Department of Electrical & Computer Engineering

ENEL 587/601 (Fall 2020)

Design experiment-Phase 3

Deadline: Dec 8, 2020

Phase #3 Project Report Guidelines:

- Wherever you are asked for answer/discussion, write it below that particular question.
- After answering all the questions, convert this word file into PDF and make sure that the name of the PDF file contains your first and last name. Please use lastname_firstname.pdf. You are required to submit just one PDF that contains all the answers.
- After you are done with that, please upload that PDF file on D2L. That's the only thing we require for submission.

Load Interconnection Study Project

Objectives: This course project is intended to provide the students with an opportunity to perform most of the technical studies that are involved in real-life network interconnections in power systems. While the test system used is small, it has most of the main features of a real system. Also, the students will be exposed to the reliability standards and the interconnection process that is in place for Alberta.

In this project, you will study a system according to applicable reliability standards, design a transmission plan to connect a new load to the network, and reinforce the system such that the final design passes the reliability tests.

Introduction

As a result of the low electric rates from the local utility, Metropolis Light and Power (MLP), under the jurisdiction of Alberta Electric System Operator, several large server farms and a new factory are going to be built in the eastern portion of the MLP service territory. With an anticipated peak load of about 75 MW and 20 MVAR, this new load also brings additional revenue to MLP. However, in order to supply this additional load, the new TULIP substation will need to be constructed. While the new customers to be connected to this substation would like to receive electricity at the 69 KV level, the new substation location is large enough to accommodate a 138/69 KV transformer if needed. Additionally, for reliability purposes, the TULIP substation needs to have at least two separate lines feeding it.

As a planning engineer for MLP, your job is to make recommendations to ensure that, with new TULIP loads, under peak loading conditions, the transmission system in the eastern region is adequate for any base case and first contingency loading situations. This is also a good opportunity not only to meet the new load, but also to fix some existing first contingency violations that may exist in the eastern portion of the MLP service territory.

The DesignCase1_2015 files provide a power flow base case model of the initial conditions of the system.

Phase 3: Transient Stability and Voltage Stability

What you completed in Phase 1 and 2 are in fact parts of interconnection study requirements that utilities generally require when a new load or generation requests interconnection to the grid. In Alberta, the process of access to the grid is described here:
https://www.aeso.ca/grid/connecting-to-the-grid/
Visit this page and familiarize yourself with the interconnection process in Alberta. In particular, the interconnection process is outlined in several stages, and roles, responsibilities, requirements, and deliverables of each stage are explained here:
https://www.aeso.ca/grid/connecting-to-the-grid/connection-process/

3.1 The 'Connection Study Scope' document, provided to you in D2L, which is a template for documenting studies, outlines the details of study requirements for an interconnection in Alberta. In particular, section 1.2 of the document, lists all study details. Look up 'Connection Study Details.doc' in project D2L folder. Note: this a living document that may get updated occasionally on AESO's website. To be consistent in this course project, please use the one that we provide you as the basis of doing this project. This template gives you a good idea of what studies need to be done, what assumptions must be made, and how the results should be documented in practice.

3.1.1 Include a short summary of section 1.2 in your project report and reflect on the type of studies and the considerations for each. (10%)

Answer: Section 1.2 summarized the scope of study to be carried out prior to obtaining approvals for the construction of new interconnection. The main objective of the study is to list out the possible connection for the project and identify the pre and post constraints of those connections which will affect the Alberta Interconnected Electrical System (AIES). In addition, the mitigation technics for the violations in order to comply the reliability standards.

Firstly, the study area should consist of the single line diagram that clearly indicates the features of transmission lines, substations, generating assets, and reactive elements along with their voltage classes. The SLD should clearly shows the interconnection with Alberta Interconnection Electrical System. Moreover, the study should describe the existing system network and the interconnecting line details with the AIES. Furthermore, all the constraints should be mentioned if available. For these constraints, practiced RAS are described or operation measures which keep the constraint under control are described. AESO Long-Term Transmission Plan associated with the Project area are mentioned along with its anticipated completion dates. Describe the impacts on the Project due to the delayed completion of the long-term plans.

Finally, all the studies listed. Studies carried out for the connection Project are and their associated considerations are shown below:

1) Load Flow Analysis: (Category A i.e., normal operating condition N-0, Category B i.e., abnormal condition N-1 and selected Category C5 i.e., loss of two circuits of a multiple circuit tower) for pre-Project and post-Project conditions.

2) Voltage Stability Analysis: (Category A, Category B and selected Category C5) for post-Project conditions. Voltage stability analysis for pre-connection scenarios is only performed if post-Project scenarios show voltage stability criteria violations.
3) Transient Stability Analysis: - (Category B and selected Category C5) for post-Project conditions
4) Motor Starting Analysis: for post-Project conditions only.
5) Short Circuit Fault studies: for pre and post project conditions.

