Bangladesh University of Engineering and Technology

Department Electrical and Electronic Engineering

Course Name: EEE 306

Course Title: Power system Laboratory

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

Level:3

Term:1

SUBMITTED BY Group 06:

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Abstract:

This project is to perform the load flow analysis on IEEE 39 bus power system is known as 10-machine new England power system. We have performed for base case as the data given in the project guideline for different bus, line, loads, fixed tap transformer, generator. After that we added HVDC line and industrial load (induction motor) and then added various device to solve the abnormalities arises for adding HVDC line and induction motor.

The objectives of this project are

1) To introduce ourselves to a practical power system,
2) To have insight about how load flows in a large power system like this.
3) To study the abnormalities arises when a new HVDC line is introduced to the system and the effect of having inductive load in the system.
4) To have an idea about how to solve the abnormalities using corrective devices in the most efficient manner.
5) To use reasonable loading limit in the equipment used in the power system to avoid any underloading for practical purpose.

We have used CYMEPSAF software for this load flow analysis and used a system frequency of 50 HZ as in our country power system works on 50HZ. Here, in this project we are not allowed to change any fundamental data such as adding or deleting any existing equipment.

Single line diagram

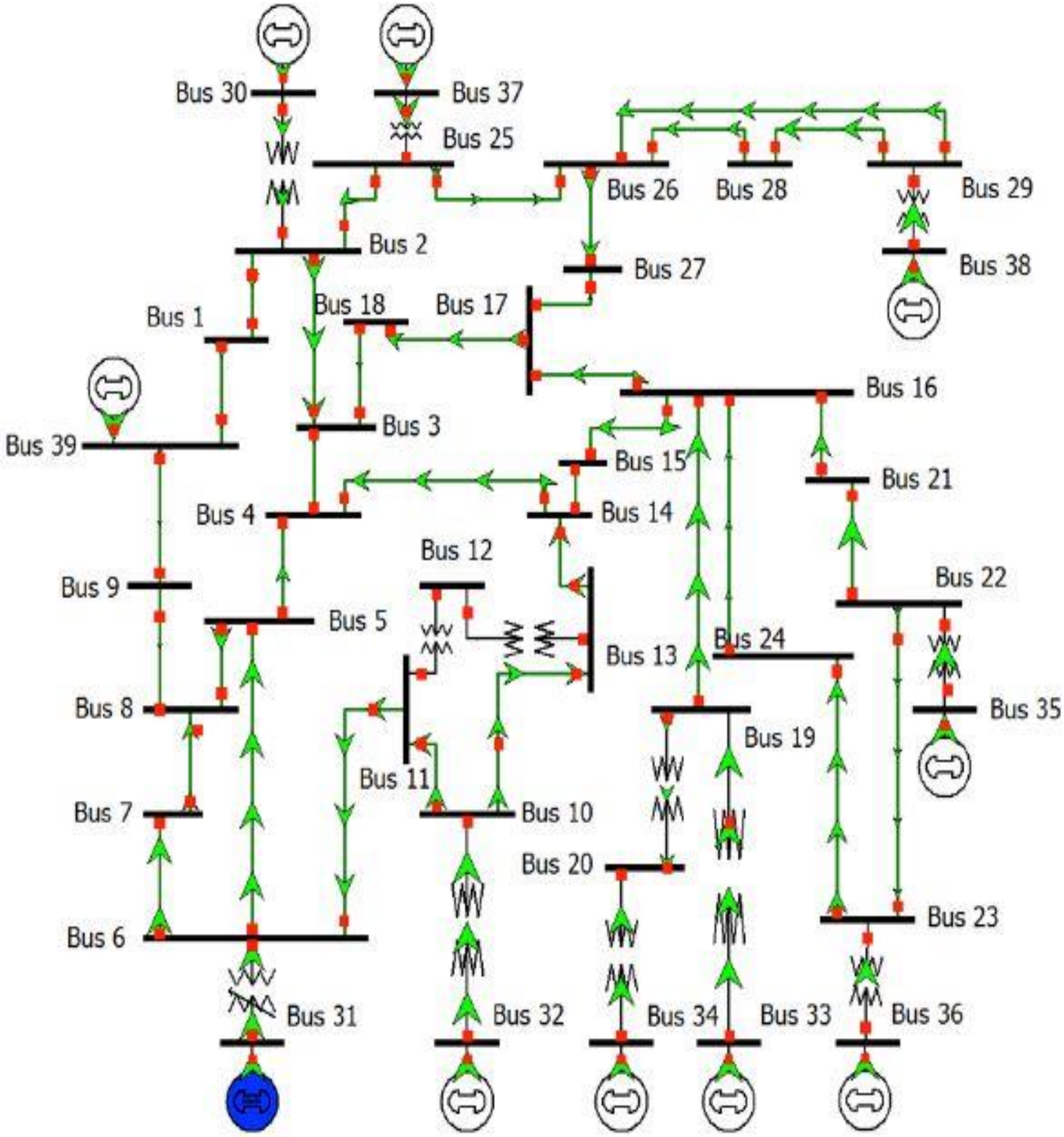


Figure 1: IEEE 39-Bus System

<u>Stepwise output and analysis</u>

<u>Step-1(Base Case analysis)</u>

First, we have used the data given in the project guideline and performed the load flow analysis in the simulating software. The system converged and no abnormalities were observed. But, a few underloading lines were observed which we can underestimate and move on to the next step.

The output of this step is shown below.

	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	L10	B05	B08	2.973	2.988		
12	L30	B25	B26	0.383	2.988		
13	L31	B26	B27	2.468	2.988		
