ETAP Workshop Notes

Contingency Analysis

Theoretical Concepts

The outage of any equipment in power system may put whole system or a part of the system under stress. Contingency analysis helps to understand that, if the system is operating safely with normal operation, then what will happen if a particular outage occurs in the system. “What If” scenarios can be considered for contingency analysis.

Contingency analysis is used to identify and study effect of different equipment outages such as transmission lines, generator, buses, transformer etc. on bus voltages, real & reactive power flow of remaining system.

Contingency analysis can be performed for a single equipment failure event (N-1 type) as well as for multiple equipment failure events (N-2 type) that is two cables out of service simultaneously or one transmission line and one generator out of service simultaneously.

In descending order contingency ranking is obtained according to the value of a scalar index which is also called as severity index or performance index (PI). The PI is a measurement of system-wide effect of a contingency event in the system. Based on the obtained values contingencies are ranked in such a manner where highest value of PI is ranked first.

Consequences of contingency event can range from:

- None - when the power system can be re-balanced after a contingency, without overloading any element based on its rating.
- Severe - when several equipment such as lines and transformers are overloaded post contingency and there is a risk of damaging overloaded equipment.
- Critical - when the power system becomes unstable and will quickly collapse.

By analysing the effects of contingency events in advance, problems and different abnormal situations such as overloading of cables & transmission lines or under voltages at buses can be identified, critical configurations can be recognized, operating constraints and limits can be applied, and corrective actions can be planned in advance to mitigate any blackout condition.

The results of contingency analysis are used initially by system planners as well, to study the effects of outages and to establish secure operating limits and constraints for the power system under different conditions.

Contingency Analysis

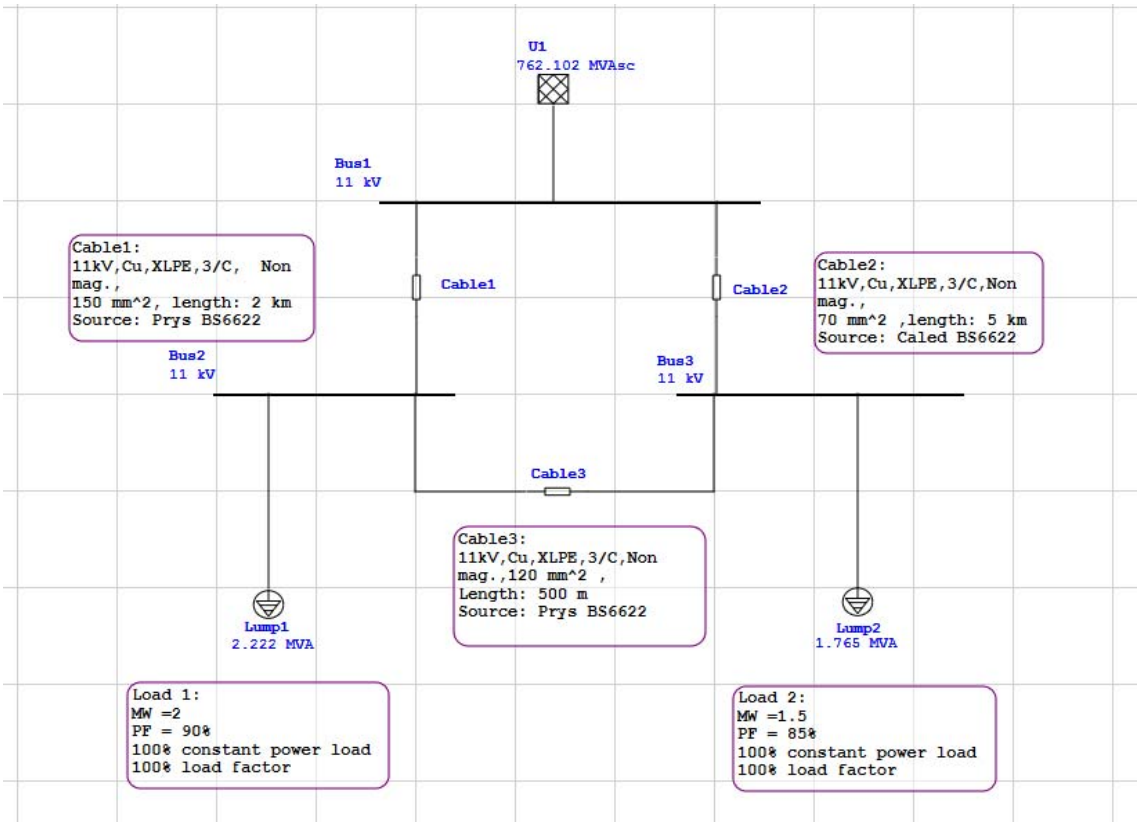
Purpose and description

The purpose of this exercise is to perform contingency analysis on a small network and to find out the most critical equipment in the network using different performance indices.

