PROJECT REPORT

ON

INVESTIGATING THE EFFECT OF HVDC CONNECTION AND LARGE INDUSTRIAL LOADS IN IEEE-39 BUS NETWORK

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GROUP NO. 2, Level-3 Term-1

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INTRODUCTION

An IEEE 39-Bus network is taken for analysis of HVDC connection and industrial heavy load analysis. This system is well known as the ten machine New England Power system. It is of nominal 50Hz frequency. One HVAC line of this system is replaced with an HVDC line. Afterwards 10 parallel induction motors are connected to observe the effects of increased loads. Load flow analysis of the entire system is performed by the help of CYME PSAF.

The objective of this project is to observe the effects and abnormalities introduced to the system because of the changes and removing those by using corrective devices.

BASE AC SYSTEM

The base AC system has ten generators (one swing) 39 bus system with a total load of 6097.1MW and 1408.9MVAR.

Table: Generator report for the base case

ID	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]
G10	1000	16.5	PV	250	197.89	318.84	78.4
G01	10000	345	PV	1000	246.08	1029.83	97.1
G02	700	16.5	SW	52.37	135.02	144.82	36.2
G03	800	16.5	PV	650	170.82	672.07	96.7
G04	800	16.5	PV	632	147.44	648.97	97.4
G05	600	16.5	PV	1016	265.13	1050.02	96.8
G06	800	16.5	PV	650	267.61	702.93	92.5
G07	700	16.5	PV	560	227.35	604.39	92.7
G08	700	16.5	PV	540	30.01	540.83	99.8
G09	1000	16.5	PV	830	62.41	832.34	99.7

Table: Summary report for the base case

Summary Data	Active Power	Reactive Power
Total generation	6180.366	1749.75
Spinning reserve	9209.634	
Static Load	6097.101	1408.9
Total load	6097.101	1408.9
Line / cable losses	55.952	-370.204
Transformer losses	27.314	711.054
Total losses	83.266	340.85

	ID						
9	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
10	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]		
11	L30	B25	B26	0.218	2.988		
12	L31	B26	B27	2.367	2.988		
13	L01	B1	B2	1.806	2.988		
14	L32	B26	B28	1.429	2.988		
15	L02	B1	B39	1.806	2.988		
16	L13	B7	B8	1.468	2.988		
17	L33	B26	B29	1.911	2.988		
18	L14	B8	B9	2.058	2.988		
19	L24	B16	B24	1.708	2.988		
20	L15	B9	B39	1.723	2.988		
21	L26	B17	B27	1.183	2.988		
22	L06	B3	B18	2.314	2.988		
23	L17	B10	B13	1.352	2.988		
24	L07	B4	B5	1.086	2.988		
25	L18	B13	B14	1.033	2.988		
26	L28	B22	B23	0.425	2.988		
27	L19	B14	B15	2.592	2.988		
28	L09	B5	B6	2.277	2.988		
29							
30	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
31	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
32							
33	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
34	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
35	T10	B2	B30	308.266	550.000		
36	T01	B12	B11	46.388	250.000		
37	T02	B12	B13	50.131	250.000		
38	T12	B19	B20	380.890	550.000		
39	T03	B6	B31	132.699	400.000		
40							
41	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
42	ID	Bus From	P Gen -	Q Gen -	Q Min -	Q Max -	

Fig. Base case abnormal report

There are no abnormality for this case except a few lines that are under loaded. Under loading doesn’t cause much problem to the system and can be either neglected or solved by simple decreasing the loading limit.

ADDING HVDC TO THE SYSTEM

HVDC allows power transmission between AC transmission systems that are not synchronized. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks.

Disadvantage

- **Converter stations** needed to connect to AC power grids are **very expensive**.
- In contrast to AC systems, designing and operating multi-terminal HVDC systems is complex.
- **power faults**
- it is practically impossible to construct an HVDC transmission system with **more than five substations**.
- The flow of current through the Earth in monopole systems can cause the electro-corrosion of underground metal installations, mainly pipelines.

Advantage

- There are no radiation & induction losses in HVDC.
- There are no dielectric losses in HVDC which increases the lifetime of the conductor.
- The HVDC transmission lines experience lower power losses as opposed to HVAC.
- There is no transfer of fault energy from one AC system to another if they are connected by a DC tie **line**.
- The corona power loss and radio interference are less as compared to AC **transmission**.

Line 15, which previously connected bus 39 to bus 9, is replaced by a high voltage direct current line. This is done by adding a rectifier and inverter bus B39_rec and B9_inv to B39 and B9 respectively through a 345/100 kV transformer.

Table: Abnormality Report after adding HVDC

BUSES OUTSIDE VOLTAGE LIMITS (100 %)						
Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]
B12	0	138	0.9	1.1	0.895	1.2
B9_INV	0	100	0.9	1.1	0.762	17.6
B5	0	345	0.9	1.1	0.892	-1.6

B6	0	345	0.9	1.1	0.897	-1.1
B7	0	345	0.9	1.1	0.867	-2.3
B8	0	345	0.9	1.1	0.857	-2.1
B9	0	345	0.9	1.1	0.773	14.1
OVERLOADED LINES & CABLES (WITHIN 100 %)						
ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]	
L21	B16	B17	6.331	5.976	8.963	
L01	B1	B2	6.181	5.976	8.963	
L02	B1	B39	6.181	5.976	8.963	
L14	B8	B9	6.617	5.976	8.963	

Abnormality report shows the buses beyond the voltage limit and the overloaded lines.

