BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Department of Electrical and Electronic Engineering

Course No.	**:** EEE 412	**Group No**	**:** 08
Course Title	**:** Power System II Laboratory	**Section**	**:** G2

Project Report on:

Analysis of South Australian 14-BUS system and Implementation of a Zonal UFLs Scheme using PSSE

Submitted to:

Asikur Rahman Jowel Lecturer Dept. of EEE, BUET	Md. Obaidur Rahman Lecturer Dept. of EEE, BUET

Level-4 **Term-2**

Submitted By:

SAMIN ZAWAD	**1706136**	AHNAF SHAHRIAR	**1706176**
MAHADI HASSAN	**1706137**	MD. FATIN ISHRAQ FARUQUI	**1706179**
MD. TAJBID ZAMAN RHYTHM	**1706152**	ZAWAD ZULFIKER	**1706193**
FARHAN HAMID	**1706175**		

1 Introduction:

In recent time, wind integration has considerably increased in power systems all around the world. As a result, the system has become greener. The dependence on coal, diesel or other hydrocarbons has sufficiently decreased in terms of power generation. But there are some disadvantages of integrating wind turbines as well. The wind turbine cannot provide inertia when any contingency occurs. So, with increasing wind integration inertia of the system decreases. Under such situation, load shedding becomes almost inevitable. But load shedding should be our last resort. So, we need to optimize the load shedding schemes in order to minimize the amount of load shed to maximize the frequency nadir in case of any contingency.

In this project, we have dealt with South Australian 14 bus power system. We have particularly focused on areas 5 and 3. In between the areas there is an interconnection of 650 MW. We simulated the case of interconnection tripping and analyzed the UFLs frequency scheme under conventional method. Then we proposed a scheme by optimization by analyzing QV curve. We ranked the busses in terms of QV curve and applied the largest load shedding in the weakest bus. Then we compared the load shedding schemes and proved why ours was more competent.

2 Objective:

- To make analysis on the grid network after disconnecting the interconnection between area 3 and area 5.
- To analyze the contingency and run a traditional UFLs scheme.
- To develop a modified UFLs scheme based on QV analysis for better optimization.
- To compare between traditional and modified UFLs scheme

3 System Analysis:

We have constructed a simulated model based on the of South East Australia 14-Generator Model. The network diagram of the studied grid is illustrated in the given figure. The system consists of 14 buses and 2 interconnected areas. Area-5 specifies the low inertia network, which is an equivalent representation of South Australia's high- voltage transmission network. As South Australia has one of the highest wind penetration levels compared to its demand in the world, it can be treated as a typical example of a low inertia wind dominated power system. Area-5 is connected to Area-3 (denotes the neighboring state Victoria) via a high voltage AC interconnection. The total wind power generation capacity in Area-5 is around 1350 MW. Due to this significant installed wind capacity, the number of fossil- fueled power plants has been considerably reduced in recent times.

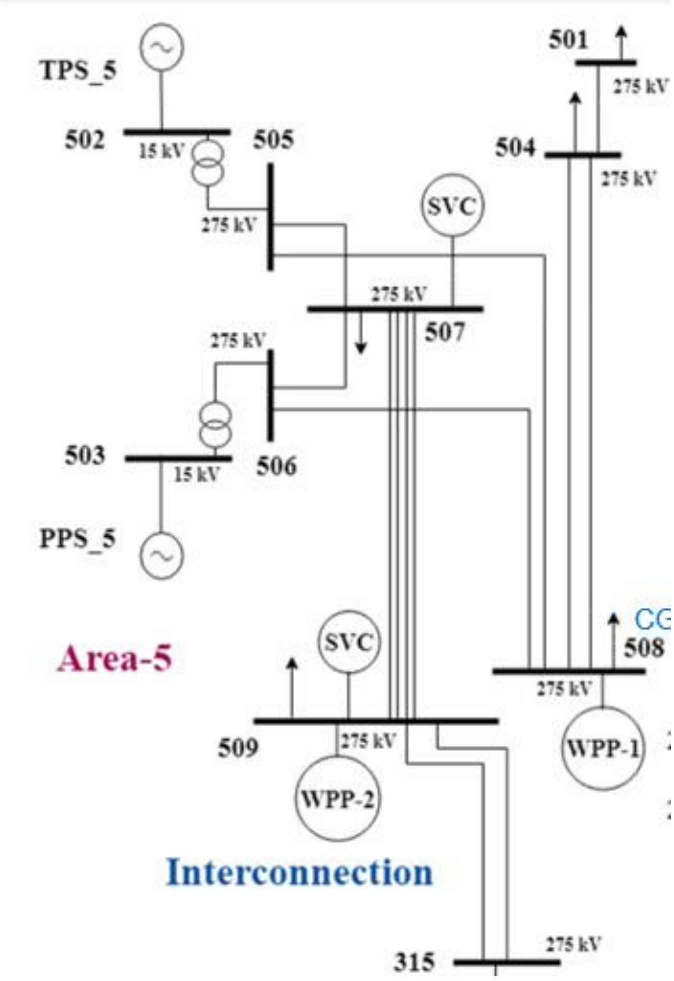


Figure: Single Line Diagram of Simulated Model

Here, we interconnect Area 5 and Area 3 through a HVAC lines. This connection is from bus 315 to bus 509. We have modeled this interconnection as (-)ve load as in practical scenario, no interconnection can provide inertial response.