14	L01	B01	B02	0.710	2.988		
15	L32	B26	B28	1.437	2.988		
16	L02	B01	B39	1.979	2.988		
17	L13	B07	B08	1.545	2.988		
18	L33	B26	B29	1.919	2.988		
19	L14	B08	B09	2.112	2.988		
20	L24	B16	B24	1.587	2.988		
21	L04	B02	B25	2.728	2.988		
22	L15	B09	B39	1.796	2.988		
23	L25	B17	B18	2.774	2.988		
24	L05	B03	B04	1.658	2.988		
25	L26	B17	B27	0.865	2.988		
26	L06	B03	B18	1.164	2.988		
27	L17	B10	B13	2.614	2.988		
28	L07	B04	B05	1.066	2.988		
29	L18	B13	B14	2.496	2.988		
30	L28	B22	B23	0.425	2.988		
31	L19	B14	B15	0.749	2.988		
32							

Figure: No Overloaded Line, No buses are out of voltage limits

32						
33	OVERLOADED TRANSFORMERS (WITHIN 100 %)					
34	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]
35						
36	UNDERLOADED TRANSFORMERS (WITHIN 50 %)					
37	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	
38	T10	B01	B30	253.427	500.000	
39	T01	B12	B11	43.037	150.000	
40	T02	B12	B13	46.418	150.000	
41	T12	B19	B20	122.592	500.000	
42						
43	GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)					
44	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]
45						
46	TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)					
47	ID	Bus From	Bus To	Tap Pos - [%]	Min Tap - [%]	Max Tap - [%]

Fig: Abnormality report of base case

Step-2 (Adding DC Line, IM, TCUL xmer)

In this step, we have added a HVDC line between Bus 39_REC to Bus 9_INV two buses we have created in this step. Two TCUL (Tap Changing Underload) Transformer to cover AC power into DC for transmission and removed HVAC Line 15 Connecting previous bus 39 and 9. Plus we have added 10 induction motor each having MVA rating of 100 in Bus 23.

Simulation Results:

After simulating the modified system, 12 buses were out of their voltage limit. Six lines namely L14, L17, L22, L9, L7, L18 were

overloaded crossing their loading limit. Transformer 3 was highly overloaded crossing its emergency limit. Some generators crossed their reactive power limits. This is because of adding HVDC line which create more power surges in these buses and addition of induction motor which creates demand for more MVAR. These reasons and their solutions will be discussed in brief in the later steps.