For the connection studies which result transmission congestion issues, AESO gives further direction for the same to get rid of normal (N-0) and abnormal (N-1) operating condition violations.
It also mentions the studies excluded for the Project (Load flow, voltage stability and transient stability all for Category C)

3.1.2 What are the load forecast scenarios that need to be considered in a connection study? (5%)

Different load forecast conditions which need to be under consideration in a connection study are as under:

- The ratio of active power to reactive power should be maintained while modifying the project load in future.
- Describe the generator's output and the AESO forecast. Present and future generation units and their dispatch levels are to be considered for the project study.
- The tie-line loading assumption between Alberta and the other nearby regions.
- For the major projects, the HVDC line connection to Alberta to be considered where the scoped study scenarios require adjustments to the pre-set HVDC flow level provided by the AESO in the Base Cases, the Engineer will provide give suggestions for new load flow settings and Var compensations.

3.1.3 What is the fault clear times for transient stability analysis for differed voltage levels that must be used? (5%)

- Fault clearing times for transient stability analysis are as shown in the following table:

Nominal	Near End	Far End
kV	**Cycles**	**Cycles**
500	4	5
240	5	6
144/138 with telecommunications	6	8
144/138 without telecommunications	6	30

- Stuck Breaker Clearing Times for Lines:

<table>
<tr><th colspan="3">Fault Clearing Time</th><th colspan="3">Fault Clearing Time</th><th colspan="3">Fault Clearing Time</th></tr>
<tr><td colspan="3">138/144 kV</td><td colspan="3">240 kV</td><td colspan="3">500 kV</td></tr>
<tr><td rowspan="2">Near End</td><td rowspan="2">Far End</td><td>2nd Ckt</td><td rowspan="2">Near End</td><td rowspan="2">Far End</td><td>2nd Ckt</td><td rowspan="2">Near End</td><td rowspan="2">Far End</td><td>2nd Ckt</td></tr>
<tr><td>(for C5 and C7 Only)</td><td>(for C5 and C7 Only)</td><td>(for C5 and C7 Only)</td></tr>
<tr><td>15</td><td>24</td><td>24</td><td>12</td><td>6</td><td>14</td><td>9</td><td>5</td><td>11</td></tr>
</table>

- Stuck Breaker Clearing Times for Transformers:

Fault Clearing Time (Cycles)						Fault Clearing Time (Cycles)					
240/138 kV						500/240 kV					
Fault on 240 kV Side			Fault on 138 kV Side			Fault on 500 kV Side			Fault on 240 kV Side		
240 kV Side	138 kV Side	2nd Ckt (for Breaker Fail)	138 kV Side	240 kV Side	2nd Ckt (for Breaker Fail)	500 kV Side	240 kV Side	2nd Ckt (for Breaker Fail)	240 kV Side	500 kV Side	2nd Ckt (for Breaker Fail)
12	6	14	15	5	24	9	5	11	12	4	14

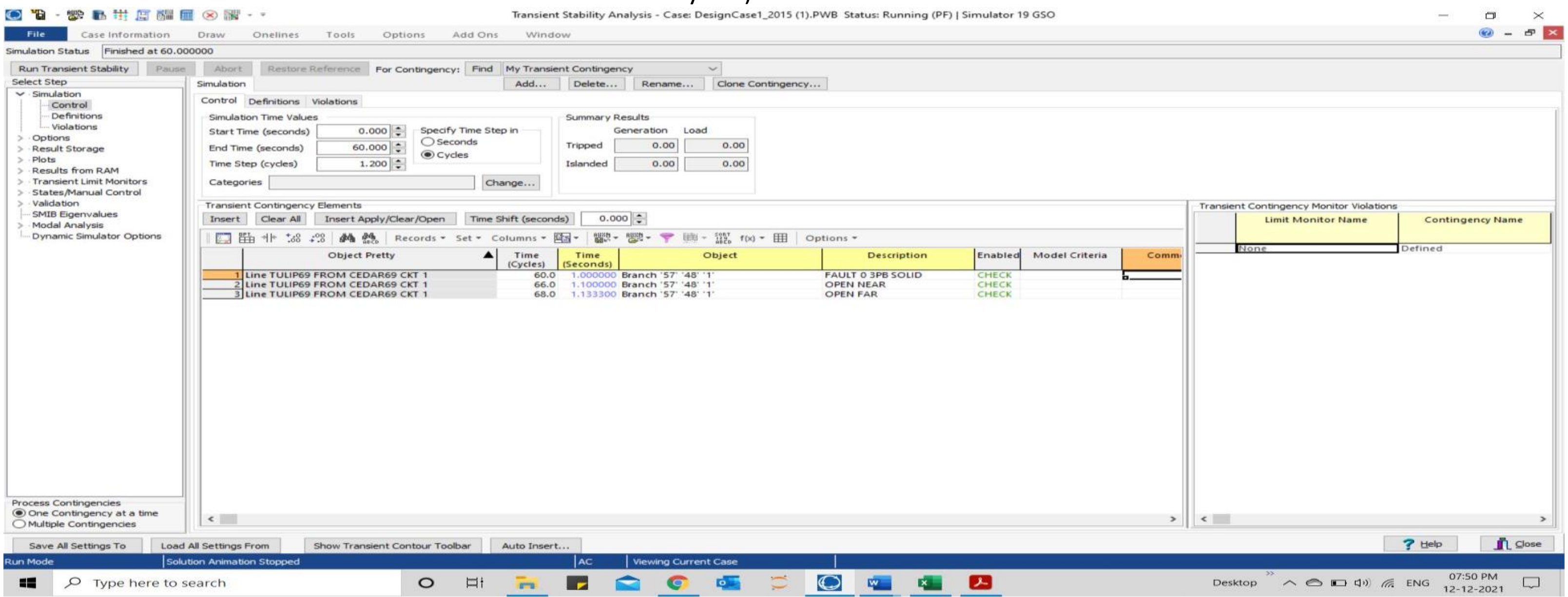
In this part of the project, and in line with the practice in Alberta, you are required to study the system with the new line additions for voltage and transient stability.

