Faculty of Engineering, Computer and Mathematical Sciences

ELEC ENG 3110 Electric Power Systems

Assignment 1

Power System Steady-State Performance

By

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1. Summary

This practical is aiming to improve Electrical Power System students' hands-on engineering practical skills associated with lecture and tutorial materials and to facilitate students to realize and understand the importance of a power system operating under steady-state performance. An assignment case has been distributed to students to explore and research on achieving the steady-state performance of an electrical power system simulated on PowerWorld. This report narrates the entire studying process of utilizing PowerWorld Simulator to adjust the power system parameters and examine its performance on contingencies, then re-adjusting the system parameters to achieve power system steady-state performance.

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2. Introduction

This practical assignment is aiming to empower electrical student engineers to explore the steady-state performance of a power system with seven buses on powerWorld, a software used to simulate High-Voltage power system operational status. During this practical study, students are conducting research on supplying power securely from power generators and to the end terminal loadings, where it generally be seen as end users to consume generated power, and properly use of appropriate operational parameters in power system elements to satisfy the requirements for achieving electrical system steady-state performance.

3. Simulation Set-Up

Setting up PowerWorld simulation software is the first step in this practical study. The course coordinator of ELEC ENG 3110 Electric Power Systems has provided students with an archive containing PowerWorld installer, guidelines and a power system case study as illustrated in Figure 1. Simply click on the installer file and follow the installation navigation to install the PowerWorld software to set up PowerWorld on the students' own devices.

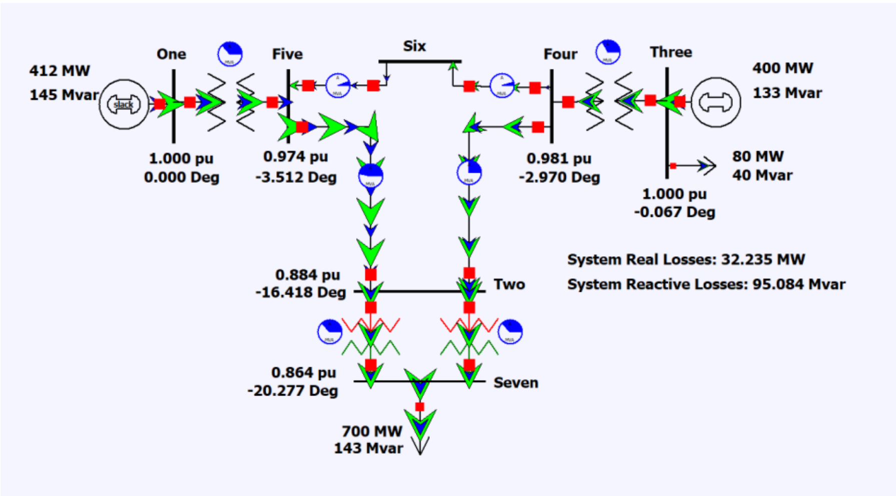

Figure 1: Power system model of the practical case study

Once properly setting up the software simulation on the device, opening the assignment case file of above power system model (Figure 1) as the resting of this practical will be work upon this power system model.

4. System Model and Parameter

After opening up assignment case power system model file on PowerWorld, students are required to examine power system current operational parameters by navigating to the tab of 'Model Explorer', where enables "system analysts and designers" to access various forms and tables where itemize essential parameters.

4.1 Nominal voltage

Nominal voltage is used to classify the voltage level of a system or equipment. It is identified as a standard value that refers to an electric power system or equipment voltage operational level on average. However, nominal voltage is not referring the highest safe operating voltage limit. Therefore, the actual voltage value is floating above/below the nominal voltage value with a satisfactory range. In this practical study case, nominal volage level of the network buses are various from voltage of 15kV to 330kV, as shown in Table 1.

Bus		
Number	Name	Nom (kV)
1	One	15
2	Two	330
3	Three	15
4	Four	330
5	Five	330
6	Six	330
7	Seven	66

Table 1: nominal voltage levels of the network buses

4.2 MVA & Equipment Current Ratings

Mega Volt-Amp (MVA) Rating is the value to describe the highest power deliverable of electric equipment, which is represented by symbol S – apparent power. It is a critical characteristic to measure the steady performance of a power system and its connected device/equipment. Generally, in an electric power system, MVA rating is used to indicate the largest power to safely flow through the specific connecting circuit elements. In PowerWorld simulation, MVA rating of each connected equipment is thoroughly itemized under "Branch Input" of the "Model Explorer" tab. Table 2 reveals MVA ratings of the connected equipment (4 lines and 4 transformers) of the system model.

Equipment MVA Rating			
From Number	To Number	Branch Device Type	Lim MVA
4	2	Line	1143.2
6	4	Line	1028.8
5	6	Line	1028.8
5	2	Line	1028.8
5	1	Transformer	1200
2	7	Transformer	1000
2	7	Transformer	1000
4	3	Transformer	1000

Table 2: Equipment MVA ratings

Equipment current rating is describing the maximum current that allows to flow through an equipment, and it can be derived from MVA Rating parameters of each equipment in this power system model. For 3 phase transformers, **Current Rating =** $\frac{\textbf{MVA Rating}}{\sqrt{3} * baseKv}$ *** 1000** (baseKv is known as nominal voltage 330 kV), and table 3 tabulates the current rating of 4 transformers.

Transformer current Ratings			
From Number	To Number	Lim MVA	Current Rating
5	1	1200	2099.46
2	7	1000	1749.55
2	7	1000	1749.55
4	3	1000	1749.55

Table 3: *Transformer Current Ratings*

Table 4 illustrates the current rating of 4 lines in Figure 1 System Model. Current ratings of transmission lines are calculated through the apparent power formula of S = V x I (kVA) x $\sqrt{3}$

Current Rating = $\frac{\text{MVA Rating}}{\sqrt{3} * baseKv}$ * 1000 *(baseKv is the nominal voltage of transmission lines)*

Transmission Line Current Rating			
From Number	To Number	Lim MVA	Current Rating
4	2	1143.2	2000.08
5	2	1028.8	1799.93
6	4	1028.8	1799.93
5	6	1028.8	1799.93

Table 4: Transmission *Line Current Ratings*

4.3 Transformer Impedance

Transformer impedance is the sum of opposition applied to AC current in the transformer including resistance(R) and reactance (X), so that it is represented by Z = R + j * x in ohms. Table 5 and Table 6 below are demonstrating per-unit transformer impedance of transformer MVA base and system MVA base respectively.

From Number	To Number	Branch Device Type	R (ohms)	X (ohms)	Z (ohms)
5	1	Transformer	0.018	0.18	0.018+j0.18
2	7	Transformer	0.015	0.15	0.015+j0.15
2	7	Transformer	0.015	0.15	0.015+j0.15
4	3	Transformer	0.016	0.16	0.016+j0.16

Table 5: Transformer impedances in per-unit of transformer MVA base

From Number	To Number	Branch Device Type	R (ohms)	X (ohms)	Z (ohms)
5	1	Transformer	0.0015	0.015	0.0015+j0.015
2	7	Transformer	0.0015	0.015	0.0015+j0.015
2	7	Transformer	0.0015	0.015	0.0015+j0.015
4	3	Transformer	0.0016	0.016	0.0016+j0.016

Table 6: Transformer impedances in per-unit of system MVA base

4.4 Transmission Line

In a power system, transmission line (overhead line) is applied to transport electricity from generator plants into consuming loads. There are several parameters that electrical engineers to take into account in analysis the power system – total line length, surge-impedance loads, line parameters in per unit on system MVA base and in per-unit of the SIL. Under PowerWorld simulation, line parameters including line length and per-unit impedance of line can be accessed and modified, once chosen the targeted line and right-click 'line information dialog', which has been tabulated in table 7.

Line impedance in per-unit on the system MVA base						
From Number	To Number	Branch Device Type	R (pu)	X (pu)	B (pu)	Length(km)
4	2	Line	0.00923	0.07752	1.15643	280
5	2	Line	0.00538	0.04474	0.65746	160
6	4	Line	0.00136	0.01124	0.16398	40
5	6	Line	0.00136	0.01124	0.16398	40

Table 7: Line impedance in per-unit on the system MVA base

Surge-impedance, Z_S, is the equivalent resistance of the transmission line and caused by transmission line distributed inductance and capacitance along the line length. It is acting as a natural characteristic of the transmission line by the formula of Zs = $\sqrt{\frac{Inductance\ in\ ohms/km}{Capactance\ in\ ohms/km}} = \sqrt{\frac{B}{X}}$ in the unit of ohm.

Based on the formula above, Surge-impedance for 4 transmission lines have been derived and listed in Table 8.