1. BUS beyond voltage limit: To convert AC voltage to DC, a rectifier is used at the beginning and the end of the HVDC. The peak voltage gets reduces due to this rectification. Thus some bus limits fall below the minimum 0.9pu set.

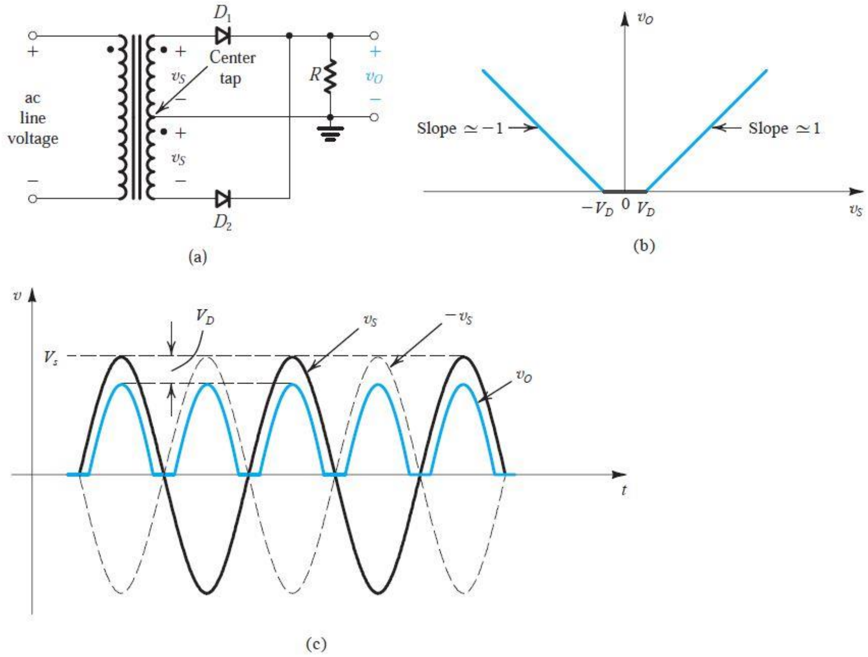
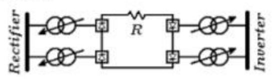


Figure 4.22 Full-wave rectifier utilizing a transformer with a center-tapped secondary winding: **(a)** circuit; **(b)** transfer characteristic assuming a constant-voltage-drop model for the diodes; **(c)** input and output waveforms.

The converter bridges are taken to be in series, fed by one transformer each.



CYMFLOW approximates the commutating reactance of the rectifier and the inverter as *Xc = (# bridges) x (reactance of transformer)*. The reactance presented by the rest of the AC network is neglected. (The network is assumed to have a high short circuit level.) The commutating reactance, DC current and firing angle determine the overlap angle.

2. Line overloaded: Three of the four overloaded lines L01, L02 and L14 are connected to or near the HVDC line.

<u>Table: Branch report of base case for L15</u>

ID	Bus From	Bus To	kV Nominal	Length	P [MW]	Q [MVAR]
L15	B9	B39	345	167.6	-78.8	-154.32

From the branch report of the base case it can be seen that the previously replaced L15 used to carry 78MW power. But for the HVDC desired power is set to 500MW. To account for this the nearby lines are pushed beyond loading limit.

<u>Table: Summary Report for HVDC</u>

Summary Data	Active Power	Reactive Power
Total generation	6216.78	2751.668
Spinning reserve	9173.22	
Static Load	6097.101	1408.9
Total load	6097.101	1408.9
Line / cable losses	87.268	200.377
Transformer losses	31.409	849.106
Total losses	119.677	1342.483
Mismatches	0.003	0.285

The total load of the system remains the same as expected. But the power loss increases. To account for the loss, more power is generated.

For finding the reasons why the loss increased we did some analysis and calculations.

Analysis:

<u>Before adding HVDC</u>

As we can see for the L15 per unit current is =1.723
Base MVA = 100 MVA
Base V= 345 kV
So, the Base I=167.349
I_L=167.349×1.723=288.34 A
Total current = 3× I_L=3×288.34=865.021 A

<u>After adding HVDC:</u>
I_{DC}= 1000 A

So we can see that current in the case of HVDC is increased.
As a result:

- I^2R loss increased.
- Increase in current means increase in load , So, the Generation P_{gen} also increase accordingly .

ADDING LOAD TO THE SYSTEM

Ten parallel induction motors are connected to bus 23 in order to increase the load of the system. This increased load causes quite a lot of abnormalities in the system as can be observed for the report.