The output of this step is given below

	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	B10	0	345.00	0.900	1.100	0.897	-14.6
6	B11	0	345.00	0.900	1.100	0.884	-14.8
7	B12	0	138.00	0.900	1.100	0.866	-15.7
8	B13	0	345.00	0.900	1.100	0.891	-16.4
9	B14	0	345.00	0.900	1.100	0.886	-20.7
10	B04	0	345.00	0.900	1.100	0.872	-22.9
11	B05	0	345.00	0.900	1.100	0.856	-16.3
12	B06	0	345.00	0.900	1.100	0.863	-15.0
13	B07	0	345.00	0.900	1.100	0.829	-16.6
14	B08	0	345.00	0.900	1.100	0.818	-16.5
15	B09	0	345.00	0.900	1.100	0.719	1.8
16	B9_INV	0	100.00	0.900	1.100	0.707	5.8
17							
18	OVERLOADED LINES & CABLES (WITHIN 100 %)						
19	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]	
20	L22	B16	B19	10.600	7.768	11.951	
21	L14	B08	B09	7.139	5.976	8.963	
22	L17	B10	B13	6.414	5.976	8.963	
23	L07	B04	B05	7.773	5.976	8.963	
24	L18	B13	B14	6.614	5.976	8.963	
25	L09	B05	B06	8.356	5.976	8.963	
26							
27	UNDERLOADED LINES & CABLES (WITHIN 50 %)						
28	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]		
29	L20	B15	B16	2.945	2.988		
30	L30	B25	B26	0.292	2.988		
31	L31	B26	B27	2.512	2.988		
32	L12	B06	B11	2.626	2.988		
33	L32	B26	B28	1.514	2.988		
34	L13	B07	B08	2.528	2.988		
35	L23	B16	B21	1.388	2.988		
36	L33	B26	B29	1.991	2.988		

	ID						
31	L31	B26	B27	2.512	2.988		
32	L12	B06	B11	2.626	2.988		
33	L32	B26	B28	1.514	2.988		
34	L13	B07	B08	2.528	2.988		
35	L23	B16	B21	1.388	2.988		
36	L33	B26	B29	1.991	2.988		
37	L25	B17	B18	1.675	2.988		
38	L16	B10	B11	2.934	2.988		
39	L26	B17	B27	1.728	2.988		
40	L06	B03	B18	0.105	2.988		
41	L27	B21	B22	2.779	3.884		
42	L08	B04	B14	2.849	2.988		
43	L29	B23	B24	0.341	2.988		
44							
45	*OVERLOADED TRANSFORMERS (WITHIN 100 %)*						
46	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
47	T03	B06	B31	924.032	800.000	850.000	
48							
49	*UNDERLOADED TRANSFORMERS (WITHIN 50 %)*						
50	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
51	T10	B02	B30	396.843	550.000		
52	T01	B12	B11	45.670	250.000		
53	T02	B12	B13	55.555	250.000		
54	T12	B19	B20	377.276	550.000		
55							
56	*GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)*						
57	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
58	G03	B32	650.00	453.53	-192.00	448.00	
59	G06	B35	650.00	579.01	-192.00	448.00	
60	G07	B36	560.00	520.31	-168.00	392.00	
61							
62	*TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)*						
63	ID	Bus From	Bus To	Tap Pos - [%]	Min Tap - [%]	Max Tap - [%]	

Fig: Abnormality report after step 02

Thus, we have found four types of severe problem in 2nd step, after adding DC line, 10 Induction motor, TCUL xmer.

STEP 3: (Generator Reactive limit problem solving)

In this step, we solved the generator reactive power overloading problem.

Solution measures: Adding SVC in bus 23.

Reasoning and explanation:

The main reason behind these is the addition of 10 new induction motor in bus 23 which forces the generator to produce more reactive power beyond their limit. **The rating of each of the induction motor is 100 MVA with power factor of 0.8 which makes reactive power demand of 100×$\sqrt{1 - .8^2}$)= 60MVAR which makes in total 600 MVAR demand for the inductive load. We have added one SVC (static VAR compensator) in bus-23 to solve the problem.**

Total reactive power at B23 is = $Q_{load} + Q_{motor}$

=84.6+600

=684.6 MVAR

The rating if SVC at bus is 700Mvar, for better result.