Surge-impedance				
From Bus	To Bus	X(ohms/km)	µB(ohms/km)	Zs(ohms)
4	2	0.306	3.764	285.125
5	2	0.305998	3.764002	285.116
6	4	0.305993	3.763999	285.122
5	6	0.305993	3.763999	285.122

Table 8: Surge-impedance of 4 transmission lines

Surge-impedance loads are the power delivered to resistive loads in the transmission line and it can be calculated as

$$\text{SIL} = \frac{Voltage^{\wedge}2}{Zs} \quad \text{with the unit of Watt.}$$

SIL of 4 transmission lines have been computed and tabulated in Table 9.

Surge-impedance Loads			
From Bus	To Bus	Z(ohms)	SIL(W)
4	2	285.125	381.9377466
5	2	285.116	381.9498029
6	4	285.122	381.9417653
5	6	285.122	381.9417653

Table 9: Surge-impedance loads of 4 transmission lines

Table 9a has demonstrated line parameters and surge impedance load in per unit. Utilizing Mathematical calculations of Zs in per unit = $\sqrt{\frac{Inductance\ in\ \text{per unit}}{Capactance\ in\ \text{per unit}}} = \sqrt{\frac{B(pu)}{X(pu)}}$ to calculate Surge impedance in unit. Then, per unit of Surge-impedance Loads can be derived via the equation of SIL in per unit = $\frac{Voltage^{\wedge}2}{Zs\ in\ per\ unit}$ with the unit of Watt.

Line parameters and Surge-impedance Loads in per-unit on the system base						
From Bus	To Bus	Length in Kilometer	X in per unit	B in per unit	Zs in per unit	SIL in per unit
5	6	40	0.0112	0.163985	0.2618	416029.5
6	4	40	0.0112	0.163985	0.2618	416029.5
5	2	160	0.0447	0.6575	0.26087	417453.8
4	2	280	0.0775	1.1564	0.258902	420622.4

Table 9a: Line parameters and Surge-impedance Loads in per-unit on the system base

5. Analysis of Base Case

After completing the "System Model and Parameters" module, PowerWorld simulation novices are now familiar with the search of different categories of power system simulation data and some basic operating status information of the power system model. In the "Basic Case Analysis Part", students will analyze the power flow and voltage status of the system in buses, loads, generators, transformers, and transmission line equipment for further evaluating the performance of the base case.

5.1 Bus

Bus, a single graph node on the power system model, represents the voltage, power flows, current and other measurable quantities flow across it. In the Figure 1 power system model, buses are allocated on entry and exit points of transformers to record real-time voltage and voltage angle across the node in the system circuit. Table 10 has revealed the bus voltage magnitude and angles in the corresponding point.

Bus					
Number	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
1	One	15	1	15	0
2	Two	330	0.88449	291.883	-16.42
3	Three	15	1	15	-0.07
4	Four	330	0.9812	323.796	-2.97
5	Five	330	0.97394	321.4	-3.51
6	Six	330	0.97846	322.892	-3.25
7	Seven	66	0.864	57.024	-20.28

Table 10: Bus Voltage and magnitude

5.2 Main Load

Main load is referring to the largest demanded consuming load in the power system model, where it is connected to bus 7 with the total power output of 700 + 143j MVA. Another load where connected with bus 3 is identified as secondary load since its power consumption is 80 + 40j MVA.

Load						
Number of Bus	Name of Bus	MW	Mvar	MVA	S MW	S Mvar
7	Seven	700	143	714.46	700	143

Table 11: Main load power flows

5.3 Generator

Generator is the equipment to supply real power and reactive power to the power system for supplying the demand of electricity consumption at the loads. Both generators are connected on top right and left with the power supply of 400 + 133.38 MVA and 412.23 + 144.7 MVA respectively.

Generator			
Number of Bus	Name of Bus	Gen MW	Gen Mvar
1	One	412.23	144.7
3	Three	400	133.38

Table 11: Power output (P & Q) from generators

5.4 Transformer and Transmission Line

Real power and reactive power flows and losses are retrieved from PowerWorld 'Branch State' generated table. Values of 'MW From' and 'Mvar Fro' illustrate the amount of power including real and reactive power flow through 4 transformers and 4 transmission lines respectively. Real and reactive power loss indicates how much of power be consumed in the transformers and transmission lines.

Real and Reactive Power flow and losses in Transformer						
From Name	To Name	Branch Device Type	MW From	Mvar From	MW Loss	Mvar Loss
Four	Three	Transformer	-318.2	-75.6	1.78	17.78
Two	Seven	Transformer	352.6	97.1	2.56	25.64
Two	Seven	Transformer	352.6	97.1	2.56	25.64
Five	One	Transformer	-409.4	-116.1	2.86	28.63

Table 12: Real and Reactive Power flow and losses in Transformer

Real and Reactive Power flow and losses in Transmission line						
From Name	To Name	Branch Device Type	MW From	Mvar From	MW Loss	Mvar Loss
Six	Four	Line	-43.4	-26.4	0.03	-15.48
Five	Two	Line	452.8	157.7	13.67	56.61
Four	Two	Line	274.8	64.7	8.72	-28.47
Five	Six	Line	-43.4	-41.6	0.04	-15.27

Table 13: Real and Reactive Power flow and losses in Transmission line

5.5 Surge-Impedance load & Power flow in Transmission Line

Line parameters and Surge-impedance Loads in per-unit on the system base and Limit MVA							
From Bus	To Bus	Length in Kilometer	X in per unit	B in per unit	Zs in per unit	SIL in per unit	Lim MVA
5	6	40	0.0112	0.163985	0.2618	416029.5	1028.8
6	4	40	0.0112	0.163985	0.2618	416029.5	1028.8
5	2	160	0.0447	0.6575	0.26087	417453.8	1028.8
4	2	280	0.0775	1.1564	0.258902	420622.4	1143.2

Table 14: Line parameters and Surge-impedance Loads in per-unit on the system base and Limit MVA

Table 14 is illustrating transmission line reactive power flows limit and their Surge-impedance Loads in per unit. Comparing the values of Surge-impedance Loads and reactive power limit (Lim MVA, last column in Table 14), it can be found that Surge Impedance load can be used to determine and evaluate the capabilities of transmission line loads. Lines with the higher Surge-impedance loads in per unit will enable the line to have the larger capable of the reactive power.

5.6 Base Case Evaluation

Overall power system has the total real power loss of 32.235 MW and total reactive power loss of 95.084 Mvar (S_{loss} = 32.235 + 95.084 MVA), which can be discovered at right side blank grid area in the system model graph on PowerWorld, as highlighted in Figure 2. Those real and reactive power is due to the consumption on the power supplying system.

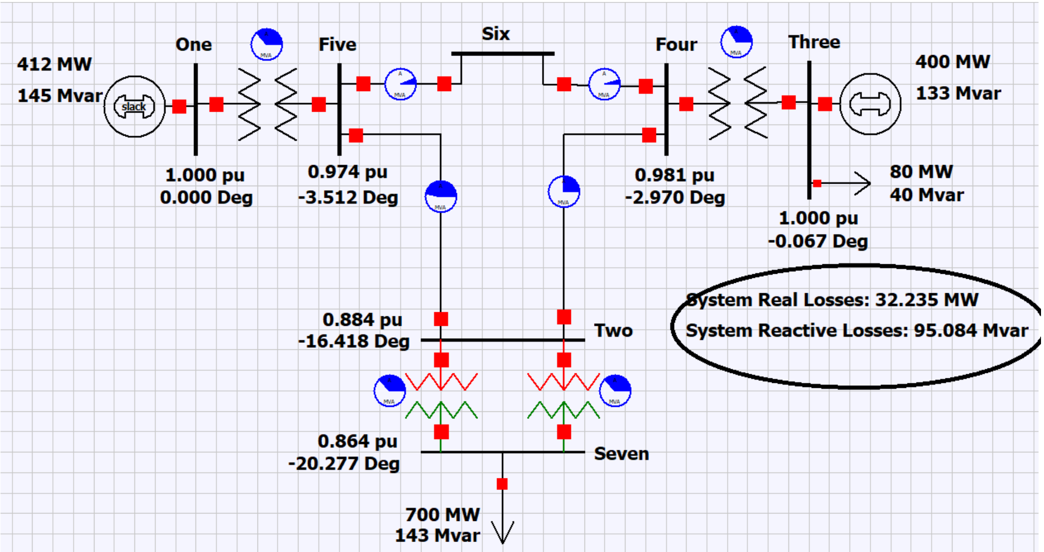

Figure 2: Real and reactive power losses of the entire power system

The performance of the base case scenario does not satisfactory as the power system does not reach the steady- state performance of power supply. Westernpower, a state-owned power company in Western Australia, has formulated certified technical rules to rule its operated power system while safely support electricity to users [1]. On the chapter 2.2 ‘Steady State Power Frequency Voltage’ of this technical rule book, it states that the lowest steady state voltage of the transmission system and its components must be above 90 percent of the nominal voltage and for the maximum voltage of steady state transmission, it must be lower than 110 percent of the nominal voltage [1]. From figure 2 where we can find that the per-unit voltage for bus 2 and bus 7 is lower than the lowest standard value of steady-state voltage – 0.9, with the voltage per-unit value of 0.884 pu and 0.864 pu. Therefore, the performance of the power system with default case is unsatisfactory.