Procedure

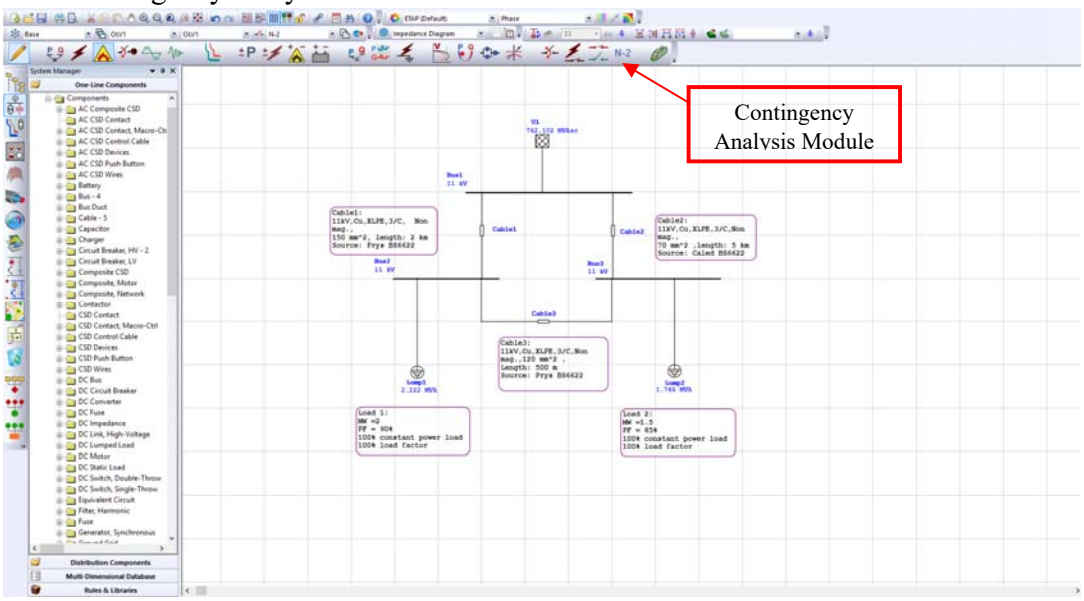
Case A: N-1 contingency study

1. Create a new project file with a name of 'Contingency Analysis'.
2. Drag and drop grid, buses, cable & lump load from AC Edit Toolbar and connect them as shown below. Enter equipment parameters for each equipment as shown below.