Table: Abnormality report after adding load

BUSES OUTSIDE VOLTAGE LIMITS (100 %)					
Bus ID	**Zone**	**kV Base**	**Vmin - [pu]**	**Vmax - [pu]**	**V sol - [pu]**
B10	**0**	**345**	**0.9**	**1.1**	**0.897**
B11	**0**	**345**	**0.9**	**1.1**	**0.885**
B12	**0**	**138**	**0.9**	**1.1**	**0.866**
B13	**0**	**345**	**0.9**	**1.1**	**0.891**
B14	**0**	**345**	**0.9**	**1.1**	**0.887**
B9_INV	**0**	**100**	**0.9**	**1.1**	**0.707**
B4	**0**	**345**	**0.9**	**1.1**	**0.872**
B5	**0**	**345**	**0.9**	**1.1**	**0.856**
B6	**0**	**345**	**0.9**	**1.1**	**0.864**
B7	**0**	**345**	**0.9**	**1.1**	**0.829**
B8	**0**	**345**	**0.9**	**1.1**	**0.818**
B9	**0**	**345**	**0.9**	**1.1**	**0.719**
OVERLOADED LINES & CABLES (WITHIN 100 %)					
ID	**Bus From**	**Bus To**	**Power Flow - [pu]**	**Loading Limit - [pu]**	**Emergency Loading Limit - [pu]**
L01	**B1**	**B2**	**6.222**	**5.976**	**8.963**
L02	**B1**	**B39**	**6.222**	**5.976**	**8.963**
L14	**B8**	**B9**	**7.138**	**5.976**	**8.963**
L17	**B10**	**B13**	**6.41**	**5.976**	**8.963**
L07	**B4**	**B5**	**7.765**	**5.976**	**8.963**
L18	**B13**	**B14**	**6.61**	**5.976**	**8.963**
L09	**B5**	**B6**	**8.349**	**5.976**	**8.963**

OVERLOADED TRANSFORMERS (WITHIN 100 %)					
ID	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**
T03	**B6**	**B31**	**923.153**	**800**	**850**
GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)					
ID	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**
G03	**B32**	**650**	**453.07**	**-192**	**448**
G06	**B35**	**650**	**578.33**	**-192**	**448**
G07	**B36**	**560**	**519.91**	**-168**	**392**

The abnormalities are observed.

1. **Overloaded Transformer**: T03 is operating at a much higher (about 125MVA) power rating that the set load limit. This is because T03 is connected to the system designated swing generator. As the load of the system is increased, the demand for power is increased. The swing generator has to provide that extra power. This causes the transformer to get overloaded.
2. **Generators over the reactive limit:** The generators have to provide more reactive power to the system due to increased load. Three of these generators end up supplying reactive power above their set maximum limit. This is much more significant for G06 and G07 as both have to supply reactive power about 130MVAR more than their maximum reactive power limit.
3. **Other:** More bus goes beyond their voltage limit and few more lines also get overloaded.

	ID	Bus ID	DBase ID	Type	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	Q max. [MVAR]	Q min. [MVAR]	Ctrled BusID	Ctrld Bus/V [pu]
1	G10	B30	G10	Generator	1000.00	16.50	PV	250.00	338.16	420.54	59.4	4.015	560.00	-240.00	B30	1.048
2	G01	B39	G01	Generator	10000.00	345.00	PV	1000.00	592.95	1162.58	86.0	11.287	5600.00	-2400.00	B39	1.030
3	G02	B31	G02	Generator	700.00	16.50	SW	898.94	561.62	1059.96	84.8	10.794	392.00	-168.00	B31	0.982
4	G03	B32	G03	Generator	800.00	16.50	PV	650.00	453.07	792.32	82.0	8.060	448.00	-192.00	B32	0.983
5	G04	B33	G04	Generator	800.00	16.50	PV	632.00	241.26	676.48	93.4	6.784	448.00	-192.00	B33	0.997
6	G05	B34	G05	Generator	600.00	16.50	PV	1016.00	309.07	1061.97	95.7	10.491	336.00	-144.00	B34	1.012
7	G06	B35	G06	Generator	800.00	16.50	PV	650.00	578.33	870.04	74.7	8.292	448.00	-192.00	B35	1.049
8	G07	B36	G07	Generator	700.00	16.50	PV	560.00	519.91	764.14	73.3	7.185	392.00	-168.00	B36	1.064
9	G08	B37	G08	Generator	700.00	16.50	PV	540.00	106.24	550.35	98.1	5.355	392.00	-168.00	B37	1.028
10	G09	B38	G09	Generator	1000.00	16.50	PV	830.00	108.42	837.05	99.2	8.155	560.00	-240.00	B38	1.026

Fig. generator report after adding motor

Removing abnormalities

***Step 1**: Adding **Static VAR compensators** for adjusting generators reactive limits*

A static VAR compensator is a set of device for providing fast acting reactive power on high voltage electricity transmission network. SVCs are devices that can quickly and reliably control line voltages. An SVC will typically regulate and control the voltage to the required set point under normal steady state and contingency conditions and thereby provide dynamic, fast response reactive power following system contingencies (e.g. network short circuits, line and generator disconnections). In addition, an SVC can also increase transfer capability, reduce losses, mitigate active power oscillations and prevent over voltages at loss of load. A SVC is a parallel combination of controlled reactor and fixed shunt capacitor shown in the figure below. The thyristor switch assembly in the SVC controls the reactor. The firing angle of the thyristor controls the voltage across the inductor and thus the current flowing through the inductor. In this way, the reactive power draw by the inductor can be controlled. The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. It improves the system stability and system power factor.

- SVC provides the reactive power needed by the system, which was provide by the overloaded generators before.
- It can also increase transfer capability, reduce losses, mitigate active power oscillations and prevent over voltages at loss of load.
- It improves the system stability, voltage regulation and system power factor.

