BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Department of Electrical and Electronic Engineering

Project Report

Project Title: Weakest Bus Identification and Voltage Stability Improvement

Course No: EEE 412

Course Title: Power System 2 Laboratory

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INTRODUCTION:

Voltage stability is a critical issue in power system operation and control. It is defined as the ability of a power system to maintain steady-state voltages at all buses in the system under normal operating conditions. Voltage stability problems can result in voltage collapse, leading to blackouts or brownouts, which can cause significant economic and social impacts. Therefore, it is essential to identify the weakest locations in the power system and improve voltage stability to ensure reliable and efficient power system operation.

Voltage stability can be analyzed using two methods one is static approach and another is dynamic approach. **Static approach** is based on conventional power flow solution where pre and post contingencies cases are known. Whereas **Dynamic approach** is set to solve highly non-linear differential equations for generator dynamics, on load tap changing transformers, variation of load properties, etc. based on real – time simulations.

We propose a methodology that involves analyzing the system's topology and computing the critical buses, followed by the placement of STATCOM and static capacitor at the identified locations. The results of our simulation show that the proposed methodology significantly improves the voltage stability of the IEEE-14 bus system, with reduced voltage deviations.

SYSTEM CONFIGURATION:

In power systems analysis and research, the IEEE 14-bus system is a popular test system. It has 11 loads, 5 generators, 14 buses, 20 transmission lines, and 5 loads. The system is meant to mimic a straightforward electrical grid with realistic features like transmission line losses, voltage caps, and generation constraints.

The system is frequently used as a testbed for evaluating and contrasting various power system analysis and control algorithms and methodologies, including power flow analysis, optimal power flow, and transient stability analysis. Demand response, load forecasting, and the integration of renewable energy sources are some of the other elements that are studied in relation to how the power system behaves.

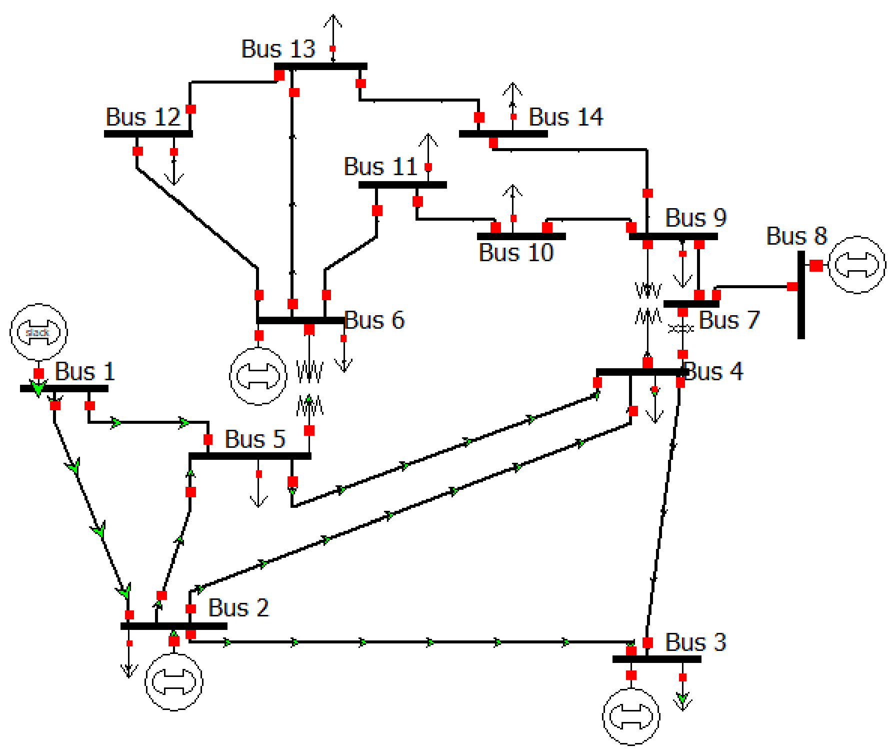


Fig: IEEE – 14 Bus System

PV CURVE:

The P-V curves are the most elementary method for predicting voltage instability. They are used to identify maximum allowable safe loading margin for a particular load bus in a power system.

The relationship between voltage and power in an electrical circuit is depicted graphically by the PV curve, sometimes referred to as the Power-Voltage curve.

The PV curve typically has the shape of an inverted parabola, meaning that the power output rises with voltage up to a certain point and then falls as voltage rises further. The maximum power point is when the power output is at its highest (MPP).

The best operating point of a generator is identified using the PV curve in practical applications in order to maximize output and efficiency. Also, it's utilized to establish the generator's output limitations and make sure they stay within safe operating ranges.

$\frac{dv}{dp} < 0$ indicates stable region, $\frac{dv}{dp} > 0$ indicates unstable region.

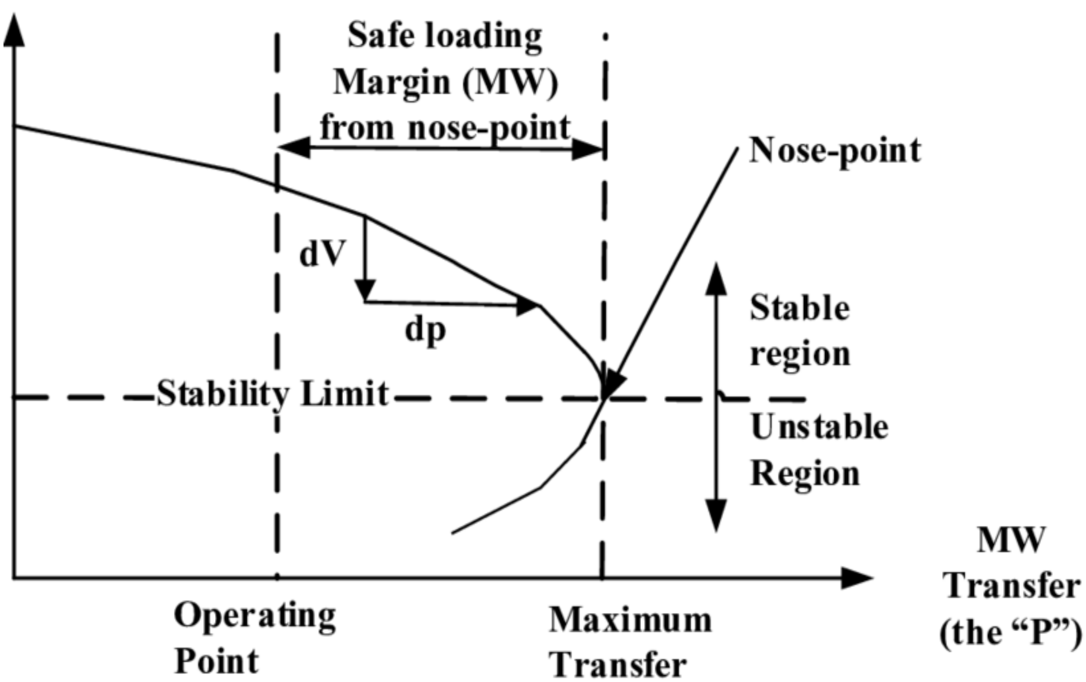


Fig: PV Curve

QV CURVE:

The reactive power-voltage curve, sometimes referred to as the QV curve, illustrates the relationship between reactive power and voltage at a particular point in a power system.

