ISLAMIC UNIVERSITY OF TECHNOLOGY

PROJECT REPORT

LOAD SHEDDING SCHEME FOR IEEE 39 BUS (NEW ENGLAND) TEST SYSTEM

COURSE CODE	EEE4632
COURSE TITLE	Power System III Lab
STUDENT IDs	200021311 200021315 200021205 200021209

Introduction

This report presents the analysis and design tasks performed on the IEEE 39-bus (New England) test system using PSAF (Power System Analysis Framework). The tasks include load flow analysis, frequency response analysis, and voltage stability assessment, among others. The system's nominal frequency is 50 Hz, and the data provided includes bus, line, transformer, generator, and load information.

Theory

Voltage stability is becoming a limiting factor in the planning and operation of many power systems. In a Power system, voltage stability involves generation, transmission and distribution. The system voltage profile should be maintained within the specified limits, such that the voltage magnitude is adequate to support the loads and avoid equipment breakdown. With the increased loading of existing power transmission systems, the problem of voltage stability and voltage collapse has become a major concern in power system planning and operation. Voltage stability is concerned with the ability of a power system to maintain acceptable voltages in the system under normal conditions and after a disturbance. A system enters a state of the voltage instability when a disturbance causes a progressive and uncontrollable decline in the voltage.

Voltage collapse is a process by which voltage instability leads to very low voltage profile in a significant part of the system. Voltage collapse has to be given the most priority because it leads to cascading blackouts in the whole network. By various voltage stability indices, it is possible to determine the stability point for the distribution and transmission system so that it can be determined the weakest bus in the system.

Voltage stability indices:

The condition of voltage stability in a power system can be found using Voltage Stability Indices. These indices can either express the critical bus of a power system or the stability of each line connected between two buses in an interconnected network or evaluate the voltage stability margins of a system. Generally, the following voltage stability indices are widely used.

A. Reactive Power Margin
B. Fast Voltage Stability Index (FVSI)
C. Voltage Sensitivity Factor (VSF)
D. Line index Lmn

For our report we have used FVSI to design our load shedding scheme

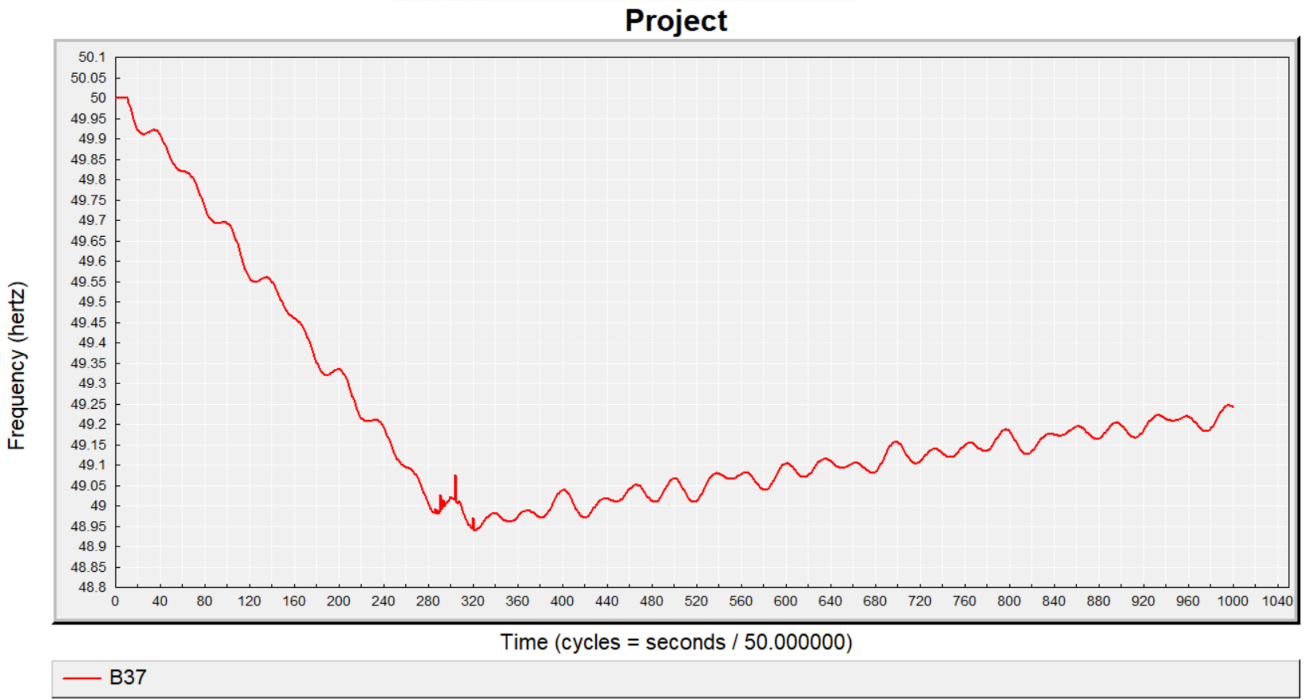
Task 1
All the data was given in the software, Newton Raphson method was used to perform the load flow analysis and the results converged.

Task 2

Frequency response analysis was performed for the outage of G08 i.e. loss of 540 MW.
The following UFLS scheme was performed for this scenario:

First frequency threshold [Hz]:	49.00000
First load shedding amount [%]:	10.00000
Second frequency threshold [Hz]:	48.50000
Second load shedding amount [%]:	10.00000
Third frequency threshold [Hz]:	48.00000
Third load shedding amount [%]:	10.00000
Relay operating time [sec.]:	0.10000