6 Adjustment of base case

As the previous base case value was not achieving the power system steady-state standard, for this section, students are looking into the adjustment process of the system parameters to satisfy power system steady-state performance. In the previous section, it has been identified that voltages per unit of bus 7 and bus 2 are lower than the minimum electric power steady-state satisfied voltage. Based upon this observation, it needs to track the value of voltage turns ratio of the transformers in the upstream circuit. By retrieving both transformers’ voltage turns ratio values, it has found that both transformers, either the one between bus 1 & bus 5 or another between bus 3 & bus 4 are all set the voltage turns ratio as 1.0. Obviously, turns ratio of both upper transformers are insufficient and needs to increase accordingly. A mathematic methodology of dichotomy has been applied in adjusting values of a group of 4 transformers’ voltage turns ratio. First, increasing the both upper transformers’ voltage turns ratio to the maximum upper bound, 10 percent higher than 1 to fulfill steady-state performance of this power system. Once both values have been set, re-run the system simulation and read the latest record of voltage across all 7 buses. The power system operational results are attached in the figure below.

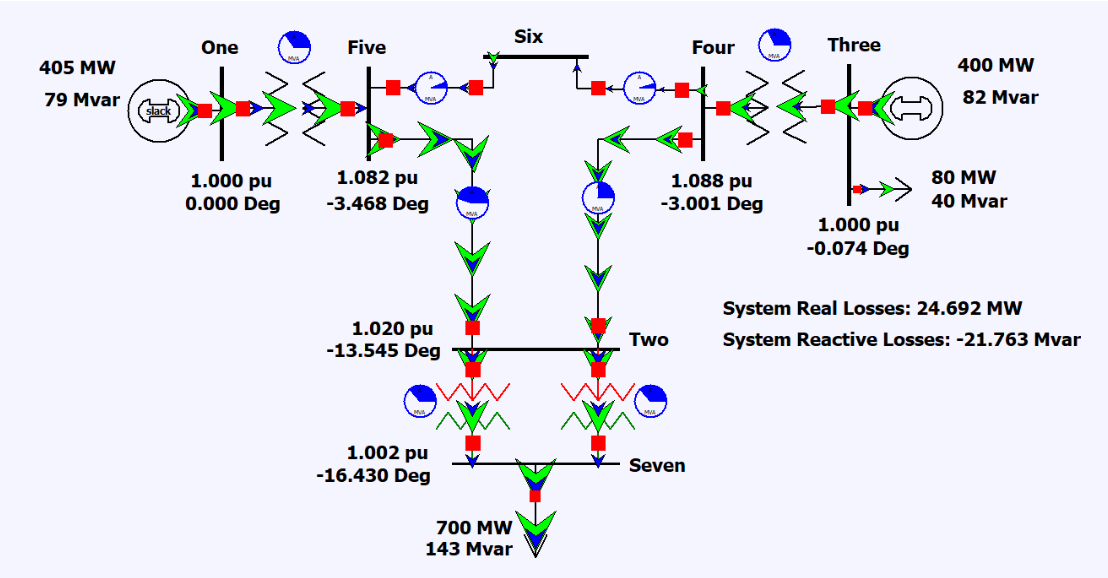

Figure 3: 2 upper transformers with the voltage turns ratio of 1.100

So it can be easily found voltage of per unit for all buses have been increased accordingly. Except bus 7, the rest of buses are exceeding the upper limits of voltage per unit. Now selecting a medium number between 1 and 1.10, 1.05 is just standing in the middle. Picking this number as the updated transformers voltage turns ratio for those on the top of the model. Likely, all bus voltage is dropped off and within the required voltage domain, but bus 2 and bus 7 with the per unit voltage lower than their specified range as figure 4 shows.

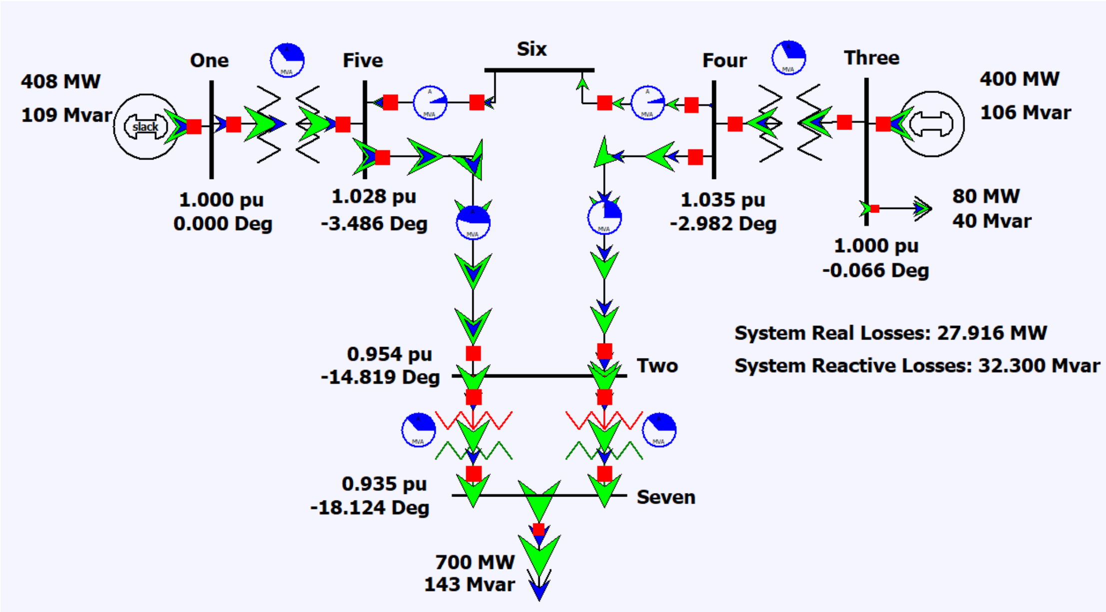

Figure 4: 2 upper transformers with the voltage turns ratio of 1.050

Next keep aligning with the dichotomy math method to pick a medium number within the range of 1.05 to 1.1. Inputting 1.075 into the voltage turns ratio parameter inputting cell for both upper transformers which are under modifications.

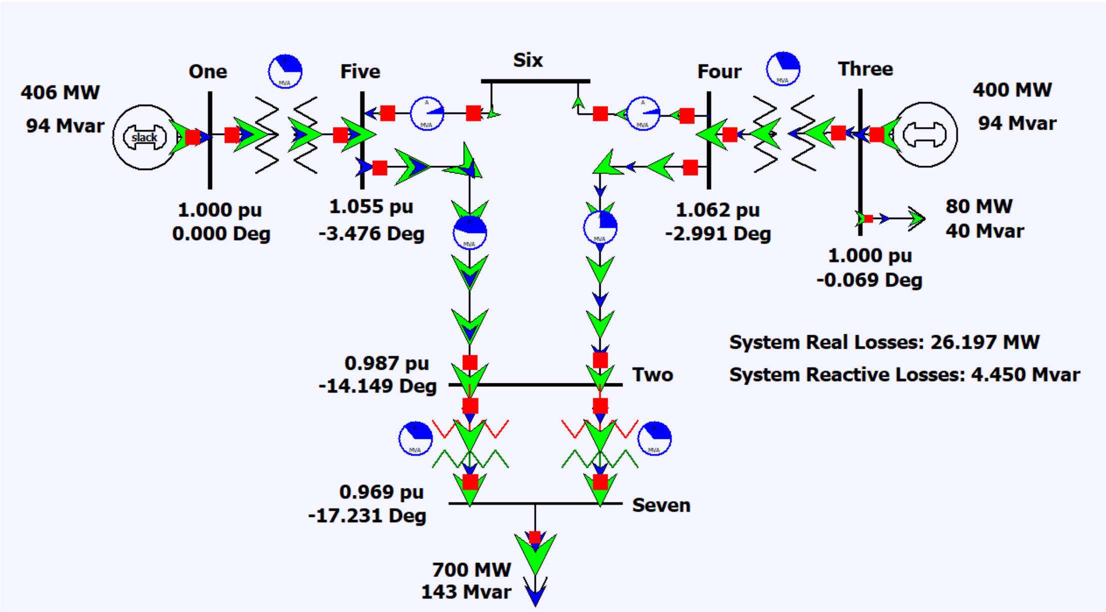

Figure 5: 2 upper transformers with the voltage turns ratio of 1.0750

From figure 5, after adjusting voltage turns ratio of 2 upper transformers to 1.0750, voltage per unit for bus 2 and 7 are remaining at the voltage lower than specified. Hence, recursively utilizing dichotomy to pick up the medium number with tighter bound until satisfying either the condition of bus 2 & 7 reach required lowest voltages, or achieving the maximum voltage boundary of bus 4, 5 & 6.