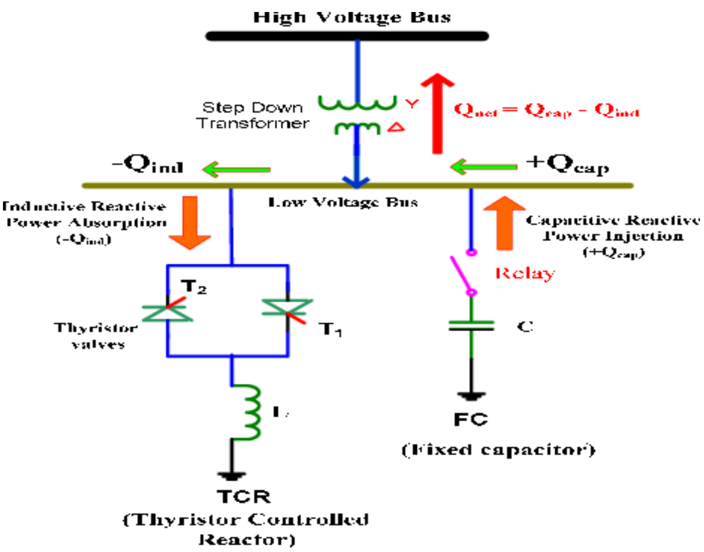


Fig. Static VAR compensator

Adding SVC at Bus35 and Bus36

- **Generator 06 exceeds reactive power limit**

SVC35 of rating Qmax= Q Gen - [MVAR]- Q Max - [MVAR]

=578.33-448

=150Mvar (approx) at B35

- **Generator 07 exceeds reactive power limit**

SVC36 of rating Qmax= Q Gen - [MVAR]- Q Max - [MVAR]

=519.91-392

=150Mvar (approx) at B36

SVC35	B35	SVC35	1	☑	1.000	B35	4.333	150.000	-50.000
SVC36	B36	SVC36	1	☑	1.000	B36	1894.342	150.000	-50.000

Fig. SVC added at B35 and B36

	ID	Bus ID	DBase ID	Type	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	Q max. [MVAR]	Q min. [MVAR]	Ctrled BusID	Ctrld Bus/V [pu]
1	G10	B30	G10	Generator	1000.00	16.50	PV	250.00	338.16	420.54	59.4	4.015	560.00	-240.00	B30	1.048
2	G01	B39	G01	Generator	10000.00	345.00	PV	1000.00	592.95	1162.58	86.0	11.287	5600.00	-2400.00	B39	1.030
3	G02	B31	G02	Generator	700.00	16.50	SW	898.94	561.62	1059.96	84.8	10.794	392.00	-168.00	B31	0.982
4	G03	B32	G03	Generator	800.00	16.50	PV	650.00	453.07	792.32	82.0	8.060	448.00	-192.00	B32	0.983
5	G04	B33	G04	Generator	800.00	16.50	PV	632.00	241.26	676.48	93.4	6.784	448.00	-192.00	B33	0.997
6	G05	B34	G05	Generator	600.00	16.50	PV	1016.00	309.07	1061.97	95.7	10.491	336.00	-144.00	B34	1.012
7	G06	B35	G06	Generator	800.00	16.50	PV	650.00	433.01	781.03	83.2	7.443	448.00	-192.00	B35	1.049
8	G07	B36	G07	Generator	700.00	16.50	PV	560.00	375.72	674.36	83.0	6.341	392.00	-168.00	B36	1.064
9	G08	B37	G08	Generator	700.00	16.50	PV	540.00	106.24	550.35	98.1	5.355	392.00	-168.00	B37	1.028
10	G09	B38	G09	Generator	1000.00	16.50	PV	830.00	108.42	837.05	99.2	8.155	560.00	-240.00	B38	1.026
11	SVC36	B36	SVC36	Static Var Compensator	150.00	345.00	PV	0.00	144.19	144.19	0.0	1.356	150.00	-50.00	B36	1.064
12	SVC35	B35	SVC35	Static Var Compensator	150.00	16.50	PV	0.00	145.32	145.32	0.0	1.385	150.00	-50.00	B35	1.049

Fig. after adding SVC at B35 and B36 generator report

GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)						
ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
G03	B32	650.00	453.07	-192.00	448.00	

Fig. G06 and G07 overloading problem solved

<u>Table Generator power before and after SVC added</u>

GENERATORS	Qgen before SVC	p.f before SVC	Qgen after SVC	p.f after SVC

G06	578.33	74.5	433.01	83.2
G07	519.91	73.3	375.72	83.0

Step 2*: Implementing Distribution Swing option for transformer and line overload*

In the load flow calculation, voltage magnitudes, voltage phase angles and certain equipment settings are computed for a given power generation schedule and a given load profile. The specified generation might not satisfy the load, or might satisfy the load in an inefficient manner, due to an inaccurate estimate of system losses.

For this reason, the operating strategy traditionally has been to allow one generation to deviate from the schedule to improve the resulting operation. This generation is called the **swing** generation. Allotting this excess power to a single generator can prove unacceptable if the deviation from the desired value is large. CYMFLOW now offers the option of distributing the swing generation to any number of generators.

Scheduled values of active power (MW) generation ("Pgen") must be provided for all the generators which are to participate in the distribution. Unlike in standard load flow calculations, the swing generator(s) must have Pgen defined as well.