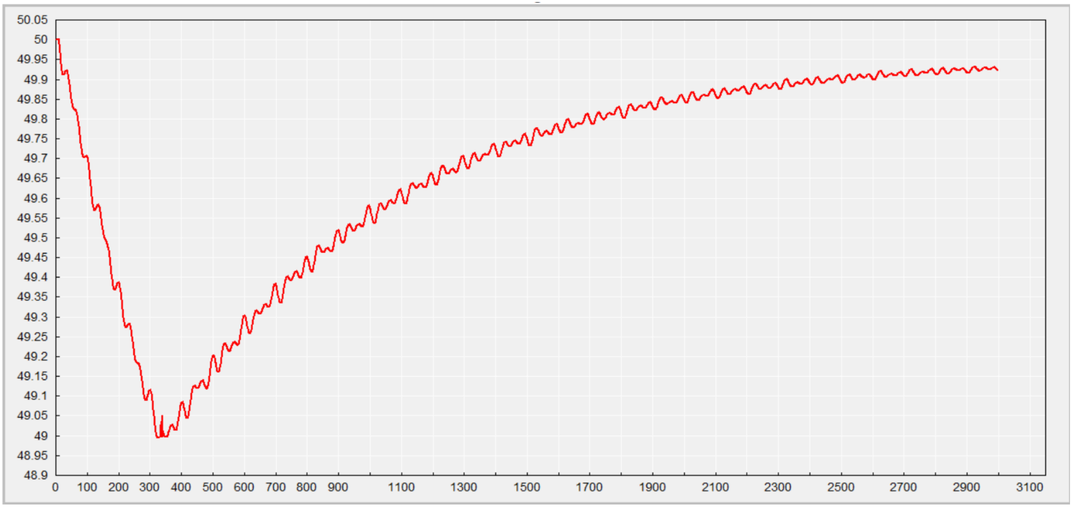
For the load frequency relief of 0.00% we got this result at Bus 37 i.e. the bus where the faulty Generator is connected:

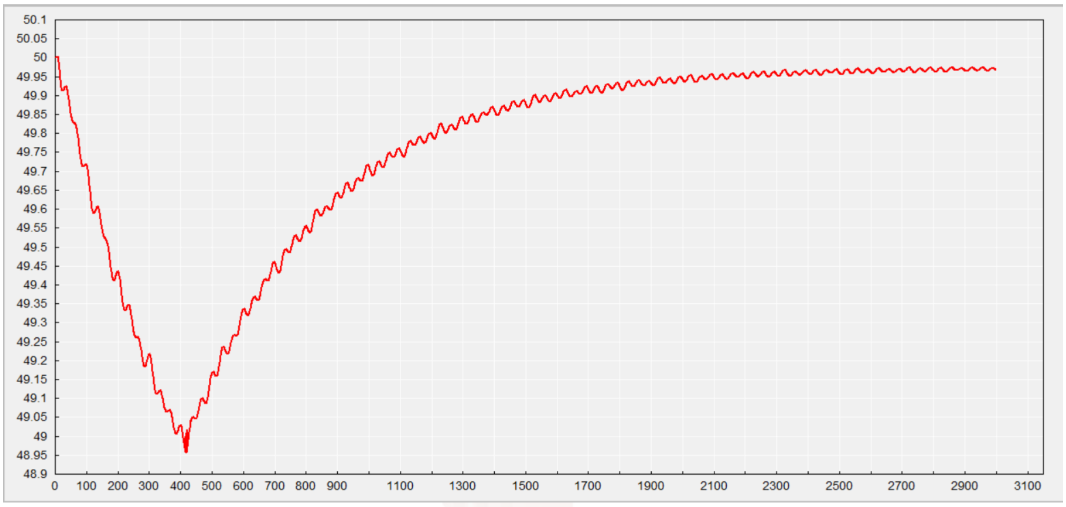


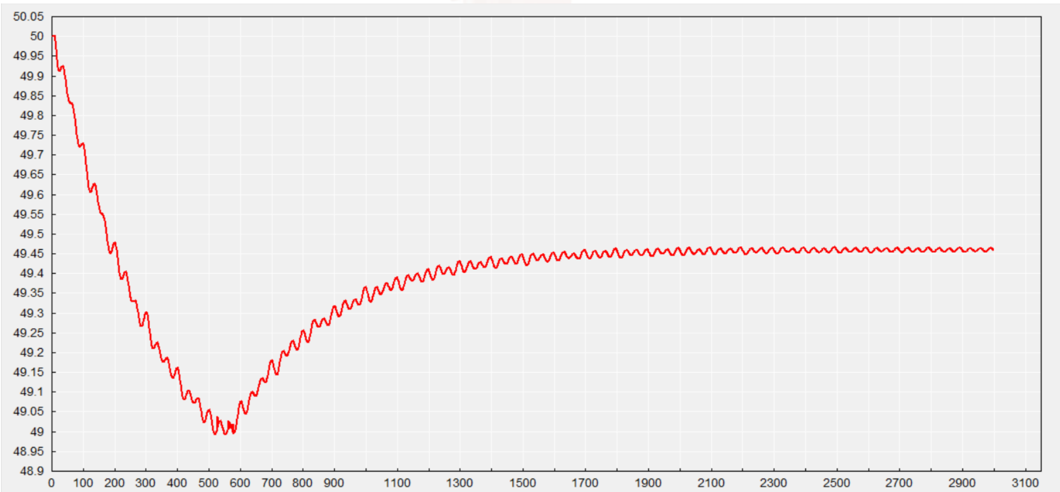
Where the nadir point is at approximately 48.95 Hz

Task 3

For Kp=1%, 2% and 3% we get the following curves:

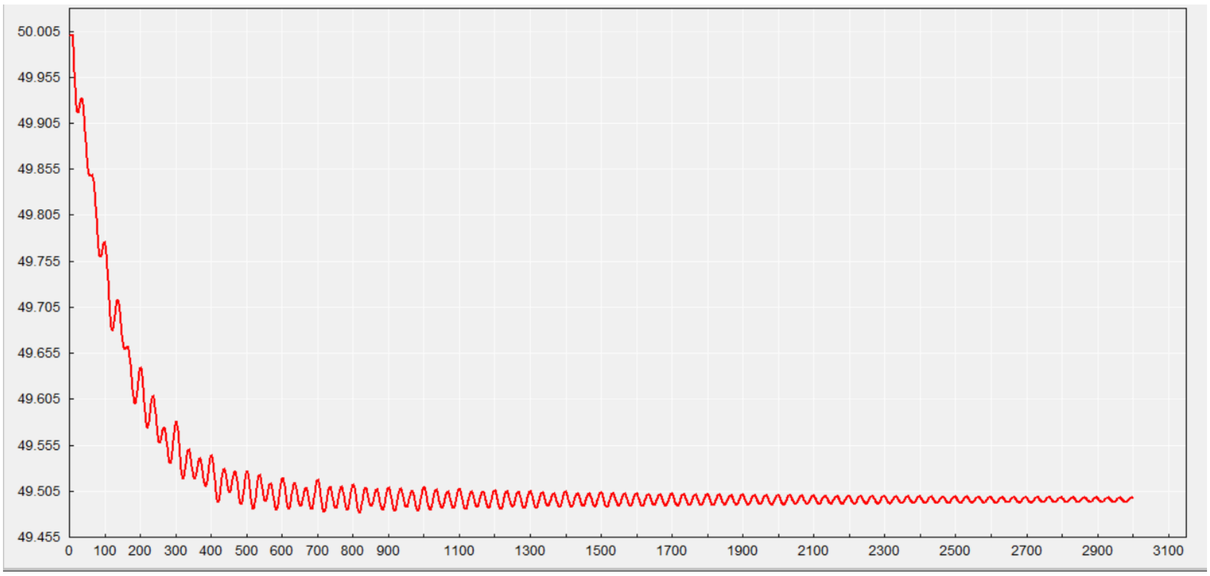






Here the nadir for kp=1% and 2% both are approximately 48.99 Hz which is already an improvement from the previous case. Moreover for kp=3% the value for nadir reaches 49.005 Hz.

For a better understanding we can take kp=8% and see that:



Here the nadir reaches 49.5 Hz which is better than we need.

Task 4

FVSI Calculation:

For stability we are using FVSI. In order to calculate FVSI we first import the line data given in the problem to matlab:

LineNo	From	To	Voltage	R	X	B	Distance
"1"	"1"	"2"	345	0.0035	0.0411	0.6987	275.5
"2"	"1"	"39"	345	0.001	0.025	0.75	167.6
"3"	"2"	"3"	345	0.0013	0.0151	0.2572	101.2
"4"	"2"	"25"	345	0.007	0.0086	0.146	57.6
"5"	"3"	"4"	345	0.0013	0.0213	0.2214	142.8
"6"	"3"	"18"	345	0.0011	0.0133	0.2138	89.1
"7"	"4"	"5"	345	0.0008	0.0128	0.1342	85.8
"8"	"4"	"14"	345	0.0008	0.0129	0.1382	86.5
"9"	"5"	"6"	345	0.0002	0.0026	0.0434	17.4
"10"	"5"	"8"	345	0.0008	0.0112	0.1476	75.1
"11"	"6"	"7"	345	0.0006	0.0092	0.113	61.7
"12"	"6"	"11"	345	0.0007	0.0082	0.1389	55
"13"	"7"	"8"	345	0.0004	0.0046	0.078	30.8
"14"	"8"	"9"	345	0.0023	0.0363	0.3804	243.3
"15"	"9"	"39"	345	0.001	0.025	1.2	167.6
"16"	"10"	"11"	345	0.0004	0.0043	0.0729	28.8
"17"	"10"	"13"	345	0.0004	0.0043	0.0729	28.8
"18"	"13"	"14"	345	0.0009	0.0101	0.1723	67.7
"19"	"14"	"15"	345	0.0018	0.0217	0.366	145.4
"20"	"15"	"16"	345	0.0009	0.0094	0.171	63
"21"	"16"	"17"	345	0.0007	0.0089	0.1342	59.7
"22"	"16"	"19"	345	0.0016	0.0195	0.304	130.7
"23"	"16"	"21"	345	0.0008	0.0135	0.2548	90.5
"24"	"16"	"24"	345	0.0003	0.0059	0.068	39.5
"25"	"17"	"18"	345	0.0007	0.0082	0.1319	55
"26"	"17"	"27"	345	0.0013	0.0173	0.3216	116
"27"	"21"	"22"	345	0.0008	0.014	0.2565	93.8
"28"	"22"	"23"	345	0.0006	0.0096	0.1846	64.3
"29"	"23"	"24"	345	0.0022	0.035	0.361	234.6
"30"	"25"	"26"	345	0.0032	0.0323	0.513	216.5
"31"	"26"	"27"	345	0.0014	0.0147	0.2396	98.5
"32"	"26"	"28"	345	0.0043	0.0474	0.7802	317.7
"33"	"26"	"29"	345	0.0057	0.0625	1.029	418.9
"34"	"28"	"29"	345	0.0014	0.0151	0.249	101.2

Then for the ease of calculation we create a 39x39 complex matrix the index of which represents the impedance between the bus numbers. For example (6,7) index of the matrix will hold the impedance between the bus 6 and 7.

```
>> z=zeros(39);
>> for i=1:34
from=str2num(LineData.From(i));
to=str2num(LineData.To(i));
z(from,to)=z(from,to)+LineData.R(i)+j*LineData.X(i);
end
```

```
>> z=z+z'
```

Point to be noted is that this is not a typical z bus matrix because the self impedances are not measured as they are not important for our FVSI calculations. Only mutual impedances have been measured and the zero values of the matrix doesn't represent short circuit but represents disconnection.

We do the same for Transformer Data. First we import the given data to MATlab:

```
Xdata =

  12×8 table
```

Name	SMVA	FromBus	ToBus	HVkV	LVkV	Rpu	Xpu
"T01"	"300"	12	11	345	138	0.0048	0.1305
"T02"	"300"	12	13	345	138	0.0048	0.1305
"T03"	"700"	6	31	345	16.5	1e-05	0.175
"T04"	"800"	10	32	345	16.5	1e-05	0.16
"T05"	"800"	19	33	345	16.5	0.0056	0.1136
"T06"	"2 X 300"	20	34	230	16.5	0.0054	0.108
"T07"	"800"	22	35	345	16.5	1e-05	0.1144
"T08"	"700"	23	36	345	16.5	0.0035	0.1904
"T09"	"700"	25	37	345	16.5	0.0042	0.1624
"T10"	"1000"	2	30	345	16.5	1e-05	0.181
"T11"	"1000"	29	38	345	16.5	0.008	0.156
"T12"	"1000"	19	20	345	230	0.007	0.138

Then we create the z matrix like matrix for the transformer line impedances.

```
>> zx=zeros(39);
>>  for i=1:12
from=Xdata.FromBus(i);
to=Xdata.ToBus(i);
zx(from,to)=zx(from,to)+Xdata.Rpu(i)+j*Xdata.Xpu(i);
end
>> zx=zx+zx';
```

Point to be noted is that this is not a typical z bus matrix because the self impedances are not measured as they are not important for our FVSI calculations. Only mutual impedances have been measured and the zero values of the matrix doesn't represent short circuit but represents disconnection.