Keep a copy of your power system powerworld file (the PowerWorld files) safe and use its duplicate for the analysis below. Note that sometimes, the changes done to the system may not be easily traced back and undone. Please use your final solution from project phase 2. For this part, perform the following steps.

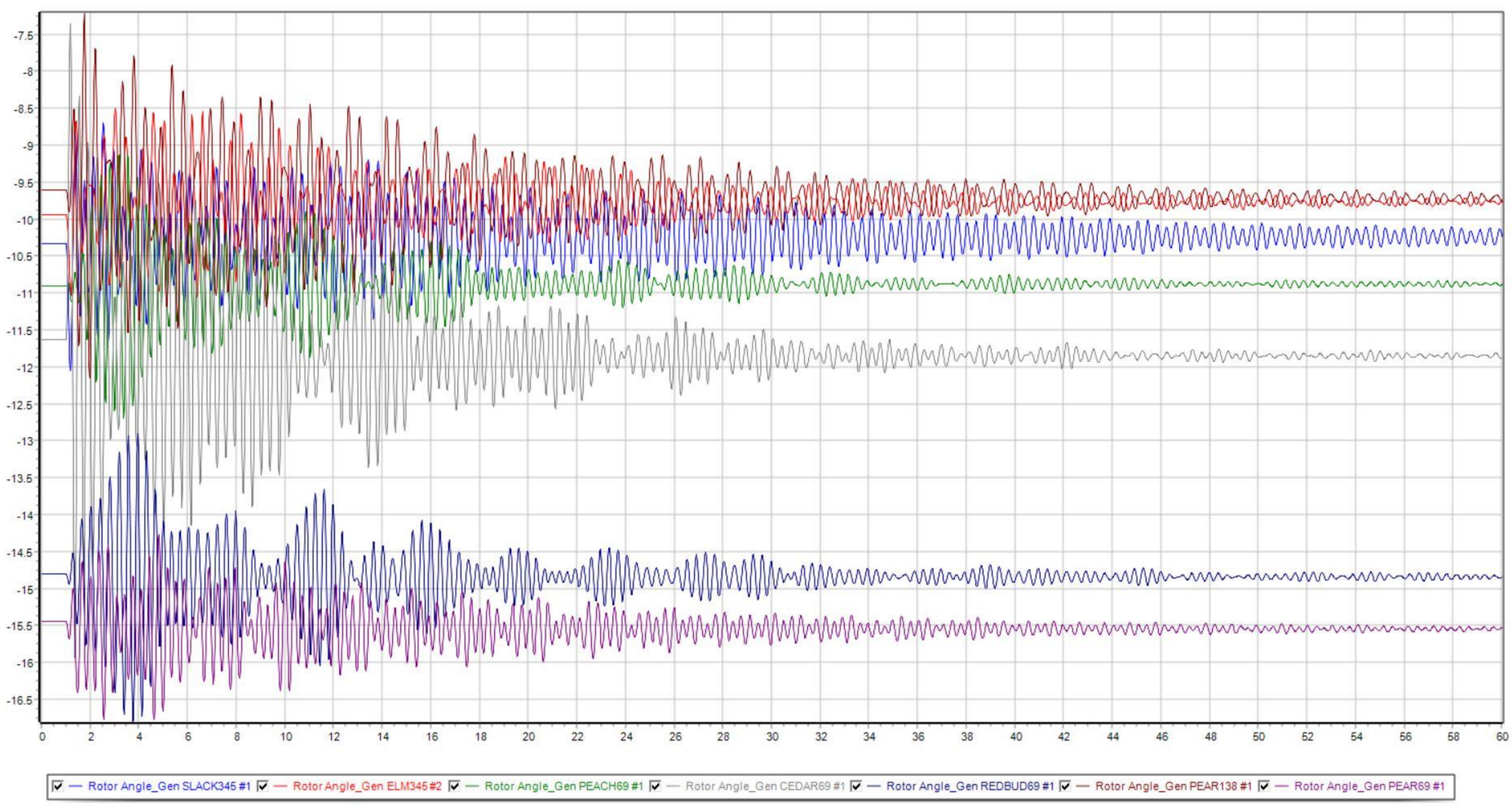
3.2 As a planning engineer, you need to demonstrate that if any fault occurs in the newly designed lines, the system will remain transient stable. Watch the following video to see how to define a fault in an element, clear the fault, and conduct transient stability studies in Power World: https://www.youtube.com/watch?v=PF8ub7EphCk

3.2.1 For each newly designed line (branch) connected to TULIP substation, apply a 3-phse balanced solid fault near the TULIP bus. Apply the fault at time =1 second. Then, open both ends of the line to clear the fault according to the guidelines of Table 2-3 in Attachment of 'Connection Study Details.doc'. The table does not mention 69 kV, and thus, assume that the fault clearing time requirements are the same for the 69 kV and 138 kV substations. Monitor, and provide a snapshot of, the rotor angle of all generators. Based on the results, comments on the transient stability of the system for each of the faults. (15%)