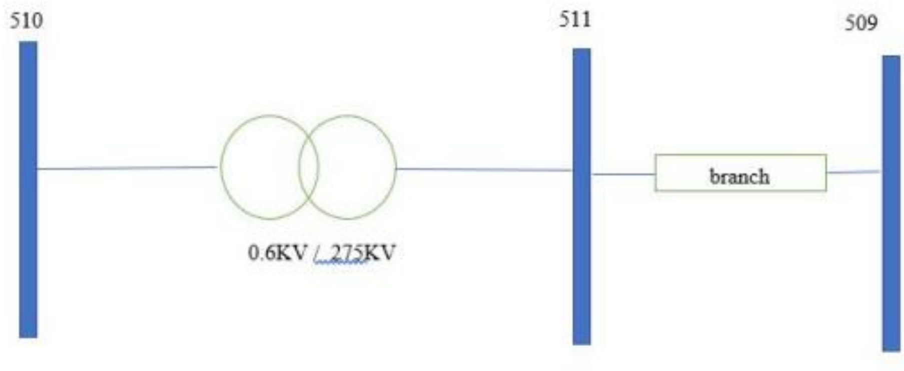


Figure: Wind Turbine connected to 509

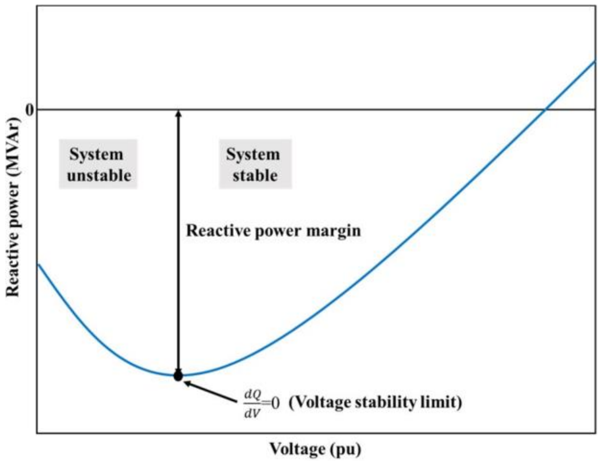
Two wind turbines are connected to bus 508 and bus 509 through dummy buses 511 and 521 respectively. Here we used dummy buses as we couldn't step up the voltage in a single stage. For this, we had to use dual stage voltage stepping up.

4 Methodology

A load shedding methodology is designed to simultaneously retain frequency and voltage stabilities. In this method, reactive power margin is deployed as a tool to determine the required amount of load to be shed at each P-Q bus. UFLs relays are set such that weaker buses encounter relatively higher amount of load cut.

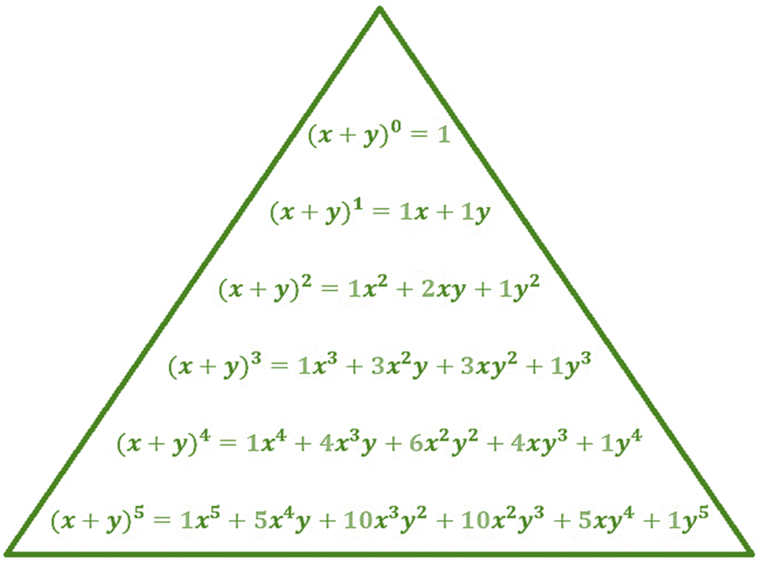
- ## Reactive Power Margin

The reactive power margin of a load (P-Q) bus is defined as the MVAr distance among the nadir point of Q-V curve and voltage axis is shown below. The lowest point of the Q-V curve denotes the voltage collapse point. The lowest reactive power margin manifests that the corresponding bus is the weakest bus in a network.