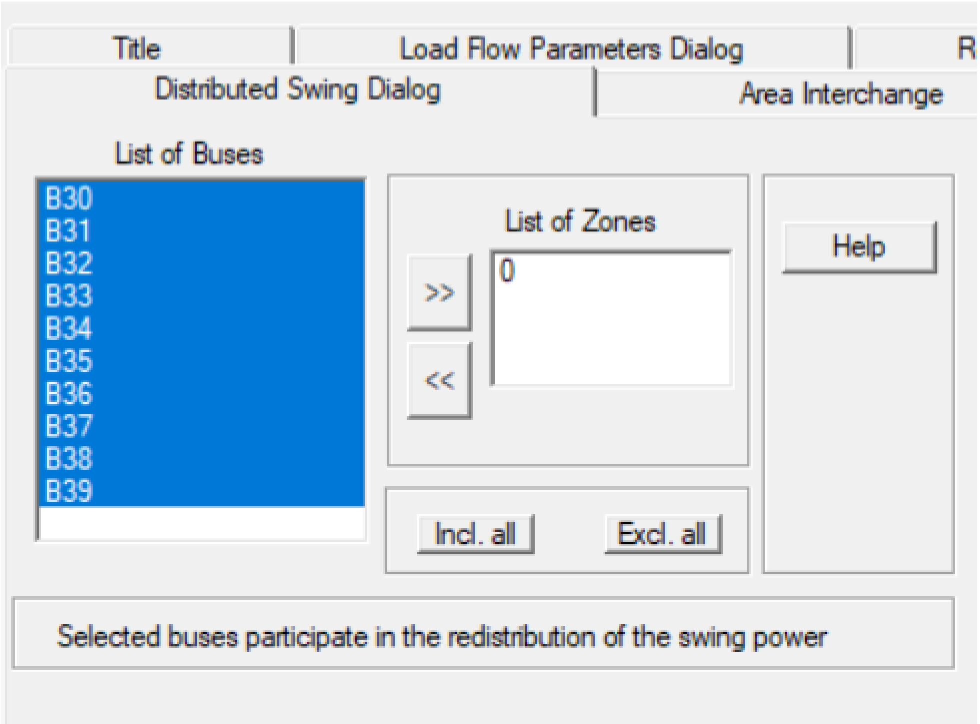
Example: The scheduled generations in a two-generator network are 10 MW and 5 MW respectively. Then, the generations at the load flow solution will take on proportions of 0.6667 and 0.3333 respectively. One possible load flow solution could be 10.20 MW and 5.1 MW.

In this Load Flow study we have chosen Swing Bus Pgen to be 300MW. Because In earlier studies we found that:

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**7026.939**	**3760.714**
Spinning reserve	8363.061	
Static Load	6097.101	1408.900
Shunt loads	0.000	-48.323
Motor loads	800.000	600.000
Total load	**6897.101**	**1960.577**
Line / cable losses	88.824	308.865
Transformer losses	40.011	1197.988
Total losses	**129.835**	**1799.853**
Mismatches	0.003	0.285

Total Generation =7026.939 MW
Total Load=6897.101 MW
Total Loss=129.835 MW
Pgen required in slack Bus= 7026.939-6897.101+129.83=259.668 MW
From this report we selected suitable generation of the Slack Bus to be 300 MW.

Load Flow Study Dialog



OVERLOADED LINES & CABLES (WITHIN 100 %)					
ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]
L10	B5	B8	3.085	1.494	8.963
L21	B16	B17	3.372	3.287	8.963
L22	B16	B19	12.141	10.756	11.951
L13	B7	B8	2.231	0.598	8.963
L06	B3	B18	0.943	0.717	8.963
UNDERLOADED LINES & CABLES (WITHIN 50 %)					
ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	
L31	B26	B27	2.913	2.988	
L32	B26	B28	1.832	1.942	
L23	B16	B21	0.880	1.046	
L33	B26	B29	2.317	2.390	
L19	B14	B15	1.469	2.091	
L29	B23	B24	0.296	0.299	
OVERLOADED TRANSFORMERS (WITHIN 100 %)					
ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]
UNDERLOADED TRANSFORMERS (WITHIN 50 %)					

Fig. Inserting all buses abnormal report

We have distributed the load to following Generator Buses:

Distributed Swing Report

	ID	P Desired [MW]	P calculated [MW]
1	G10	250.00	290.74
2	G02	300.00	348.89
3	G03	650.00	755.92
4	G08	540.00	628.00
5	G09	830.00	965.26
6	G01	1000.00	1162.96

As per the condition stated in the Project instruction, We cannot add new XMER, line or cables in between Buses, we had to look for alternative solutions.
Things we have considered for load distribution is given below:

1. Included Generators:

   G01, G02, G03, G08, G09, G10 is included in the distribution Swing because they have sufficiently higher MVA rating. Among them G01 has a rating of 10000. So as expected more Pgen was assigned to that generator compare to others.

   Pgen of G02 (slack generator) was selected from previous requirements.

2. Excluded Generators:

   G06 and G07 was excluded as they were already outside there reactive limits. Also there calculated MVA before distribution was already near to rated MVA. So more Pgen will cause them to work outside there MVA rating

   G05 (duplicity =2) and G06 was excluded. They were connected to Bus 34 and Bus 35 respectively. If they are considered in swing bus distribution they Generates more Pgen and overloads the line 22 which is located in between Bus 19 and Bus 16 as there is no alternative line to where Generated Pgen will be divided. AS we can not add extra line nor we can change the line limits above 2000 we had to exclude them from the distribution