Case 1: Fault created on the line TUPIL69 to CEDAR69; three phase balanced solid fault near the TULIP69 bus; fault created at time = 1 second and cleared by opening the line. (for 69kV, fault clearing time considered same as that of 138kV which is 6 cycles, i.e., 0.1 second hence fault effectively cleared for near end at time = 1 + 0.1 = 1.1 second = 66 cycles and for far end at time = 1 + 0.1333 = 1.1333 seconds = 68 cycles)

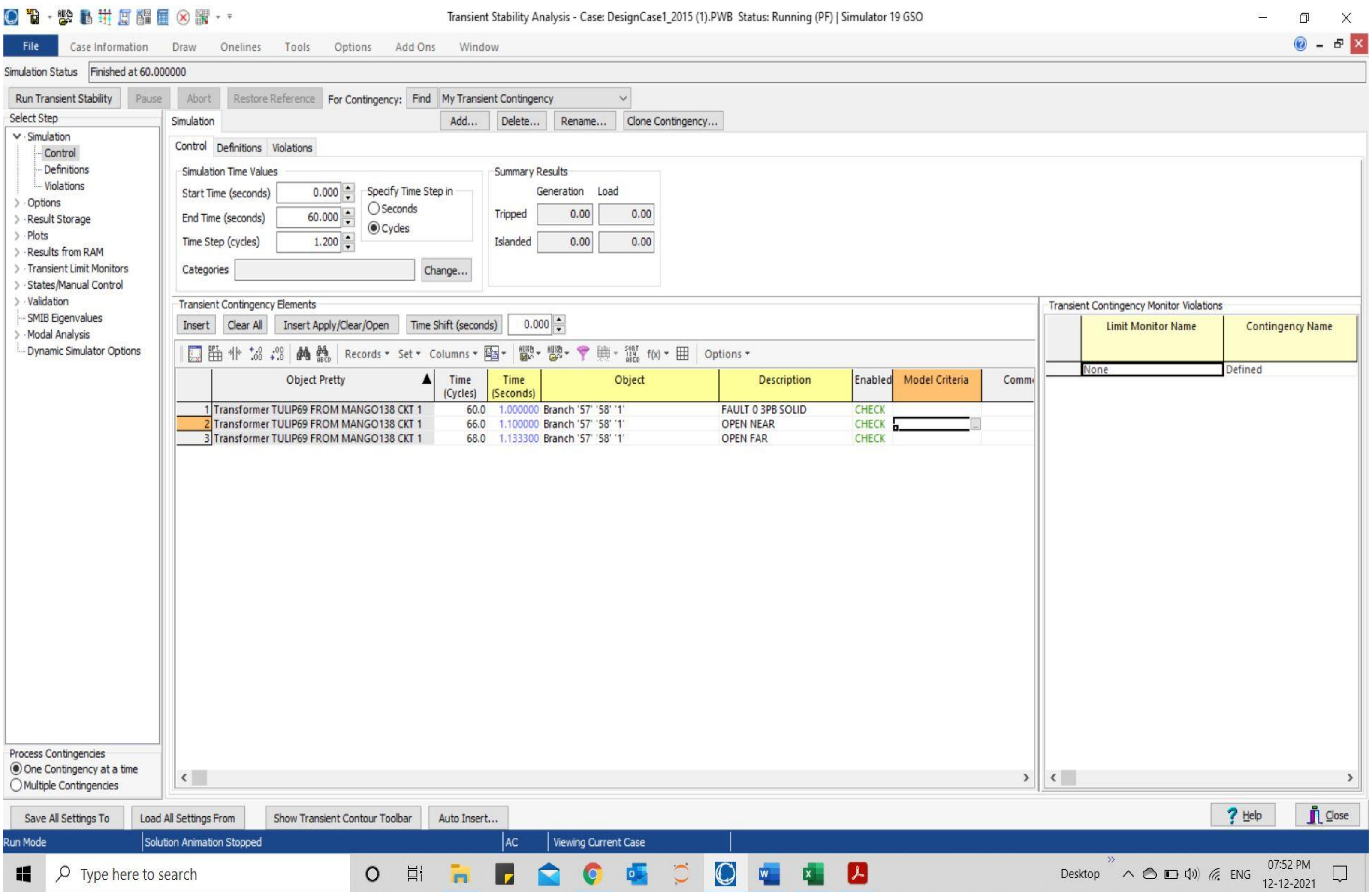


The result of this case is shown in the following plot of Rotor Angle (in degree) Vs Time (in second)