The QV curve is crucial for power system analysis since it demonstrates a power system's ability to regulate voltage. It shows the system's capacity to keep the voltage steady in the face of shifting loads and reactive power requirements.

Reactive power is normally on the y-axis and voltage is on the x-axis when the QV curve is presented. It displays the lowest and maximum reactive power that the system can supply or absorb at a certain voltage level.

QV curves are used by power system designers and engineers to design and improve the performance of the power system. The power system's planning and operation can benefit from the QV curve, particularly when figuring out how much reactive power is needed for generators, transformers, and other components.

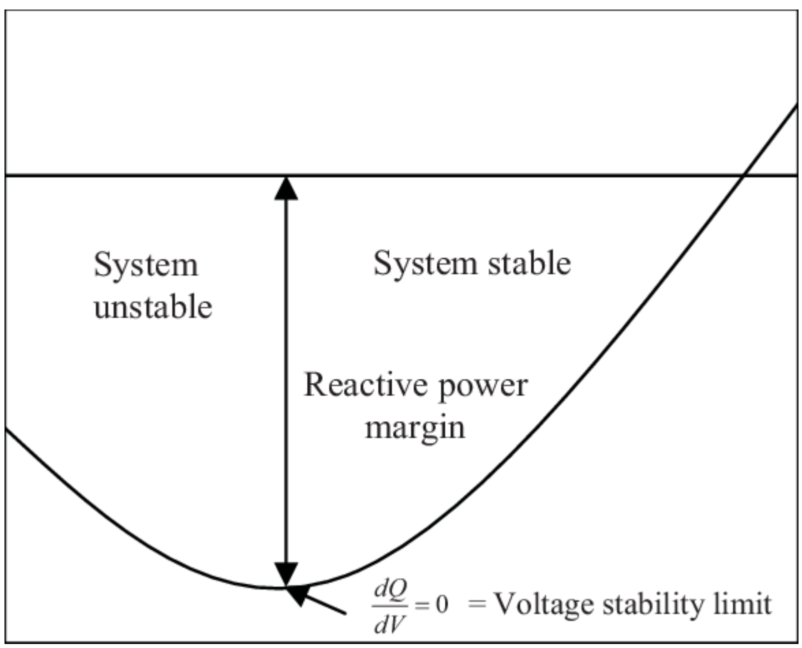
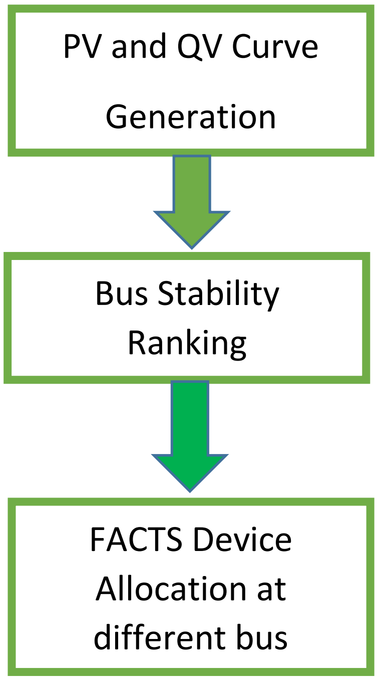


Fig: QV Curve

WORKFLOW:

We have define a workflow based on IEEE-14 Bus system, where we have found out the PV and QV curve of the system. Then Based on that ranking is done. Then after the voltage profile is done, we have allocated the FACTS device for improving the stability of the system.



BUS 14 PV CURVE:

For this analysis, the active power, P is systematically increased in steps for a particular load bus and the corresponding load bus voltage magnitude is observed. Then, the power is plotted along X-axis while the corresponding bus voltage is plotted along Y-axis.

We have done the simulation first in PSSE Software first.

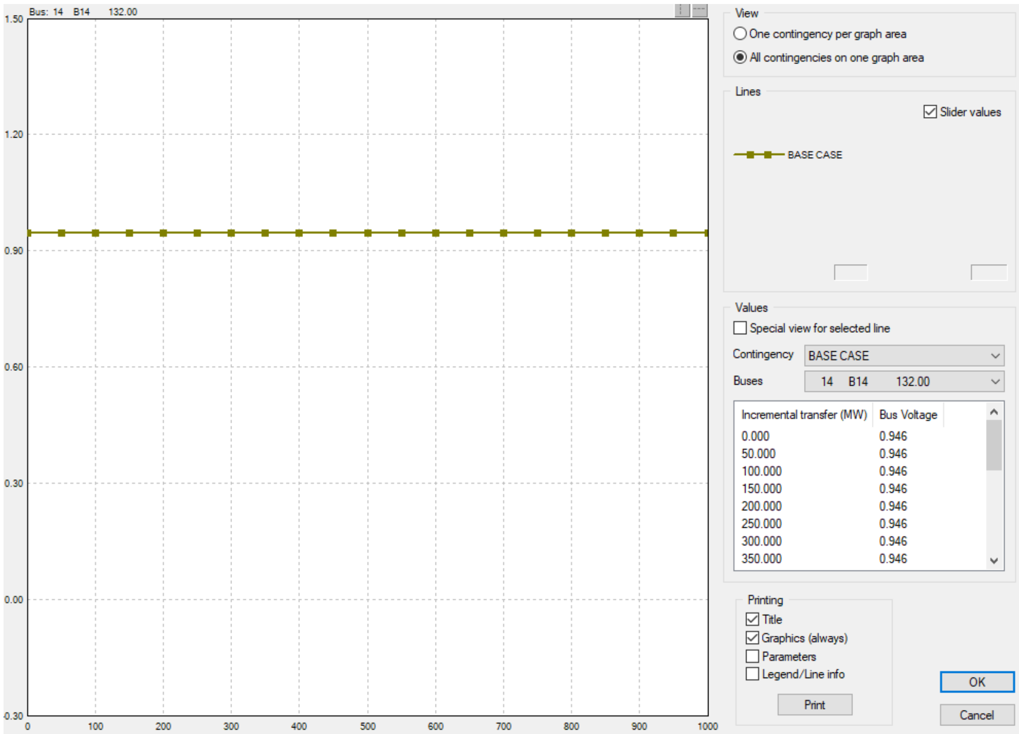


Figure: PV curve from PSSE.

We found anomaly in the curve generate in the software PSSE. The was supposed to be quadratic but we got a linear one. So, we had to switch to MatPower from PSSE.