Simulation Result :

After simulating the system, generator reactive power limit problem has been solved but still some buses were out of their voltage limit. T03 was still out of its emergency limit and line overloading remained the same. Another approach could be to connecting SVC individually at each of the generator having reactive power limit problem. As SVC has a high price tag and take large place to install, it would not be an economical or efficient solution that’s why we have chosen bus 23 having the most reactive power demand to connect SVC and eradicate the problem.

The output of this step is shown below-

L27	B21	B22	3.086	3.884		
L08	B04	B14	2.842	2.988		
L29	B23	B24	0.872	2.988		

OVERLOADED TRANSFORMERS (WITHIN 100 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
T03	B06	B31	913.116	800.000	850.000	

UNDERLOADED TRANSFORMERS (WITHIN 50 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
T10	B02	B30	378.919	550.000		
T01	B12	B11	44.878	250.000		
T02	B12	B13	56.432	250.000		
T12	B19	B20	378.815	550.000		

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 - [%]	

From the above abnormality report, we can see that, there is no such gen, which are at reactive limit

Step-4 (Buses outside voltage limit problem solving)

In this step, we have opted to solve bus voltage out of limit problem.

Solution Measures:

Connecting shunt capacitor at different buses. (B11, B12, B04, B09)

Reasoning and explanation:

To approach this problem, we have used shunt capacitor instead of SVC as SVC is more expensive than shunt capacitor. So, we can solve the problem without having to spend much. **We know that bus voltage must stay between .9 to 1.1pu , to be more specific between 5% of either side of 1 for most economic transmission of power.** The addition of HVDC line caused the bus voltage to be less than minimum. **Adding shunt capacitor increases bus reactive power which in turn increases bus voltage.**

The value of shunt capacitor used in different buses is shown below with necessary calculations.

- **1st Shunt Capacitor at B11**

Our 1st problem was at B11.

Bus 11 was connected with L12, L16 and T01.

The sum of reactive power of all three things are = L12 + L16 + T01

= -218+247+35

= **64 MVAR**

So, **rating of Shunt capacitor at B11 was 70MVAR.**

Adding this Shunt capacitor, the bus B11 became fixed.

Similar calculations are used for the next three shunt capacitor.

- **<u>2nd Shunt Capacitor at B12</u>**

Here, reactive power at Bus 12 is 88MVar

So, **a shunt capacitor rating of 90MVar was connected at B12**

Thus, problem of voltage limit was solved at B11 and B12

- **<u>3rd Shunt Capacitor at B04</u>**

Here, reactive power at Bus 04 is 184MVar

So**, a shunt capacitor rating of 184 MVAR was connected at B04**

B04 problem was solved

- **<u>4th Shunt Capacitor at B09</u>**

Finally, we have connected a large shunt capacitor at B09 to compensate all other remaining buses, to solve the problem of bus outside voltage limit problem.

The rating of shunt capacitor is 260MVar.

<u>Simulation Result</u>

After the simulation has been done, **no buses were out of their per unit voltage limit but T03 was overloaded as before and four lines namely (L22, L07, L18, L09) were overload but two lines L14, L17 overloading problem have been solved as shunt capacitor is used in the buses connecting the line or nearby buses**

Simulation abnormality report after step 04

BUSES OUTSIDE VOLTAGE LIMITS (100 %)

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

OVERLOADED LINES & CABLES (WITHIN 100 %)

ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]
L22	B16	B19	10.286	7.768	14.939
L07	B04	B05	6.984	5.976	8.963
L18	B13	B14	6.017	5.976	8.963
L09	B05	B06	7.287	5.976	8.963

UNDERLOADED LINES & CABLES (WITHIN 50 %)

ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]
L10	B05	B08	0.984	2.988
L20	B15	B16	1.870	2.988
L30	B25	B26	0.093	2.988
L11	B06	B07	2.688	2.988
L21	B16	B17	2.794	2.988
L31	B26	B27	2.163	2.988
L12	B06	B11	1.454	2.988
L32	B26	B28	1.428	2.988
L13	B07	B08	0.267	2.988

OVERLOADED TRANSFORMERS (WITHIN 100 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]
T03	B06	B31	861.608	800.000	850.000

UNDERLOADED TRANSFORMERS (WITHIN 50 %)

ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]
T10	B02	B30	326.644	550.000
T01	B12	B11	27.101	250.000
T02	B12	B13	19.963	250.000
T12	B19	B20	381.323	550.000

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 - [%]

Step-5 (Transformer overloading problem solving)

Now, we are going to solve transformer overloading problem.