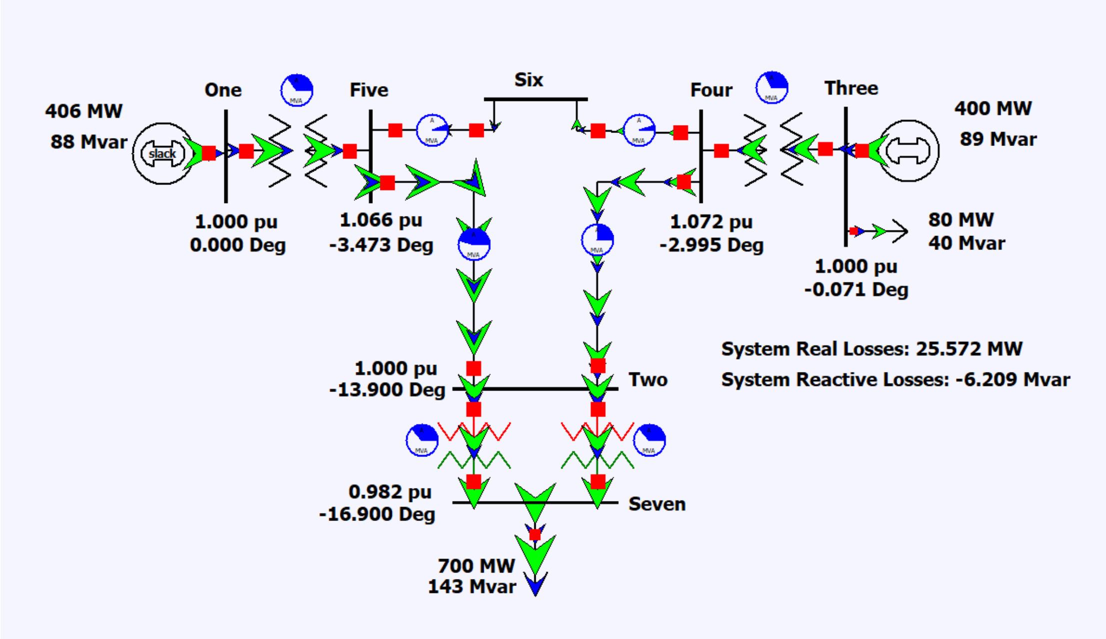

Figure 6: 2 upper transformers with the voltage turns ratio of 1.0850

Eventually, as the bound of dichotomy is tightened to 1.084 and 1.086, picking up 1.085 as the updated voltage turns ratio for both upper transformers and surprisingly, as shown in figure 6, the voltage per unit of bus 2 has reached 1.000 pu, the minimum required voltage, while the voltages for bus 4, 5 & 6 are still within the acceptable range.

Keep applying the same methodology to adjust the voltage turns ratio for the rest 2 transformers and when turns ratio at 0.95, the bus 7 will have the voltage of 1.038 per unit which is successfully fulfill all listed specification of voltages for all 7 buses, as figure 7 demonstrates.

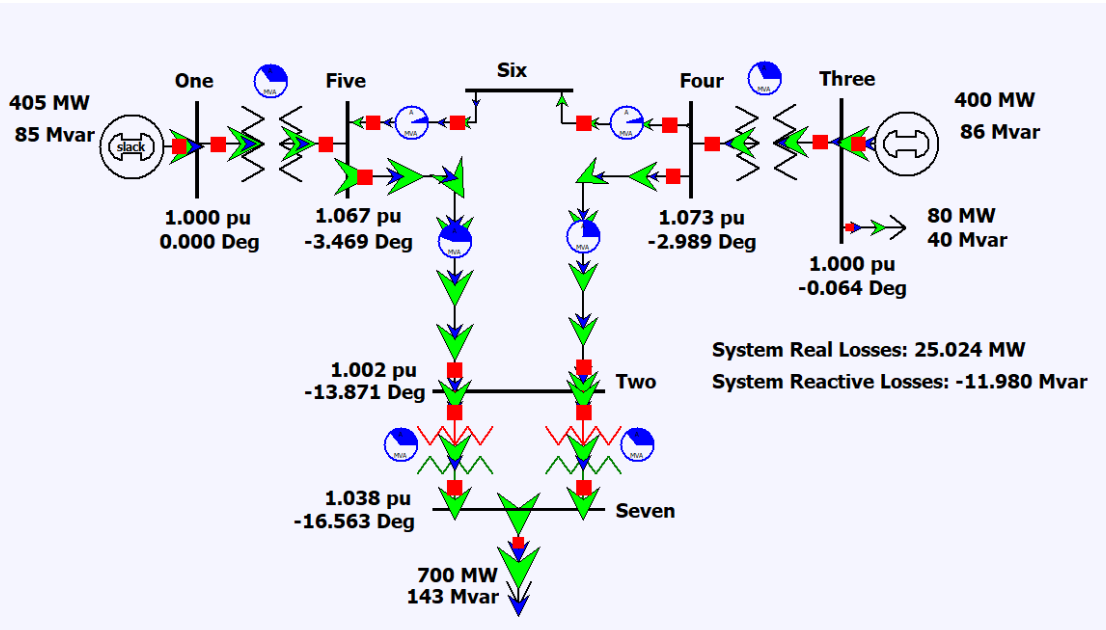

Figure 7: 2 upper transformers with the voltage turns ratio of 1.0850 & transformers between bus 2 and 7 with ratio of 0.95

It is necessary to be aware of value of voltage turns ratios for the 2 transformers between bus 2 and 7 need to be remaining the same while adjusting. This is due to 2 transformers are connected in parallel, if the voltage turns ratio for both of them are the same, so that both transformers will undergoing a uniform power distribution. Also, under this scenario, it can keep the power system have the redundancy of power supply in the case of 1 of the transformers disconnected or malfunction. The blue metrics shown in Figure are illustrating the power distributed status when it goes through system-connected equipment. Obviously, 2 blue metrics to measure the power flow through transformers between bus 2 and 7, which are literally equivalent to distribute power flows. However, a boundary test has illustrated the worst case of tap-ratio for those 2 transformers. In this case, the voltage turns ratio for the left is setting to 0.9 and on the other side, the voltage turns ratio is staying 1.1. Figure 7a intuitively demonstrated why both turn ratios for transformers between bus 2 and 7 need to be equivalent. Otherwise, 1 transformer on another side will undergo extremely uneven power flows, comparing another. If either transformer is out of service or disconnects, the entire power system will shut down without redundancy on supplying power if unexpected happening.

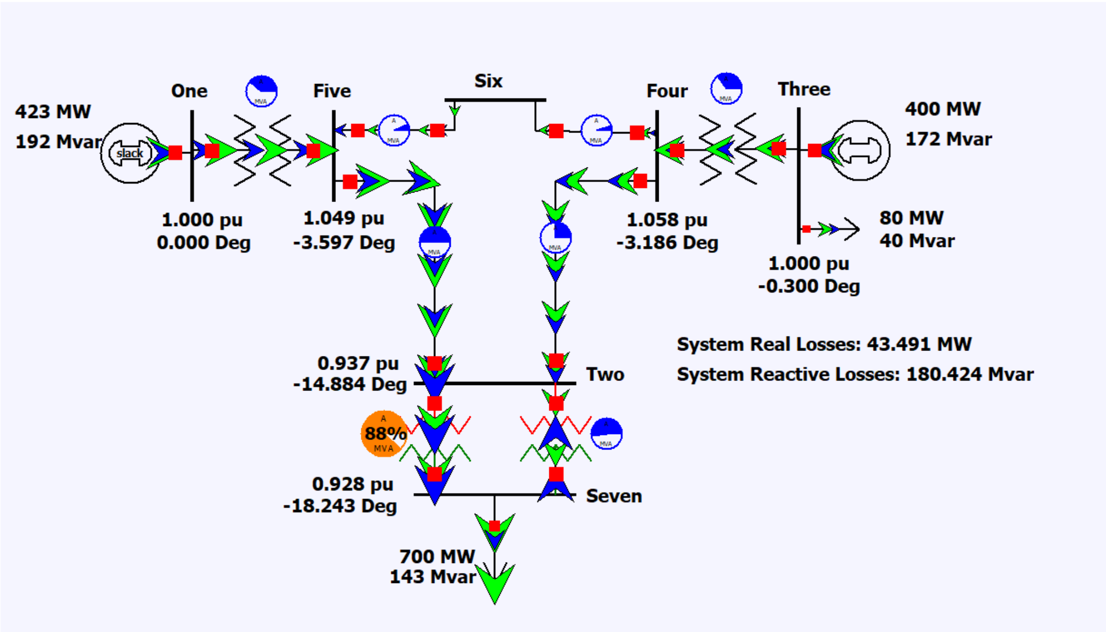

Figure 7a: Boundary Test for transformers between bus 2 and 7 with vary voltage tap ratio
(Left with 0.9 voltage tap ratio while right with 1.1 voltage tap ration)