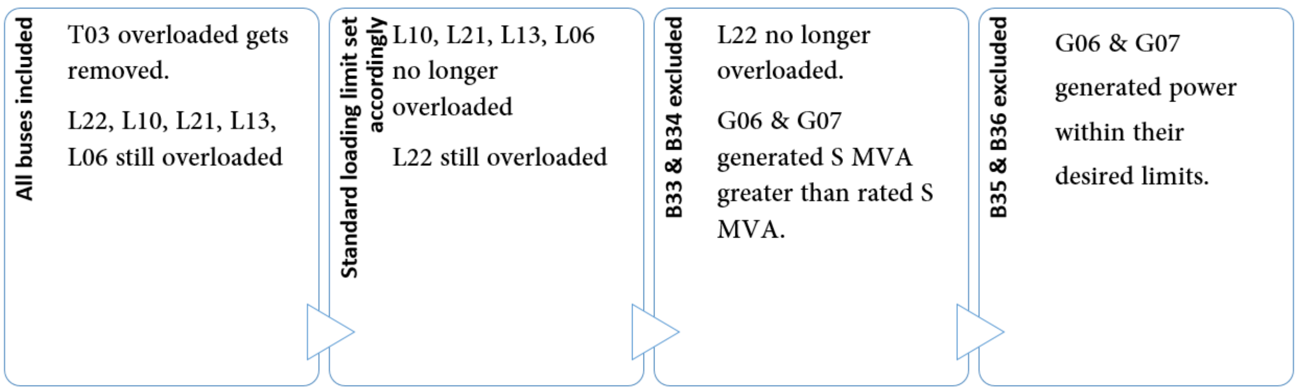
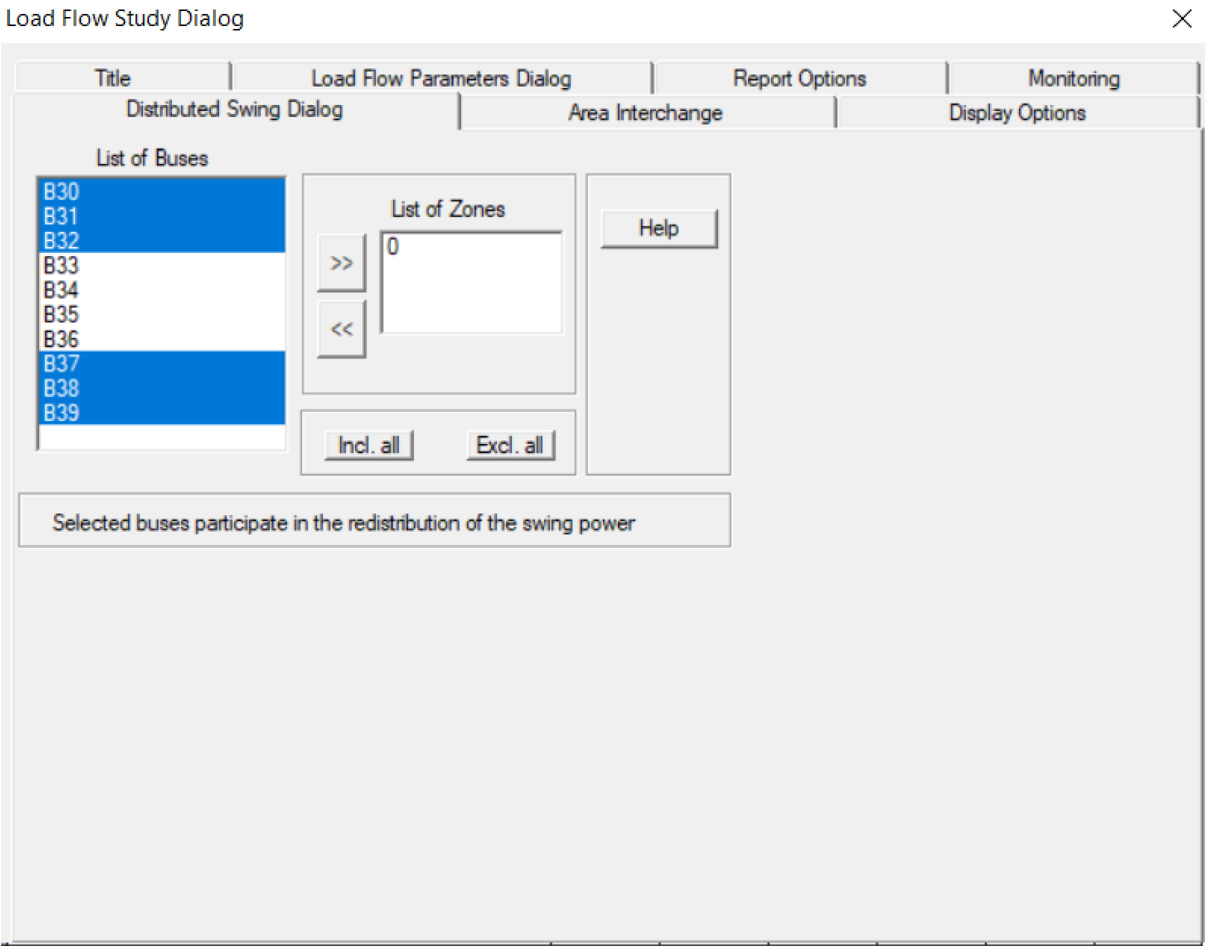


Fig. Steps followed



OVERLOADED LINES & CABLES (WITHIN 100 %)

ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]

UNDERLOADED LINES & CABLES (WITHIN 50 %)

ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]

OVERLOADED TRANSFORMERS (WITHIN 100 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]

