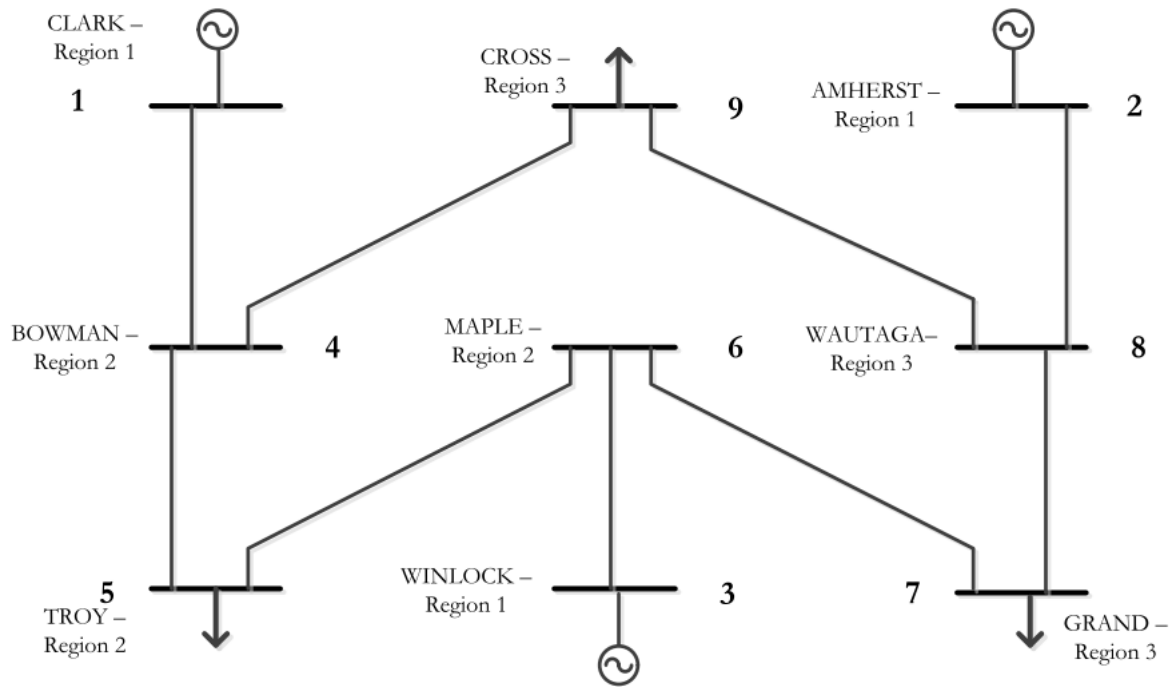


Cluster Operating State Labeling

The labeling of operating states for each cluster was first performed through specific-case analysis of given system topology, and then, based on obtained results of specific-case analysis, a general labeling rule, based on average normalized state-average voltage and angle, was abstracted.

Specific-Case Analysis

The operating state of the system was obtained by analyzing the power system topology presented on the figure below. For correct calculation of complex voltage drops, data was reverted to unnormalized values (just in this step).



Generator Outage

As a generator outage indicator, the complex voltage difference between generator bus and its adjacent bus was taken, since, in case of generator outage, we would not have any power flows through the line, and therefore the voltages would be the same and voltage difference would be zero, while in full operation mode, due to power flows we would have some voltage drop. For each time instance, the minimum voltage difference between generator bus pairs (1-4, 2-8 or 3-6) was taken as a representative, and a cluster average was computed. Obtained indicators are presented in table below. From these results, it was easy to conclude that the 53-element cluster represented the Generator Outage Operating State, as it had the lowest indicator (by 2 orders of magnitude).

Cluster	Size	Gen Outage Indicator
Cluster 1	47	0.049993246
Cluster 2	49	0.068610393
Cluster 3	51	0.051508629
Cluster 4	53	0.000385087

Line Outage

Analogous to previous case, for line outage indicator the complex voltage difference between all line connected buses was analyzed, since with line outage, due to reverted power flows, the complex voltage difference would be much higher than in line operation mode. For each time instance, the maximum voltage difference between all line connected bus pairs was taken as a representative, and a cluster average was computed. Obtained indicators are presented in table below. From these results, it was easy to conclude that the 47-element cluster represented the Line Outage Operating State, as it had the highest line outage indicator.

Cluster	Size	Line Outage Indicator
Cluster 1	47	0.420821642
Cluster 2	49	0.271459139
Cluster 3	51	0.194577563
Cluster 4	53	0.102339771

High Load and Low Load

With the generator and line outage states eliminated, the high load and low load state were easily classified by computing the average state voltage and average state angle, and averaging it over the whole cluster. In high load scenarios, high currents would induce higher complex voltage drops, which would result in lower voltage amplitudes and higher (more negative) voltage angles. In low load operation, we would have the opposite situation. Obtained results are presented in the table below. It is apparent that the 49-element cluster represents the high load operating state, while the 51-element cluster represents the low load operating state.

Cluster	Size	Avg. Angle	Avg. Voltage
Cluster 1	47	7.490167452	0.980965654
Cluster 2	49	-22.93925331	0.928008447
Cluster 3	51	12.86152229	1.000334883
Cluster 4	53	-5.933008246	0.989641167

General Labeling Rule

Based on 2D plot of normalized state-average angle (x-axis) and voltage (y-axis), a distinct cluster grouping was observed, as is presented on the figure below, and then, based on obtained system-specific labels (47-Line Outage, 49-High Load, 51-Low Load, 53-Generator Outage), and cluster positions, a general labeling rule was abstracted:

- 1) The cluster with the highest state-average voltage is labeled as Low Load State.
- 2) The cluster with the lowest state-average voltage is labeled as High Load State.
- 3) From two remaining clusters:
 - a) The cluster with higher state-average angle is labeled as Line Outage State.
 - b) The cluster with lower state-average angle is labeled as Generator Outage State.