Solution Measures:

Increasing generation power of some generator (G01, G03,G10) by 50MW.

Reasoning and Explanation

T03 is connected between bus 6 to bus 31, better known as swing bus used for the better stabilization of power demand of the system. By definition this bus can absorb provide any amount of power demanded by the system. As HVDC line and induction generation is introduced in the system it creates more power demand forcing the swing generator to produce large amount of power. The swing generator is connected to T03. **Due to high power flow this transformer overloads and crossed its emergency limit. To minimize the pressure in swing generator we have increased the generation power of G01, G03, G10 by 50MW**. As, we know that this slight increase in generation power could be achieved with just increase of incoming fuel rate without having to make any outer changer in the generator or system. The output after this step is shown below-

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	B02	B30	353.338	550.000
T01	B12	B11	22.418	250.000
T02	B12	B13	15.144	250.000
T12	B19	B20	381.701	550.000

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 - [%]

Bus | Generator | Motor | Shunt | Static Load | Branch | DC Line Report | Transformer | Abnormal Report | Summary Report

STEP 6: (Line overloading problem Solving)

L22, L07, L09 still has overloading problems.

Solution Measures:

Changing the loading limit of line L22, L07, L09 respectively 1800,1200 & 1200.

Reasoning and explanation:

To solve the line overloading problem, we have increased the loading limit of L22 to 1800, L07 to 1200 and L09 to 1200. After completing this step only the line underloading and transformer underloading problem remained. These are not major problems in case of load flow study. The improvements are shown below:

Simulation result after step 06

	ID		
1			
2	BUSES OUTSIDE VOLTAGE LIMITS (100 %)		
3			
4	Bus ID	Zone	kV Ba
5			
6	OVERLOADED LINES & CABLES (WITHIN 100 %)		
7	ID	Bus From	Bus T
8			
9	UNDERLOADED LINES & CABLES (WITHIN 50 %)		
10	ID	Bus From	Bus T
11	L10	B05	B08
12	L20	B15	B16
13	L30	B25	B26
14	L11	B06	B07
15	L21	B16	B17
16	L31	B26	B27
17	L12	B06	B11
18	L32	B26	B28
19	L13	B07	B08
20	L23	B16	B21
21	L33	B26	B29

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	B02	B30	353.338	550.000	
T01	B12	B11	22.418	250.000	
T02	B12	B13	15.144	250.000	
T12	B19	B20	381.701	550.000	
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 - [%]

From the above abnormality report we can see that, there is no overloading problem. Thus, we have achieved our project goal

Complete Summary Report:

LOAD FLOW STUDY PARAMETERS	
Study :	UNTITLED
Time :	Sat Jul 24 12h05m42s 2021
Method :	Fast Decoupled
Constraints :	Not applied
Flat start :	Yes
Tcul txfo used as fixed tap :	Yes
Block Q-flow Txfo Adjustment	n\a
Block P-flow Txfo Adjustment :	n\a
Block Switchable Shunt Adjustment :	n\a
Block DC Link Adjustment :	No
Base power :	100.00 [MVA]
Tolerance :	0.100 [MVA]

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**6995.844**	**2528.772**
Spinning reserve	8394.156	
Static Load	6097.100	1408.900
Shunt loads	0.038	-572.287
Motor loads	800.000	600.000
Total load	**6897.138**	**1436.613**
Line / cable losses	65.503	-103.568
Transformer losses	32.225	902.502
Total losses	**98.728**	**1091.934**
Mismatches	-0.021	0.226