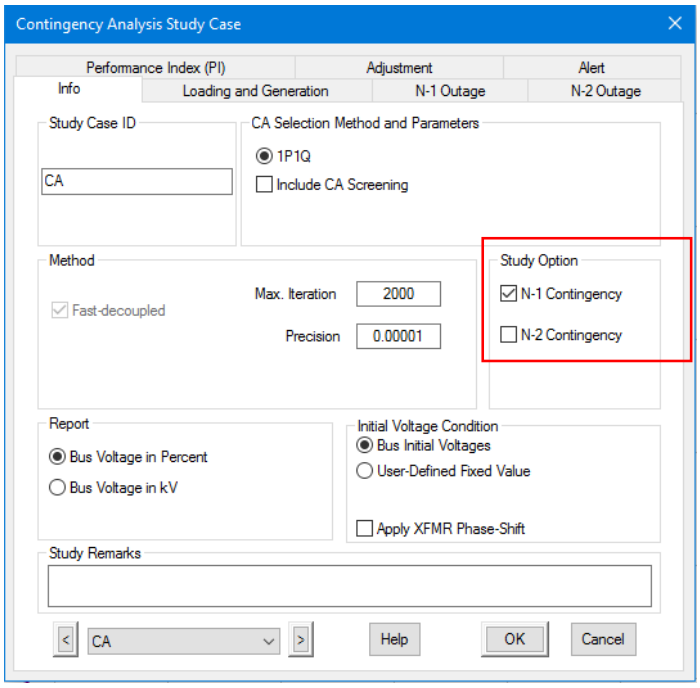


Contingency Analysis

3. Go to contingency analysis module on the Mode Toolbar

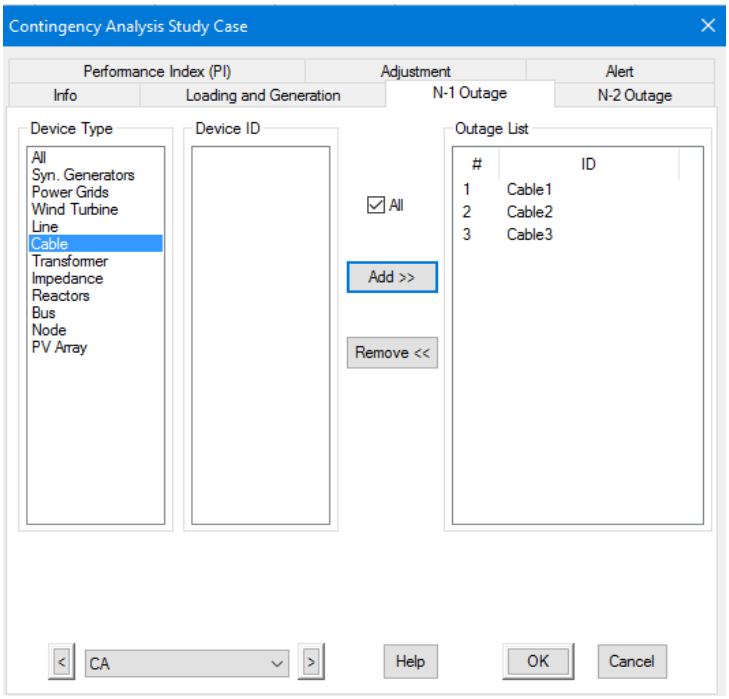


4. Go to contingency analysis study case. On the info page select ‘N-1 contingency’ option under ‘study-options’ section.



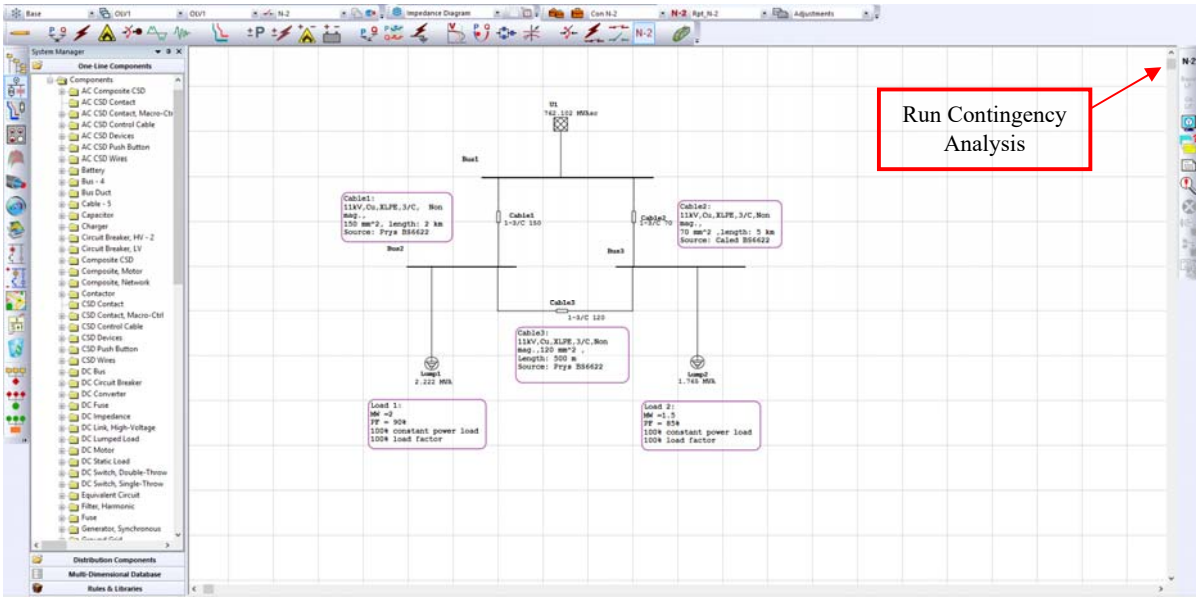
Contingency Analysis

5. Go to 'N-1 Outage' page in contingency analysis study case. Select all cables and add them into outage list using the Add button