We then find the total impedance of line and transformer

```
>> Ztot=z+zx;
```

Now from the load flow analysis done on task 1 we use the resultant output for further calculations:

We take Q_{Load} and V_{Source} from the simulation,

	ID	Zone	kV Base	V sol [kv]	Ang sol [deg]	Vmin [kv]	Vmax [kv]	P Gen [MW]	Q Gen [MVAR]	P Load [MW]	Q Load [MVAR]	P motor [MW]	Q motor [MVAR]	P shunt [MW]	Q shunt [MVAR]
1	B1	0	345.00	346.23	-9.5	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	B10	0	345.00	330.77	-5.6	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	B11	0	345.00	329.24	-6.5	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	B12	0	138.00	128.80	-6.5	124.20	151.80	0.00	0.00	7.50	88.00	0.00	0.00	0.00	0.00
5	B13	0	345.00	328.94	-6.4	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	B14	0	345.00	326.15	-8.3	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	B15	0	345.00	324.19	-8.4	310.50	379.50	0.00	0.00	320.00	153.00	0.00	0.00	0.00	0.00
8	B16	0	345.00	329.02	-6.7	310.50	379.50	0.00	0.00	329.00	32.00	0.00	0.00	0.00	0.00
9	B17	0	345.00	330.81	-8.0	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	B18	0	345.00	330.62	-9.1	310.50	379.50	0.00	0.00	158.00	30.00	0.00	0.00	0.00	0.00
11	B19	0	345.00	332.07	-0.6	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	B2	0	345.00	339.17	-6.3	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	B20	0	230.00	222.17	-1.6	207.00	253.00	0.00	0.00	628.00	103.00	0.00	0.00	0.00	0.00
14	B21	0	345.00	328.87	-3.9	310.50	379.50	0.00	0.00	274.00	115.00	0.00	0.00	0.00	0.00
15	B22	0	345.00	335.90	1.3	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	B23	0	345.00	334.63	1.1	310.50	379.50	0.00	0.00	247.00	84.00	0.00	0.00	0.00	0.00
17	B24	0	345.00	331.11	-6.5	310.50	379.50	0.00	0.00	308.00	-92.20	0.00	0.00	0.00	0.00
18	B25	0	345.00	343.08	-4.8	310.50	379.50	0.00	0.00	224.00	47.20	0.00	0.00	0.00	0.00
19	B26	0	345.00	339.50	-6.1	310.50	379.50	0.00	0.00	139.00	17.00	0.00	0.00	0.00	0.00
20	B27	0	345.00	333.22	-8.3	310.50	379.50	0.00	0.00	281.00	75.50	0.00	0.00	0.00	0.00
21	B28	0	345.00	340.74	-2.1	310.50	379.50	0.00	0.00	206.00	27.60	0.00	0.00	0.00	0.00
22	B29	0	345.00	341.71	1.0	310.50	379.50	0.00	0.00	283.00	26.90	0.00	0.00	0.00	0.00
23	B3	0	345.00	331.57	-9.5	310.50	379.50	0.00	0.00	322.00	2.40	0.00	0.00	0.00	0.00
24	B30	0	16.50	16.50	-3.7	14.85	18.15	250.00	99.04	0.00	0.00	0.00	0.00	0.00	0.00
25	B31	0	16.50	16.50	0.0	14.85	18.15	548.24	243.59	9.20	4.60	0.00	0.00	0.00	0.00
26	B32	0	16.50	16.50	2.0	14.85	18.15	632.00	248.09	0.00	0.00	0.00	0.00	0.00	0.00
27	B33	0	16.50	16.50	13.6	14.85	18.15	632.00	145.78	0.00	0.00	0.00	0.00	0.00	0.00
28	B34	0	16.50	16.50	3.7	14.85	18.15	508.00	187.11	0.00	0.00	0.00	0.00	0.00	0.00
29	B35	0	16.50	16.50	6.8	14.85	18.15	650.00	215.48	0.00	0.00	0.00	0.00	0.00	0.00
30	B36	0	16.50	16.50	10.1	14.85	18.15	560.00	144.07	0.00	0.00	0.00	0.00	0.00	0.00
31	B37	0	16.50	16.50	2.4	14.85	18.15	540.00	44.08	0.00	0.00	0.00	0.00	0.00	0.00
32	B38	0	16.50	16.50	8.5	14.85	18.15	830.00	72.53	0.00	0.00	0.00	0.00	0.00	0.00
33	B39	0	345.00	345.00	-11.4	310.50	379.50	1000.00	205.47	1104.00	250.00	0.00	0.00	0.00	0.00
34	B4	0	345.00	323.50	-10.6	310.50	379.50	0.00	0.00	500.00	184.00	0.00	0.00	0.00	0.00
35	B5	0	345.00	325.48	-9.6	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	B6	0	345.00	327.70	-8.2	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	B7	0	345.00	322.22	-11.8	310.50	379.50	0.00	0.00	233.80	84.00	0.00	0.00	0.00	0.00
38	B8	0	345.00	322.34	-12.2	310.50	379.50	0.00	0.00	522.00	176.00	0.00	0.00	0.00	0.00
39	B9	0	345.00	339.75	-11.8	310.50	379.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

And only Import necessary part to MATlab

BusNo	Vs	Ql
"1"	346.23	0
"10"	330.77	0
"11"	329.24	0
"12"	128.8	88
"13"	328.94	0
"14"	326.15	0
"15"	324.19	153
"16"	329.02	32
"17"	330.81	0
"18"	330.62	30
"19"	332.07	0
"2"	339.17	0
"20"	222.17	103
"21"	328.87	115
"22"	335.9	0
"23"	334.63	84
"24"	331.11	-92.2
"25"	343.08	47.2
"26"	339.5	17
"27"	333.22	75.5
"28"	340.74	27.6
"29"	341.71	26.9
"3"	331.57	2.4
"30"	16.5	0
"31"	16.5	4.6
"32"	16.5	0
"33"	16.5	0
"34"	16.5	0
"35"	16.5	0
"36"	16.5	0
"37"	16.5	0
"38"	16.5	0
"39"	345	250
"4"	323.5	184
"5"	325.48	0
"6"	327.7	0
"7"	322.22	84
"8"	322.34	176
"9"	339.75	0