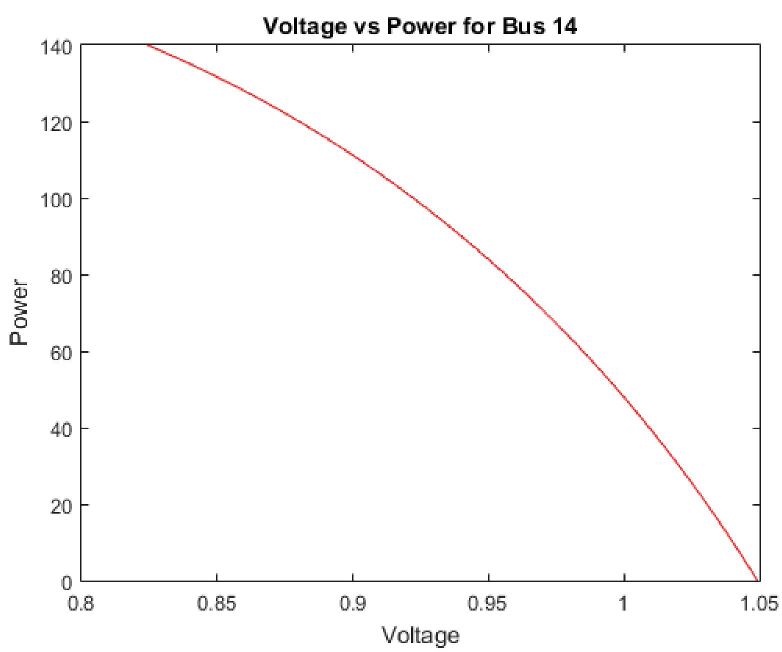


Figure: PV curve from Matpower.

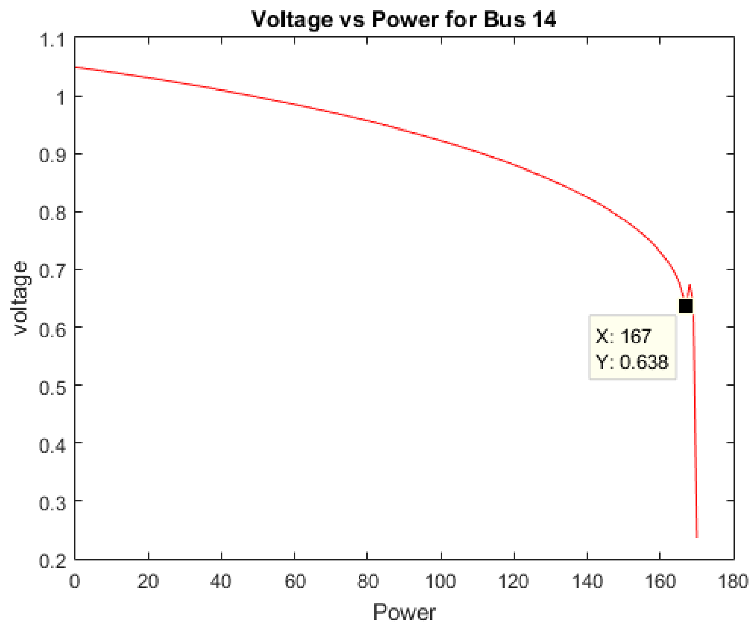
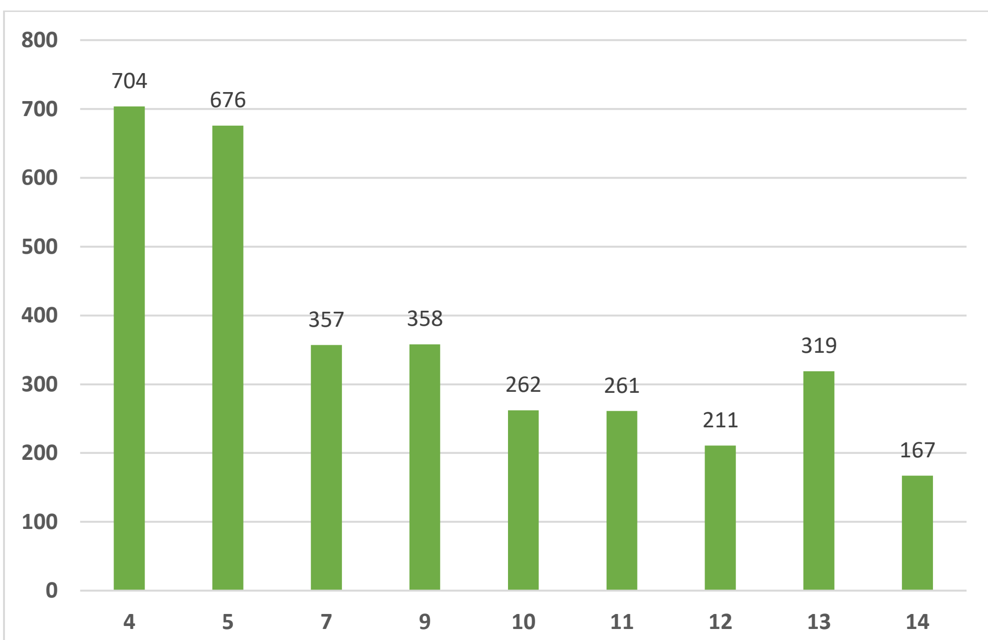


Figure: Knee point at PV curve.

RANKING BASED ON PV CURVE:



BUS 14 QV CURVE:

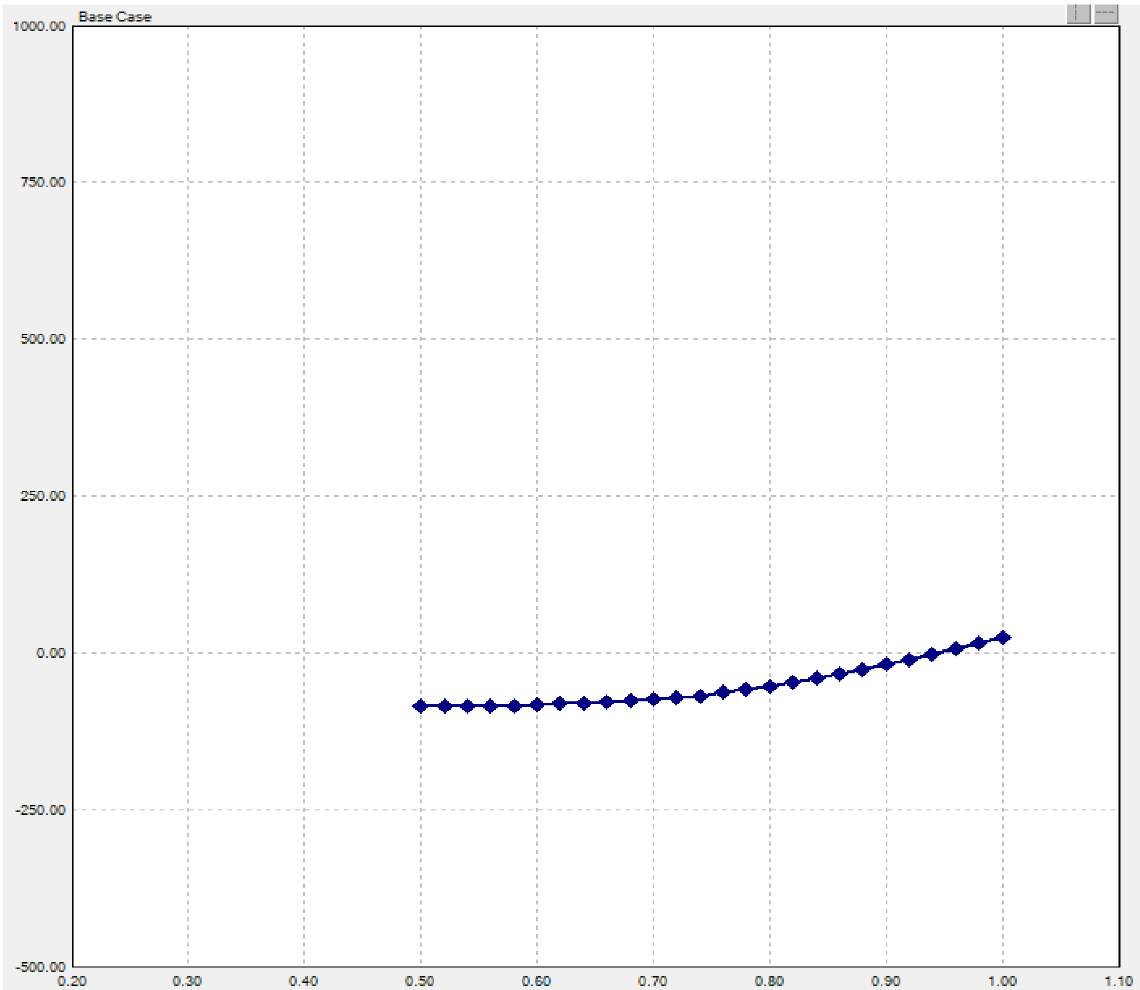


Fig: QV curve of bus 14

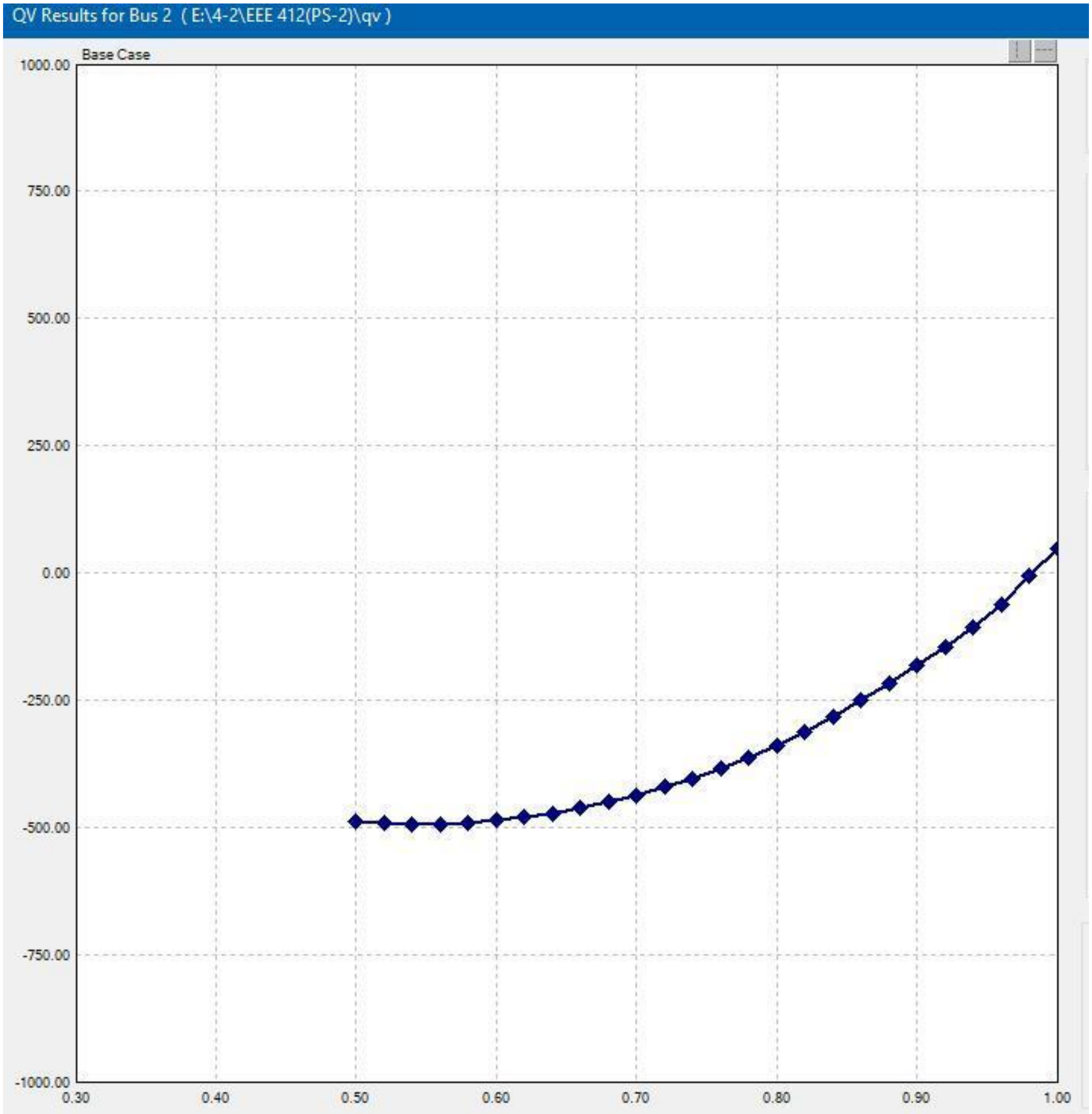


Fig: QV curve of bus 2

This is the strongest bus of the system.

Bus Name	MW	MVAR	MVA	Percent	Voltage/ratio	Angle (Deg)	Losses (MW)	Losses (MVAR)	Area and Zone Name	
10 B					0.9576PU	-17.3062				
					126.40KV				1	1
TO LOAD-PQ	9.	5.800	10.7							
TO 9	-4	0.968	4.95				0.0085	0.0227	1	1
TO 11	-4	-6.76	7.93				0.0563	0.1318	1	1
11 B					0.9747PU	-17.1593				
					128.66KV				1	1
TO LOAD-PQ	3.	1.800	3.93							
TO 6	-7	-8.70	11.6				0.1349	0.2824	1	1
TO 10	4.	6.900	8.07				0.0563	0.1318	1	1
12 B					0.9820PU	-17.7124				
					129.63KV				1	1
TO LOAD-PQ	6.	1.600	6.30							
TO 6	-7	-3.02	8.49				0.0919	0.1913	1	1
TO 13	1.	1.429	2.32				0.0124	0.0112	1	1
13 B					0.9750PU	-17.7426				
					128.70KV				1	1
TO LOAD-PQ	13	5.800	14.6							
TO 6	-1	-9.52	20.2				0.2851	0.5615	1	1
TO 12	-1	-1.41	2.30				0.0124	0.0112	1	1
TO 14	6.	5.143	8.04				0.1163	0.2367	1	1
14 B					0.9459PU	-18.5329				
					124.86KV				1	1
TO LOAD-PQ	14	5.000	15.7							
TO 9	-8	-0.09	8.83				0.1109	0.2359	1	1
TO 13	-6	-4.90	7.80				0.1163	0.2367	1	1

Fig: Power flow solution from PSSE.