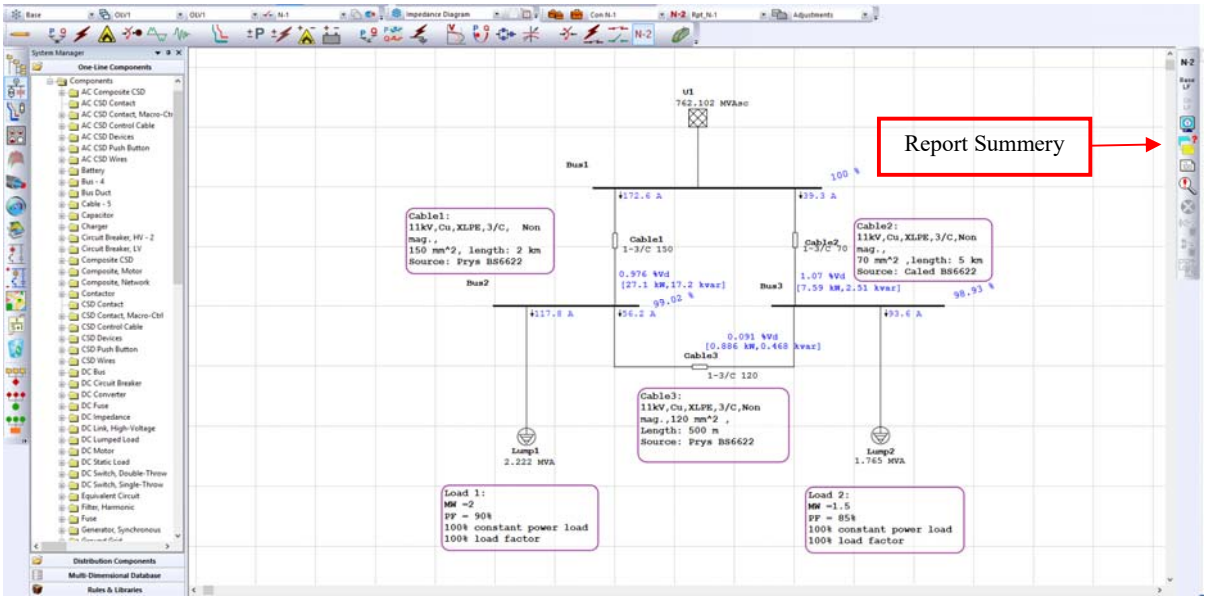


6. Run the contingency analysis using the button on Contingency Analysis Toolbar as shown below.

Contingency Analysis

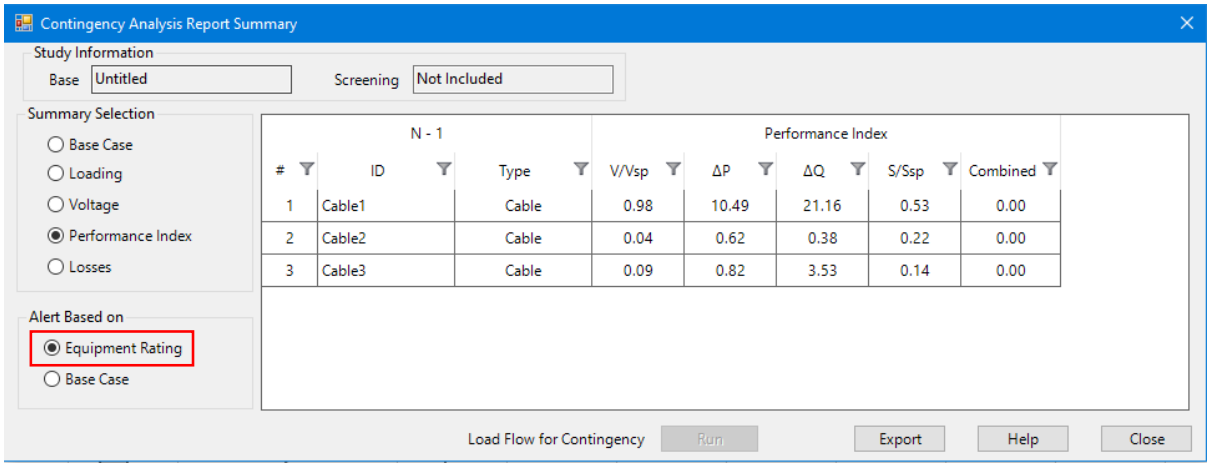


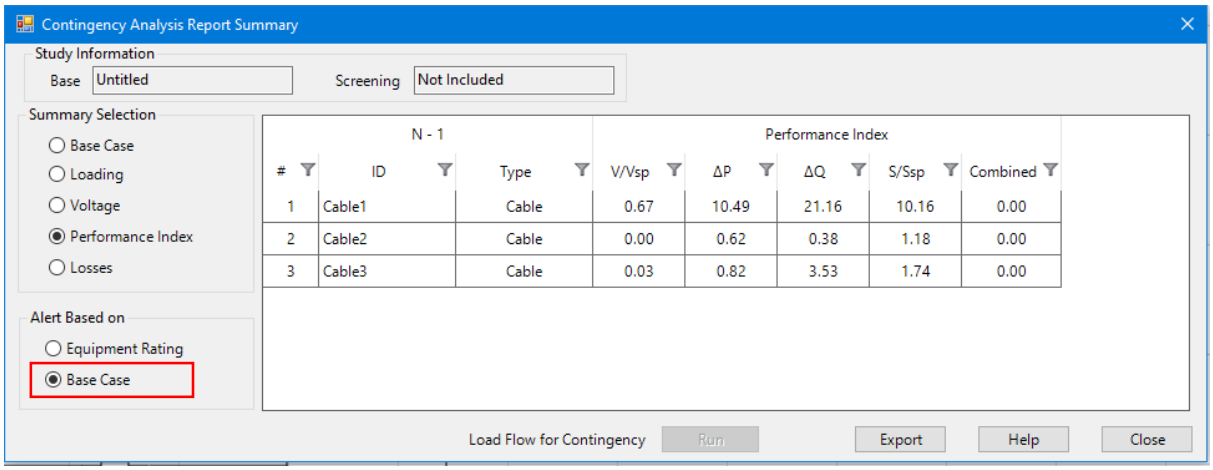
7. Open report summery using the button on Contingency Analysis Toolbar as shown below to check performance indices.



Contingency Analysis

8. In Contingency Analysis Report Summary click on performance indices to display the results based on Equipment Rating or Base Case under option 'Alert Based on'





9. Notice that, for outage of cable 1, all performance indices including Bus Voltage Security Index, Real Power Flow Change Index, Reactive Power Flow Change Index and Branch Overloading Security Index are highest as compared other outage conditions. So cable 1 is the critical cable in the network.
10. Performance indices for the outage of cable 1 can be calculated as shown below:

Contingency Analysis

A. Bus Voltage Security Index (PIV / Vsp)

$$PI_{V/Vsp} = \left[\sum_{n=1}^{N}\left(\left(V_{n\_PostCon} - V_{n\_Spec}\right)/V_{limit}\right)^2\right]/N$$

Calculation based on 'Equipment Rating'

$V_{n\_PostCon}$: Post contingency bus voltage for Bus n in percentage value.

V_{n_Spec}: Specified bus voltage base for Bus n in percentage value, 100% in this case