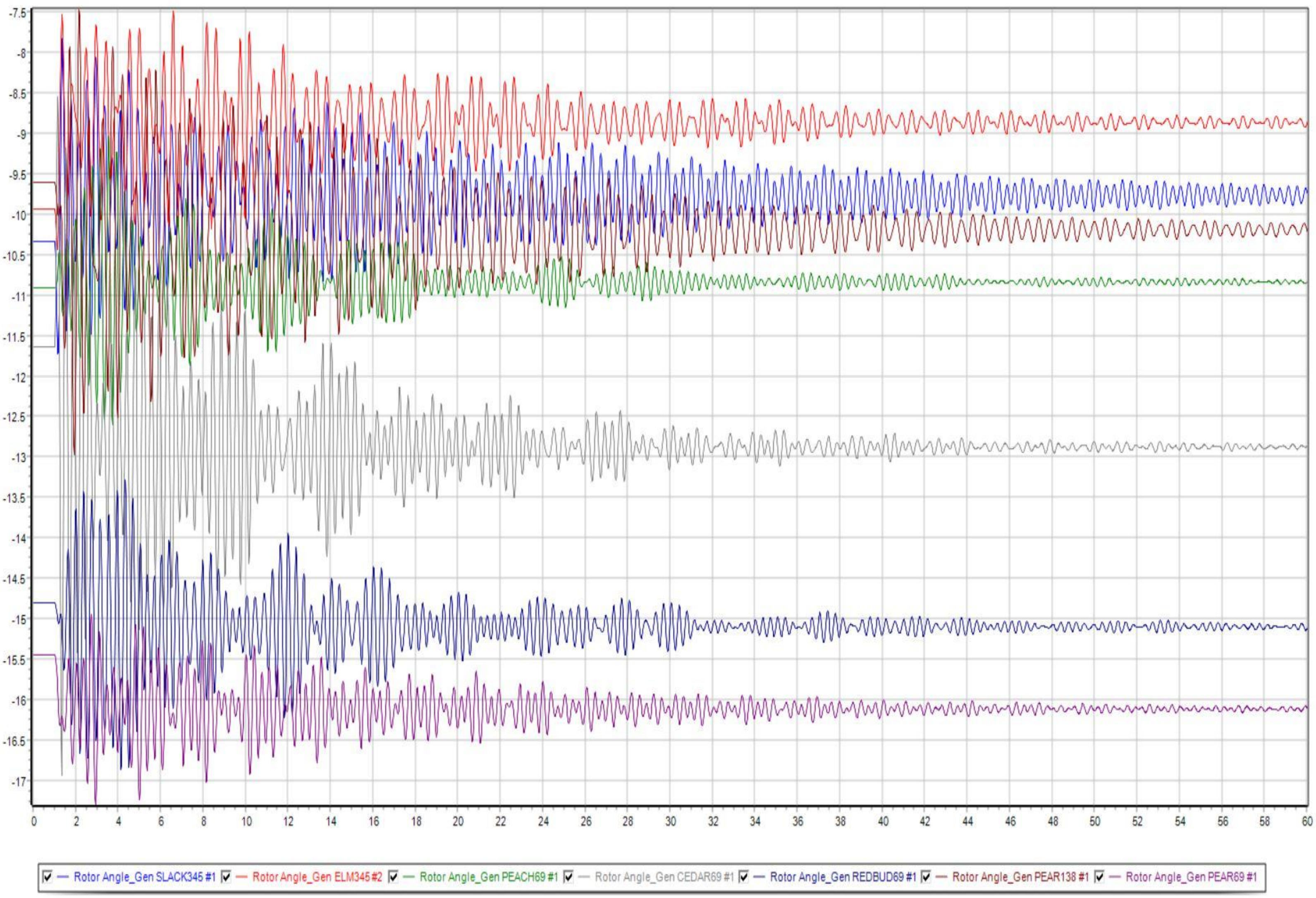


From the plot of rotor angles of all the generators, it can be seen that the rotor angles oscillate and eventually get stabilized **(System Stable)** close to the initial angle (prior to applying the fault i.e. normal operation). In addition to that, maximum deviation in rotor angle is seen for the generator CEDAR69#1 and is located on the CEDAR69 bus which is the nearest to the fault location compare to all other generators. Other generators also experience deviation in rotor angle but not as large as that of Gen CEDAR69#1 because other generators are farther from the fault location.

Case 2: Fault created on the branch of TUPIL69 to MANGO138; three phase balanced solid fault near the TULIP69 bus; fault created at time = 1 second and cleared by opening the line. (for 69kV, fault clearing time considered same as that of 138kV which is 6 cycles, i.e., 0.1 second hence fault effectively cleared for near end at time = 1 + 0.1 = 1.1 second = 66 cycles and for far end at time = 1 + 0.1333 = 1.1333 seconds = 68 cycles)