Comparison between SVC and Shunt capacitor

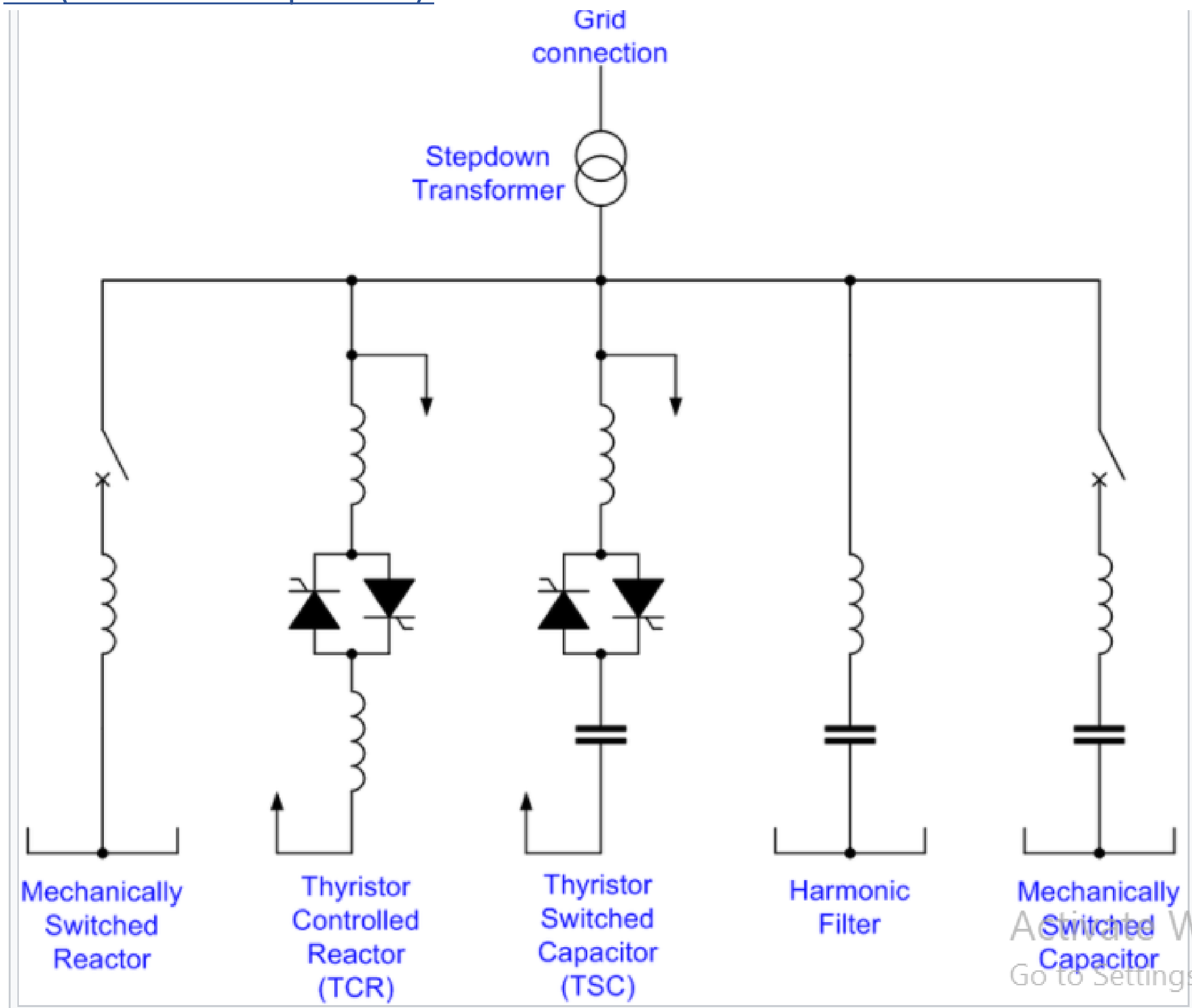
Static Var Compensator is “a shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage)”. SVC is based on thyristors without gate turn-off capability. The operating principal and characteristics of thyristors realize SVC variable reactive impedance. SVC includes two main components and their combination: Thyristor-controlled and Thyristor-switched Reactor (TCR and TSR); and Thyristor-switched capacitor (TSC).

The Static Var Compensator is connected parallel with the load to be compensated. The system provides reactive power in proportion to the system supply voltage.