V_{limit}: Limit for bus voltage critical alert

V_{limit}: |Vcritical – 100%|

N: Number of buses in the system.

Bus Voltage Security Index of highest ranking cable 1				
	Bus 1	**Bus 2**	**Bus 3**	
$V_{n\_Post\ Con}$ (%)	100	93.85	94.06	Post contingency bus voltage
$V_{n\ Spec}$ (%)	100	100	100	Specified bus voltage rating
V_{limit} (%)	5	5	5	Bus Voltage critical alert limit specified in alert page of study case
N	3			
$PI_{(Individual)}$	0	1.51	1.41	
PI= Σ $PI_{(individual)}$ /N	**0.98**			

Calculation based on 'Base case'

Bus Voltage Security Index of highest ranking cable 1				
	Bus 1	**Bus 2**	**Bus 3**	
$V_{n\_Post\ Con}$ (%)	100	93.85	94.06	Post contingency bus voltage
$V_{n\ Spec}$ (%)	100	99.02	98.93	Specified bus voltage as per base case result
V_{limit} (%)	5	5	5	Bus Voltage critical alert limit specified in alert page of study case
N	3			
$PI_{(Individual)}$	0	1.069	0.949	
PI= Σ $PI_{(individual)}$ /N	**0.68**			

Contingency Analysis

B. Real Power Flow Change Index ($PI_{\Delta P}$)

$$PI_{\Delta P} = \left[\sum_{n=1}^{N} \left((P_{n\_PostCon} - P_{n\_Base})/P_{n\_Base}\right)^2\right]/N$$

$P_{n\_PostCon}$: Post contingency real power flow for Bus n.
P_{n_Base}: Base case real power flow for Bus n.
N: Number of branches in the system