RANKING BASED ON QV CURVE FROM PSSE:

Bus ID	Reactive Power Margin	Strength
2	500	strong
3	220	strong
4	280	strong
5	250	strong
6	125	weak
7	180	Moderate
8	136	Moderate
9	157	Moderate
10	187	Moderate
11	114	weak
12	92	weakest
13	117	weak
14	85	weakest

REACTIVE POWER MARGIN IMPROVEMENT:

$$Q_i^{margin} = Q_i^* - Q_i^0 \qquad (1)$$

where Q_i^{margin} is the reactive power margin of i^{th} bus, Q_i^* and Q_i^0 denote the reactive power consumption at collapse and base operation points for i^{th} bus, respectively.

Here the Q_i^* denotes the system before the collapse. And the Q_i^0 is the system that the desired amount of reactive power margin we want to have at each bus of our system. We have tried to set reactive power margin at each buses to be greater than 100MVar.

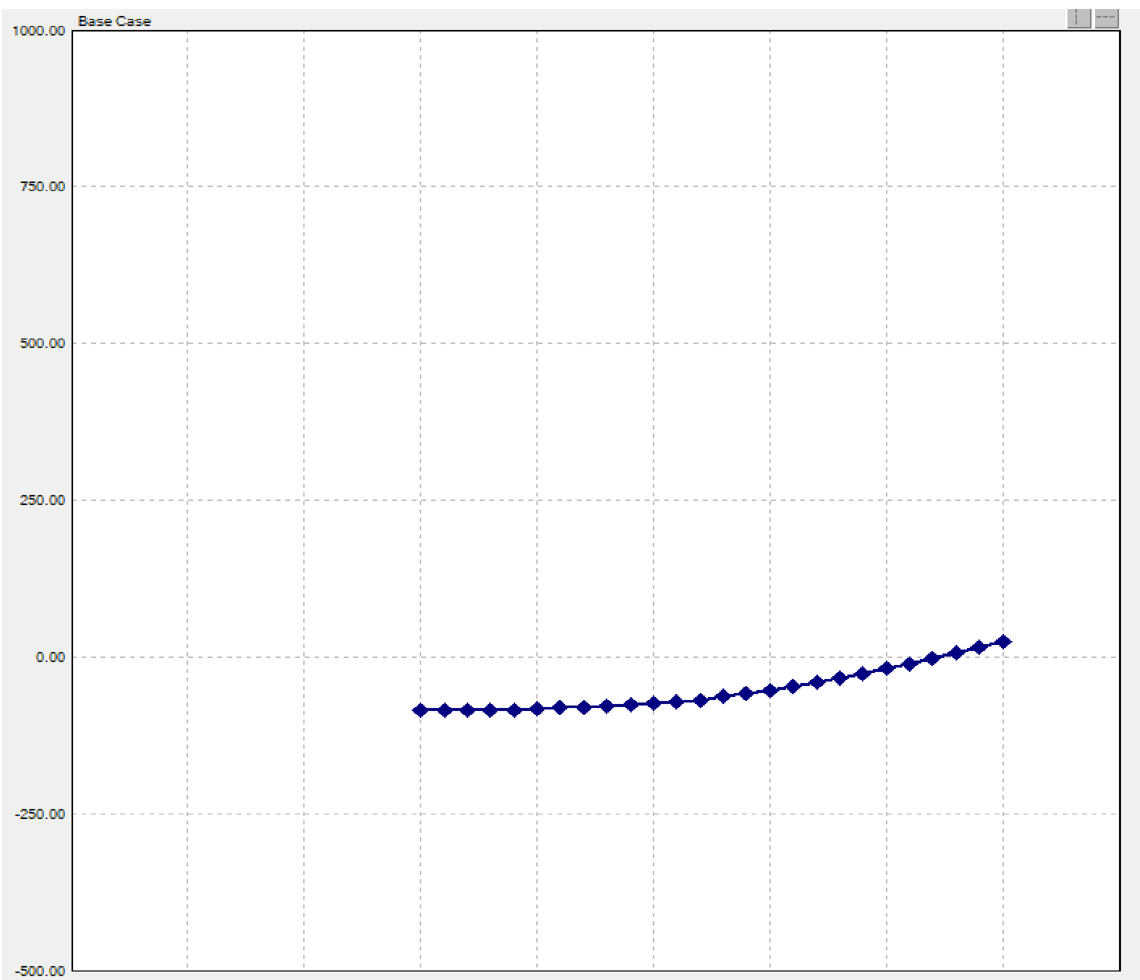


Fig: QV curve of bus 14 before reactive power injection

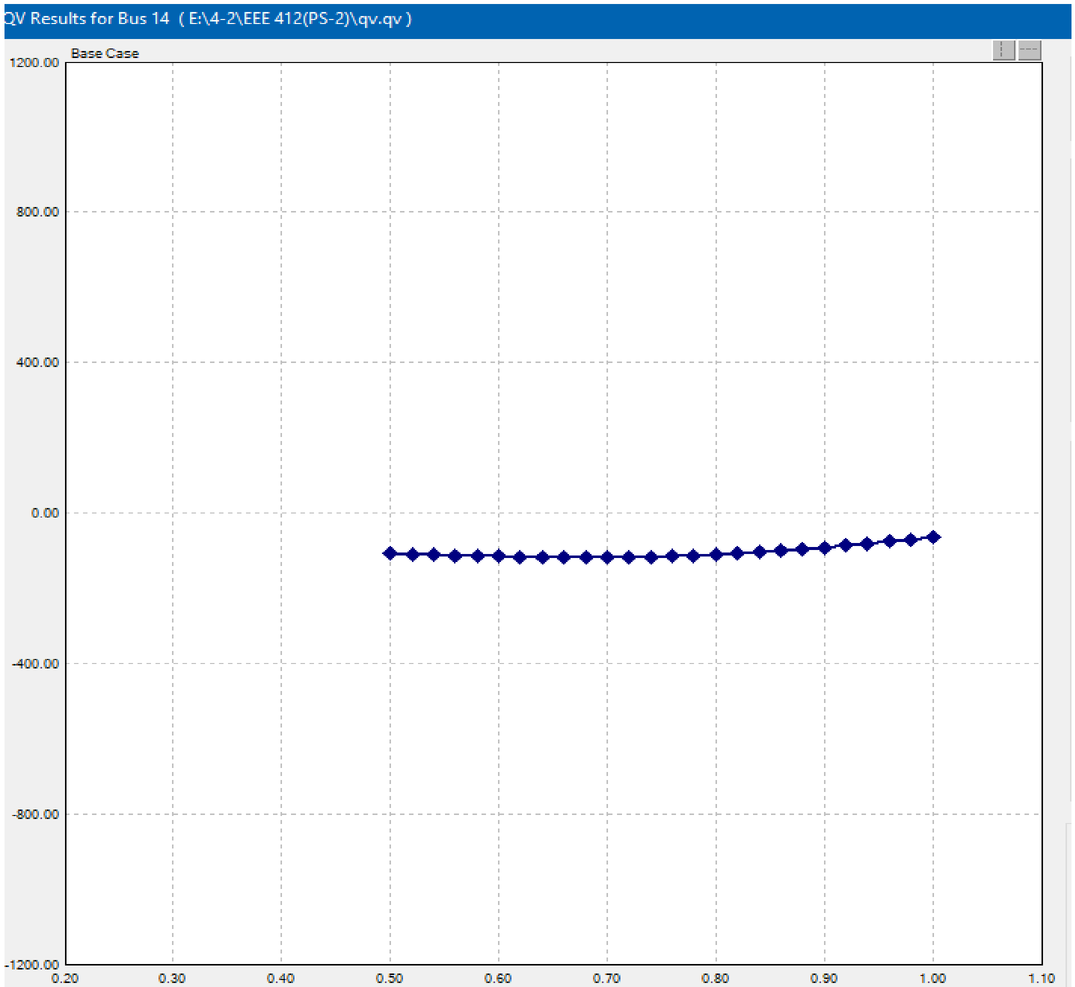


Fig: QV curve of bus 14 after reactive power injection

From these two above graphs we see the reactive power margin of bus 14 was 85 MVAR. After injecting 90 MVAR which was calculated from load flow analysis in PSSE reactive power margin is 118 MVAR.