Then first we separate the loading buses

```
Final=BusVQ((BusVQ.Ql~=0),:)
```

```
Final =

  19×3 table
```

BusNo	Vs	Ql
"12"	128.8	88
"15"	324.19	153
"16"	329.02	32
"18"	330.62	30
"20"	222.17	103
"21"	328.87	115
"23"	334.63	84
"24"	331.11	-92.2
"25"	343.08	47.2
"26"	339.5	17
"27"	333.22	75.5
"28"	340.74	27.6
"29"	341.71	26.9
"3"	331.57	2.4
"31"	16.5	4.6
"39"	345	250
"4"	323.5	184
"7"	322.22	84
"8"	322.34	176

Now we calculate the FVSI for all the connected buses to the load and use the maximum value as the FVSI of that load bus. The formula used for finding FVSI is:

$$FVSI_j = max\left(\frac{4 * Z_{ij} * Q_j}{V_i^2 * X_{ij}}\right);$$

Where j is the load bus, i is the source and ij is source to load.

```
FVSI=[];
for i=1:height(Final)
   FVSI(i,:)=max(abs((4*abs(Ztot(str2num(Final.BusNo(i)),:))*Final.Ql(i))./...
        (Final.Vs(i)*Final.Vs(i)*1000*imag(Ztot(str2num(Final.BusNo(i)),:)))));
end
```

Then the sort it in Descending order:

```
Sol=[table(Final.BusNo),table(FVSI)];
[~,idx]=sort(FVSI,'descend');
sortedBus=Sol(idx,:)
```

And Finally we get out busses sorted according to their FVSI index

	Var1	FVSI	
	"31"	6.7585e-05	Zone 1
Weaker	"12"	2.1233e-05	
	"39"	8.4083e-06	
	"20"	8.3577e-06	
	"4"	7.0465e-06	Zone 2
	"8"	6.8011e-06	
	"15"	5.8497e-06	
	"21"	4.2606e-06	
	"24"	3.3706e-06	
	"7"	3.2484e-06	Zone 3
	"23"	3.0065e-06	
	"27"	2.7322e-06	
	"25"	2.0682e-06	
	"16"	1.1878e-06	
	"18"	1.1018e-06	Zone 4
	"28"	9.5495e-07	
	"29"	9.2546e-07	
	"26"	5.9286e-07	
Stronger	"3"	8.7644e-08	

Here the buses had been sorted from weaker to stronger.

Task 5

Now we divided the buses at different zones.

Bus Number	Zone
31	1
12	
39	
20	
4	2
8	
15	
21	
24	
7	3
23	
27	
25	
16	
18	4
28	
29	
26	
3	
Rest	0

We put non loaded buses at zone zero which doesn't require any load shedding. The weaker buses are at zone 1 and the strongest at zone 4. We apply more load cut at the weaker buses and less load cut at the stronger ones.

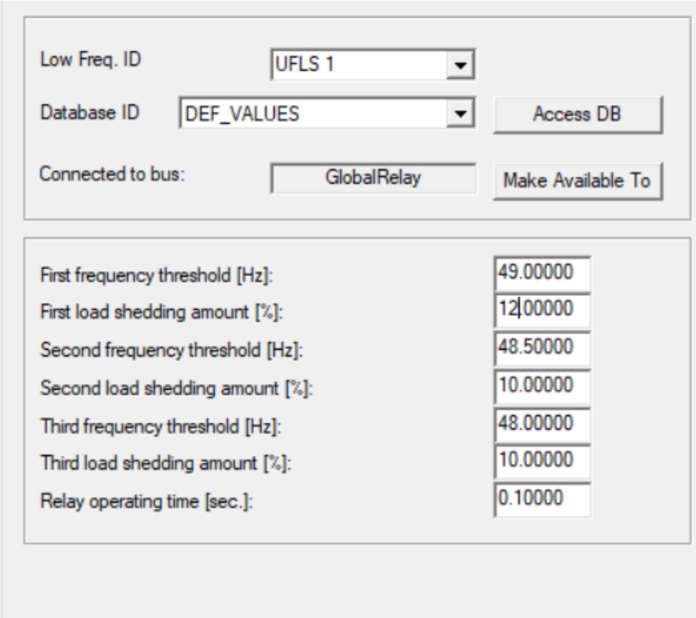
After putting the zones to the bus number according to the FVSI index we get something like this:

Bus No	Zone
B1	0
B10	0
B11	0
B12	1
B13	0
B14	0
B15	2
B16	3
B17	0
B18	4
B19	0
B2	0
B20	1
B21	2
B22	0
B23	3
B24	2
B25	3
B26	4
B27	3

Bus No	Zone
B28	4
B29	4
B3	0
B30	0
B31	1
B32	0
B33	0
B34	0
B35	0
B36	0
B37	0
B38	0
B39	1
B4	2
B5	0
B6	0
B7	3
B8	2
B9	0

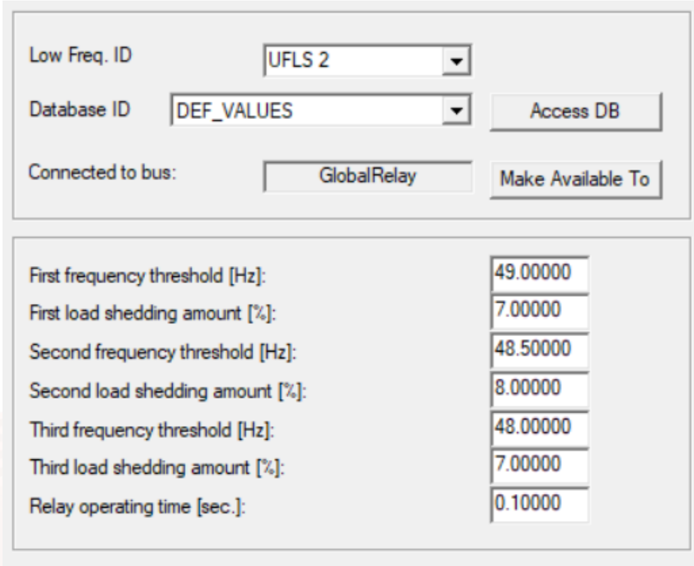
Now we look at the load shedding scheme for each of the zones:

For **Zone 1** which needs the highest load cut the load shedding scheme is like this:



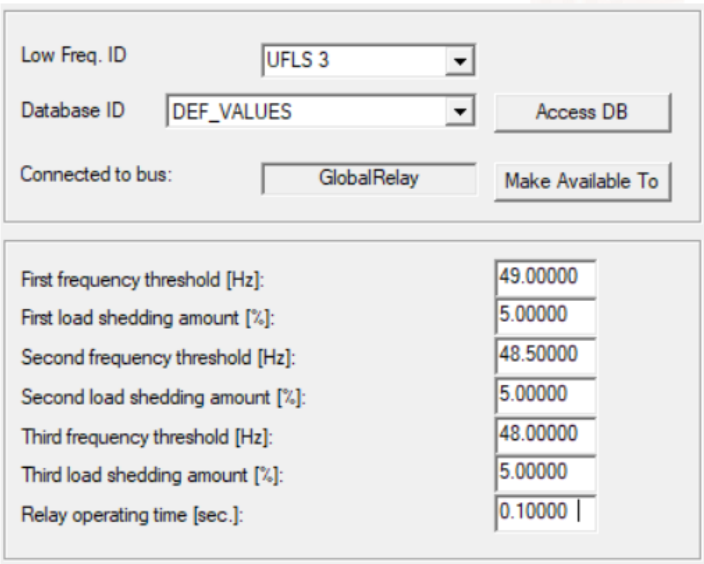
Low Freq. ID	UFLS 1
Database ID	DEF_VALUES
Connected to bus:	GlobalRelay
First frequency threshold [Hz]:	49.00000
First load shedding amount [%]:	12.00000
Second frequency threshold [Hz]:	48.50000
Second load shedding amount [%]:	10.00000
Third frequency threshold [Hz]:	48.00000
Third load shedding amount [%]:	10.00000
Relay operating time [sec.]:	0.10000

For **Zone 2** that is more stable than zone 1:



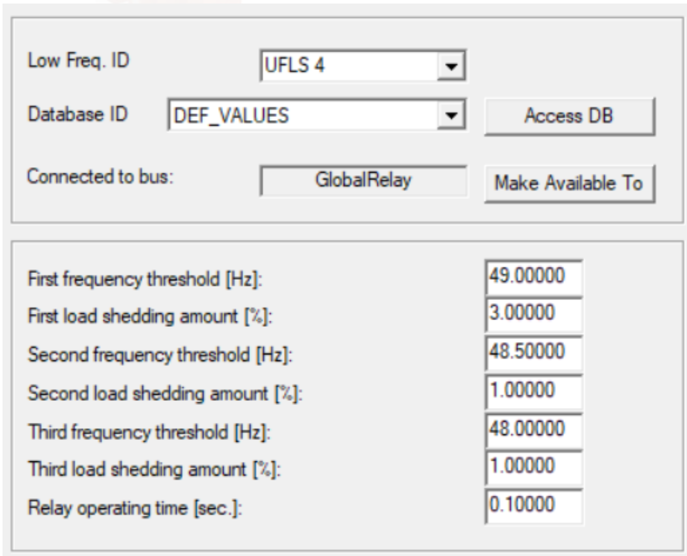
Low Freq. ID	UFLS 2
Database ID	DEF_VALUES
Connected to bus:	GlobalRelay
First frequency threshold [Hz]:	49.00000
First load shedding amount [%]:	7.00000
Second frequency threshold [Hz]:	48.50000
Second load shedding amount [%]:	8.00000
Third frequency threshold [Hz]:	48.00000
Third load shedding amount [%]:	7.00000
Relay operating time [sec.]:	0.10000

For **Zone 3**:



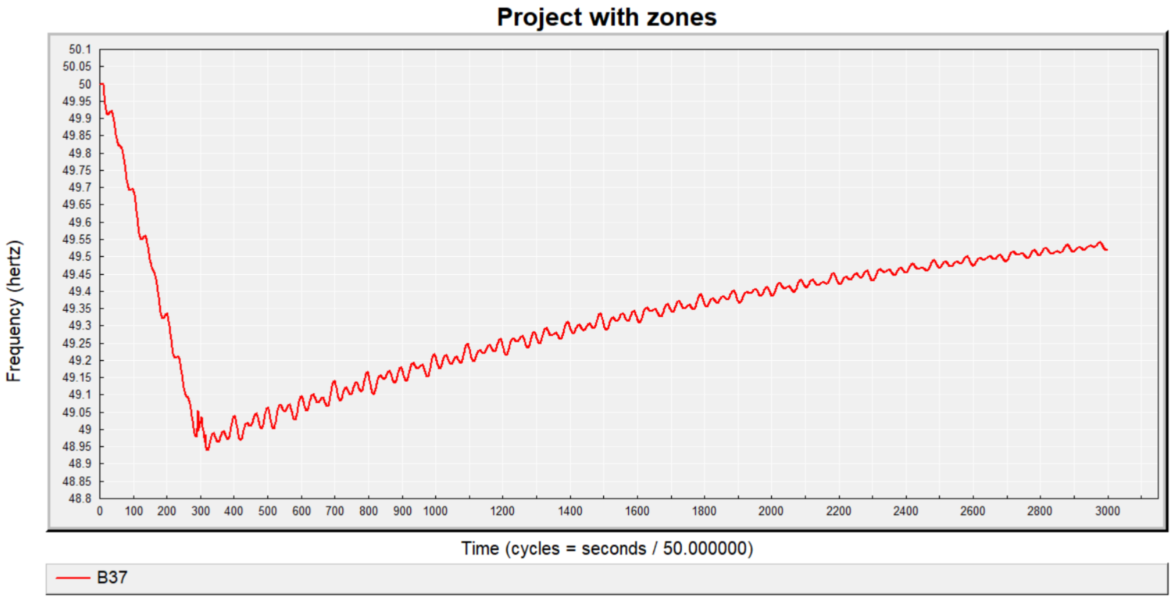
Low Freq. ID	UFLS 3
Database ID	DEF_VALUES
Connected to bus:	GlobalRelay
First frequency threshold [Hz]:	49.00000
First load shedding amount [%]:	5.00000
Second frequency threshold [Hz]:	48.50000
Second load shedding amount [%]:	5.00000
Third frequency threshold [Hz]:	48.00000
Third load shedding amount [%]:	5.00000
Relay operating time [sec.]:	0.10000