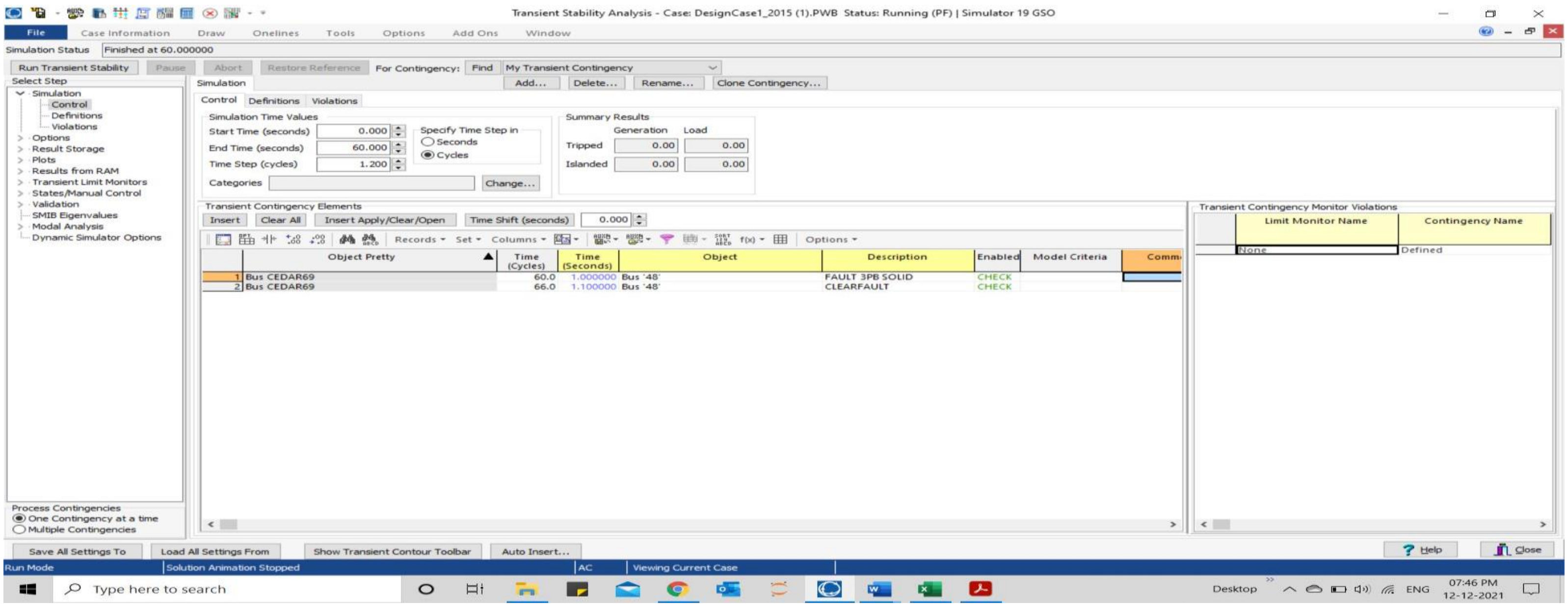
The result of this case is shown in the following plot of Rotor Angle (in degree) Vs Time (in second)



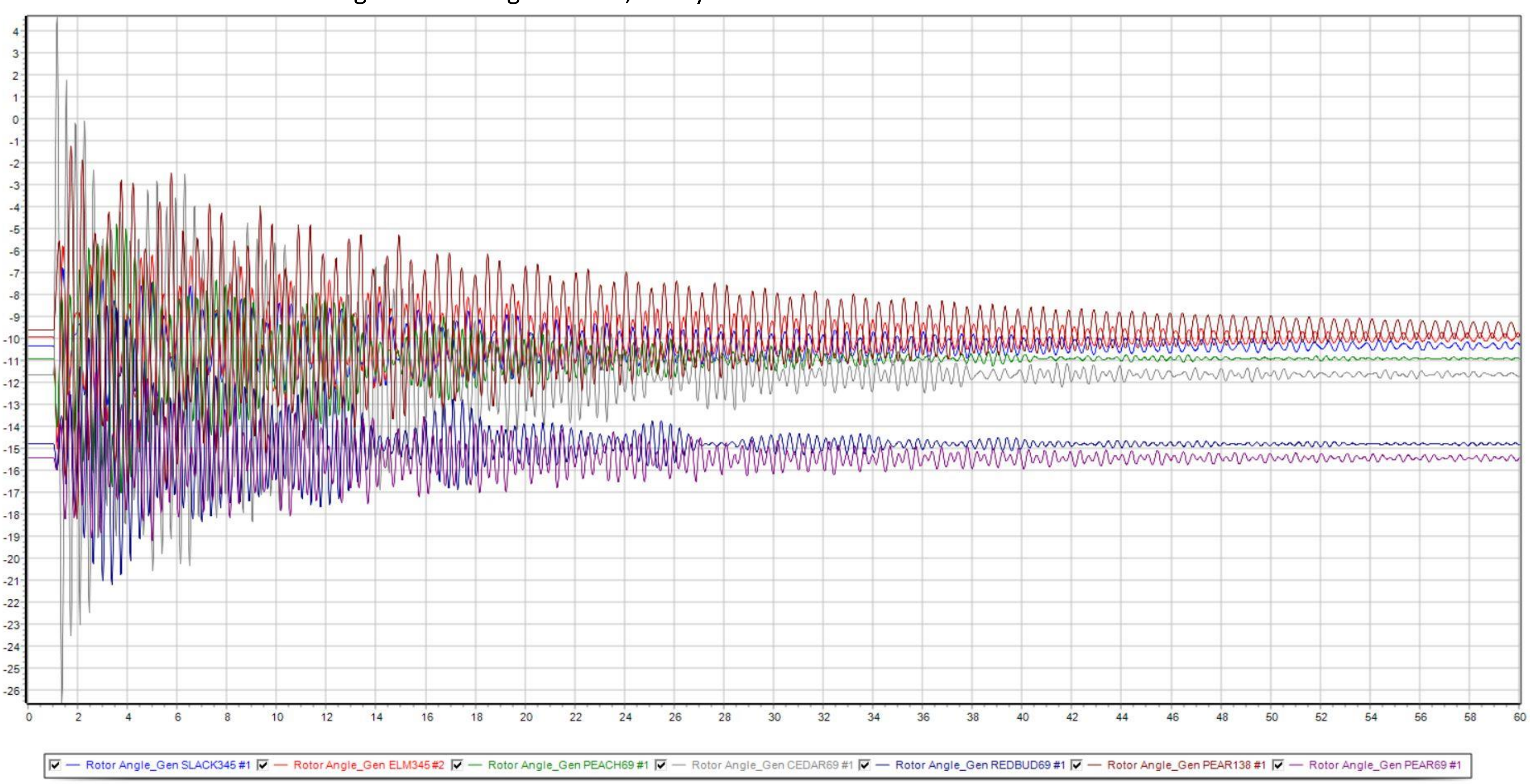
From the figures it can be seen that the rotor angles of all the generators oscillate hence the system stays **stable** after clearing the fault (by opening the faulted element from the system). Gradually the rotor angles get stabilized but this time, the rotor angle stabilizes at an angle different than the initial angle.