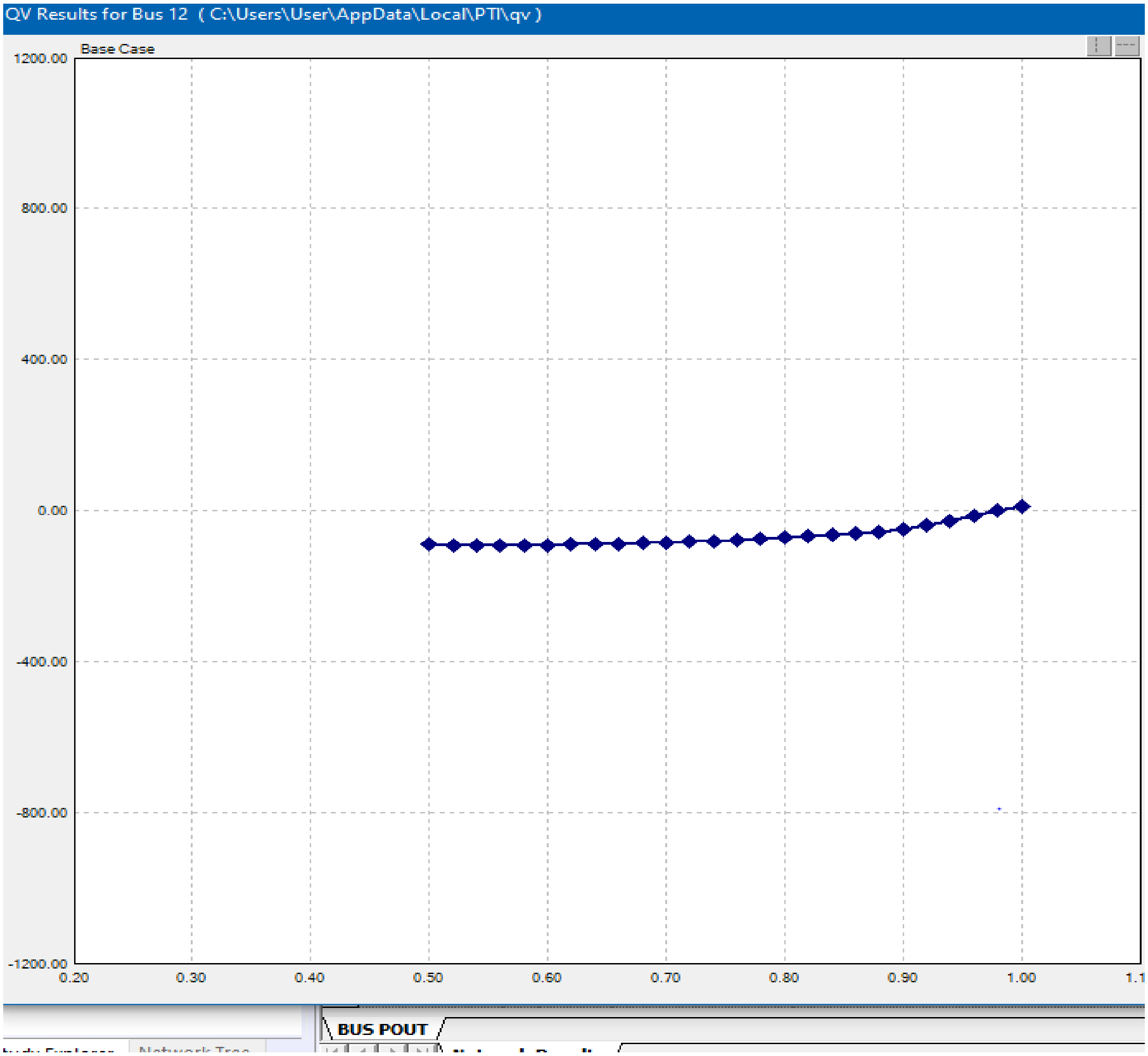


Fig: QV curve of bus 12 before reactive power injection

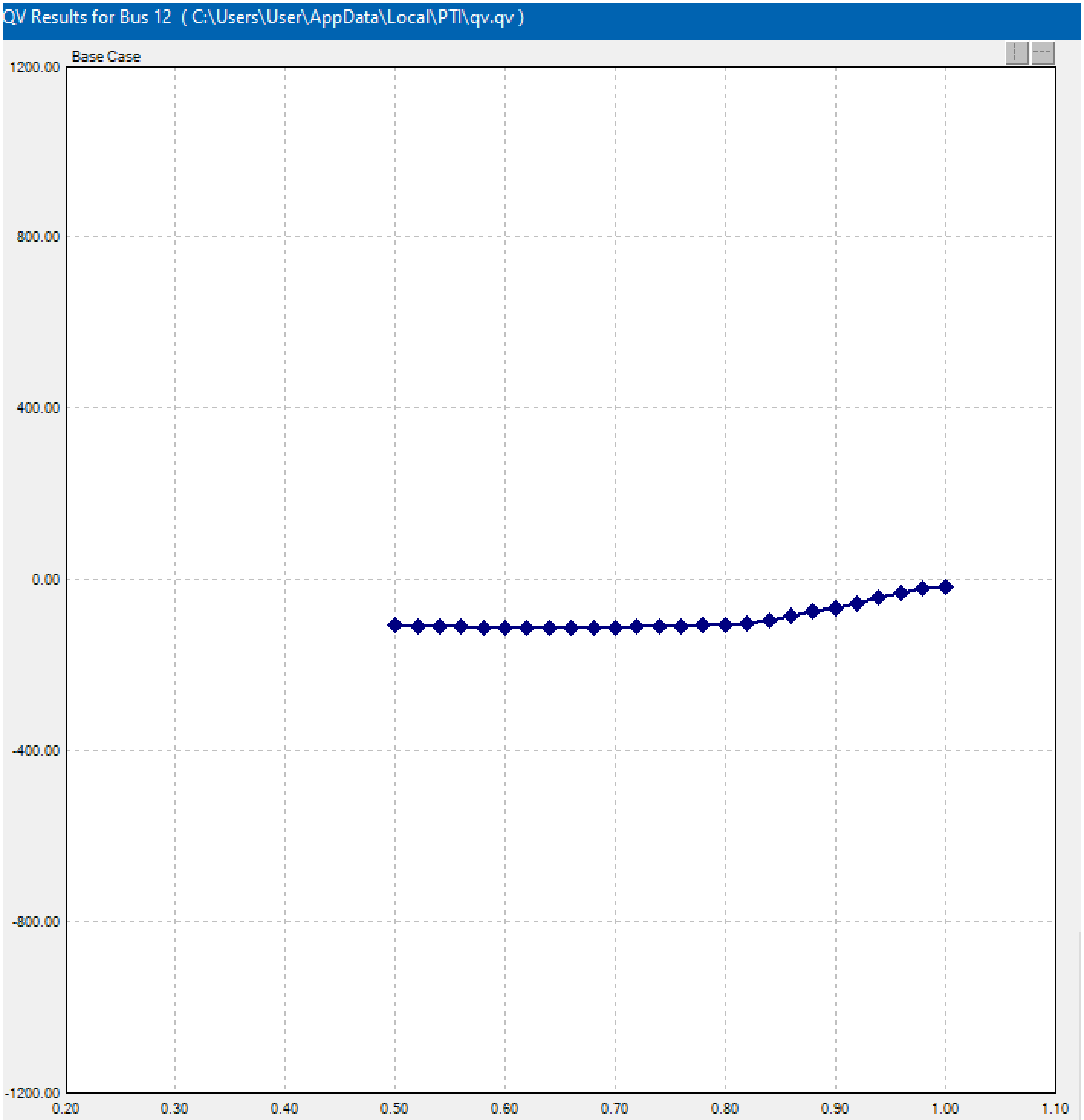


Fig: QV curve of bus 12 after reactive power injection

From these two above graphs we see the reactive power margin of bus 12 is 92 MVAR. After injecting 94 MVAR which was calculated from load flow analysis in PSSE reactive power margin is 113.85 MVAR.

FACTS DEVICE ALLOCATION ALGORITHM:

Step 1: Perform the power flow analysis for both pick load and light load condition with a SVC considered to be connected at each of the selected load buses.

Step2: Finding out the VAR Requirements (Capacitive / Inductive) to maintain a nominal voltage (or suitable accepted voltage magnitude) at the SVC Bus.