Finally for **Zone 4** which needs the least amount of load cut:



Low Freq. ID	UFLS 4
Database ID	DEF_VALUES
Connected to bus:	GlobalRelay
First frequency threshold [Hz]:	49.00000
First load shedding amount [%]:	3.00000
Second frequency threshold [Hz]:	48.50000
Second load shedding amount [%]:	1.00000
Third frequency threshold [Hz]:	48.00000
Third load shedding amount [%]:	1.00000
Relay operating time [sec.]:	0.10000

And we get the time vs frequency plot using kp=0 at bus 37 like this:

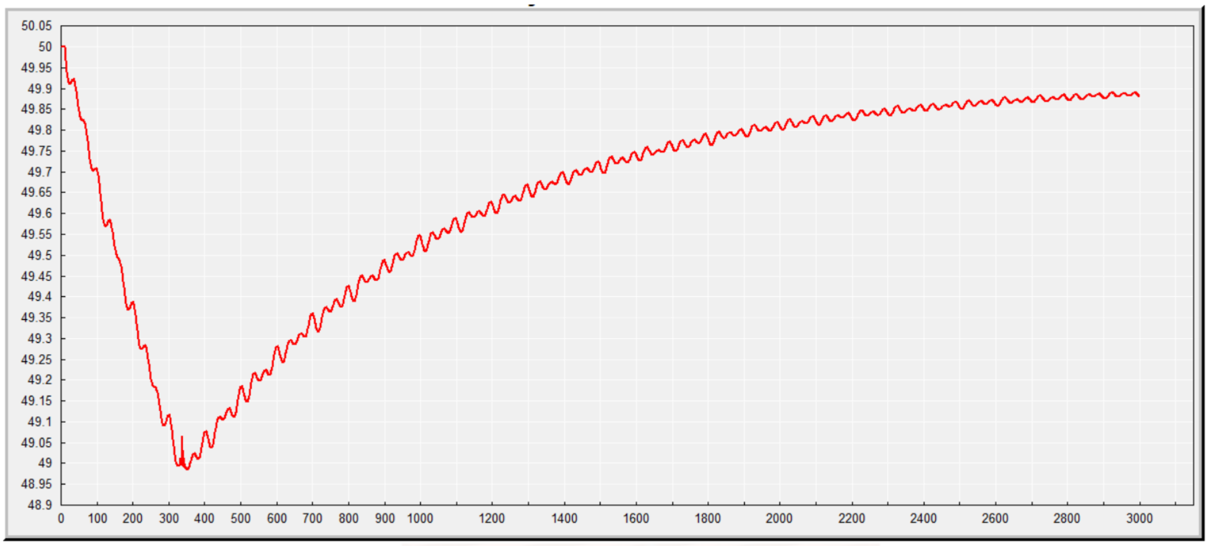


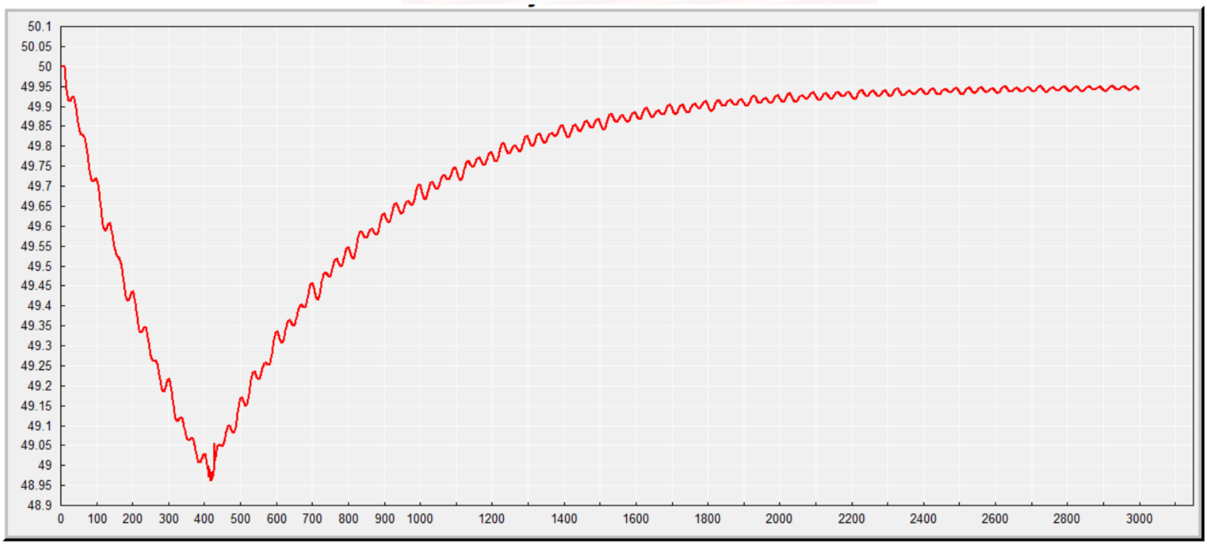
Here the nadir is approximately 48.95 Hz.