3.2.2 In a different experiment, apply a three-phase solid fault at CEDAR69 substation. Clear the fault after 6 cycles, and monitor all rotor angles. Is the system stable? With try and error find the critical clearing time beyond which the system falls into instability. (15%)

Fault created on CEDAR69 bus at time = 1 second and cleared at time = 1.1 second i.e. 6 cycles after the fault initiated.



As shown in the figure below, the rotor angles of all the generators oscillate and finally stable to their original rotor angle. Hence, the system remains stable



Now, with try and error method to find a critical clearing time

Sr. No.	Time at which fault is being cleared (in second)	System stability result from Power-World
1	1.20	Stable
2	1.30	Stable

3	1.31	Stable
4	1.314	stable
5	1.315	Unstable
6	1.32	Unstable

The critical clearing time = 1.314 – 1 second
= 0.314 second
= 18.84 cycles

If the fault is cleared in 0.314 second after the fault is initiated, the system will remain stable However, beyond that time if the fault remained persist, the system would lose its stability.

3.3 Power-Voltage (PV) stability analysis is required as a part of load connection studies to investigate the system's voltage stability margins under Category A condition and critical Category B contingencies. In practice, and as summarized in lectures, alternative system load scenarios (e.g., summer and winter) are considered and to save time, a limited number of contingencies and critical buses are identified. For this project, we only consider the base load, and look at all contingencies, and one bus, i.e., the new substation. Follow the following steps:

3.3.1 Make yourself familiar with the process of voltage stability analysis by referring to lecture notes, and the WECC voltage stability methodology , found here: https://www.wecc.biz/Reliability/WECC%20Voltage%20Stability%20Methodology.pdf

3.3.2 Make yourself familiar with the process of voltage stability analysis in PowerWorld. Use the tutorial here: http://www.powerworld.com/files/S06PVCurves.pdf . A summary of this tutorial is also provided to you for your convenience (PowerWorld_PVCurves_Summary.pdf).

3.3.3 For this project, you are required to examine if the new load bus meets voltage stability requirement. To do so, follow the following steps:

3.3.3.1 Define the source of supplying any load increments. Use only the slack generator for this purpose. Make sure that you increase the power limit of your slack generator by a 1000 MW so the case can increase the load and generation for determining PV curves.

3.3.3.2 Define the new substation, i.e., TULIP69 as the sink. This is basically to tell the voltage stability process to increase the load at this bus gradually and find the saddle node bifurcation (nose) point on the PV curves.

3.3.3.3 Let the process to look for at least 4 critical scenarios in Setup Common Options. This will force Power World to look for other critical nose points after finding the first one. Also, in Setup Advanced Options, make sure you keep the PQ ratio of the load constant for the analysis. This basically forces the program to increase active and reactive power proportionally when determining the PV curve, which is the realistic case.