Step3: Select the suitable size of SVC (Capacitive / Inductive range) based on overall requirement of SVC reactive power output for various locations.

WE have used SVC here to compensate the system.

STEP1:

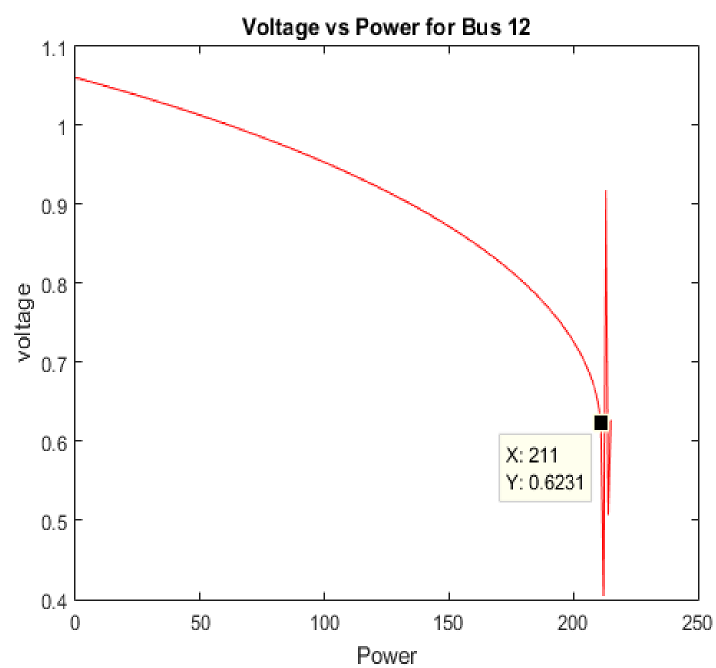


Fig: PV Curve at bus 12 before SVC

STEP2:

We have run the simulation by using a proper value of SVC So that the voltage having 100MW load will be 1.0 per unit.

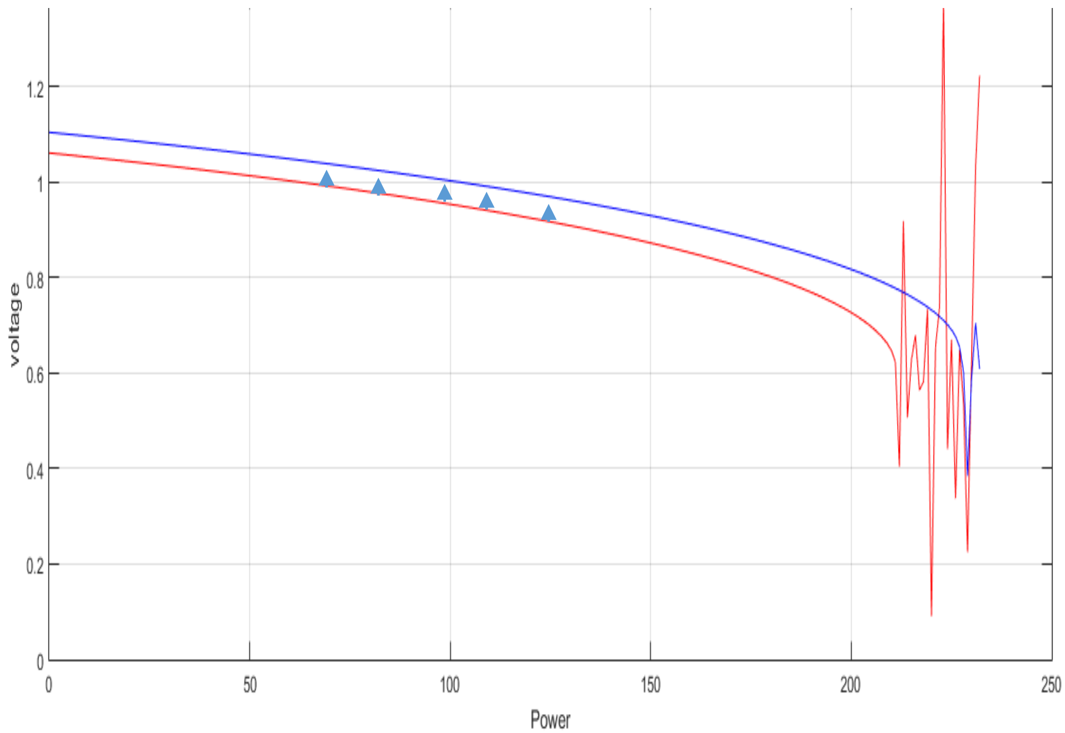


Fig: PV Curve at bus 12

So we have used 30 MVar capacitive load to the bus. After using that, we have noticed the level of the graph shifted up so that the voltage having 100MW load is 1.0 per unit.