6.1 After and Before Tap-adjustment System parameters

Before tap-adjustment for Bus Voltage				
Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
One	15	1	15	0
Two	330	0.88449	291.883	-16.42
Three	15	1	15	-0.07
Four	330	0.9812	323.796	-2.97
Five	330	0.97394	321.4	-3.51
Six	330	0.97846	322.892	-3.25
Seven	66	0.864	57.024	-20.28

After tap-adjustment for Bus Voltage				
Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
One	15	1	15	0
Two	330	1.00205	330.676	-13.87
Three	15	1	15	-0.06
Four	330	1.07281	354.029	-2.99
Five	330	1.06657	351.967	-3.47
Six	330	1.07067	353.32	-3.23
Seven	66	1.03824	68.524	-16.56

Table 15: Before and After tap-adjustment Bus Voltage

After tap-adjustment transformer Tap Ratio			
From Number	To Number	Branch Device Type	Tap Ratio
5	1	Transformer	1.000
2	7	Transformer	1.0000
2	7	Transformer	1.0000
4	3	Transformer	1.0000

After tap-adjustment transformer Tap Ratio			
From Number	To Number	Branch Device Type	Tap Ratio
5	1	Transformer	1.085
2	7	Transformer	0.95
2	7	Transformer	0.95
4	3	Transformer	1.085

Table 16: Before and After tap-adjustment transformer Tap Ratio

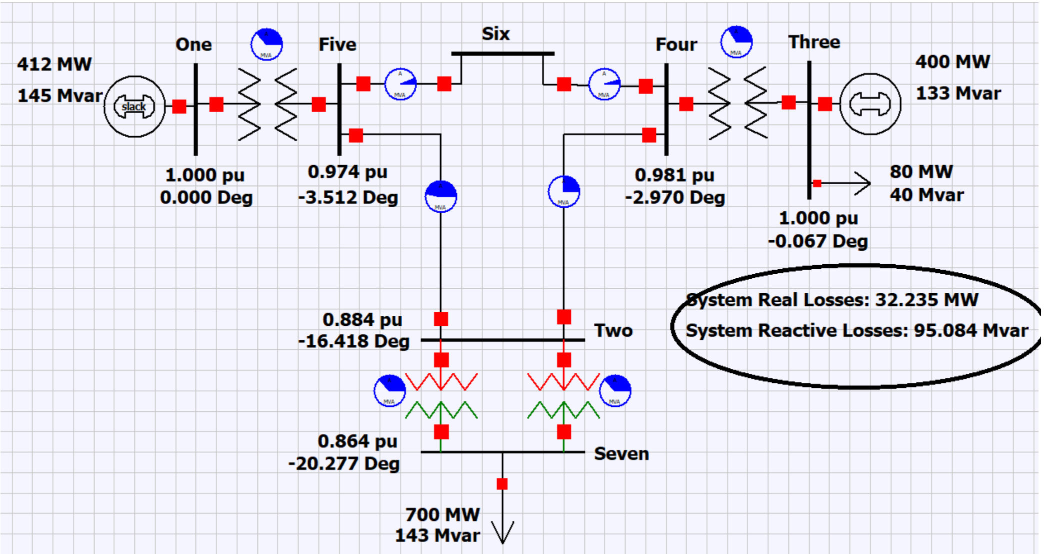

Figure 8a: Before tap-adjustment system losses

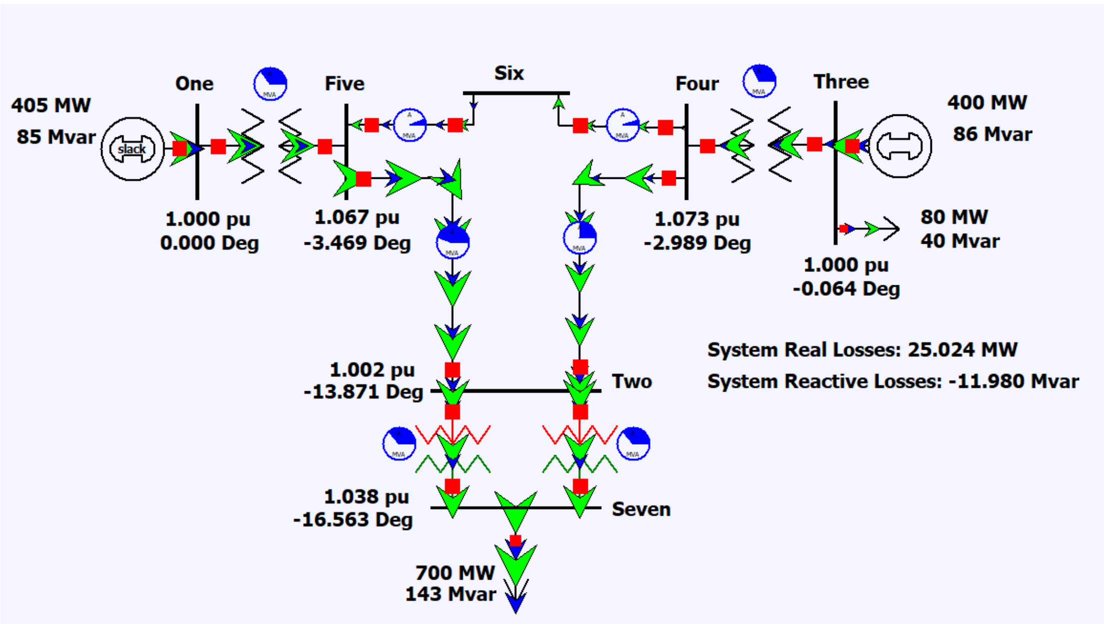

Figure 8b: After tap-adjustment system losses

7 Effect of Contingencies

A good power system will consider some contingency that might happen with the proper likelihood and in its design, the electrical power system will have redundancy to cope and keep operating while contingency happens. In this part, students will analysis the effect of contingencies of the designated equipment disconnected and observe what will be affected. System contingencies will undergo test upon the work of section 6, where adjusted voltage turns ratio of 4 transformers and resulting all buses fit all question-raised specifications.

7.1 Transmission line from bus 5 to 2 disconnected

In the power system simulation software of PowerWorld, it has the feature to connect/disconnect with any branches connected on the main system. Simply click the red node on the system model graph, the selected node and its connected wire will be suspended, which means no current and power will flow through the wire and wire-connected equipment. Once blocking the transmission line from bus 5 to 2, as figure 9 showing, the software simulator will automatically stop running while popping with a window saying the "the system no longer supplies the load BLACKOUT".

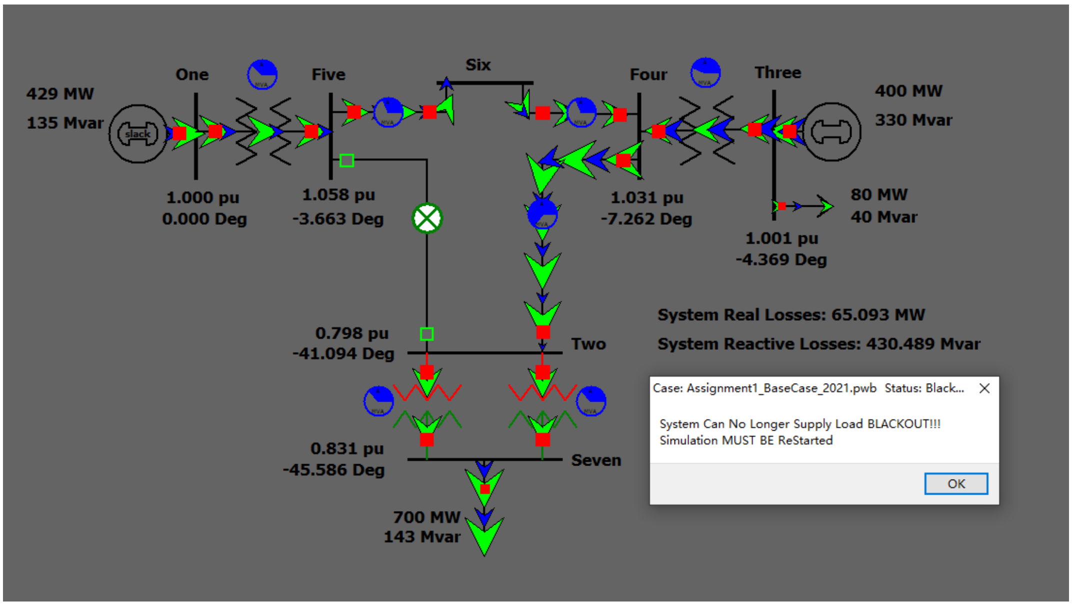

Figure 9: Transmission line from bus 5 to 2 disconnected

Disconnecting transmission line from bus 5 to 2 is resulting the entire power system shutdown and system no longer provide power to loads. A reasonable interpretation for this scenario is when transmission line from bus 5 to 2 disconnected, current and power flow out from transformer between bus 1 and 5 goes into the transmission line between bus 5 & 6, then flows into the line between bus 4 & 6. Afterwards, current and power goes from transformer between bus 4 and 3 are merging with the current and power flow where from the transformer connected with bus 1 and 5 and all current and power flows are flood into the transmission line (from bus 4 to 2) and causes system triggered relay protection to protect high loading in the transmission line (Between bus 4 and 2). However, one way to avoid system shutdown while disconnecting transmission line from bus 5 to 2 is to lower the voltage turns ratio of the transformer between bus 1 and 5 down to 0. 915 by applying mathematical dichotomy. As a result, the system now is able to operate as normal regardless of disconnection of the transmission line from bus 5 to 2.