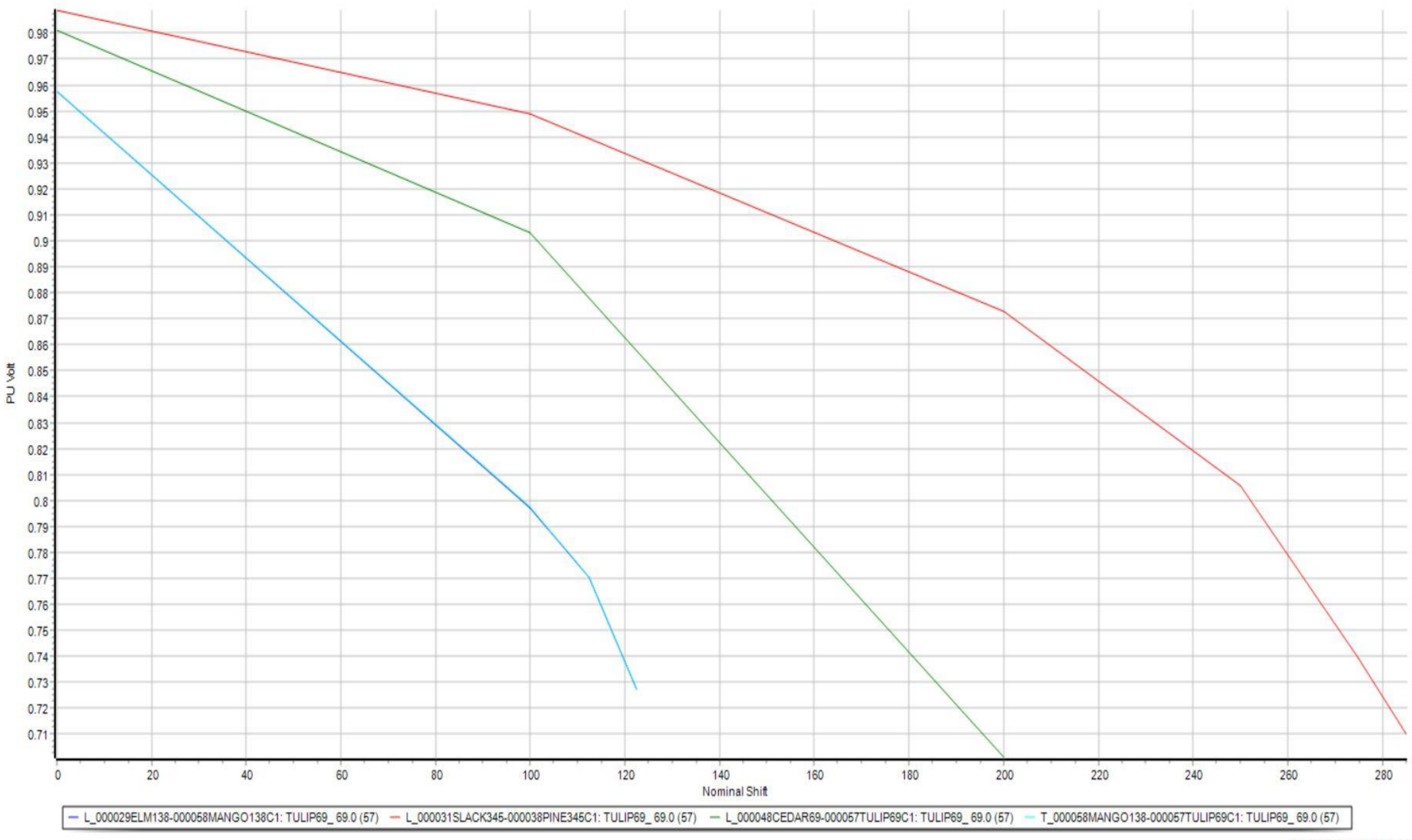
3.3.3.4 Include all possible branch contingencies in your analysis.

3.3.3.5 The objective here is to track the voltage of the new substation TULIP69 for its voltage stability margin. In PV results page, run and provide the detail of all contingencies that were found critical in your report. (10%)

Here, 4 contingencies found to be critical.

Scenario	Critical?	Critical Reason	Max Shift	Max Export	Max Import	# Vi-ol	Worst V Viol	Worst V Bus	Max P Mism Bus #	Max P Mism Bus Name	Max MW Mism	Max Q Mism Bus #	Max Q Mism Bus Name	Max Mvar Mism
T_000058MANGO138-000057TULIP69C1	YES	Reached Nose	122.5	150.7	-118.37	0			57	TULIP69	0.9285	57	TULIP69	8.0564
L_000048CEDAR69-000057TULIP69C1	YES	Reached Nose	200	206.53	-189.7	0			48	CEDAR69	0.3681	57	TULIP69	6.5792
L_000029ELM138-000058MANGO138C1	YES	Reached Nose	122.5	150.72	-118.37	0			57	TULIP69	0.9328	57	TULIP69	8.0902
L_000031SLACK345-000038PINE345C1	YES	Reached Nose	285	305.78	-266.82	0			38	PINE345	0.6397	57	TULIP69	4.7877

3.3.3.6 Plot the PV curve for all critical scenarios, as found by the program for this bus. Include a snapshot of the plots in your report. (20%)



It can be seen from the plot that the worst contingency case is the outage of the branch ELM1380-MANGO138(Max 0.9328 MW power mismatch). Although, outage of TULIP69-MANGO138 branch is almost the same worst contingency as maximum MW power mismatch is 0.9285. Also, the endpoints of those curves represent the nose point for the respective contingency case.

3.3.3.7 Based on the PV curves you plotted for this bus, determine ETC, TTC, TRM and ATC for this bus according to the WECC's voltage stability margin requirement. Ignore Category C issues. (20%)

In Category B:- When the line ELM138-MANGO138 is opened i.e. worst contingency case is the outage of line ELM138-MANGO138.

For calculating ETC, TTC, TRM and ATC, the worst hit contingency case is to be considered.
From the figure (with 4 critical case), the nose occurs at 122.5 MW

Hence TTC = 122.5 MW

According to WECC voltage stability margin,

TRM = 5% of TTC
= 0.05 * 122.5 MW
= 6.125 MW

The base load committed to TULIP69 substation is 75 MW

Hence ETC = 75.00 MW
Now, ATC = TTC – TRM – ETC
= 122.5 – 6.125 – 75.00 MW
= 41.375 MW.

<u>Conclusion:</u>

1. ETC (Existing transmission commitment) = 75 MW
2. TTC (Total transfer capability) = 122.5 MW
3. TRM (Transmission reliability margin) = 6.125 MW
4. ATC (Available transfer capacity) = 41.375 MW