This has been done using Binary selection method in MatPower.

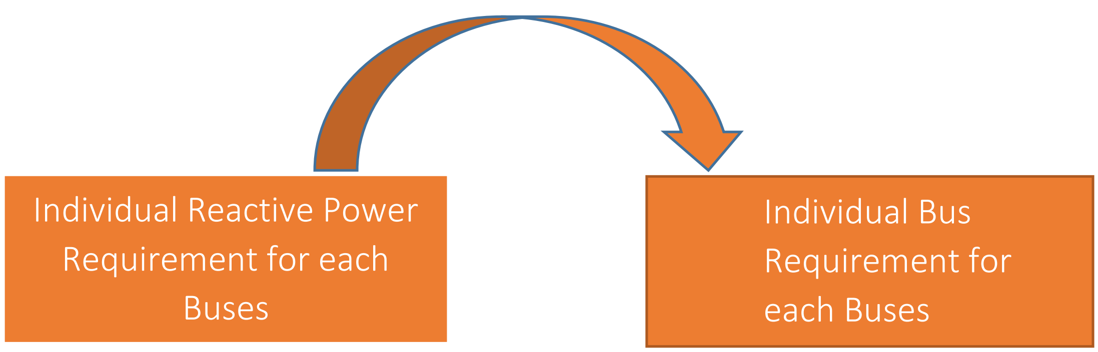
Individual Bus Voltage Improvement:

After doing the same analyzes for every buses, we have found out the table below:

Bus	Reactive Power
14	-30
13	10
12	-30
11	-5
10	0
9	45
7	47
5	10
4	17

STEP3:

After improving each bus voltages now we are going to improve the overall voltage profile of each buses.



After applying proper amount of capacitive and inductive compensator for each buses, we have improved the overall stability of the system as well as improved the voltage profile for each buses.

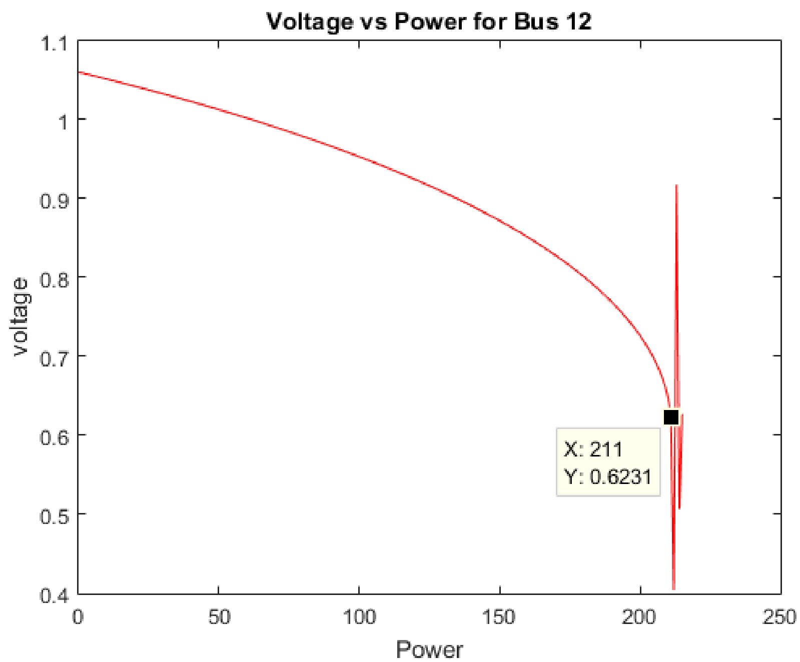


Fig: Before the SVC

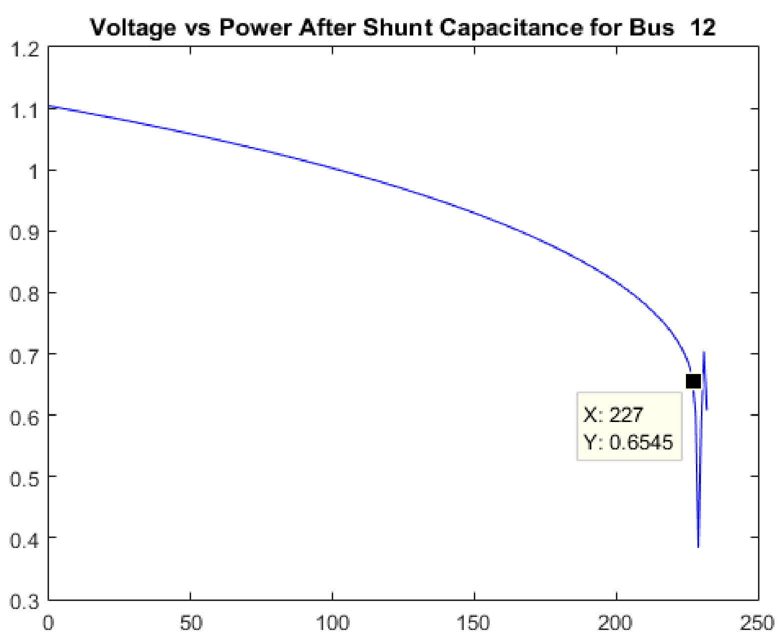


Fig: After the SVC

RESULTS:

The simulation results show that the proposed methodology significantly improves the voltage stability of the IEEE-14 bus system. The voltage deviation at the critical buses is reduced. Moreover, the proposed methodology has a minimal impact on the system's overall stability and does not affect the power quality at the other buses.

CONCLUSION:

In conclusion, identifying the weakest locations in the power system and improving voltage stability is essential for reliable and efficient power system operation. The proposed methodology using synchronous condenser and static capacitor placement has shown to be an effective technique for voltage stability improvement in the IEEE-14 bus system. The results of our simulation studies indicate that the proposed methodology can be applied to other power systems to improve voltage stability and prevent voltage collapse.

REFERENCE PAPERS:

1. Selection of static VAR compensator location and size for system voltage stability improvement

[https://www.sciencedirect.com/science/article/abs/pii/S0378779699000826?casa_token=PZK2B7wKpP8AAAAA:7RAw2GnCf0BhLHrbhgNexrJTCp302YoreJz-TxV4bNGw9jGefhrUrmMiAq7PGobPhpSm5SI2z48]

2. Weakest Location Exploration in IEEE-14 Bus System for Voltage Stability Improvement Using STATCOM, Synchronous Condenser and Static Capacitor

[https://ieeexplore.ieee.org/document/7912980]