UNDERLOADED TRANSFORMERS (WITHIN 50 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]
T10	B2	B30	368.774	550.000
T01	B12	B11	45.635	250.000
T02	B12	B13	43.672	250.000
T12	B19	B20	378.665	550.000
T03	B6	B31	361.366	400.000

GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)

ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]

TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)

ID	Bus From	Bus To	Tap Pos - [%]	Min Tap - [%]	Max Tap - [%]

Fig. After implementing distributed swing

***Step 3**: Static VAR Compensator for Bus voltages beyond limit*

A major drawback of HVDC systems using line-commutated converters is that the converters inherently consume reactive power. The AC current flowing into the converter from the AC system lags behind the AC voltage so that, irrespective of the direction of active power flow, the converter always absorbs reactive power, behaving in the same way as a shunt reactor. The reactive power absorbed is at least 0.5 Mvar/MW under ideal conditions and can be higher than this when the converter is operating at higher than usual firing or extinction angle, or reduced DC voltage.

Although at HVDC converter stations connected directly to power stations some of the reactive power may be provided by the generators themselves, in most cases the reactive power consumed by the converter must be provided by banks of shunt capacitors connected at the AC terminals of the converter. The shunt capacitors are usually connected directly to the grid voltage but in some cases may be connected to a lower voltage via a tertiary winding on the converter transformer.

Since the reactive power consumed depends on the active power being transmitted, the shunt capacitors usually need to be subdivided into a number of switchable banks (typically four per converter) in order to prevent a surplus of reactive power being generated at low transmitted power.

The shunt capacitors are almost always provided with tuning reactors and, where necessary, damping resistors so that they can perform a dual role as harmonic filters.

Voltage-source converters, on the other hand, can either produce or consume reactive power on demand, with the result that usually no separate shunt capacitors are needed (other than those required purely for filtering).

	ID	Bus ID	DBase ID	Duplic	Status	Q	Ctrl'd Bus	L	Q Max	Q Min
1	SVC09	B9	SVC09	1	☑	1.000	B9	971.457	340.000	-50.000

BUSES OUTSIDE VOLTAGE LIMITS (100 %)

Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]

Fig. No bus outside voltage limit

COMPARISON BETWEEN SHUNT CAPACITOR BANK AND SVC:

Cost Comparison:

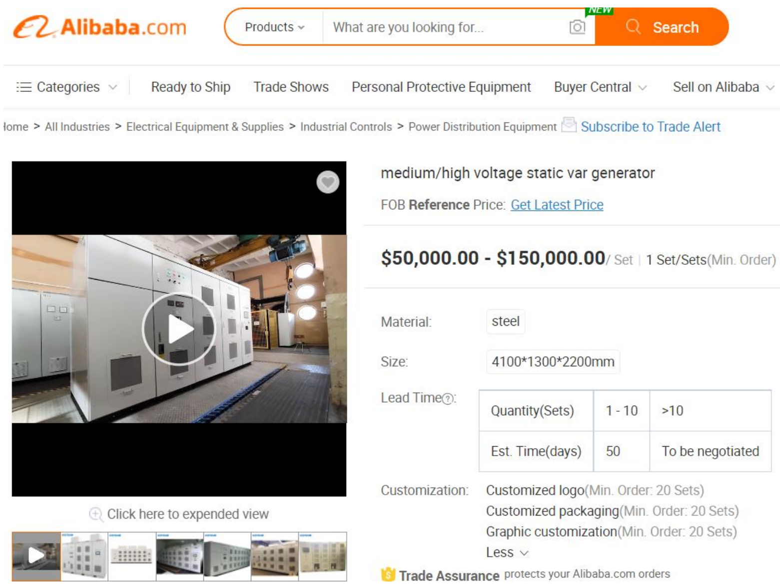


Fig: Price of SVC

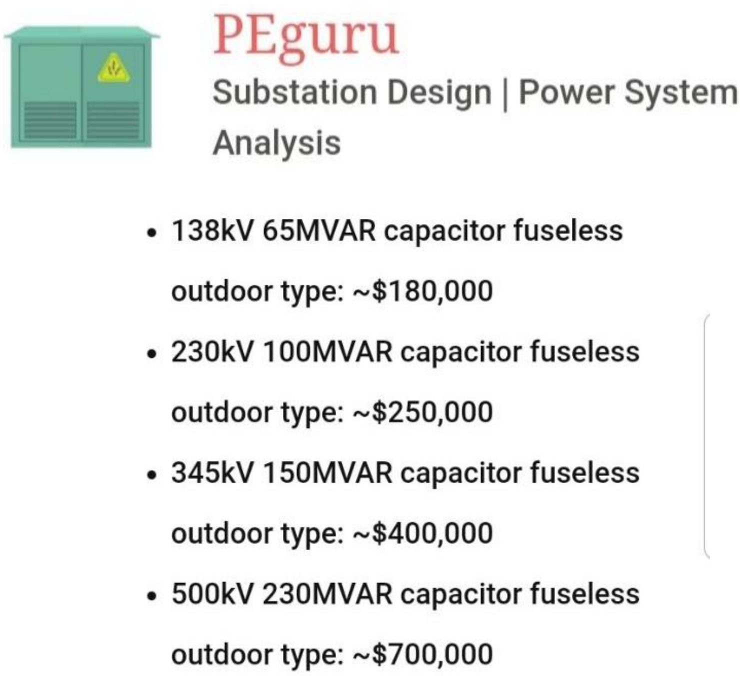


Fig: Price of Capacitor Bank

We have used SVC’s over shunt capacitor because

- Shunt capacitor bank in MVAR range very costly. It requires high installation and maintenance costs
- One SVC is more cost efficient than Multiple shunt capacitors needed if in KVAR range.