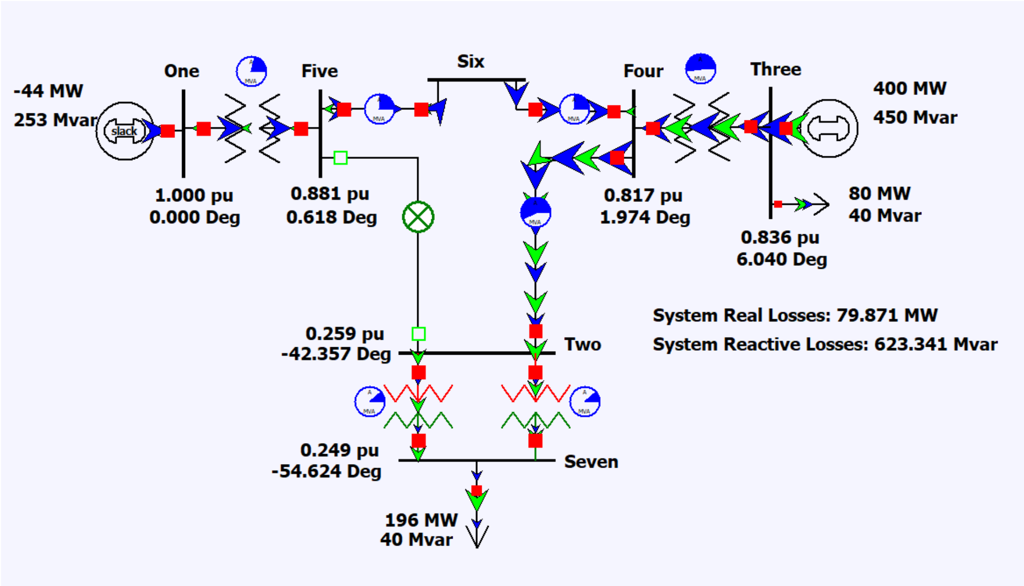

Figure 10: Transmission line from bus 5 to 2 disconnected
(While lower the voltage turns ratio to 0.915 for transformer between bus 1 and 5)

7.2 Transmission line from bus 4 to 2 disconnected

Recovering voltage turns ratio of the transformer between bus 1 and 5 back to 1.085 and continuing to test the effect contingencies under the scenario of disconnecting transmission line from bus 4 to 2. Figure 11 illustrates the system does not encountering blackout and disruption while disconnect transmission line form bus 4 to 2. Comparing with previous scenario, blocking the transmission line between bus 4 and bus 5 will not blackout the entire power system due to the line between bus 5 and 2 with a higher loading capacity to deliver power to the end-loadings.

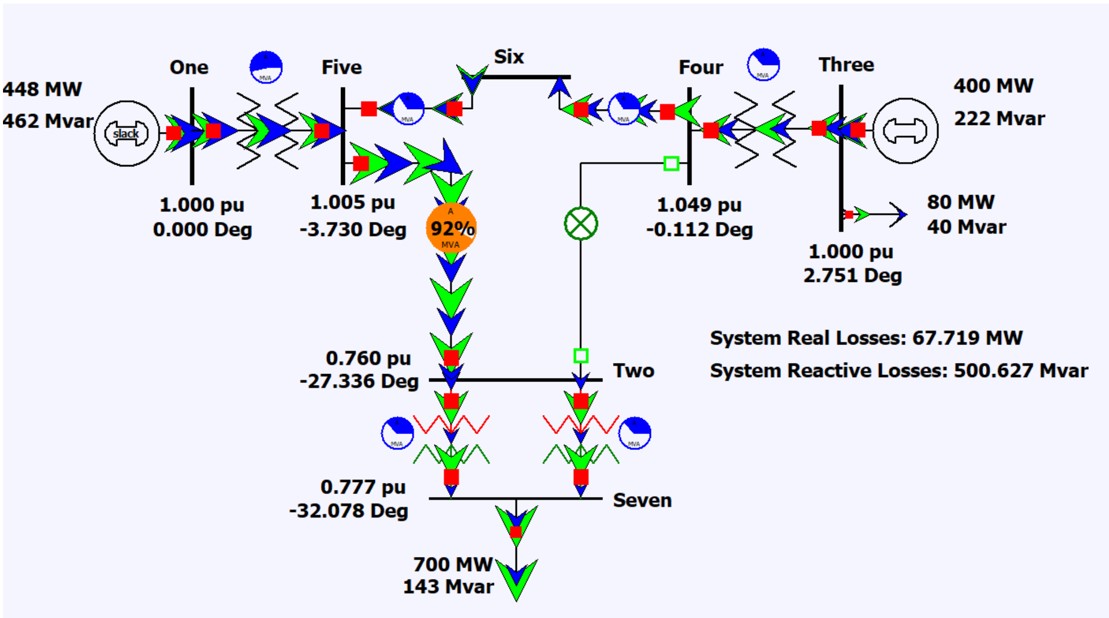

Figure 11: Transmission line from bus 4 to 2 disconnected

7.3 Transmission line from bus 5 to 6 disconnected

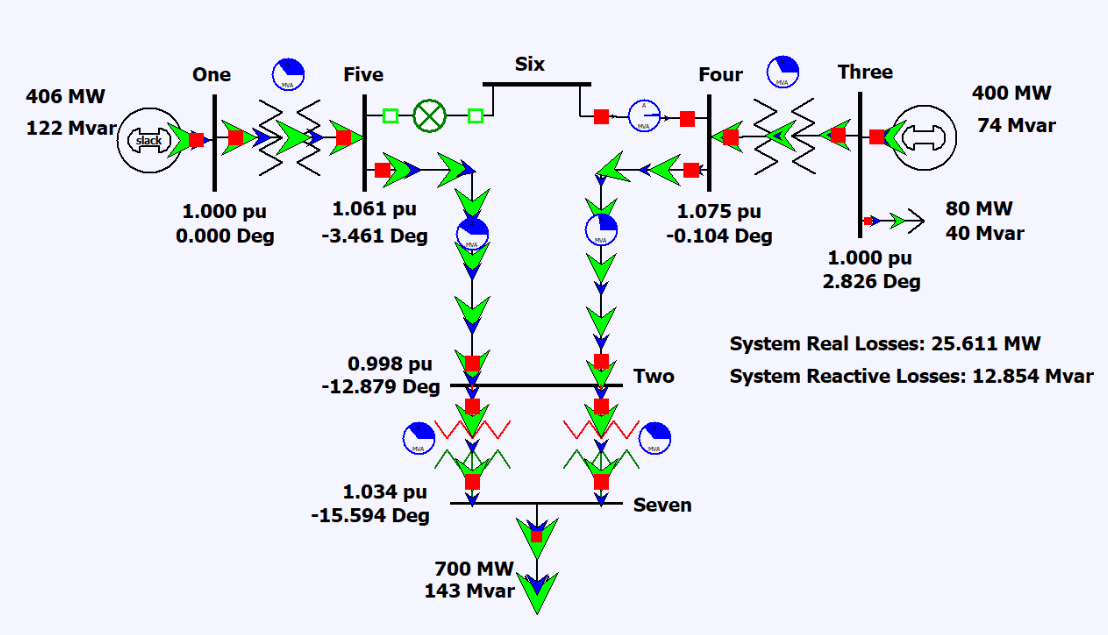

Figure 12: Transmission line from bus 4 to 2 disconnected

After disconnecting the transmission line from bus 4 to 2, the system is operating as normal and blackout consequences without presenting. This shows the power system has already had redundancy on preventing the whole system from shutting down happens.

