system's branches and nodes.

Table I. Results Summary

Case	Open Switches			Actual Voltage Levels [p.u.]					
	Initial	Isolation	Restoration	Initial		Isolation		Restoration	
				Min	Max	Min	Max	Min	Max
I	6,10,13, 17,24,27	**2**,6,10,13, 17,24,27,**30**	**2**,6,**13**,17,24,27,**30**	0.9618	1.0000	0.9618	1.0000	0.9194	1.0000
II			**2**,6,**10**,17,24,27,**30**					0.9552	1.0000

CONCLUSION AND FUTURE WORK

This study aimed to clarify the importance of considering actual system's data when performing restoration. The disregard or assumptions on customers' power demand levels can imply on a misleading restoration solution. This challenge can be address by increasing metering and communication capabilities. However, the required investment to have a fully observable network is high. Based on that, State Estimation (SE) is an attractive solution that can efficiently use the available metering devices along side with historical and forecasting data to find a suitable state of the network's load and generation levels. The continuation of this study is focused on integrating SE into the restoration problem.

ESTCP
TEXAS TECH UNIVERSITY
TEXAS TECH UNIVERSITY Department of Electrical & Computer Engineering
GLEAMM GLOBAL LABORATORY FOR ENERGY ASSET MANAGEMENT AND MANUFACTURING