Identification of the operational states

From the K-Means clustering results, the average voltage on each bus in each cluster is shown in **Table 1**.

Table 1. Average Voltage on each bus in each cluster

	Cluster No. / Bus No.	0	1	2	3
Average voltage values on each bus in each Cluster (p.u)	**1**	1	1	1	1
	2	1	1	1	1
	3	1	1	1	1
	4	0.97226025	0.99053891	0.89559255	0.98963788
	5	0.94489448	0.99382867	0.84984147	0.97737314
	6	1.00571067	1.01430785	0.95419099	0.99961627
	7	0.98198279	1.01129671	0.90401914	0.98271912
	8	0.98933334	1.01009278	0.93823635	0.99548786
	9	0.93450935	0.98294903	0.81019551	0.96193623
Average Voltage of each cluster (p.u)		0.980966	1.000335	0.928008	0.989641
Cluster's size		48	51	49	53

Higher load rate means increase in current, which cause the larger active power losses on the line and larger voltage drop. Oppositely, lower load rate stands for the lower voltage drop and thus, higher voltages on the buses. From the table, the voltages on each bus could be compared among the four clusters: Cluster 1 and Cluster 2 has the highest and lowest average voltages, respectively. So Cluster 2 represents the state "High load rate during peak hours" while Cluster 1 represents "Low load rate during night".

To analyze the state "Shut down of generator for maintenance", disconnect a generator (on bus 1, 2 or 3), from the single line diagram we can see that when shut down a generator, there is no current injection to related generator bus and leads to no current flow from this bus to its connected bus (i.e. no voltage drops between the bus 1 and 4, bus 2 and 8 or bus 3 and 6). The results of the calculation for each cluster are shown as below:

Table 2. Results of average voltage drops for each cluster

	Cluster No. / Line No.	0	1	2	3
Average voltage drops (p.u)	**1-4**	0.02774	0.009461	0.104407	0.010362
	2-8	0.010667	0.01009	0.061764	0.004512
	3-6	0.00571	0.01431	0.045809	0.000384
Average Voltage drops for each cluster (p.u)		0.014706	0.011287	0.07066	0.005086

From Table 2 we can see that the lowest average voltage drops between line 1-4, 2-8 and 3-6 is Cluster 3, this means that Cluster 3 represents the state “Shut down of generator for maintenance”

As for state “Disconnection of a line for maintenance”, based on Thévenin equivalent theory the equivalent two node circuit is shown below:

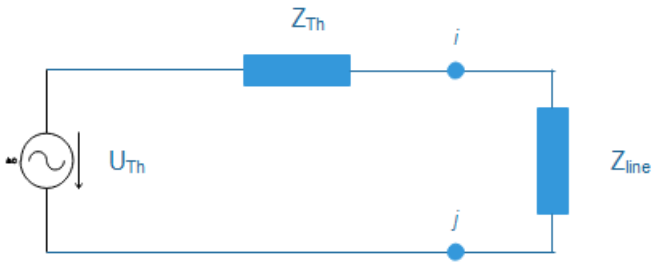

Figure 1. Thévenin equivalent circuit

When disconnect one line between bus i and j, the voltage between i and j will be increased, since the equivalent impedance of the line between the two nodes increase (if open-circuit the line impedance is considered as ∞). In order to prove that Cluster 0 represent the “Disconnection of a line for maintenance”, the average voltage differences between i and j can be calculated and results are listed in the table below:

Cluster No.	**0**	**1**	**2**	**3**
Average Voltage difference between two nodes	0.028439	0.010731	0.073323	0.015632

The largest average voltage difference between two nodes is Cluster 2 and then Cluster 0, as analyzed above when “High load rate during peak hours” the currents are the largest which means the voltage drops on the lines are the largest. When disconnect a line for maintenance, the current will not increase that much, thus Cluster 0 can represent the state “Disconnection of a line for maintenance”.

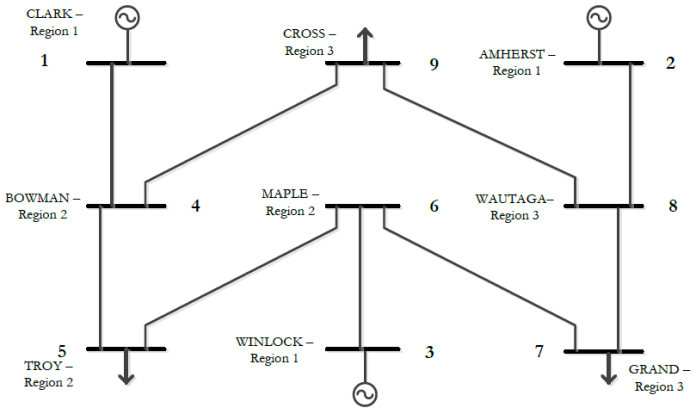

Figure 2. Single line diagram of the system provided by assignment description