Thyristor-controlled reactors (TCR) generate an SVCs inductive power whilst passive filter capacitor banks generate its capacitive power. As TCRs also generate harmonic currents, the capacitor banks are fine tuned to reduce both harmonics generated by the load and the system itself.

<u>The single line diagram of SVC:</u>

SVC(Static VAR Compensator):



Shunt Capacitor:

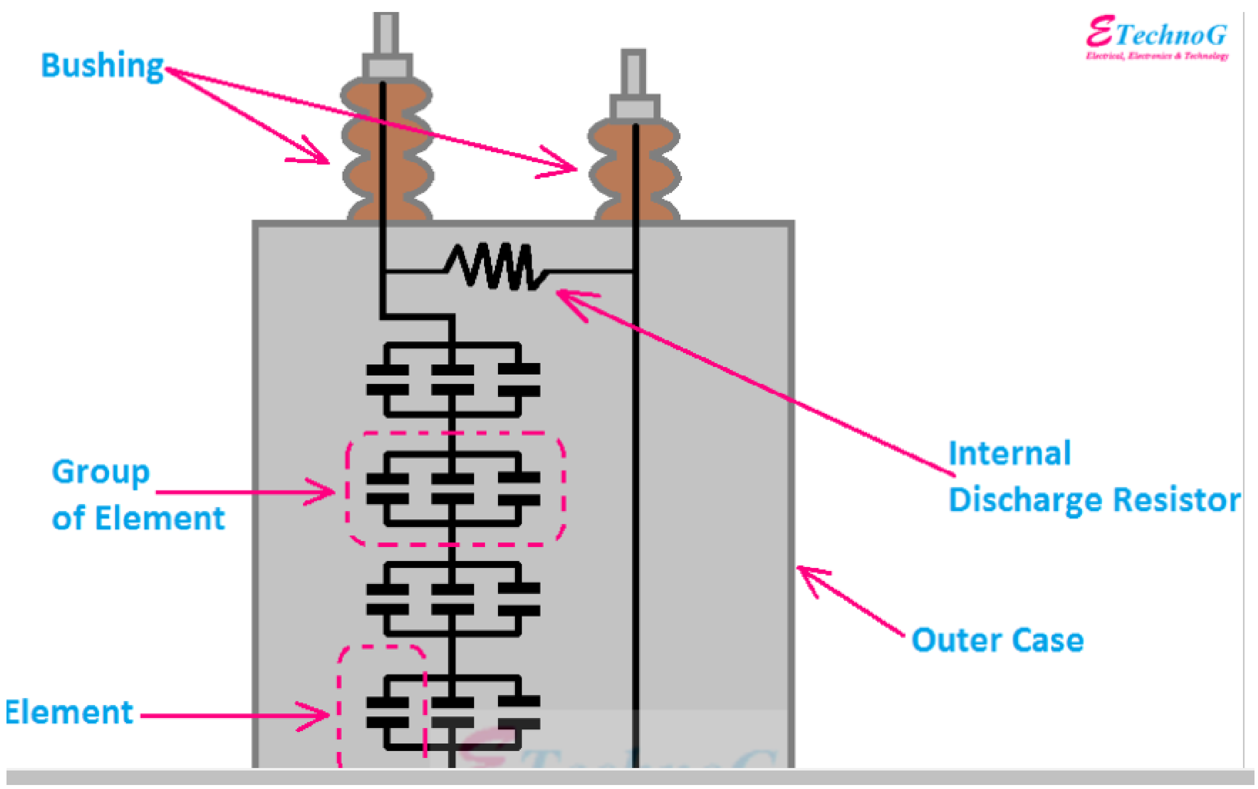
Shunt capacitors are an integral part of a power system because it helps in power factor correction. The fact that this apparatus can be deployed anywhere in a circuit or a power network makes it the ideal option for this work. Shunt capacitors are also relatively cheaper than series capacitors and easy to install.

In a power distribution system, electrical engineers place a connector in parallel throughout the transmission. This gadget is known as a shunt capacitor. The shunt capacitor helps balance power transmission issues such as low voltage regulation, poor reliability, and power factors. Moreover, it can divide into HV capacitor and LV capacitor.