7.4 Transformer #2 from bus 2 to 7 disconnected

The transformer #2 from bus 2 to 7 disconnected from the system does not affect whole system operations. Under normal operational conditions, each transformer between bus 2 and 7 is undertaking uniform power flowing and voltage transforming, and in usual under stable operational conditions, reactive power flows through the transformer is at 36.3% of the limit of reactive power capability of transformer. Essentially, although transformer #2 disconnects, transformer #1 still has tolerance to undertake the double workload and thus, it is operating at the 73.2% of the limit reactive power capability. Therefore, the system has the capability and redundancy to working relying on only 1 transformer between bus 2 and 7.

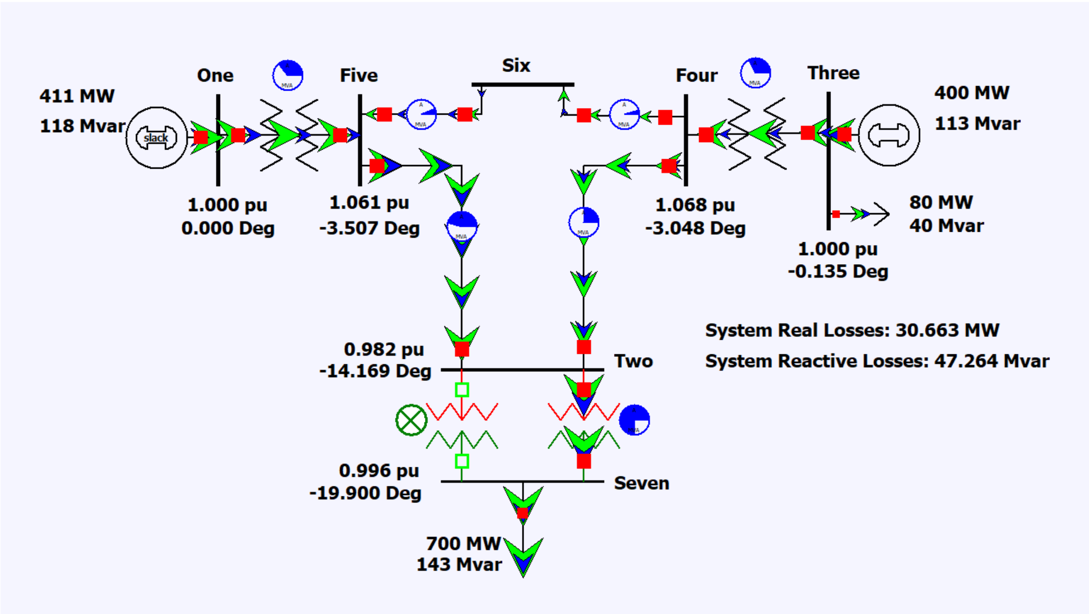

Figure 13: Transformer #2 from bus 2 to 7 disconnected

Effect of concurrencies is a critical criterion to examine the system steady-state performance. The worst case is when the transmission line from bus 5 and 3 disconnected as it caused whole system blackout and service disruption. Disconnecting the transmission line between bus 4 to 2 and between bus 5 to 6, as well as disconnecting transformer # 2 are testing the system reaction of concurrencies and it has shown this power system is having the adequate redundancies in response to the contingencies.

8 Voltage control and stability with SVC

In order to improve the steady-state performance of the power system, from section 7, the worst case of contingencies have been identified. In this section, students will conduct a study of installing a Static Var Compensator to empower the system with satisfactory steady-state performance under the worst contingency case as well. In the practical instruction, it has instructed that Static Var Compensator can be represented by a generator with pure reactive power and 0 real power output.

First, drag the generator from 'Network' bar under 'Draw' on the top panel of PowerWorld Simulator and move it to connect with bus 2. Once it positioned at right place, double clicking the newly created generator and setting power, max power and min power to zeros, as well as modifying min Mvar to -9999 and max Mvar to 9999. Then, re-run this power system and disconnecting transmission line from bus 5 to 2. At this moment, power system is not encountering blackout and some reactive power flows out from the Static Var Compensator which with the outputting Mvar value displaying on its ‘head’.

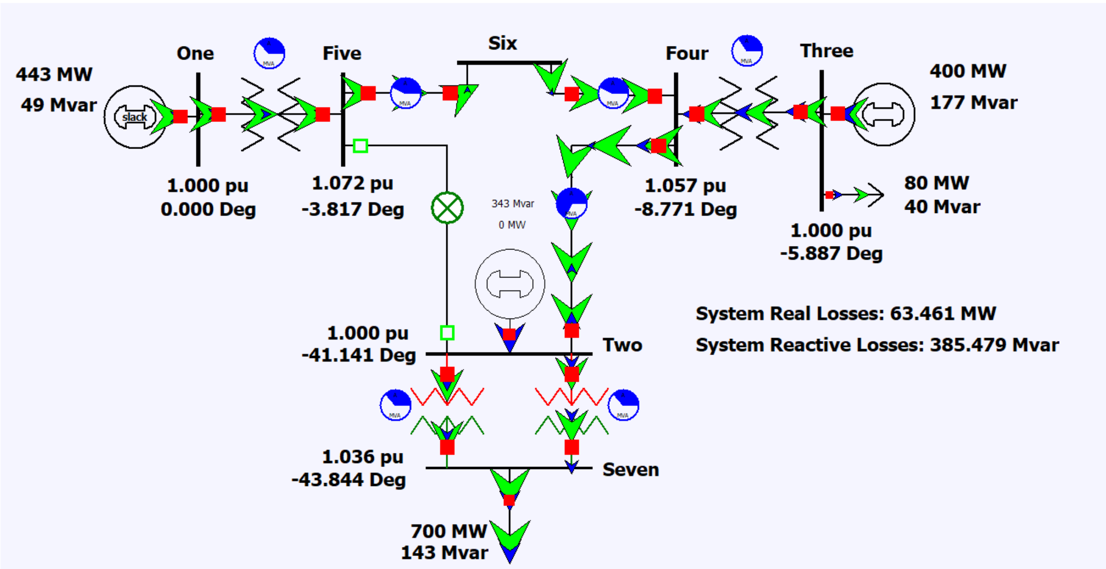

Figure 14: Disconnecting Transmission line from bus 5 to 2 after installing SVC

The Static Var Compensator has supplied additional reactive power to the system and its end load. Comparing with the original 2 generators where lying on both top sides generated reactive power, with the same demand reactive amount, but due to SVC connected with bus 2 can compensate partial reactive power to fill its shortage. So, as a result, the transmission line from 4 to 2 is no longer needs to overloading reactive power and thus, this scenario has addressed and significantly improve the steady-state performance of this power system under the worst contingency.

To fulfill the question-raised specification of letting Bus 2 voltage achieve 1.05 pu, mathematical methodology dichotomy is utlised to determine the output Mvar of the Static Var Compensator. Initially, the output Mvar is 343Mvar which labelled in figure 14.

However, the objective of voltage of bus 2 is 1.05 and it needs to increase the SVC output Mvar amount until Bus 2 reaches the voltage of 1.05 pu.

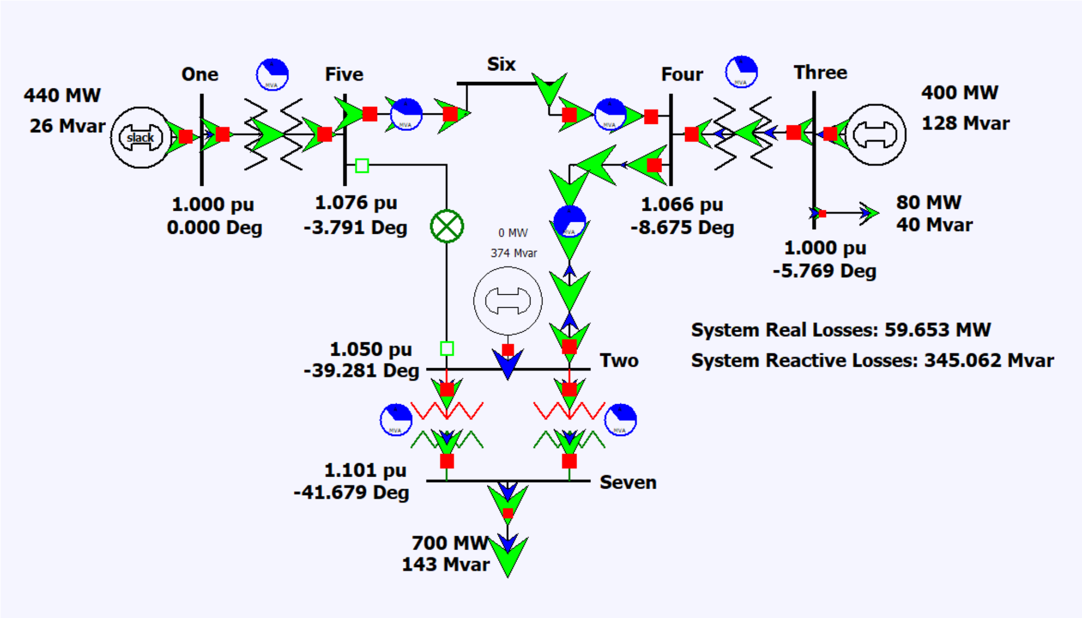

Figure 15: Disconnecting Transmission line from bus 5 to 2 after installing SVC
(Bus 2 achieve the voltage of 1.05 pu)