- ## Modified Load Shedding Scheme

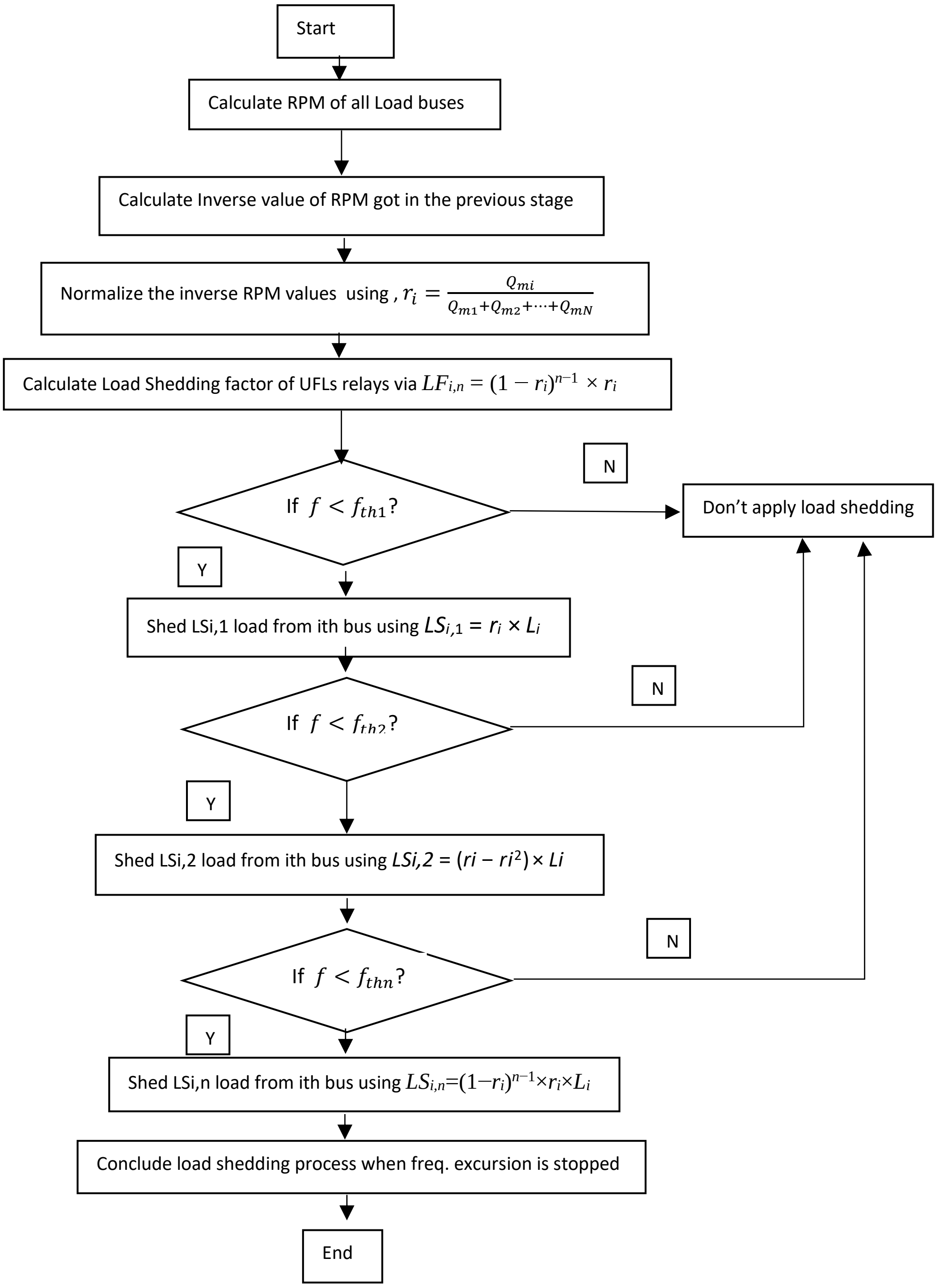
Firstly, reactive power margins for all P-Q buses are calculated using the procedures mentioned in previous sub-sections. To preserve voltage stability, greater amount of load needs to be shed at weaker buses. As mentioned earlier, a lower reactive power margin indicates a weaker bus. Therefore, inverse values of reactive power margins are determined. Then, these values are normalized to calculate an index called reactive margin factor. For the *n*-th stage, the amount of load shedding encountered by *i*-th load bus can be expressed using equation, $\boldsymbol{LS_{i,n}=(1-r_i)^{n-1}\times r_i\times L_i}$. This equation represents as pascal's triangle, e.g. $\boldsymbol{LS_{i,6} = (r_i - 5r^2 + 10r^3 - 10r^4 + 5r^5 - r^6) \times L_i}$. we can also check it from 6th row of the following triangle.



As mentioned earlier, the inverse of reactive power of load buses is used to calculate the reactive margin factor because of getting which bus and how much it should be shed in percentage in our proposed load shedding scheme. As it got higher when it's reciprocal for the weakest bus, we have to load shed higher than the other.

In the proposed method, normalization is done while calculating the reactive margin factor of all load buses using the equation $\boldsymbol{r_i = \frac{Q_{mi}}{Q_{m1}+Q_{m2}+\cdots+Q_{mN}}}$. Thus, the impact of load variation does not significantly affect the values of reactive margin factor. Therefore, the load shedding factors determined in a specific load level can be generally used for other load conditions.

- **Steps for Implementation:**



- ## Centre of Frequency

To eliminate small signal oscillations in the measured frequency, an equivalent system frequency after a synchronous generator trip is computed by,

$$f_{eq} = \frac{\sum_{i=1}^{i=n}(H_i * S_i * f_i)}{\sum_{i=1}^{i=n}(H_i * S_i)}$$

Where S_i is the rated MVA of i^{th} synchronous generator, H_i denotes the inertia constant of i^{th} synchronous generator, f_i is the frequency of i^{th} synchronous generator and n denotes the total number of committed synchronous generator.

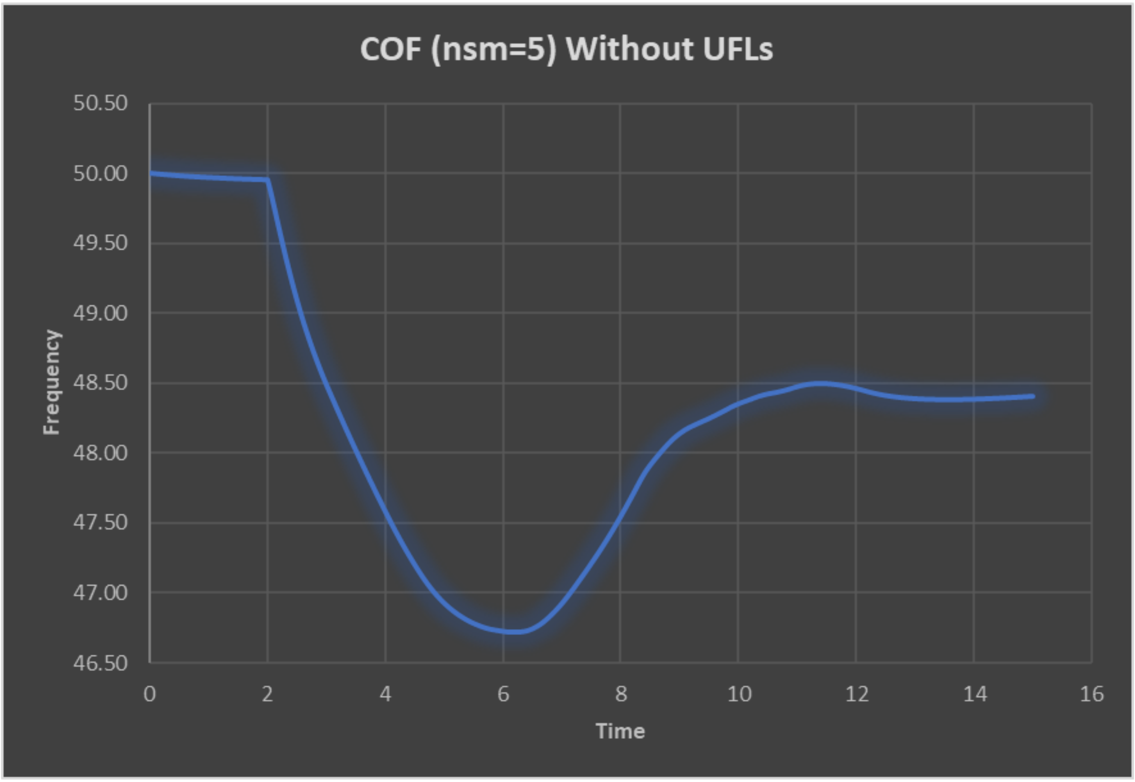
- ## Nadir Calculation:

After exporting the data of frequency deviation from PSSE to Excel we have implemented the above formula to calculate the center of frequency (COF) and plotted it in the software. We have also compared the conventional and modified load shedding scheme to get a visual representation of Nadir improvement.