Real Power Flow Change Index of highest ranking cable 1				
	Cable1	**Cable2**	**Cable3**	
$P_{n\_Post\ Con}$ (kW)	0	3747	-2004	Post contingency real power flow
$P_{n\ base}$ (kW)	2823	712.4	796.4	Base case real power flow
N	3			
$PI_{(Individual)}$	1.00	18.14	12.36	
PI= Σ $PI_{(individual)}$ /N	**10.50**			

C. Reactive Power Flow Change Index ($PI_{\Delta Q}$)

$$PI_{\Delta Q} = \left[\sum_{n=1}^{N} \left((Q_{n\_PostCon} - Q_{n\_Base})/Q_{n\_Base}\right)^2\right]/N$$

$Q_{n\_PostCon}$: Post contingency reactive power flow for Bus n.
Q_{n_Base}: Base case reactive power flow for Bus n.
N Number of branches in the system.

Reactive Power Flow Change Index of highest ranking cable 1				
	Cable1	**Cable2**	**Cable3**	
$Q_{n\_Post\ Con}$ (kVAR)	0	1981	-970.9	Post contingency reactive power flow
Q_{n_base} (kVAR)	1686	232	700.5	Base case reactive power flow
N	3			
$PI_{(Individual)}$	1	56.83	5.69	
PI= Σ $PI_{(individual)}$ /N	**21.18**			

Contingency Analysis

D. Branch Overloading Security Index ($PI_{S/Ssp}$)

$$PI_{S/Ssp} = \left[\sum_{n=1}^{N} \left(S_{n\_PostCon}/S_{Limit}\right)^2\right]/N$$

Calculation based on 'Equipment Rating'

$S_{n\_PostCon}$: Post contingency branch load flow for Branch n, MVA for transformers and Amps for other branches.

S_{Limit}: Branch overloading limit, in this case S_{Limit} = Ampacity * S_{Crit_Alert}.

N Number of branches in the system

Branch Overloading Security Index of highest ranking cable 1				
	Cable1	**Cable2**	**Cable3**	
$S_{n\ post\ Con}$ (A)	0	222.5	-124.3	Post contingency branch current flow
Ampacity (A)	292.4	191.7	260.8	Cable allowable ampacity/capacity specified in cable editor capacity page
$S_{critAlert}$	100%	100%	100%	Branch loading violation critical alert limit specified in alert page of study case
S_{limit}	292.4	191.7	260.8	
N	3			
$PI_{(Individual)}$	0	1.347	0.227	
PI= Σ $PI_{(individual)}$ /N	**0.53**			

Calculation based on 'Base case'

$S_{n\_PostCon}$: Post contingency branch load flow for Branch n, MVA for transformers and Amps for other branches.

S_{Limit}: Branch overloading limit in this case S_{limit} = S_{Base} * (1 + S_{crit_Dev}).