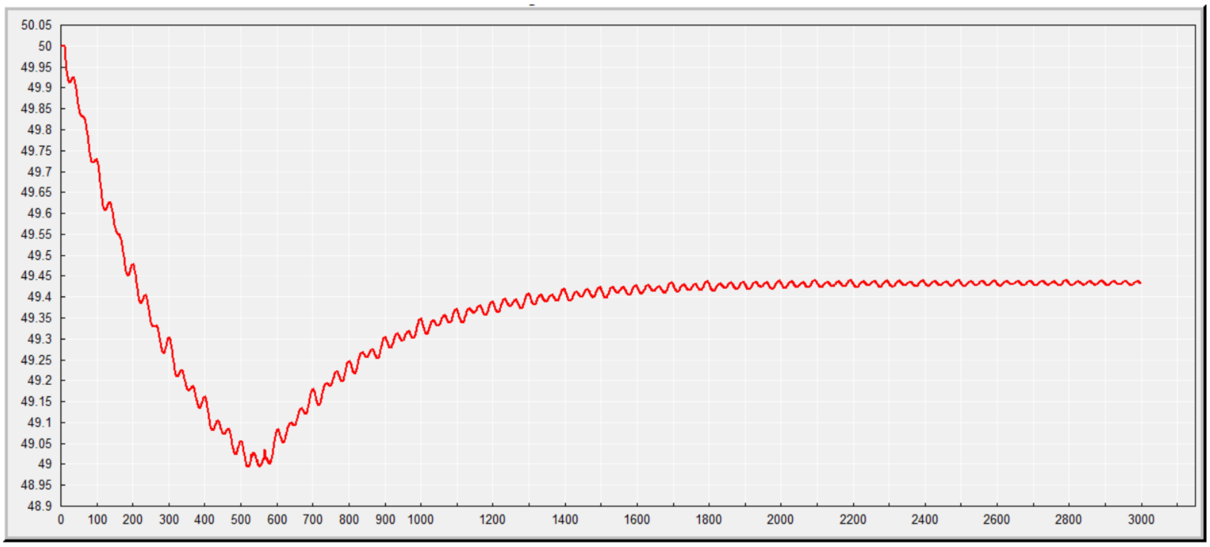
We can see that even though the response may seem like same as before dividing to zones but if we look the bigger picture, in the previous case a huge amount of load was cut from all the loads however in this case only that huge percentage was cut from a small set of loads and overall the load cut is less.

Task 6:

Now we run the simulation using kp=1, 2 & 3 respectively and see the results.

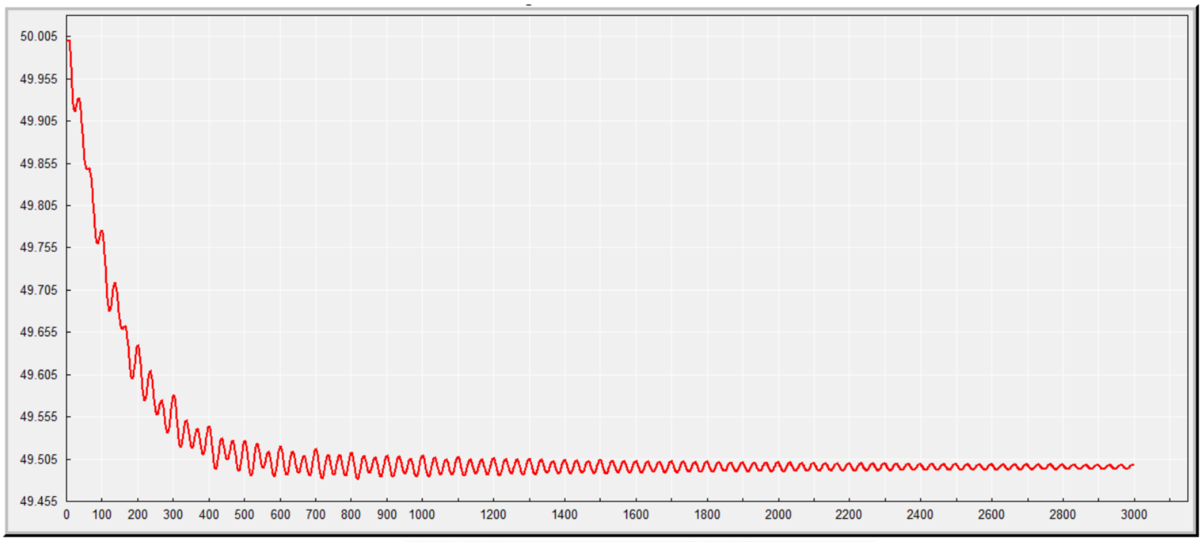






Here the nadir for kp=1% and 2% both are approximately 48.99 Hz which is already an improvement from the previous case. Moreover for kp=3% the value for nadir reaches 49.005 Hz.

For a better understanding we can take kp=8% and see that:



Here the nadir reaches 49.5 Hz which is better than we need.

Conclusion:

In this report, voltage stability was determined using the Fast Voltage Stability Index (FVSI) technique. Simulations were performed using PSAF software. The FVSI has revealed the stability margins of various lines. This investigation also showed that higher reactive power loads result in higher FVSI values, which indicate instability.

It was essential to include the impedance of the lines as well as the transformers when performing the assessment in order to give the most accurate results. Systems in which more than one line is connected to a single bus require a combination of individual and combined assessments for a complete investigation.

The impact of changes in reactive power and the sensitivity of FVSI indicate that accurate load models should be kept updated. Management strategies, such as capacitor banks and reactive power compensation, should be used. The impedance of transformers should be accurately modeled, and its maintenance and upgrade will enhance stability.

Further work can include a dynamic stability assessment combined with FVSI for further detail. Advanced analytics like machine learning can be applied for higher prediction accuracy. The PSAF combined with MATLab was proven a very effective tool for FVSI calculation, but further software and algorithms for this and other programs in the pipeline are vital as power systems evolve.

Contribution List for Project Members

Member 1: Annim Jannat (200021311)

Task: Overall coordination, Data Compilation and Simulation

- Compiled the data from the problem and helped to input the data
- Distributed the work among the members
- Organized and formatted data for use in PSAF software simulations by manual data entry or online image to excel converter
- Task 1, 2 & 3

Member 2: Fariha Alam Urbana (200021315)

Task: Simulation and Load Shedding Schemes

- Set up and ran simulations using PSAF software for load flow analysis
- Helped with data entry
- Designed the UFLS settings
- Task 1, 5, 6

Member 3: Faek Bin Rahman (200021205)

Task: FVSI calculation and MATLab

- Task 4

Member 4: Kushal Muhammed (200021209)

Task: Data entry, Report Writing and Presentation

- Helped with initial data entry
- Compiled and organized all findings into a comprehensive report.
- Wrote the conclusion and discussion sections, summarizing key insights and recommendations.
- Prepared and delivered the final presentation.