Frequency Response Analysis

i. Without UFLs Analysis:

Firstly, we implemented the 650 MW system without any UFLS. The number of synchronous machines which were active were 5. We tripped the interconnection and observed the frequency which came out to be as following:



The nadir of this frequency plot was 46.72 Hz which is quite dangerous for the system but this kind of response was expected as there were no employment of UFLs. But practical systems always have UFLs.

ii. Trivial UFLs scheme analysis

So, next, we implemented UFLs but of trivial or conventional scheme. The conventional scheme is as follows:

Bus ID	1st stage frequency threshold	1st stage load shedding %	2nd Stage frequency threshold	2nd stage load shedding %	3rd stage frequency threshold	3rd stage load shedding %
504	49.25	20	48.75	20	48.25	10
507	49.25	20	48.75	20	48.25	10
508	49.25	20	48.75	20	48.25	10
509	49.25	20	48.75	20	48.25	10

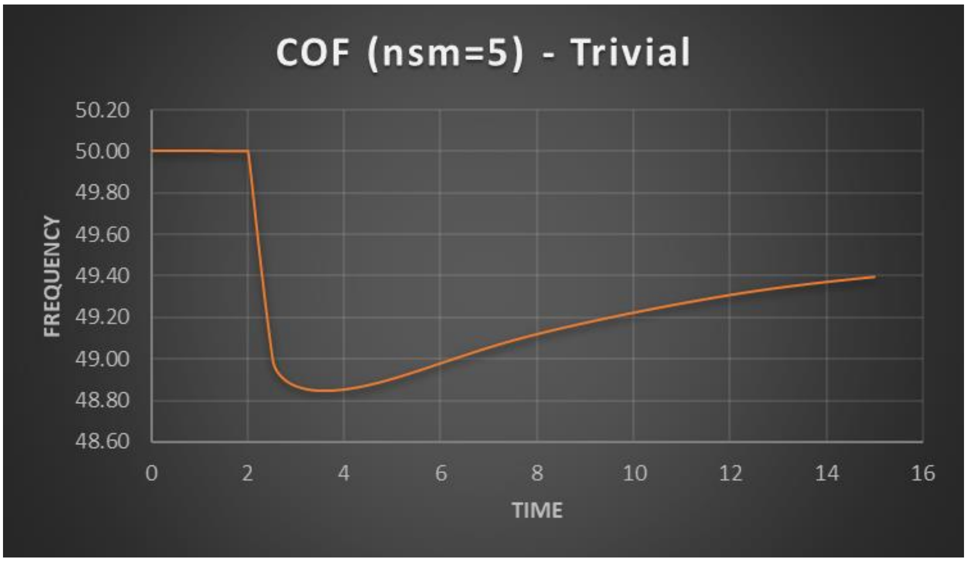
We implemented the load shedding schemes in the dyr file. The changes we made were as follows:

```
/trivial/
509 'LDSHBL' * 49.25 .150 0.2 48.75 .150 0.2 48.25 .150 0.1 0.00 /
507 'LDSHBL' * 49.25 .150 0.2 48.75 .150 0.2 48.25 .150 0.1 0.00 /
504 'LDSHBL' * 49.25 .150 0.2 48.75 .150 0.2 48.25 .150 0.1 0.00 /
508 'LDSHBL' * 49.25 .150 0.2 48.75 .150 0.2 48.25 .150 0.1 0.00 /
```

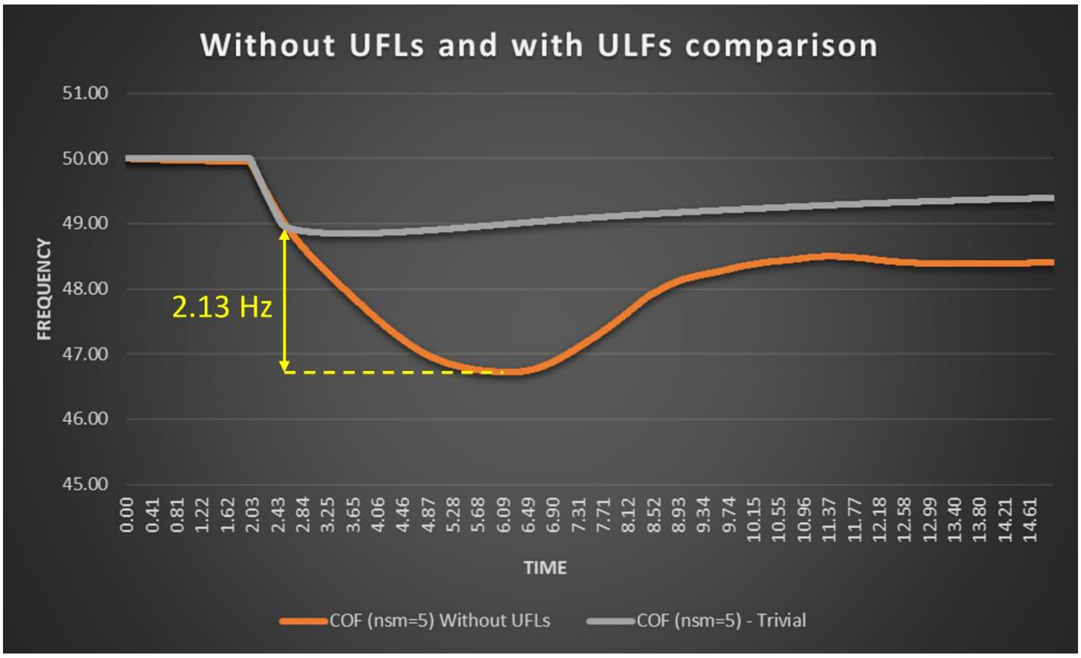
Next, we determined the center of frequency (COF) by taking the data files from PSSE to excel and implementing the formula for COF mentioned in the methodology. A working picture of the excel file is given below:

time	502(1)	502(2)	502(3)	502(5)	503(1)			S	H	S*H	502(1) nev	502(2) nev	502(3) nev	502(5) nev	503(1) nev	SUM	COF (nsm=	nadir
0	9.31E-11	9.31E-11	9.31E-11	9.31E-11	-1.97E-05		502(1)	3.00E+02	4.00E+00	1200.00	6.00E+04	6.00E+04	6.00E+04	6.00E+04	6.25E+04	3.03E+05	50.00	49.19
0.002	9.31E-11	-2.16E-10	-2.16E-10	-2.16E-10	-2.75E-05		502(2)	3.00E+02	4.00E+00	1200.00	60000	60000	60000	60000	62510.78	3.03E+05	50.00	
0.004	9.31E-11	-1.46E-09	-1.46E-09	-1.46E-09	-3.54E-05		502(3)	3.00E+02	4.00E+00	1200.00	60000	60000	60000	60000	62510.29	3.03E+05	50.00	
0.006	9.31E-11	-3.94E-09	-3.94E-09	-3.94E-09	-4.32E-05		502(5)	3.00E+02	4.00E+00	1200.00	60000	60000	60000	60000	62509.8	3.03E+05	50.00	
0.008	9.31E-11	-8.08E-09	-8.08E-09	-8.08E-09	-5.10E-05		503(1)	1.67E+02	7.50E+00	1250.25	60000	60000	60000	60000	62509.31	3.03E+05	50.00	
0.01	9.31E-11	-1.43E-08	-1.43E-08	-1.43E-08	-5.87E-05					6050.25	60000	60000	60000	60000	62508.83	3.03E+05	50.00	
0.012	9.31E-11	-2.29E-08	-2.29E-08	-2.29E-08	-6.65E-05						60000	60000	60000	60000	62508.34	3.03E+05	50.00	
0.014	9.31E-11	-3.43E-08	-3.43E-08	-3.43E-08	-7.42E-05						60000	60000	60000	60000	62507.86	3.03E+05	50.00	

From excel we plotted the graph which came out as follows:



Here the frequency nadir is at 48.85 Hz.
Now we can plot the 2 curves in the same figure for comparison and we can see significant nadir improvement. The comparison curve is given below:

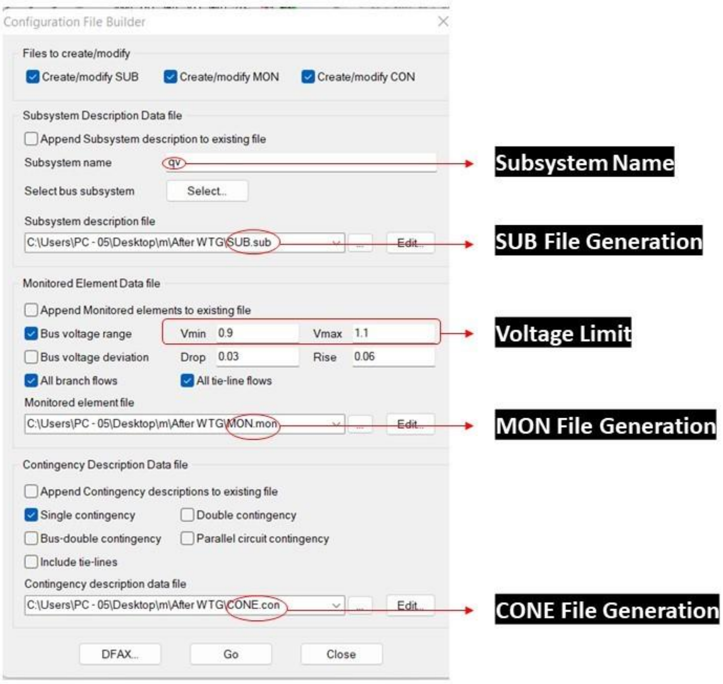


We can see that, 2.13 Hz of frequency improvement after addition of UFLs.

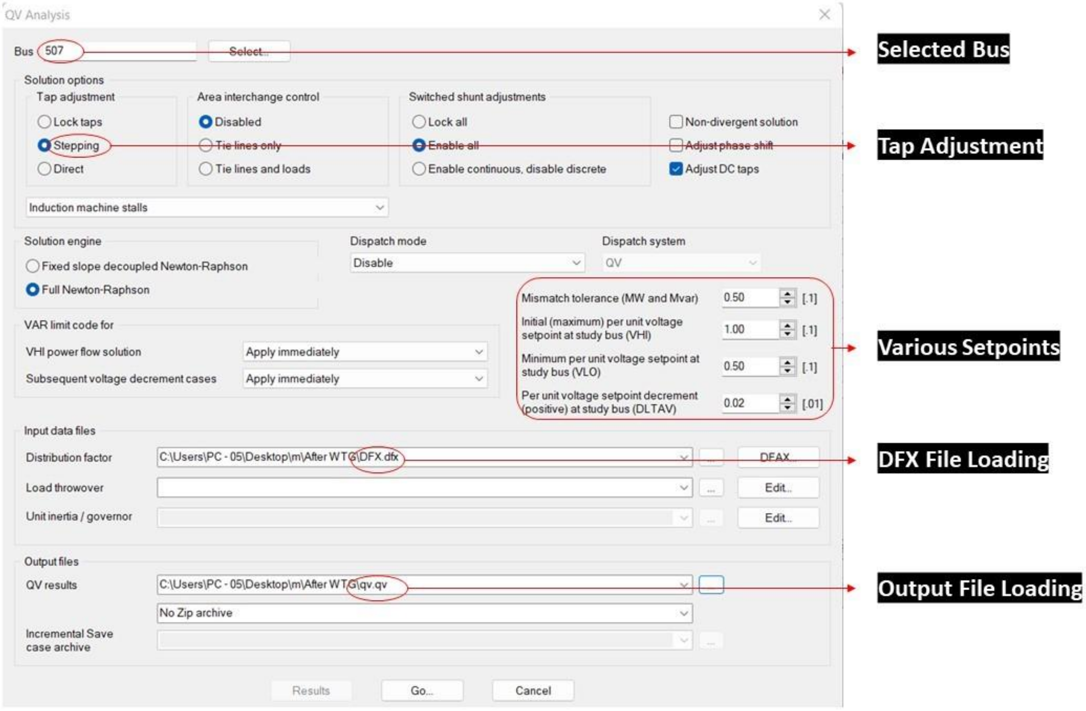
iii. Ranking of Bus from QV analysis:

We calculated the strength of the bus from QV analysis from PSSE. The stepwise strength ranking of busses are given below:

Step 1: First we have to generate .sub, .con and .mon files. From these files .dfx file will be generated.

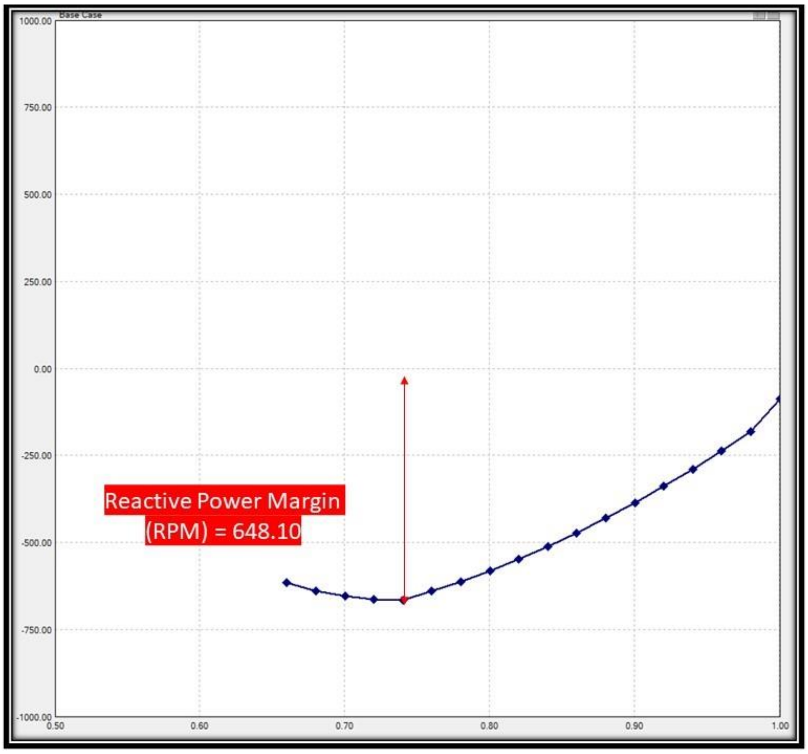


Step 2: Next we have to load the dfx files and set voltage limits which should be monitored.



Step 3: From this we get the QV curve of the selected bus, in this case, bus number 507. From the curve we can determine the reactive power margin (RPM).

BUS 507



The other busses are similarly determined and summarized in the next step.

iv. Bus strength ranking from QV analysis:

The higher the RPM, the greater the stability. So we can summarize the strength of the busses as follows:

Bus ID	Reactive power margin (RPM)	Strength
504	745.08	2
507	648.10	3
508	874.04	1
509	270.73	4

The weaker busses should be load shedded more which we will be able to see in the next section.

v. Reactive power margin factor

The RPMs are inversed because as strength of the bus is inversely proportional to the amount of load shed, we inversed the RPMs and normalized them. Then we calculated the reactive power margin.

Bus ID	Reactive Power Margin (MVAR)	Reactive power margin (pu)	Inverse of RPM	Reactive margin factor
504	745.08	7.45	0.1342	0.1734
507	648.10	6.48	0.1543	0.1994
508	874.4	8.74	0.12	0.1477
509	270.73	2.70	0.3703	0.4787

vi. Calculation of Load shedding percentage

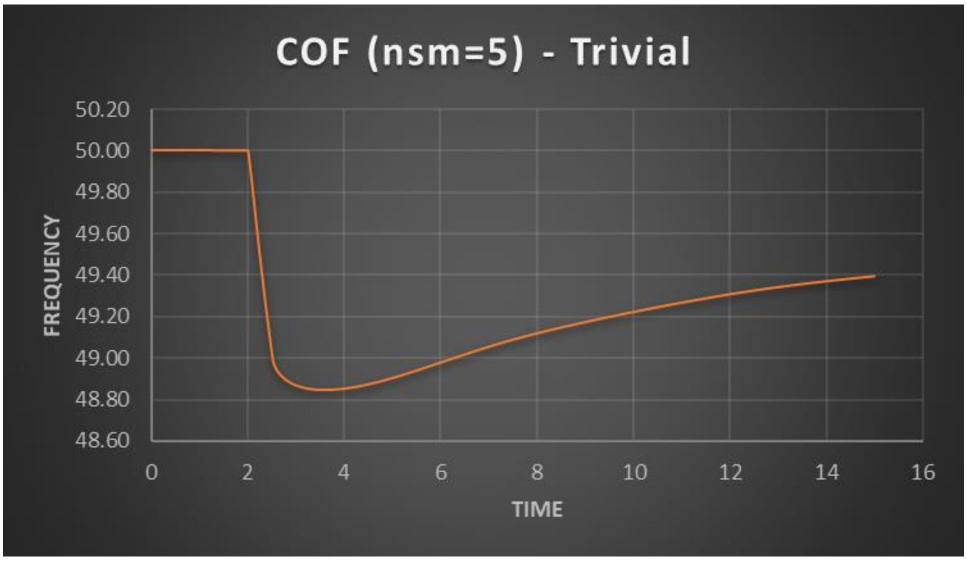
From Pascal's triangle methodology, we can determine our proposed scheme's load shedding percentage. The load shedding percentage is summarized in the table below:

Bus ID	1st stage frequency threshold	1st stage load shedding %	2nd Stage frequency threshold	2nd stage load shedding %	3rd stage frequency threshold	3rd stage load shedding %
504	49.25	17.34	48.75	14.32	48.25	11.84
507	49.25	19.94	48.75	15.95	48.25	12.77
508	49.25	14.77	48.75	12.58	48.25	10.71
509	49.25	47.87	48.75	24.94	48.25	12.99

vii. Application of Proposed Scheme:

The proposed scheme plots for nsm = 5 and 4 are given below along with the trivial ones for comparison:

Trivial UFLs (nsm = 5):



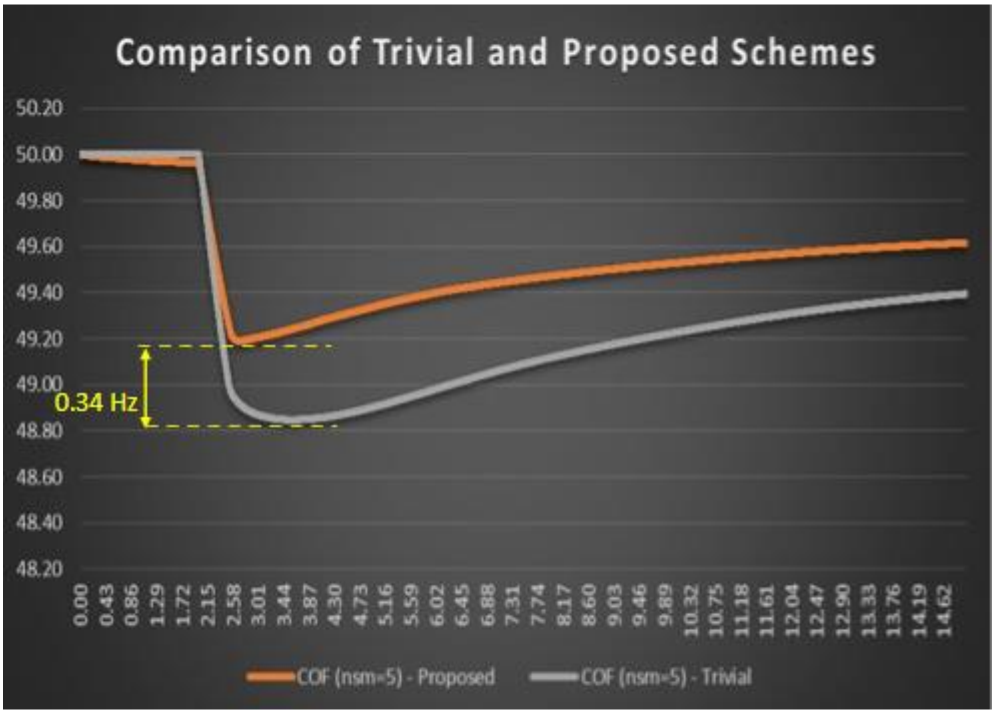
Here frequency nadir = 48.85 Hz.

Proposed UFLs (nsm = 5):

Here Nadir = 49.19 Hz.

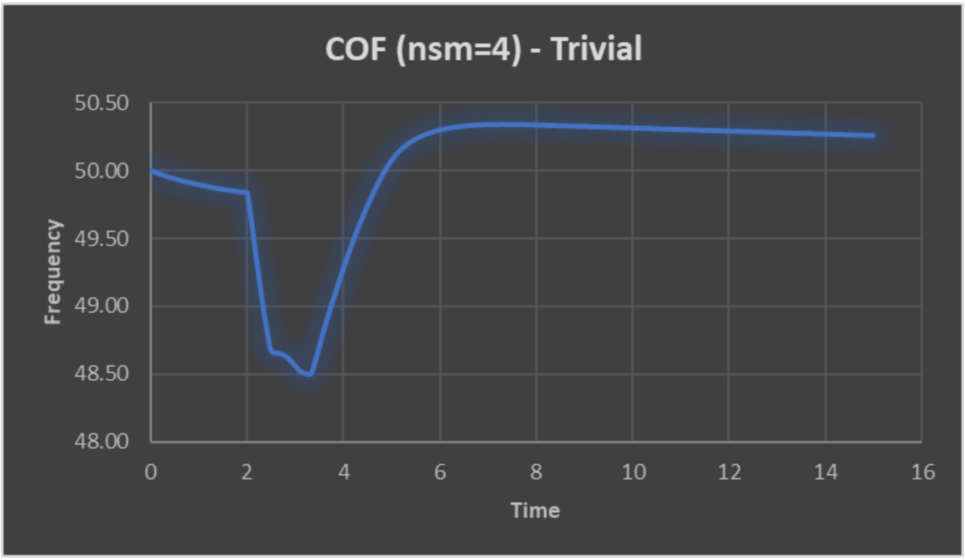
So, only one stage load shedding was required in both the cases. So, it causes a total load shedding of 355 MW in both the cases.

The comparison of 2 schemes can be seen from the following figure:



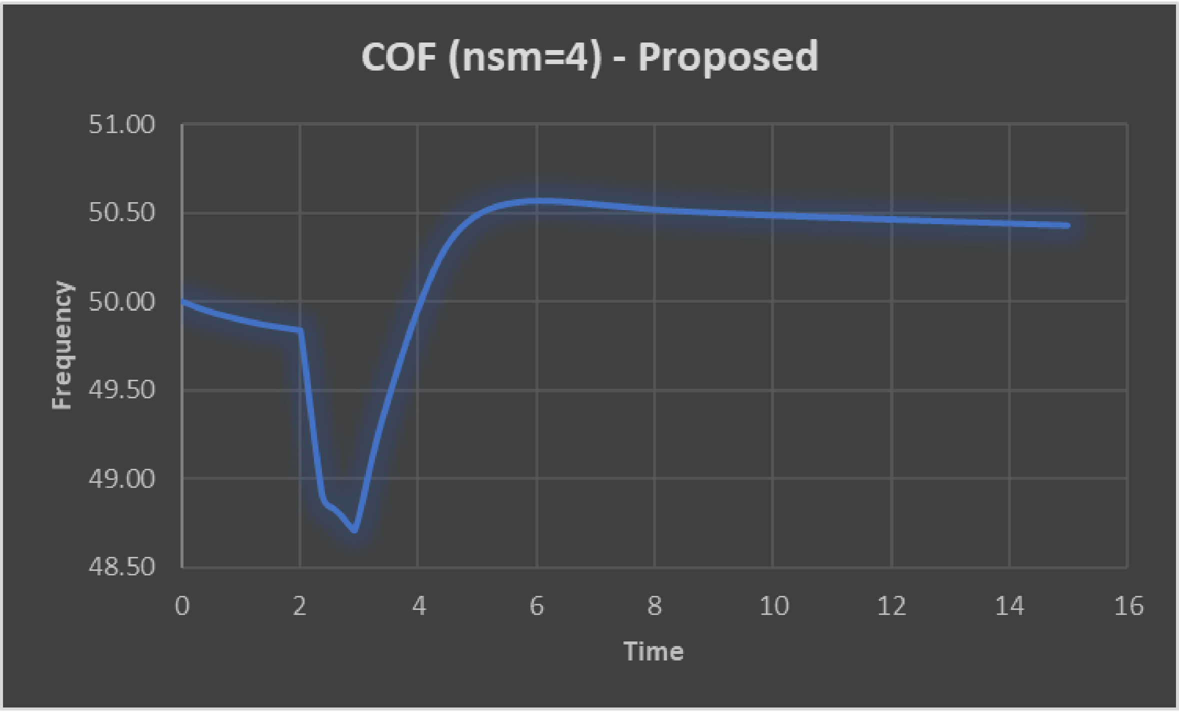
Here, we can see the frequency nadir improvement of 0.34 Hz. Now we will see the case for nsm = 4.

Trivial UFLs (nsm = 4):



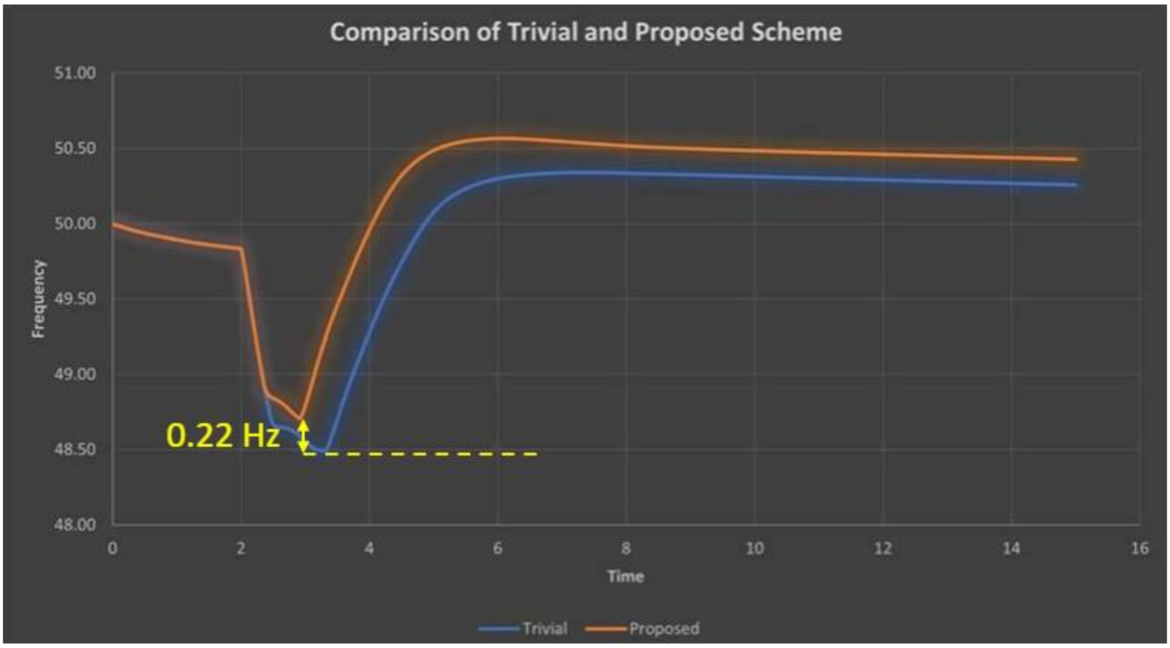
Here, nadir = 48.49 Hz.

Proposed UFLs (nsm = 4):



Here, frequency nadir = 48.71 Hz. In both the cases, 2nd stage of load shed was activated, which means total of 505 MW was shed.

We can see the frequency comparison plots from nsm = 4.



Here we can frequency nadir improvement by 0.22 Hz. So, for nsm = 4 case, the frequency response improved.

Conclusion:

In this project, a load-shedding mechanism based on frequency and voltage stability is created in order to increase the frequency resilience of low-inertia power systems in the context of significant wind power penetration. The project's description of load shedding mechanisms is mostly centralized and measurement-based. Due to communication delays, these strategies may not operate effectively in a big network.

To simultaneously maintain voltage and frequency stabilities after a contingency, a larger percentage of load shedding is applied to somewhat weaker buses. In order to do this, a generic formulation of load shedding amount is developed based on reactive power margin and adheres to Pascal's triangle rule. Due to the loss of an interconnection in a low inertia network employing UFLS settings, the effectiveness of the suggested solution is tested. According to the simulation findings, the suggested load shedding algorithm guarantees a suitable frequency response even when there is a substantial penetration of wind energy. System performance is compared to that of a traditional UFLS scheme to validate the suggested scheme.

When the suggested approach is used, frequency nadirs are seen to significantly improve in all circumstances. Moreover, there are less load cuts on the network. The designed load shedding technique clearly offers more frequency stability than the traditional one, as a result.

Last but not least, it is important to note that the suggested plan is general in nature. Hence, maintaining voltage stability while enhancing frequency responsiveness is applicable to all power systems, especially when non-synchronous renewable energy sources are being heavily included into the grid.