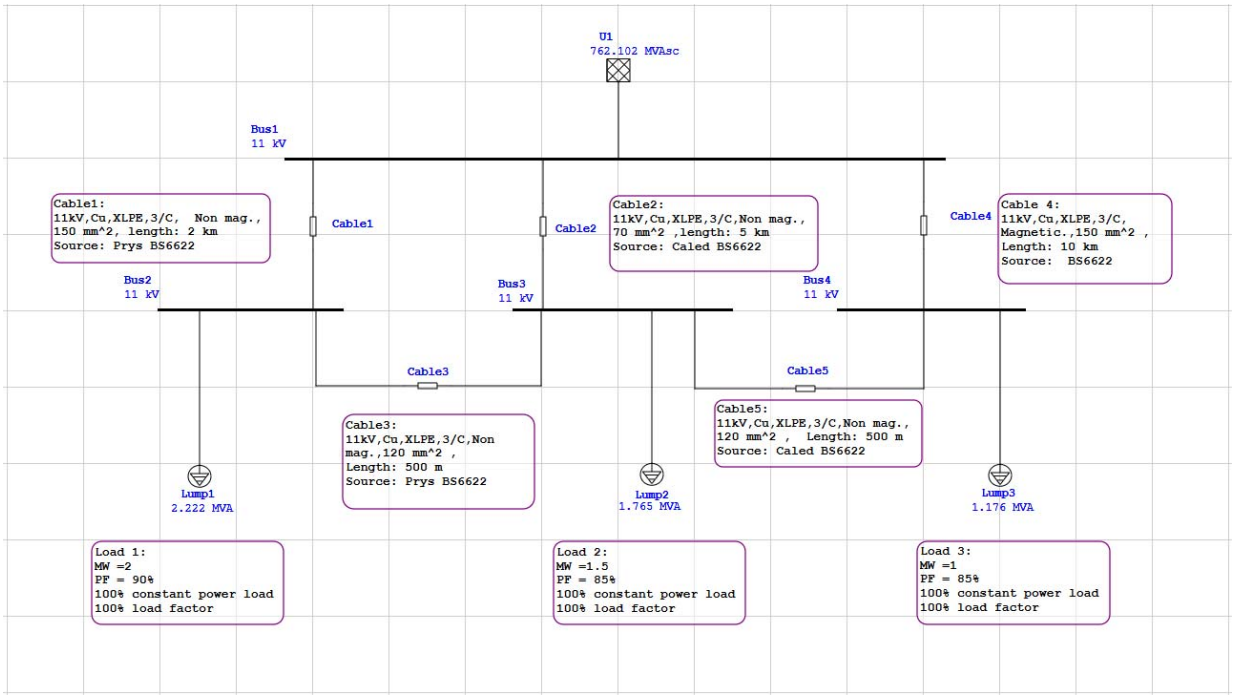
N Number of branches in the system

Contingency Analysis

Branch Overloading Security Index of highest ranking cable 1				
	Cable1	**Cable2**	**Cable3**	
$S_{n\_post\ Con}$ **(A)**	0	222.5	-124.3	Post contingency branch current flow
S_{Base} **(A)**	172.6	39.3	56.2	Current flowing through cable as per base case results
S_{Cri_Dev}	10%	10%	10%	Branch loading deviation critical alert limit specified in alert page of study case
S_{limit}	189.86	43.23	61.82	
N	3			
$PI_{(Individual)}$	0	26.490	4.043	
$PI= \Sigma\ PI_{(individual)} /N$	**10.18**			