Example, for Q=65 to 230MVar

Cost of shunt capacitor capacitor= $180,000~700,000

Cost of SVC= $50,000~150,000

We have required Capacitors in Bus 5 to 9. So total cost will be higher in case of using shunt capacitor banks than the one SVC.

SVC of rating 340 Mvar is connected to B9 (required Q is calculated using P and Q values of B9 from the first ring contribution report).

	ID					
1						
2	BUSES OUTSIDE VOLTAGE LIMITS (100 %)					
3						
4	Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [
5						
6	OVERLOADED LINES & CABLES (WITHIN 100 %)					
7	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emerger Loadin Limit - [
8						
9	UNDERLOADED LINES & CABLES (WITHIN 50 %)					
10	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	
11	L10	B5	B8	0.952	2.988	
12	L20	B15	B16	1.997	2.390	
13	L11	B6	B7	2.320	2.988	
14	L13	B7	B8	0.633	1.494	
15	L23	B16	B21	1.069	1.195	
16	L03	B2	B3	2.769	2.988	
17	L05	B3	B4	1.924	2.689	
18	L08	B4	B14	2.597	2.689	
19						
20	OVERLOADED TRANSFORMERS (WITHIN 100 %)					
21	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emerger Loadin Limit - [MVA]
22						
23	UNDERLOADED TRANSFORMERS (WITHIN 50 %)					
24	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	
25	T10	B2	B30	366.233	550.000	
26	T01	B12	B11	46.374	250.000	
27	T02	B12	B13	42.898	250.000	
28	T12	B19	B20	378.784	550.000	
29	T03	B6	B31	354.730	400.000	
30						
31	GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)					

	ID					
1						
2	BUSES OUTSIDE VOLTAGE LIMITS (100 %)					
3						
4	Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [
5						
6	OVERLOADED LINES & CABLES (WITHIN 100 %)					
7	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emerger Loadin Limit - [
8						
9	UNDERLOADED LINES & CABLES (WITHIN 50 %)					
10	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	
11	L10	B5	B8	1.617	2.988	
12	L20	B15	B16	2.262	2.390	
13	L11	B6	B7	2.824	2.988	
14	L13	B7	B8	0.919	1.494	
15	L23	B16	B21	1.142	1.195	
16	L05	B3	B4	2.308	2.689	
17	L06	B3	B18	0.268	0.299	
18	L08	B4	B14	2.682	2.689	
19						
20	OVERLOADED TRANSFORMERS (WITHIN 100 %)					
21	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emerger Loadin Limit - [MVA]
22						
23	UNDERLOADED TRANSFORMERS (WITHIN 50 %)					
24	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	
25	T10	B2	B30	378.582	550.000	
26	T01	B12	B11	43.146	250.000	
27	T02	B12	B13	46.290	250.000	
28	T12	B19	B20	378.254	550.000	
29	T03	B6	B31	391.915	400.000	
30						
31	GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)					

Fig. Abnormal report using SVC (LHS) and Shunt capacitor (RHS)

Identical reports were obtained when shunt capacitors were used instead. However, the number and hence cost was more.

CONCLUSION

	ID						
1							
2	***BUSES OUTSIDE VOLTAGE LIMITS (100 %)***						
3							
4	**Bus ID**	**Zone**	**kV Base**	**Vmin - [pu]**	**Vmax - [pu]**	**V sol - [pu]**	**Ang sol - [deg]**
5							
6	***OVERLOADED LINES & CABLES (WITHIN 100 %)***						
7	**ID**	**Bus From**	**Bus To**	**Power Flow - [pu]**	**Loading Limit - [pu]**	**Emergency Loading Limit - [pu]**	
8							
9	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
10	**ID**	**Bus From**	**Bus To**	**Power Flow - [pu]**	**Loading Limit - [pu]**		
11							
12	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
13	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**	
14							
15	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
16	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**		
17	T10	B2	B30	368.774	550.000		
18	T01	B12	B11	45.635	250.000		
19	T02	B12	B13	43.672	250.000		
20	T12	B19	B20	378.665	550.000		
21	T03	B6	B31	361.366	400.000		
22							
23	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
24	**ID**	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**	
25							
26	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
				Tap Pos	Min Tap	Max Tap	

Fig. final abnormal report

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**6998.835**	**3128.149**
Spinning reserve	8391.164	
Static Load	6097.101	1408.900
Shunt loads	0.000	0.000
Motor loads	800.000	600.000
Total load	**6897.101**	**2008.900**
Line / cable losses	66.113	-134.600
Transformer losses	34.627	959.801
Total losses	**101.735**	**1119.200**
Mismatches	0.000	0.049

Fig.final summary report

At the end of the solution, we obtain reports with zero abnormalities. We have tried our best to keep the solution method as cost efficient, feasible and smart as possible, regardless of the constraints set and that of the software itself. We have pur forward fair justification behind each step more than any other group, and presented mathematical calculations to justify the ratings of component added.

This project has improved our understanding of a power system overall. We believe we have learned a lot and we can implement the knowledge acquired in our near future. Thanks to our respected course teachers for giving us a reasonable and effective project. Although it was tedious, it was fruitful. We draw an end to our project by the submission of this report here. We hope we have put forward everything that the course instructors asked for. We urge you to excuse any shortcomings from our side.