Finally, outputting Mvar of Static Var Compensator is determined to be at 374 Mvar for fulfilling the specification to achieving bus 2 voltage of 1.05 pu. Under current situation, the Static Var Compensator connected to bus 2 is supplying lagging reactive power because output Mvar Q > 0 and is capacitive in nature. However, it might be unable to identify the SVC leading reactive power capacity due to if its output Mvar < 0 and the SVC is in inductive nature which will consume the reactive power in the system. Previously, the worst case of contingency as transmission line from bus 5 to 2 disconnected has been analyzed and deduced it caused by reactive power overload the transmission line from 4 to 2, which leads system relaying protection automatically shutting down the entire system over security consideration. If the Static Var Compensator turns to the role of "reactive power consumer', transmission line from bus 4 to 2 overload situation will be further deteriorated and unhelpful for improving the steady-state performance of the system.

9 Increase in SVC capacity due to increase in load

In this part of practical, students will investigate the situation of main load demand increased by 200 MW and generator #3 outputting real power increased by 200 MW as well. Once modified output power and power demand for the generator on the top right and load respectively, re-running the simulating power system under the worst case of contingencies. However, as figure 16 reveals the SVC capacity determined in the above section cannot enabled to survive the worst line-outage contingency. This circumstance can be interpreted as the similar cause due to heavily overloading on transmission line from bus 4 to 2.

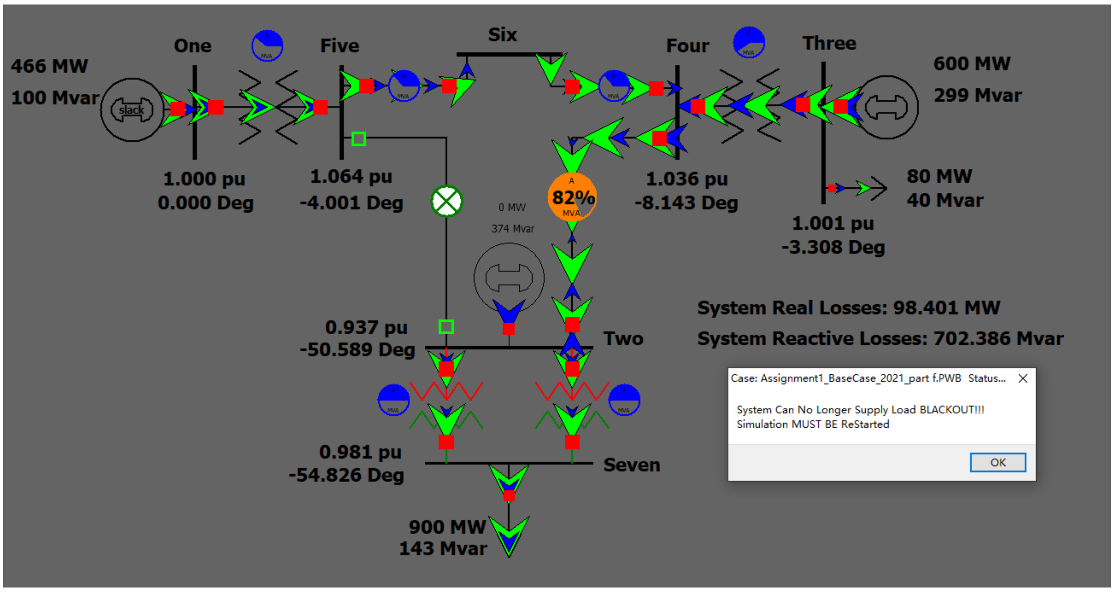

Figure 16: SVC capacity to survive system while power demand and output increased by 200MW
(with the output power of SVC equal to 374 Mvar)

In order to achieve secure supply power to 900 MW load, resetting the output Mvar range from minimum -9999 Mvar to maximum 9999 Mvar to determine the SVC capacity which can survive the worst line-outage contingency. So the SVC capacity has determined at 618 Mvar output of lagging reactive pow The system does not encounter blackout and service disruption at the worst case of contingency while all equipment connected in this system are within satisfactory limits to perform the steady-state performance of the system. Figure 17 and table 17 are showing the system operational status of the transmission and line as well as bus voltage are all within limits and fulfill the requirements of secure supply power to 900 MW load.

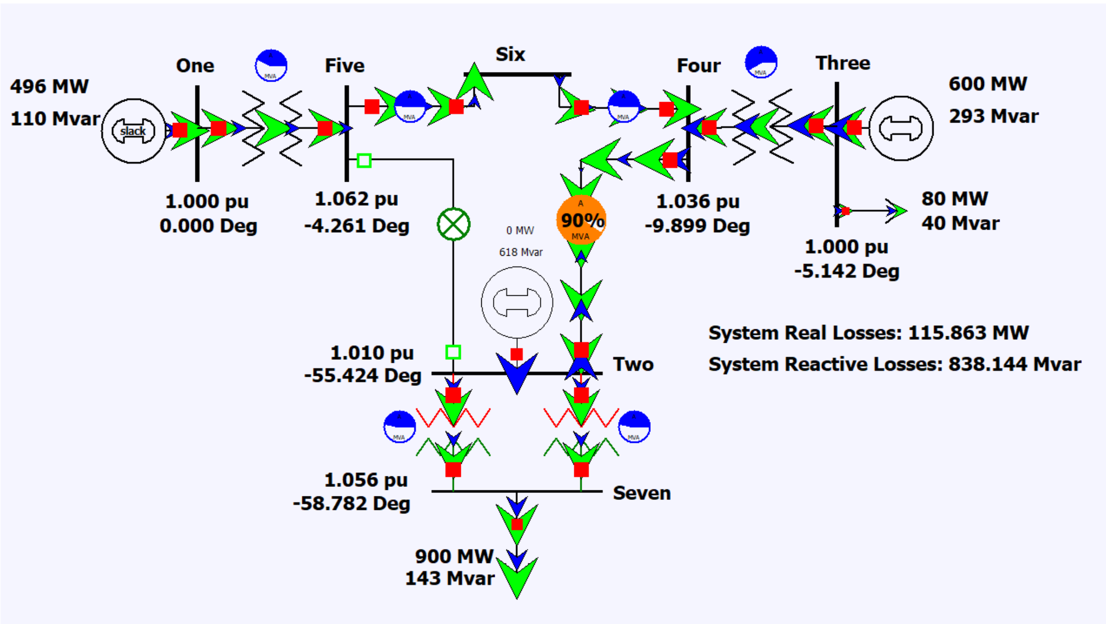

Figure 17: SVC capacity to survive system while power demand and output increased by 200MW
(with the output power of SVC equal to 618 Mvar)

Line and transformer parameters after increasing SVC capacity to 618 Mvar									
From Number	To Number	Branch Device Type	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
6	4	Line	489	64.5	493.2	1028.8	47.9	3.02	7.19
5	2	Line	0	0	0	1028.8	0	0	0
4	2	Line	1000.6	257.2	1033.1	1143.2	90.4	95.04	676.37
5	6	Line	492	71	497.1	1028.8	48.3	2.99	6.49
4	3	Transformer	-514.6	-199.9	552.1	1000	57.8	5.35	53.54
2	7	Transformer	452.8	99.4	463.6	1000	46.4	2.79	27.94
2	7	Transformer	452.8	99.4	463.6	1000	46.4	2.79	27.94
5	1	Transformer	-492	-71	497.1	1200	42.3	3.87	38.69

Table 17: Line and transformer parameters after increasing SVC capacity to 618 Mvar

10 Conclusion

In this practical assignment, students are deeply studying the characteristics of the steady-state performance of an electrical power system and learning how to adjust system parameters to perform a steady-state power system on PowerWorld simulator, as well as applying theoretical knowledge to improve a power system case for achieving steady-state requirements. The whole practical working process is from PowerWorld simulation set-up, search system parameters on PowerWorld 'Model Explorer' dashboard, analysis the system base case, adjust the base case to satisfy voltage limits range of 0.9 pu - 1.1pu, examine multiple contingencies and system reaction, installing an additional Static Var Compensator (SVC) to improve system performance on the worst contingency. The outcome of this practical is a developed electrical power system with an additional Static Var Compensator improved upon the assignment case, which can operate smoothly without encountering blackout when the worst case of contingency happened.