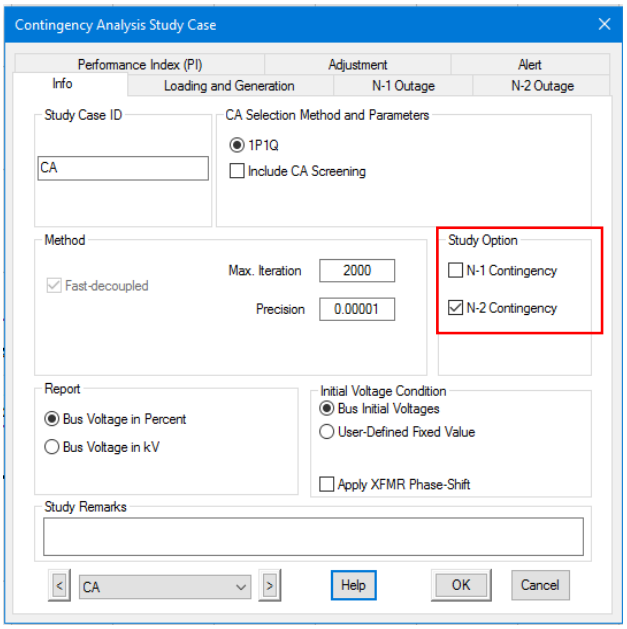
Case B: N-2 contingency study

11. Add two more cables in the network as shown below.



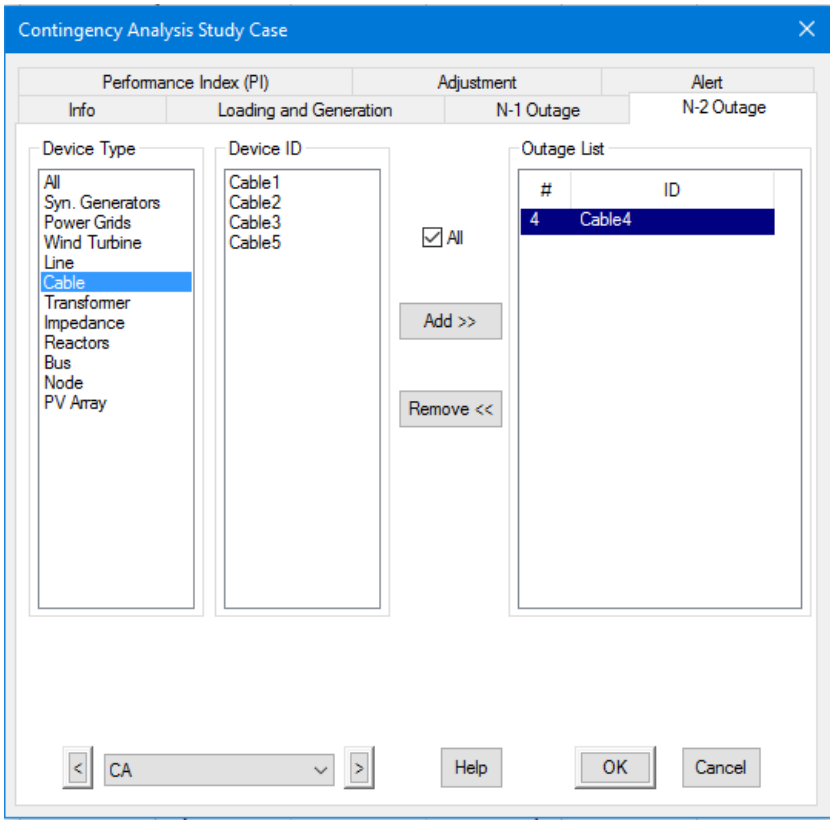
Contingency Analysis

12. Go to contingency analysis study case. On the info page select ‘N-2 contingency’ option under ‘study-options’ section.

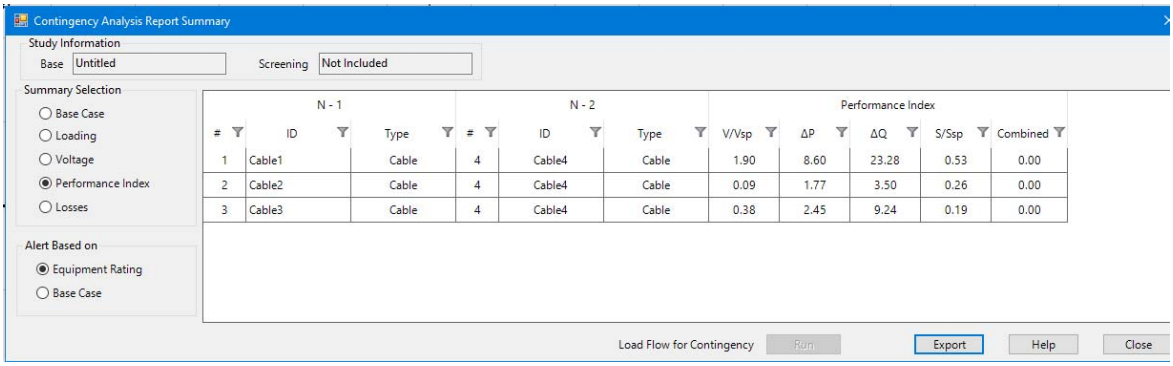


13. Go to N-2 Outage page in Contingency Analysis Study Case and add cable 4 in outage list.

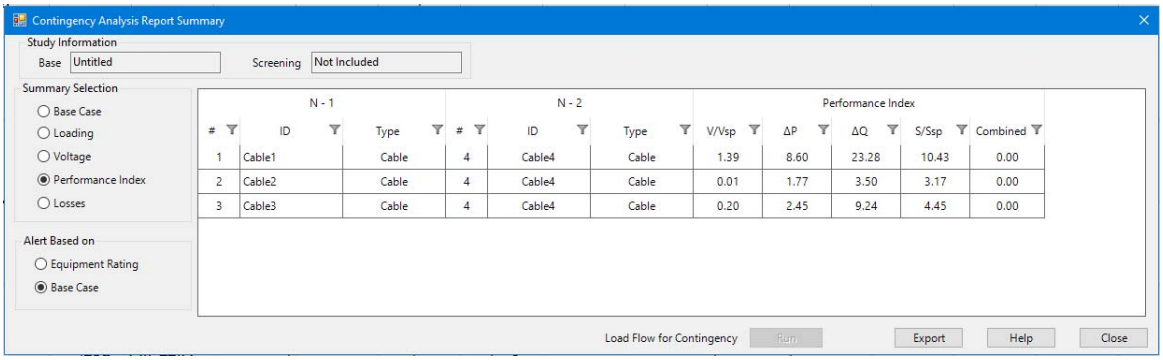
Contingency Analysis



14. Run the contingency analysis.
15. In report summery click on performance indices to display the results.



Contingency Analysis



16. For outage of cable 1 and cable 4 together as shown above, all the performance indices including Bus Voltage Security Index, Real Power Flow Change Index, Reactive Power Flow Change Index and Branch Overloading Security Index are highest as compared to other outage conditions.