A lag between the voltage and current causes a decrease in the electrical power factor, which leads to an increase in the demand for more power from the source. In the long run, the cycle leads to power surges and loss of lines, also known as inductive reactance.

To counteract this flaw, engineers can introduce a capacitive reactance into the system. Using several units rather than one creates a reliable reactance against recurring inductive reactance. This group of capacitor units is referred to as a capacitor bank.

The internal figure is given below:



Comparison on SVC and shunt capacitors:

In the load flow analysis we did, the work of shunt capacitors could have been performed by SVC too. But, shunt capacitors being the the money friendly option persuaded us to use in a few occasions instead of SVC.

HVDC Transmission and Advantages of HVDC Transmission Over HVAC transmission:

High voltage direct current (HVDC) power systems use D.C. for transmission of bulk power over long distances. For long-distance power transmission, HVDC lines are less expensive, and losses are less as compared to AC transmission. It interconnects the networks that have different frequencies and characteristics.

The main advantages of HVDC over HVAC:

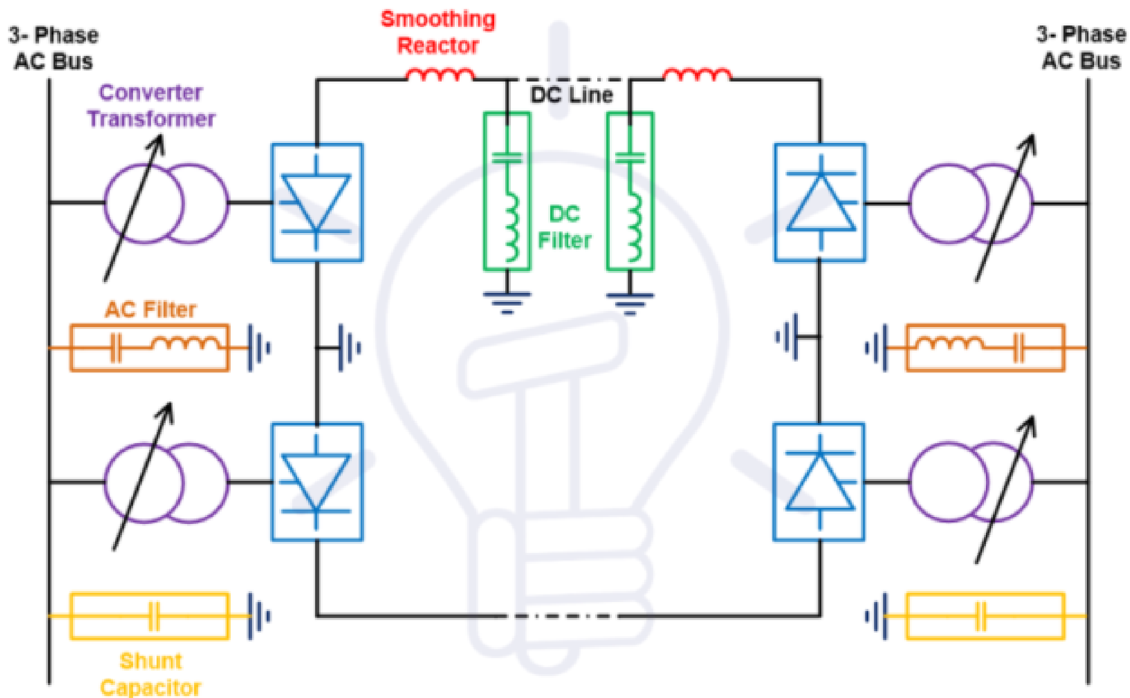
1.Low cost of transmission

2.Reduced power losses

3.No radiation and induction losses

4.Fast fault clearance

5.Low Noise interference



Components of HVDC Transmission Line

Discussion:

During the implementation of the system we had a variety of problems including overloaded lines,buses out of voltage limit,overloaded transformer,generators over reactive limit etc.We solved them using multiple processes like using SVCs,shunt capacitors,increasing generations of other generators,increasing line limit of loading lines etc.It enabled us the knowledge on how practical power systems work and how to solve abnormalities relating to power system.

Reference:

1. https://electrical-engineering-portal.com/what-is-the-static-var-compensator-svc

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